SolidGround™
GIC Neutral Blocker

Power and productivity for a better world™ ABB

Operational Experiences of an HV Transformer Neutral Blocking Device

Fred R. Faxvog, Emprimus
Michael B. Marz, American Transmission Co.

- ***Fully operational in the Wisconsin Power Grid***

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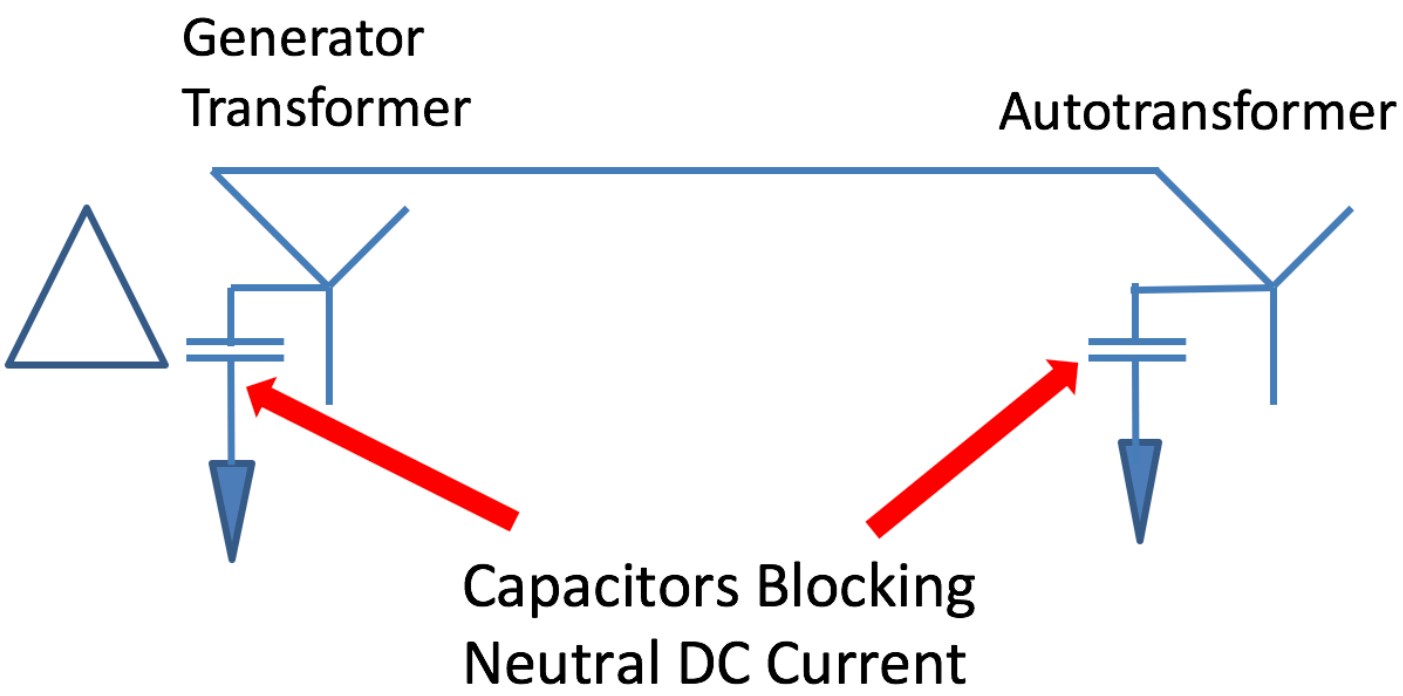
The most effective way to block GIC and EMP E3 induced DC currents:

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



Capacitors <u>block DC current</u> (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."

-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

“Uneconomic Dispatch”

Utilities’ current procedural response to solar storms

- Procedures trend GIC for **20 minutes** to verify it is in fact GIC
- If confirmed, turn down generation at sites experiencing or anticipating high GIC in order to maintain voltage control while turning up generation at other locations at higher cost
- Procedures do not decrease the amount of GIC on the Network
- Costs $100’s of millions each year - “Uneconomic” Dispatch
- Increases risk to circuit breaker operation due to a lack of voltage zero crossings
- Will not work for large **GMD** (“100-year” Solar Super Storm) or nuclear EMP **E3** events

Procedures are not sufficient

- Utility operating procedures do not decrease the amount of GIC in the grid.
  - GIC and its damaging harmonics continue to flow throughout the grid and cause issues for utilities and customers
- Reacting to the initial GMD impact is too late
- NOAA and MISO GMD Warning leaves insufficient Margin of Safety

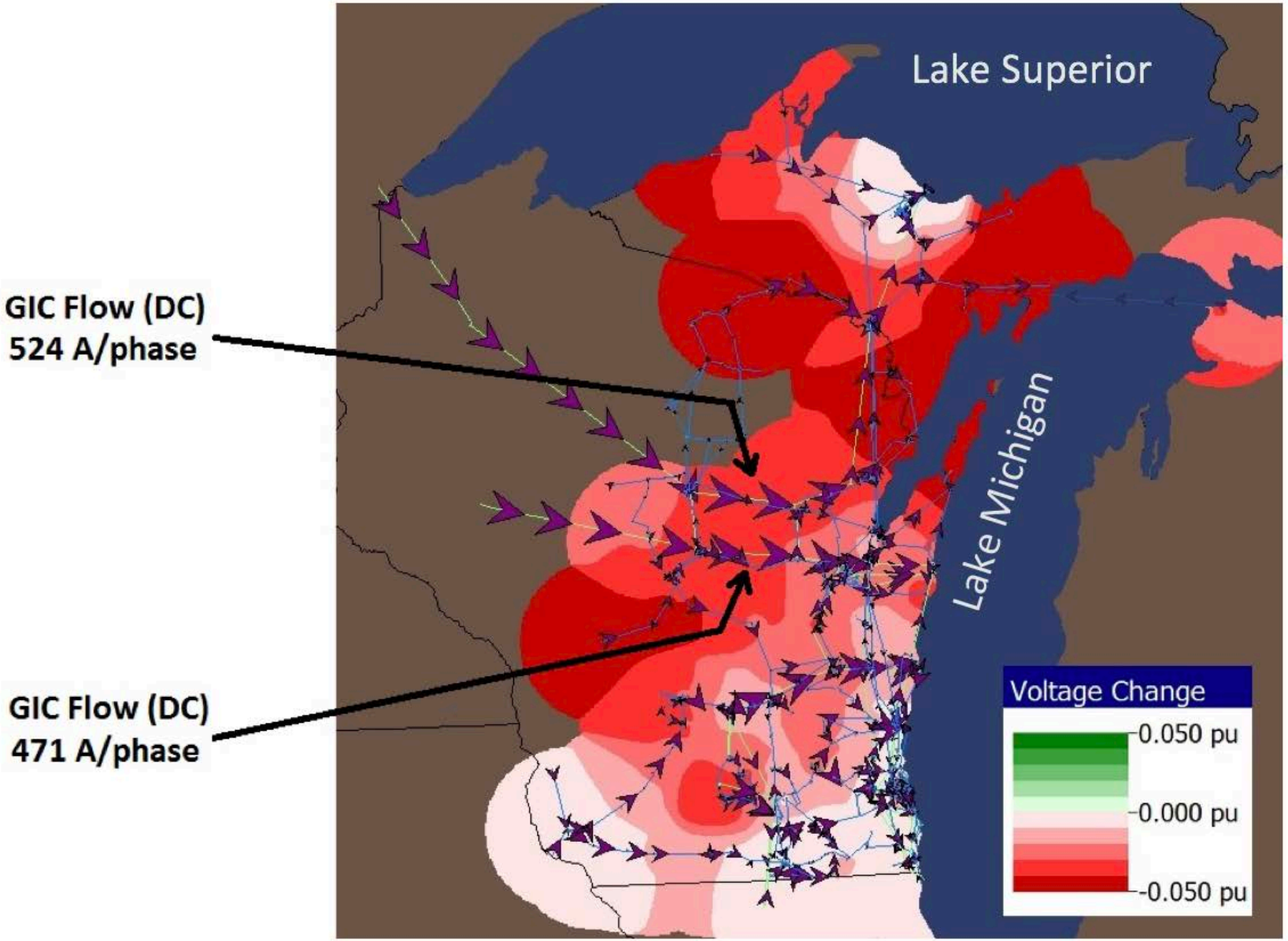
GIC must be blocked to ensure reliable high quality power

GIC must be blocked or significantly reduced to prevent:

- Damage to Customer equipment due to Harmonics
  - As documented by insurance companies
- Voltage Collapse (Blackout over large areas)
  - Mis-operation of SVC Capacitor Banks - Inability of capacitor banks to switch on and off with continual GMD field polarity changes
- Damage to Large Power Transformers (LPTs)
  - Very long lead times (up to 2 years) to build
  - Transformers are custom built - 3 different designs for every 4 transformers built
- Damage to Breakers
  - High Voltage breakers unable to interrupt Direct Current
  - Mis-operation of controls
- Damage to Generator Rotors

