

# Historic Event GMD Analysis

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PowerWorld Simulator Users Group

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# **Non-Uniform Field Modeling and Historic Event Files**



# 3-D Earth Models

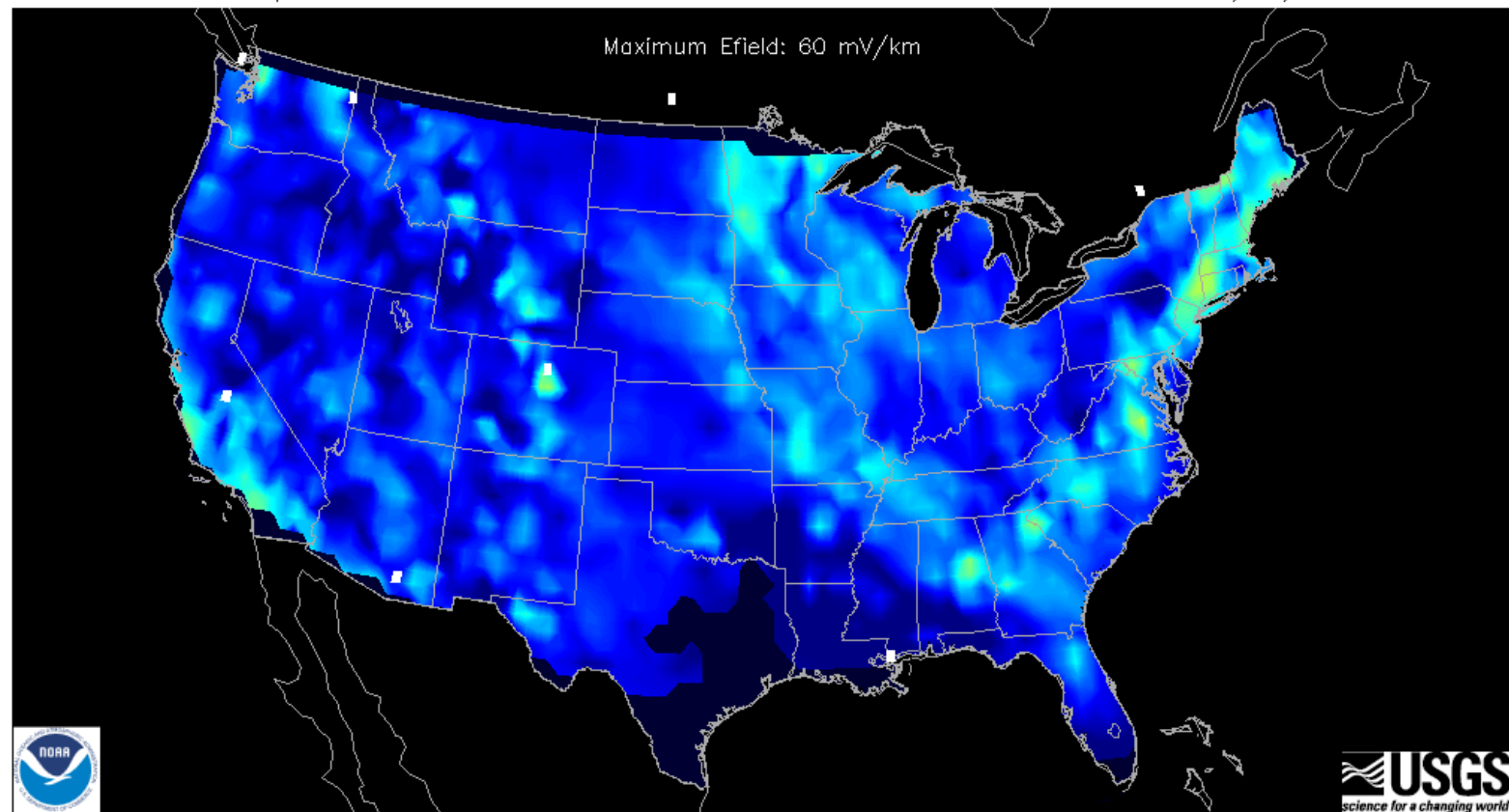
- 3-D Earth Models produce more complex and realistic non-uniform surface E-field behavior based on empirical measurements
  - Earthscope (NSF funded 2003-2018)
  - US Magnetotelluric (MT) Array
  - Empirical Magnetotelluric Transfer Functions (EMTF): hosted by NOAA/SWPC
- Data gaps still exist, most notably in Canada and parts of Texas
- PowerWorld Simulator's time-varying E-field Calculation Mode can make use of these inputs as researchers and industry develop them



# Emprical EMTF – 3D Model (CONUS)

Geoelectric Field Map Version 2

2025/04/17 21:11:30UTC



1 10 100 1000 10000  
Intensity Scale (mV/km)  
Geomagnetic Data provided courtesy of USGS & NRCAN  
Model validation is ongoing – see web page  
One-minute averaged values – 0.5 x 0.5 degree grid  
Map Creation Time: 2025-04-17T21:16:02UTC  
Interpolation method: SECS (16 stations reporting)  
Empirical EMTF interpolated to 0.5 degree grid  
EMTF's courtesy of Earthscope/OSU/USGS

<https://www.swpc.noaa.gov/products/geoelectric-field-models-1-minute>

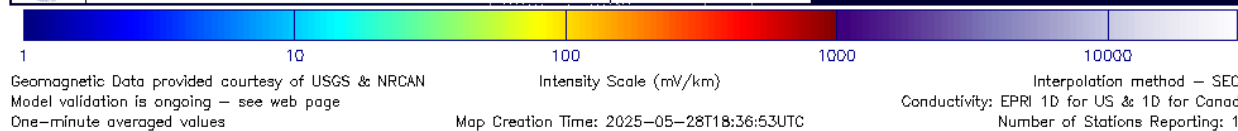