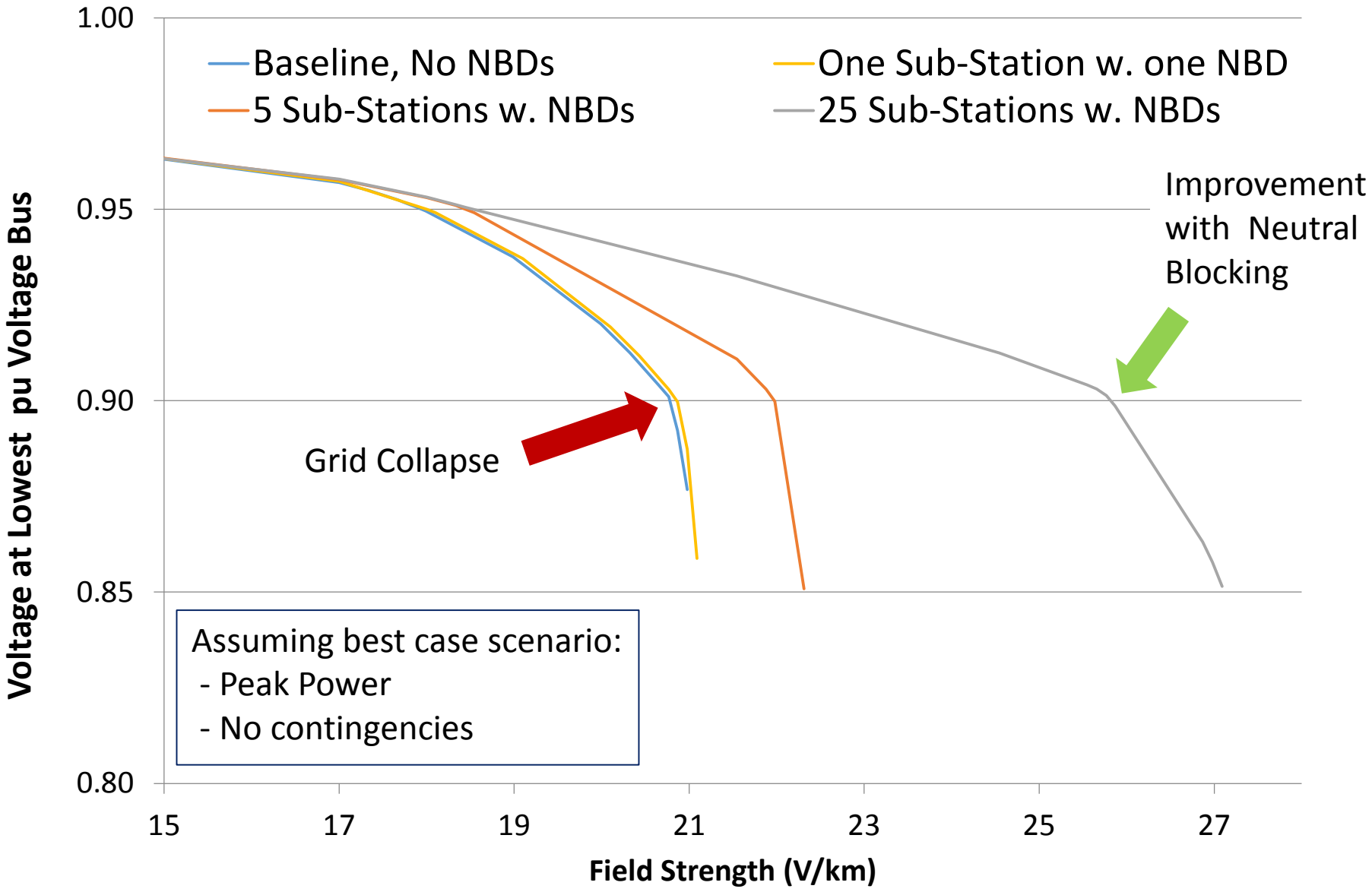
Emprimus worked with ATC and other utilities to determine requirements for SolidGround™

- Fully automatic protection (no delay or operator action required)
- Continuously maintains a grounded neutral 100% of the time
- Maintains a solid metallic neutral ground during normal operation
- Automatically effectively grounds a transformer through a low impedance capacitor bank only when needed
- Fail-safe, Robust design, with Industry Standard Components
- Robust spark gap (dual redundant) for overvoltage protection
- Works on nearly all HV Transformer designs. Scalable to protect the entire grid from a “100-year” GMD or Nuclear EMP event.

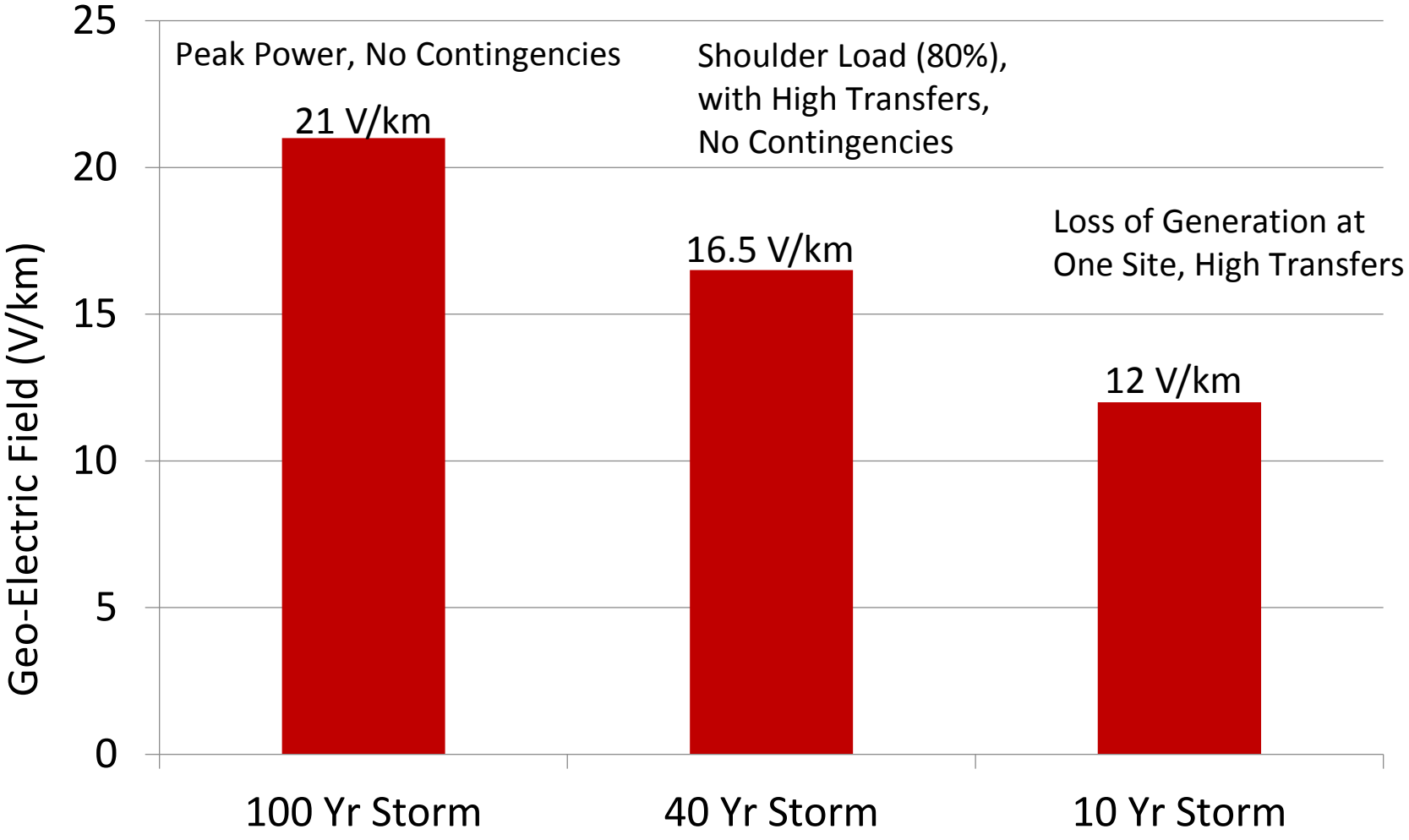


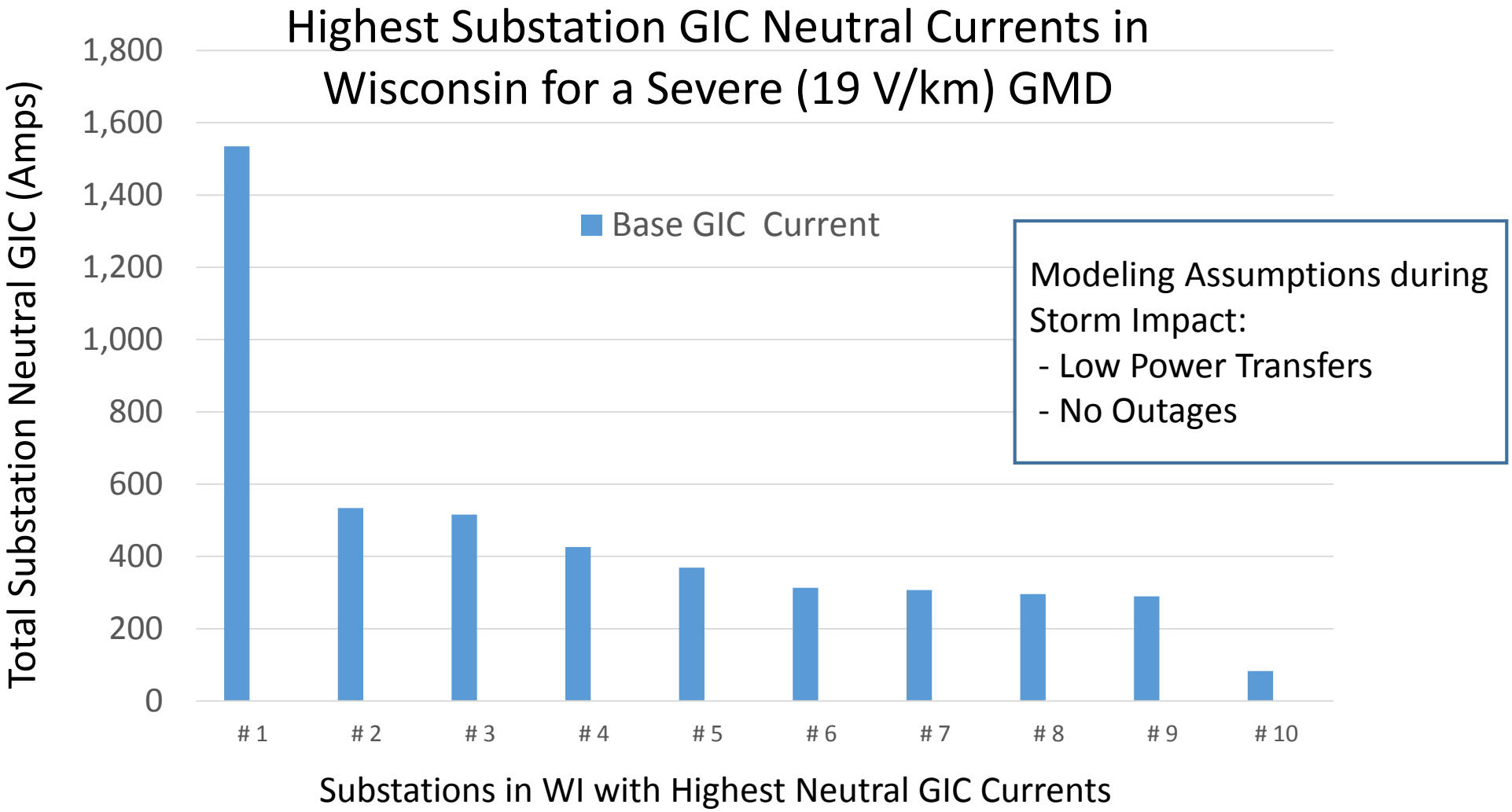
ATC WI and Upper MI Voltage Decrease Map for a 19 V/km Geo-Electric East-West Field.

ATC Grid Improved Protection Against Voltage Collapse with NBDs

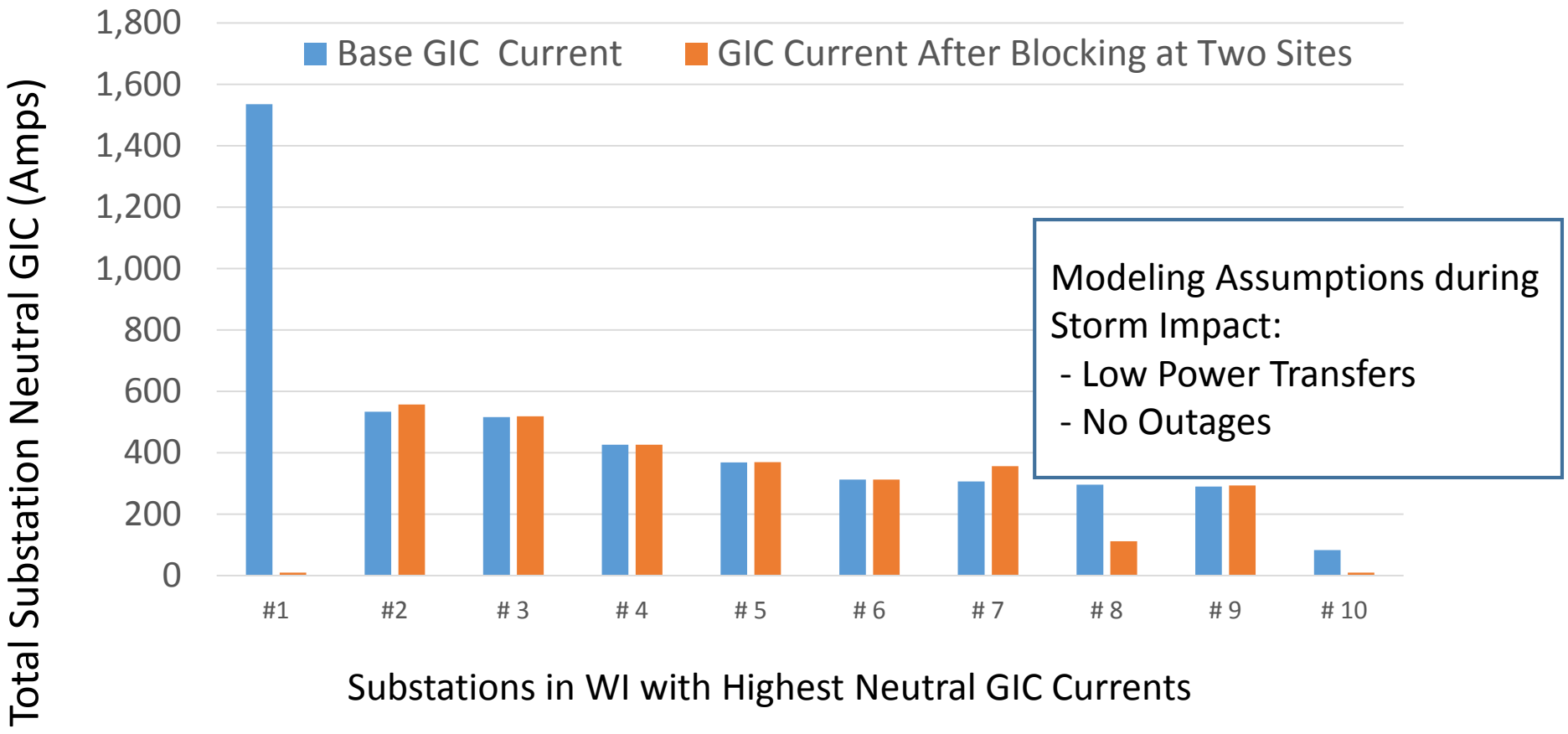


ATC Grid Voltage Collapse for three Scenarios





Modeling of GIC Currents for a Severe (19 V/km) GMD at Worst Field Angle (W to E).
Modeled Assumptions: Low Power Transfer in Grid and No Outages. Base GIC current is shown in Blue



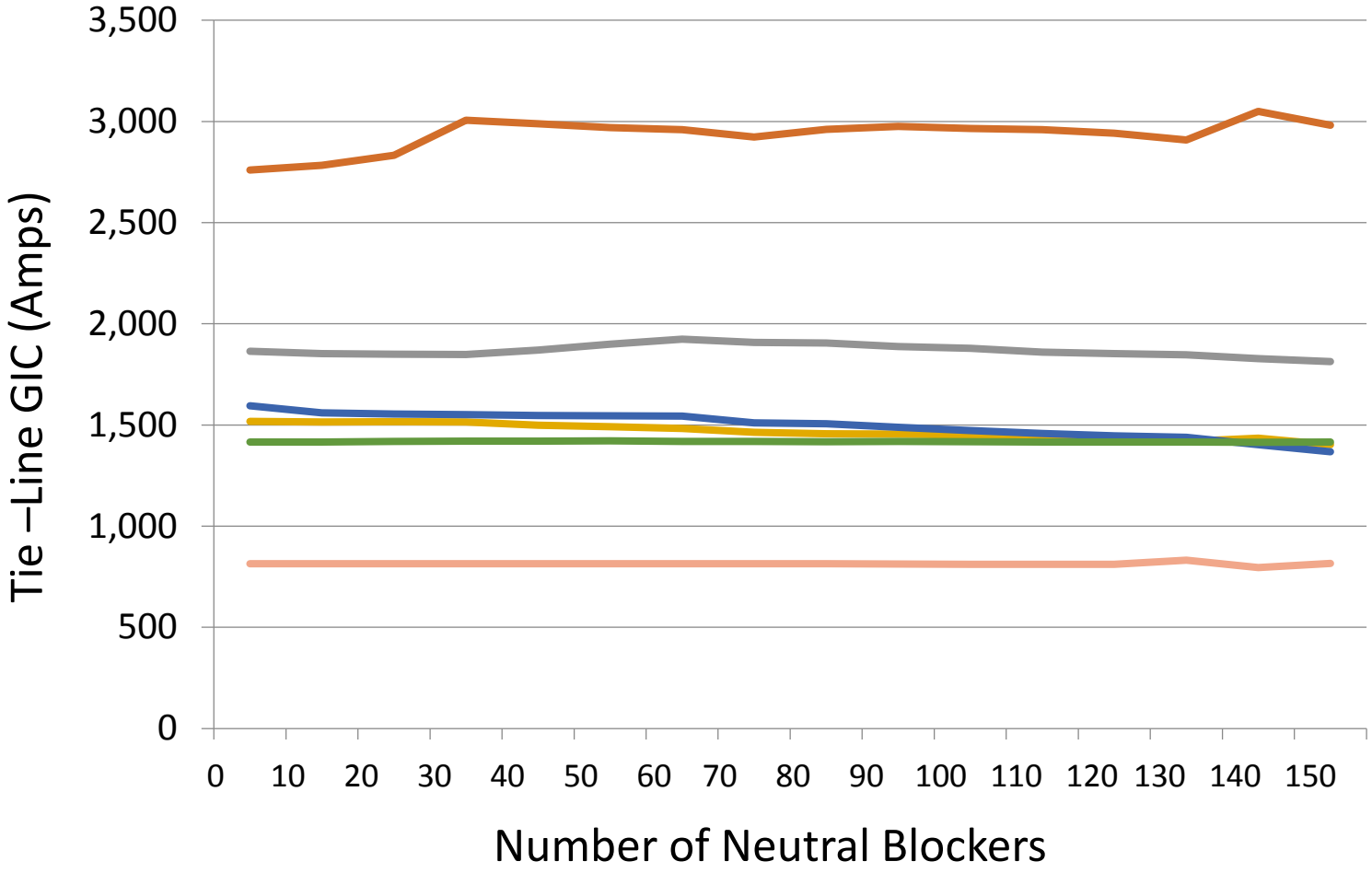
Modeling of Highest GIC Currents for a Severe (19 V/km) GMD at Worst Field Angle (W to E).
Modeled Assumptions: Low Power Transfer in Grid and No Outages. Base GIC currents are shown in Blue and GIC currents <u>after</u> Neutral Blocking at Two Sites (#1 and #10) are shown in Orange.

Network Priority for Neutral Blocking Devices

- Power Network Modeling shows the highest priority locations for the Installation of Neutral Blocking Devices
  - Select the substations, five at a time, that have the highest GIC currents for NBDs – then re-run the model
  - Typically GSUs followed by the first down-stream Auto-Transformers & SVCs show the highest GIC currents
  - All Transformers at a given site should have Neutral Blocking

One NBD device can protect one to three transformers if located together

Little to no change in GIC to ATC Neighbors for a severe (20 V/km) GMD Storm



Results derived from PowerWorld ™ modeling of Wisconsin Grid

Modeling shows Minimal NBD Whack-a-Mole effects to Wisc. ATC's Top Six (6) Tie-Lines with Neighbors as Neutral Blockers were applied

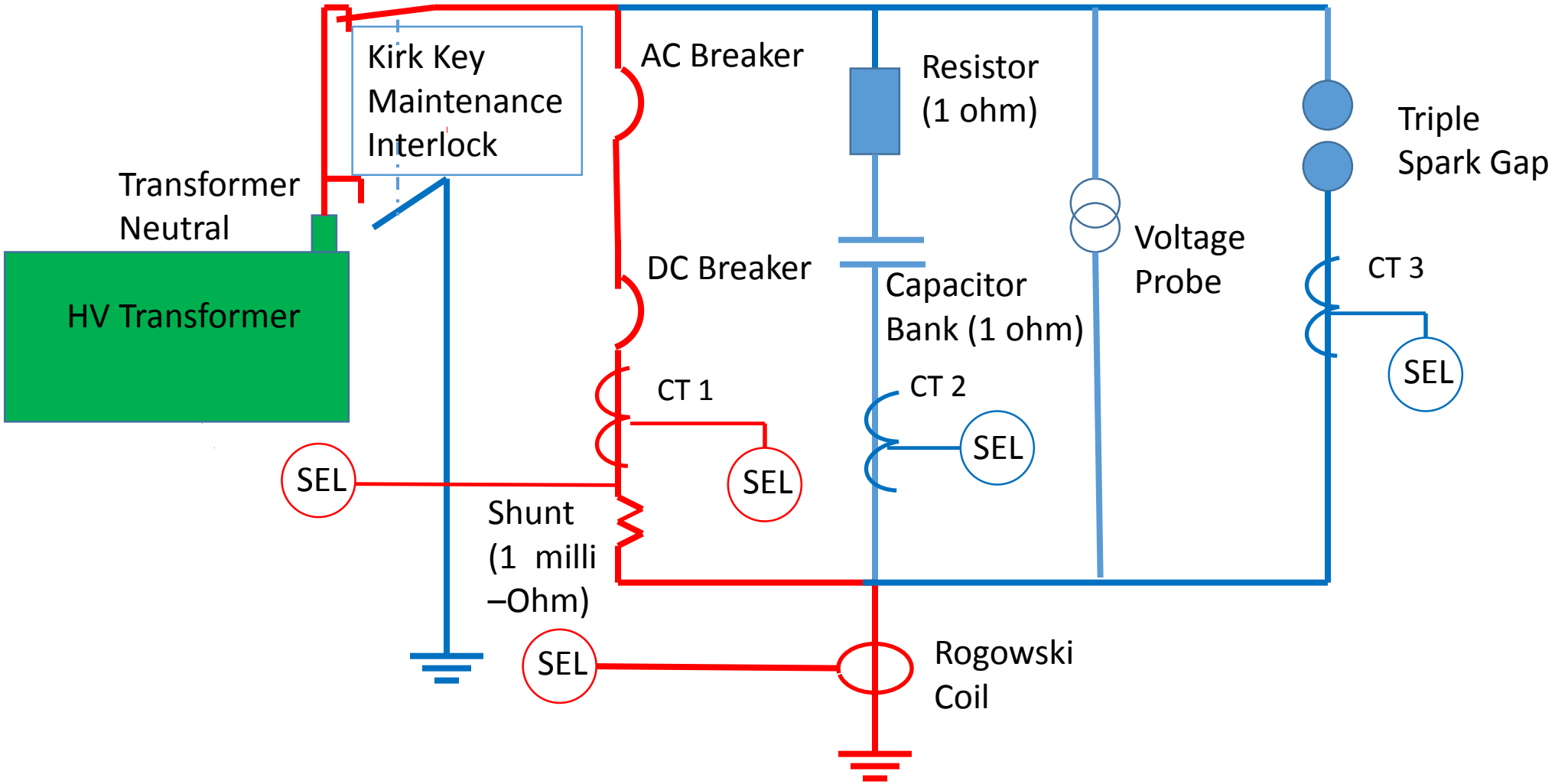
Neutral Blocking on 10% to 20% of HV & EHV Transformers:

- Significantly reduces Total Network GIC
- Significantly reduces Harmonics in the network
- Significantly reduces Reactive Power (VAR) consumption
- Minimizes the “Whack-a-Mole” effects
- Reduces the potential for Voltage Collapse

% of Transformers with Blocking	% Reduction of Total Network GIC	% Decrease in Reactive (VAR) Consumption
7 %	13.7 %	14.6 %
14 %	27.3 %	29.3 %
21 %	41.0 %	43.7 %

Results derived from PowerWorld ™ modeling of the Wisconsin ATC Power Grid

Benefits of Reducing Total Network Geomagnetic Induced Current (GIC) in the Wisconsin ATC Power Grid



Neutral Blocking Device (SolidGround™) Circuit Diagram

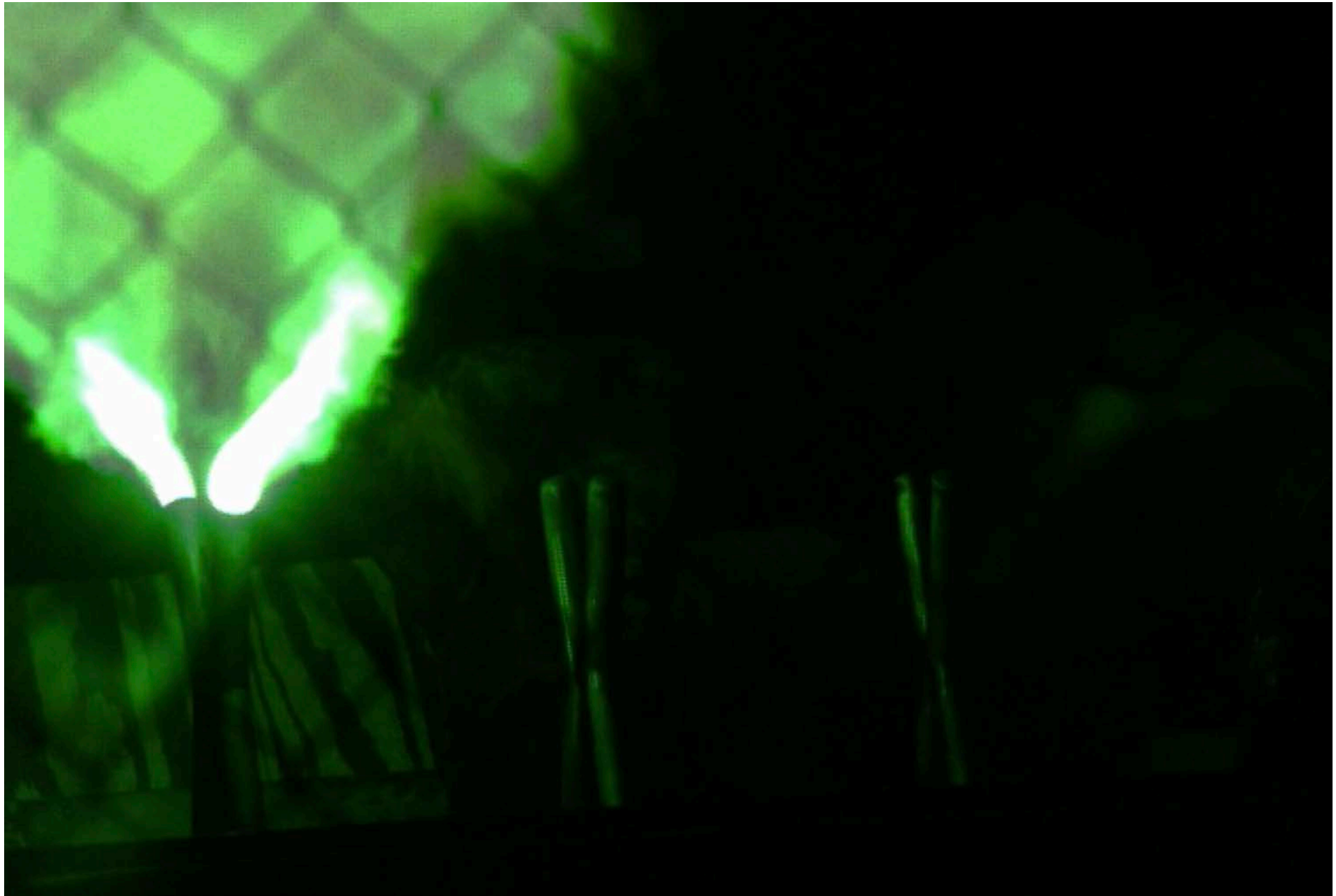
DuraGap™ - Spark Gap

- Robust patented Spark Gap (**dual redundant**)
- Reliable overvoltage protection for **repeated** high fault (**20kA**) currents with no cool down.
- Static device – no triggering electronics, or fragile electrodes. Preferred by utilities over the MOV (EPRI)
- Installed/operational on grid

At KEMA, DuraGap™ easily carried 20 faults with 10kV breakdown and 20kA. No degradation was found.

***20kA rating can be increased as needed**

DuraGap™ test at KEMA



AMERICAN TRANSMISSION COMPANY®

Helping to keep the lights on,
businesses running
and communities strong®

Operational Experiences of an HV Transformer Neutral Blocking Device

Michael B. Marz, Principal Transmission Planning Engineer

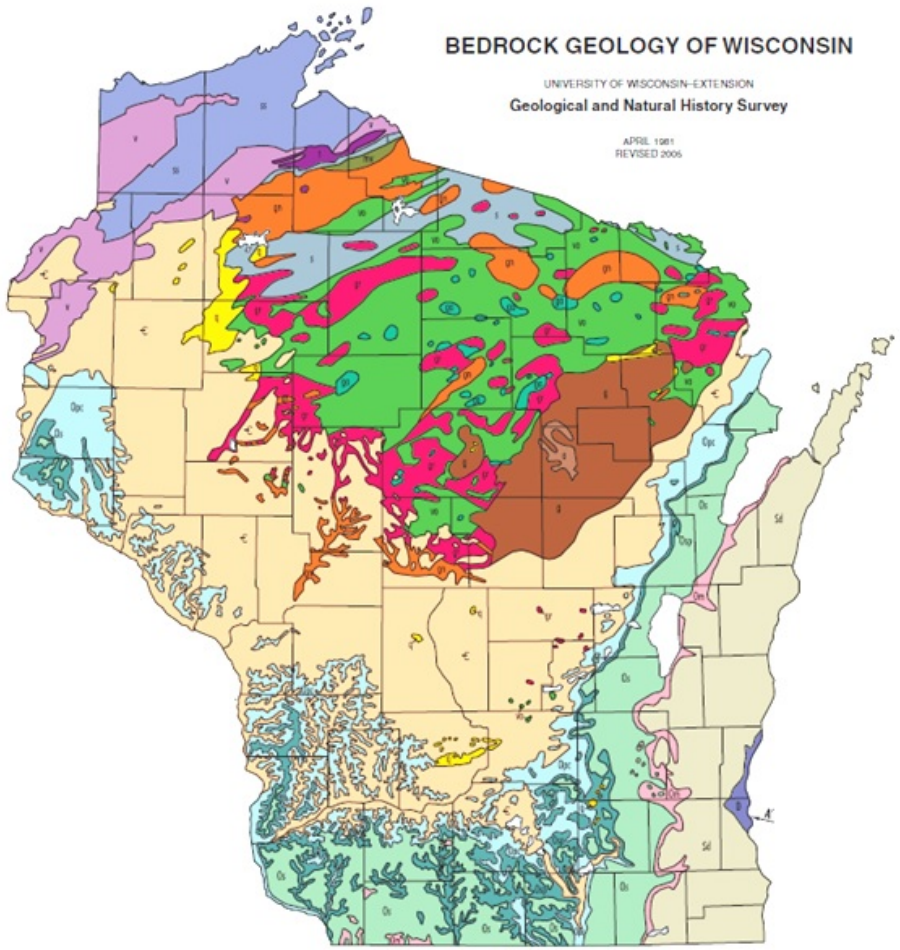
53rd Annual Minnesota Power System Conference
November 7, 2017, St. Paul, MN

American Transmission Company

- First multi-state, transmission-only USA utility (2001)
- 69 kV to 345 kV
- >9600 miles of lines
- 548 substations
- Operate Reliably & Plan Economically for Future Load and Generation

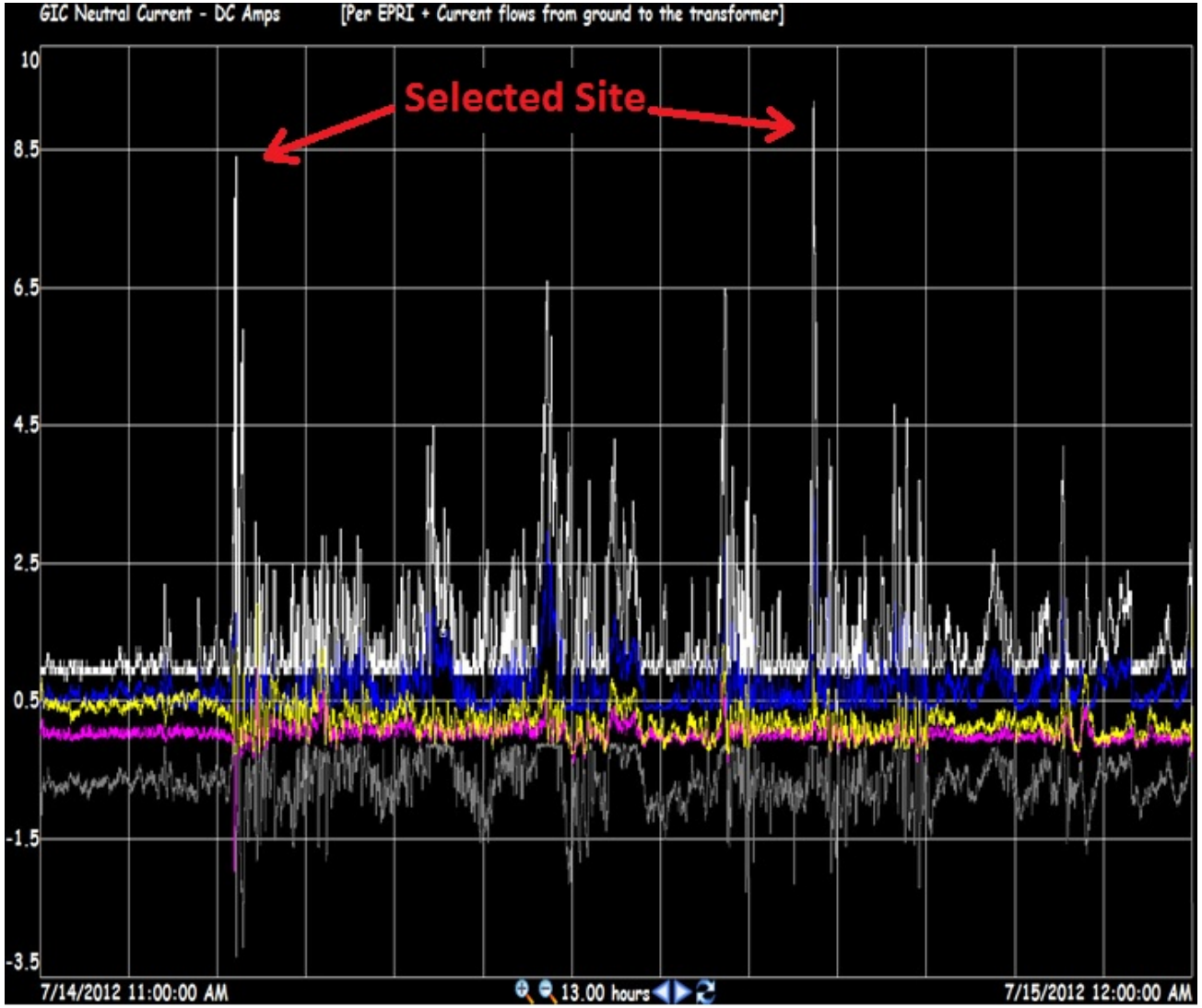
Why Did ATC Buy an NBD in 2013?

- Concern About GIC on Our System
  - Northerly Location (Igneous Rock)
  - New Long High Voltage Lines
  - Area Geology (High R Soils)
  - System Discontinuities
  - Results of Previous GMD Study
- Coming Regulations (TPL-007)
  - Improved Analysis Tools and Understanding of System and Equipment Vulnerabilities
  - If a Corrective Action Plan Needed, NBD would be One More Tool Available
- Need to Understand Technology and Application



Selecting NBD Substation/Location

- Remote from Generation (Limit GSU Effects)
- Long (160 miles) Radial 345 kV Line Connection
- Only One Transformer at Substation
- Historically High GIC Levels



Operational in February 2015

- 25’ from 345/138 kV, 300 MVA Autotransformer
- Connected Between Transformer Neutral & Ground Grid
- Control Signals to Control House and EMS

Bought in 2013 – Operational in 2015

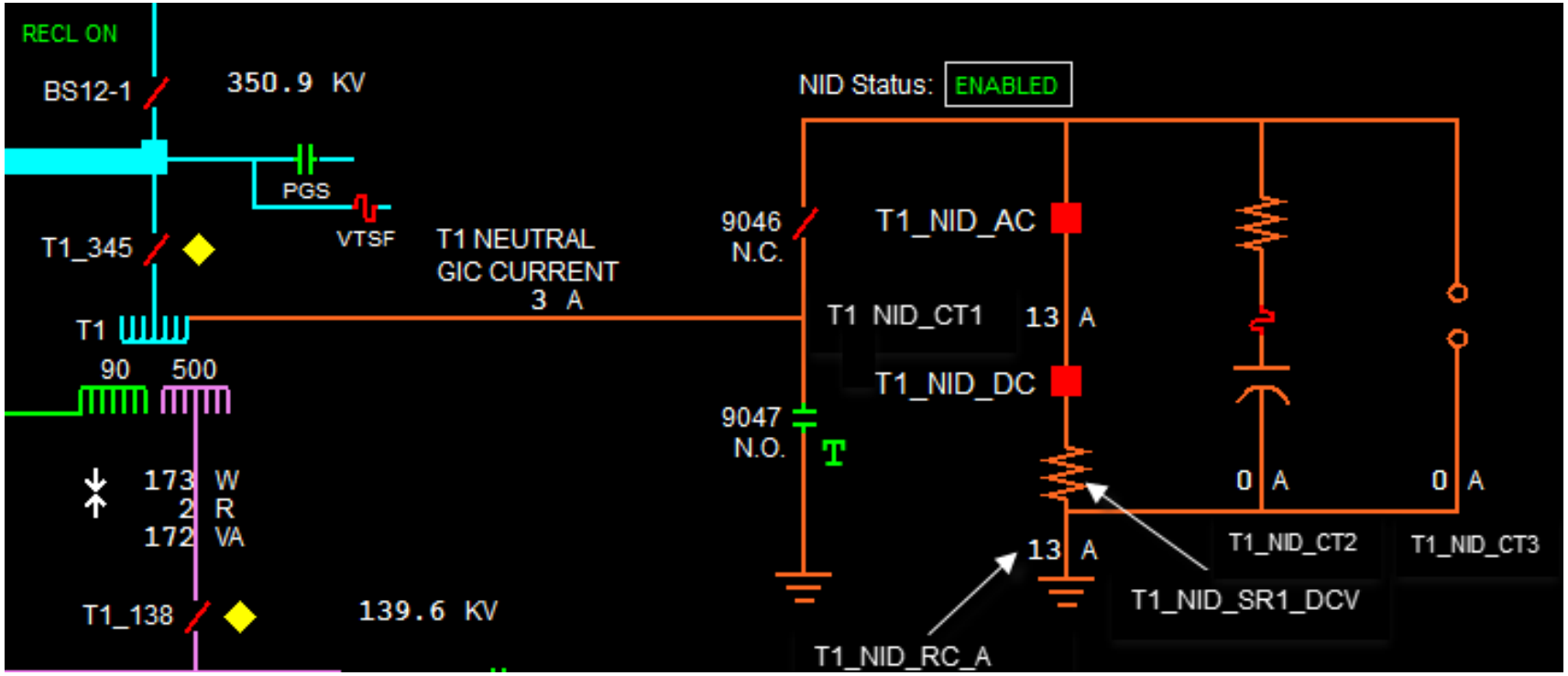
- Bought Prototype, Installed Commercial
  - Operations, Commissioning, Protection, Construction, etc., Input
- Enhancements
  - Voltage Probe
  - Grounding
  - Spark Gap Replaced MOVs
  - Bypass Switch Position Indicators
  - Major and Minor Alarms Defined

Acceptance Testing/Commissioning

- Simulator Used to Validate Software
  - Normal Conditions (Enter/Exit Blocking Mode)
  - Contingencies and Failures Modeled
    - Failed Breakers, Faults, Unbalanced Current, loss of Transformer Neutral, etc.
- Field Tests Confirmed
  - Sensors Properly Connected
  - Control Center Communications
- Operated In Automatic Response Mode

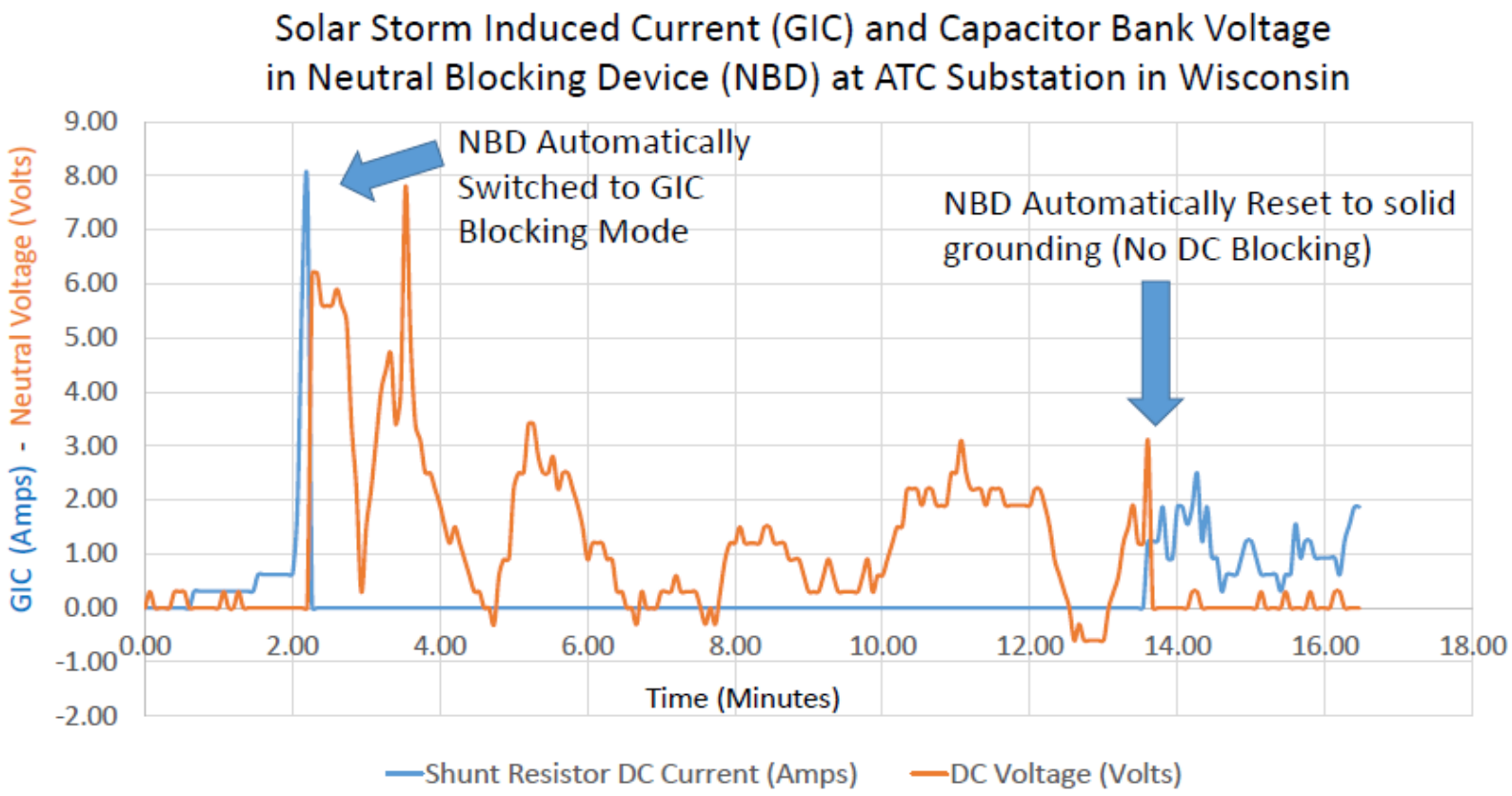
EMS View of the NBD

- Operators Monitor, But Don't Activate
- ATC Monitors Transformer Neutral Currents



June 22, 2015 Operation

- GIC > 5 A for 5 Seconds Blocking Mode Triggered
- Out of Blocking Mode After 10 Minutes if V < 8 V



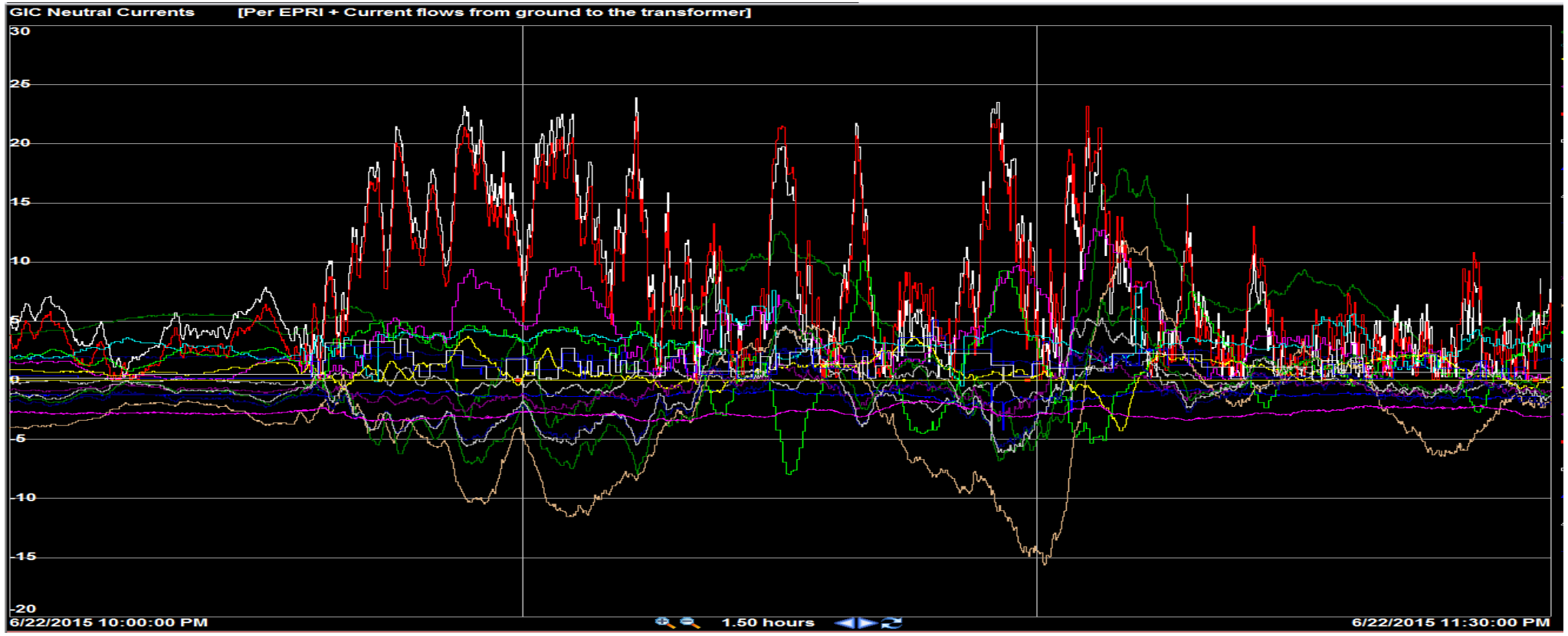
14 Automatic Operations June 22-23

- **Initial V and I Settings Low for Test Purposes**

Date (m/d/yr)	GMD Storm K-Index	Time Triggered into Protection Mode (CST)	Protection Mode Duration (minutes)
6/22/2015	Kp=7	13:34:00	11
“	“	14:51:36	10
“	“	15:02:12	“
“	“	15:17:48	“
“	“	22:21:09	“
“	“	22:31:17	“
“	“	22:44:30	“
“	“	22:55:30	“
“	“	23:05:46	“
“	“	23:46:37	“
6/23/2015	“	00:09:58	“
“	“	00:20:50	“
“	“	00:32:02	“
“	“	00:51:57	“

June 22, 2015, K8, 10:00-11:30 PM

- ATC Monitored Neutral Currents
- NBD Only In Service When Criteria Met



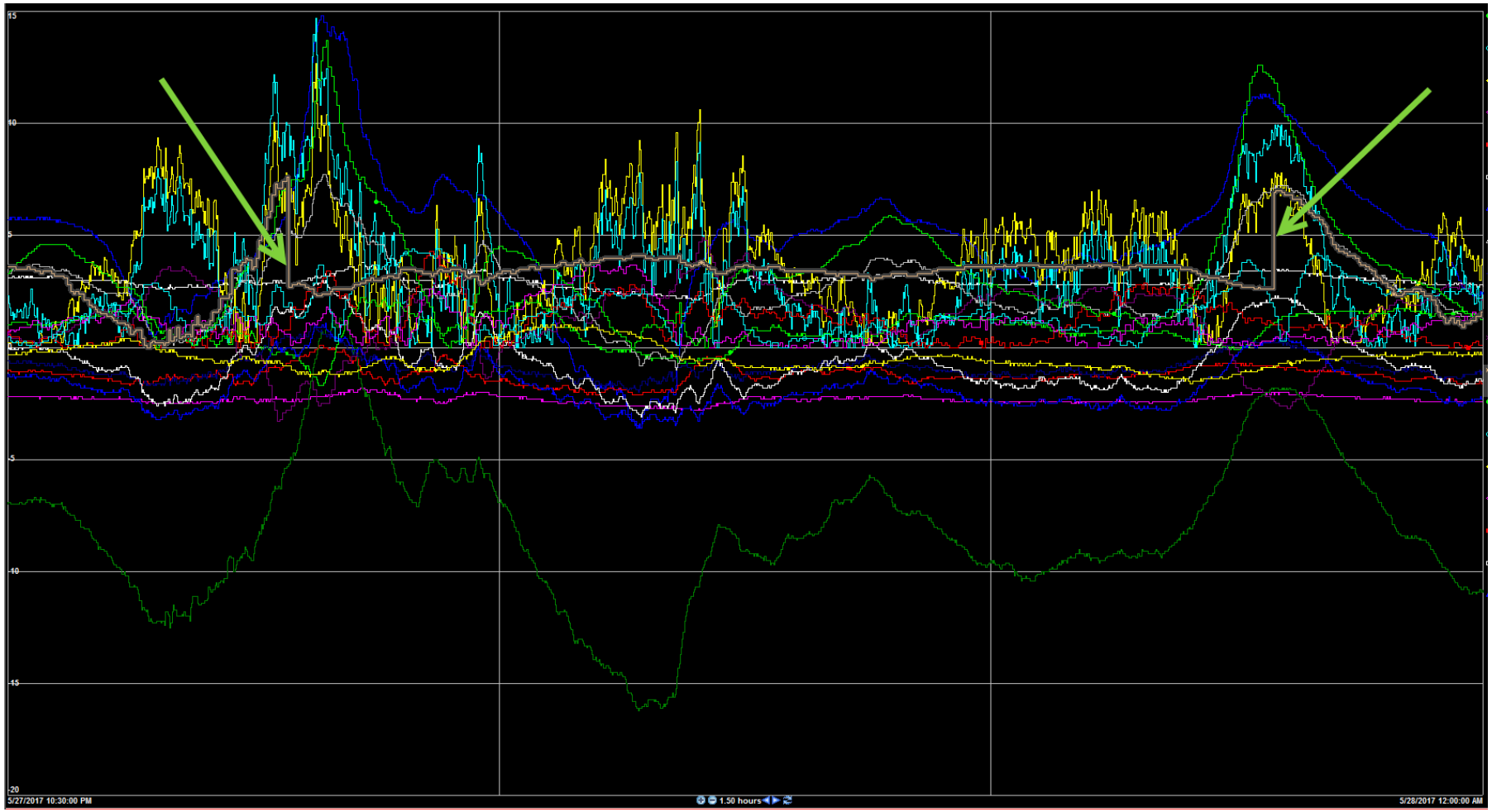
July 2016 to Sept. 2017 Operations

- **Blocking Duration Increased from 10 to 60 Minutes**

Date (m/d/yr)	GMD Storm K-Index	Time Triggered into Protection Mode (CST)	Protection Mode Duration (minutes)
7/19/2016	Kp=6	18:51:04	60
“	“	20:11:32	“
3/1/2017	“	18:08:52	“
“	“	23:59:24	“
5/27/2017	“	22:47:00	“
7/16/2017	“	14:45:24	“
9/7/2017	Kp=7	18:01:09	“
“	“	20:20:04	72
9/8/2017	“	07:20:18	60
“	“	08:29:40	“
“	“	09:35:24	“
“	“	10:42:44	“

May 27, 2017, No “Whack-a-Mole”

- GIC Drop at NBD Location – No Increase Elsewhere



NBD Operational Experience

- Device Is Operating as Designed
  - Blocks GIC Preventing Adverse Effects
  - Missed Some Storms for Station Equipment Outages Not Related to NBD
- Taking NBD Out of Service Straightforward
- No Need to Adjust Relays or Other System Equipment
- Low Maintenance

For more information please contact

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Thanks for Your Attention

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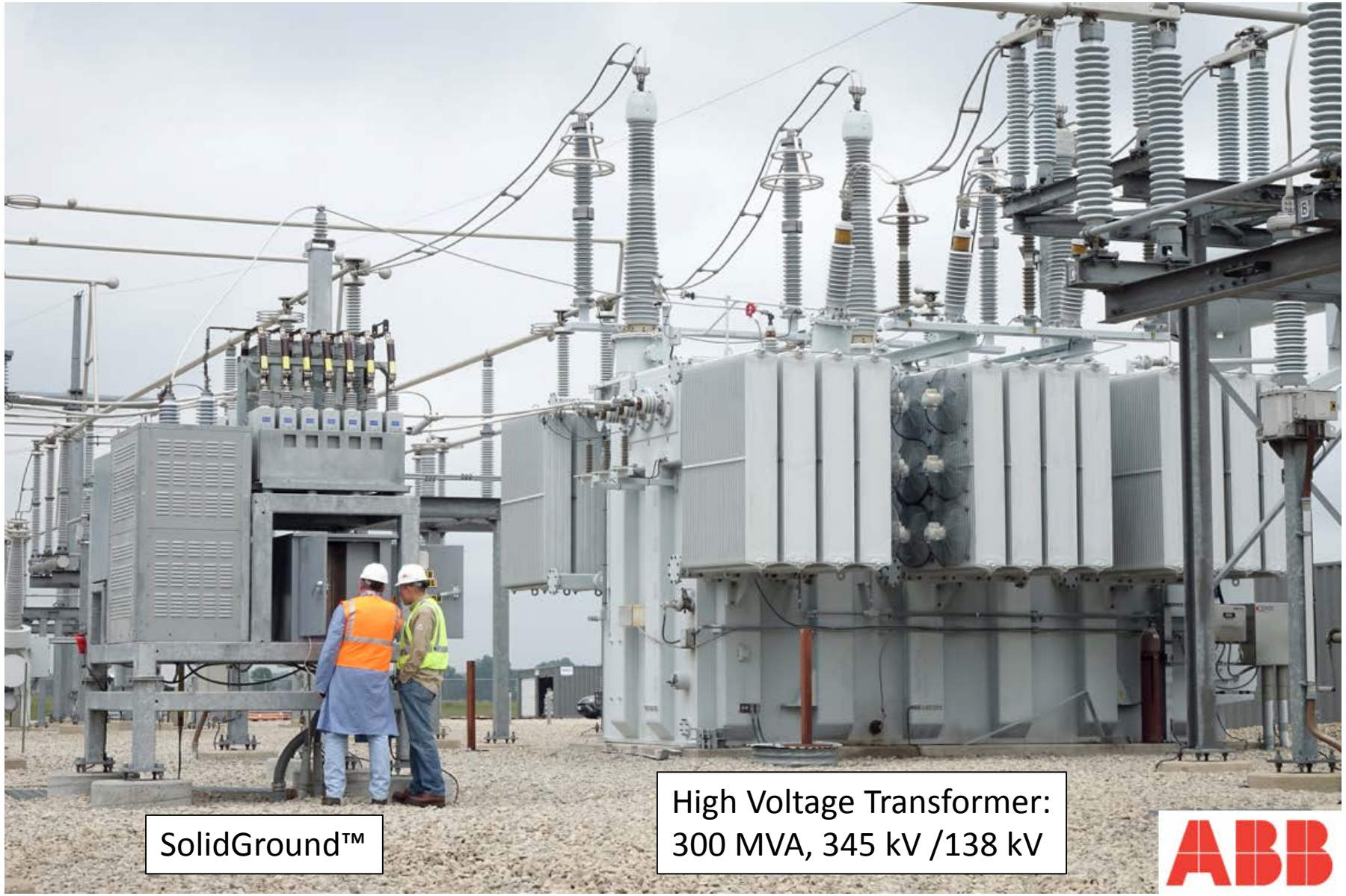
Backup Slides

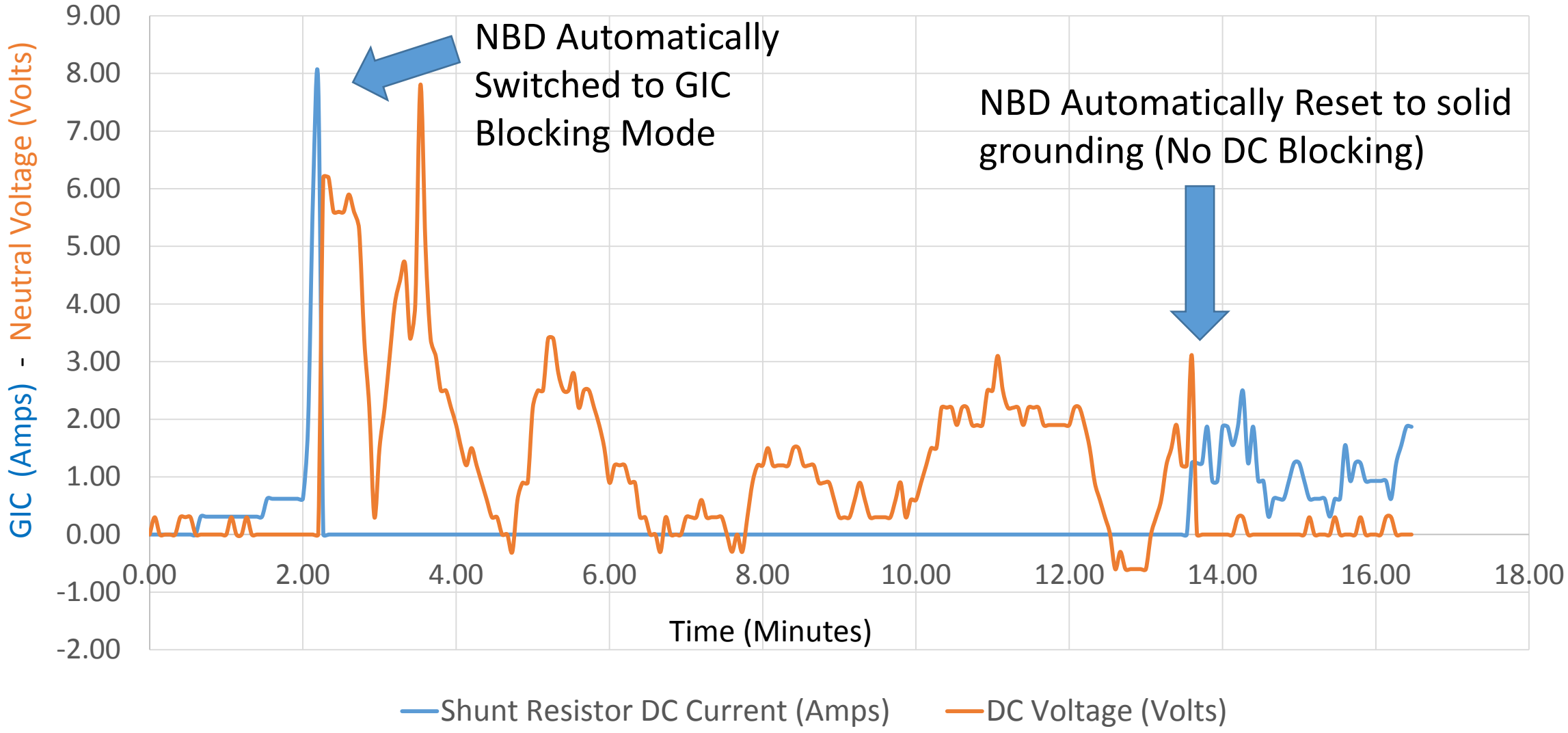


SolidGround™ Neutral Blocking Device Installed and Operational at a Northern Wisconsin ATC Substation

Selection of NBD Installation Site, Acceptance Testing and Commissioning

- Sight Selection Criteria:
  - Substation that supplies bulk power to the Upper Peninsula of Michigan
  - Substation Remote from generation sites
  - Connecting transmission line that historically experienced significant GIC flows
  - Substation with only one transformer
- Acceptance Testing and Commissioning
  - Software testing was validated using an NBD electric model simulator
  - Commissioning included simulating the NBD and software through a list of potential operation and contingency conditions
  - Communications and sensor data connections to the controller were also verified

Solar Storm Induced Current (GIC) and Capacitor Bank Voltage in Neutral Blocking Device (NBD) at ATC Substation in Wisconsin



Recording of Neutral Blocking Device (NBD) Automatic Operation on June 22, 2015 – Blue Trace is GIC Current (Amps) - Orange Trace is Capacitor Bank Voltage (Volts)

	Table I – NBD Automatic GMD		
	Protection Operations - June 2015		
Date (m/d/yr)	GMD Storm K - Index †	SG Triggered into Protection Mode CST	Duration in Protection Mode (Min.)
6/22/2015	Kp = 7	13:34:00	11
"		14:51:36	10
"		15:02:12	"
"		15:17:48	"
"		22:21:09	"
"		22:31:17	"
"		22:44:30	"
"		22:55:30	"
"		23:05:46	"
"		23:46:37	"
6/23/2015		00:09:58	"
"		00:20:50	"
"		00:32:02	"
"		0:51:57	"
	14 Protection Operations in June 2015		

Table II- NBD Automatic GMD Protection Operations - July 2016 to Oct 2017			
Date (m/d/yr)	GMD Storm K - Index †	SG Triggered into Protection Mode CST	Duration in Protection Mode (Min.)
7/19/2016	Kp = 6	18:51:04	60
		20:11:32	60
3/1/2017	Kp = 6	18:08:52	60
3/1/2017		23:59:24	"
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"		10:42:44	"
12 Protection Operations June 2016 thru Sept 2017			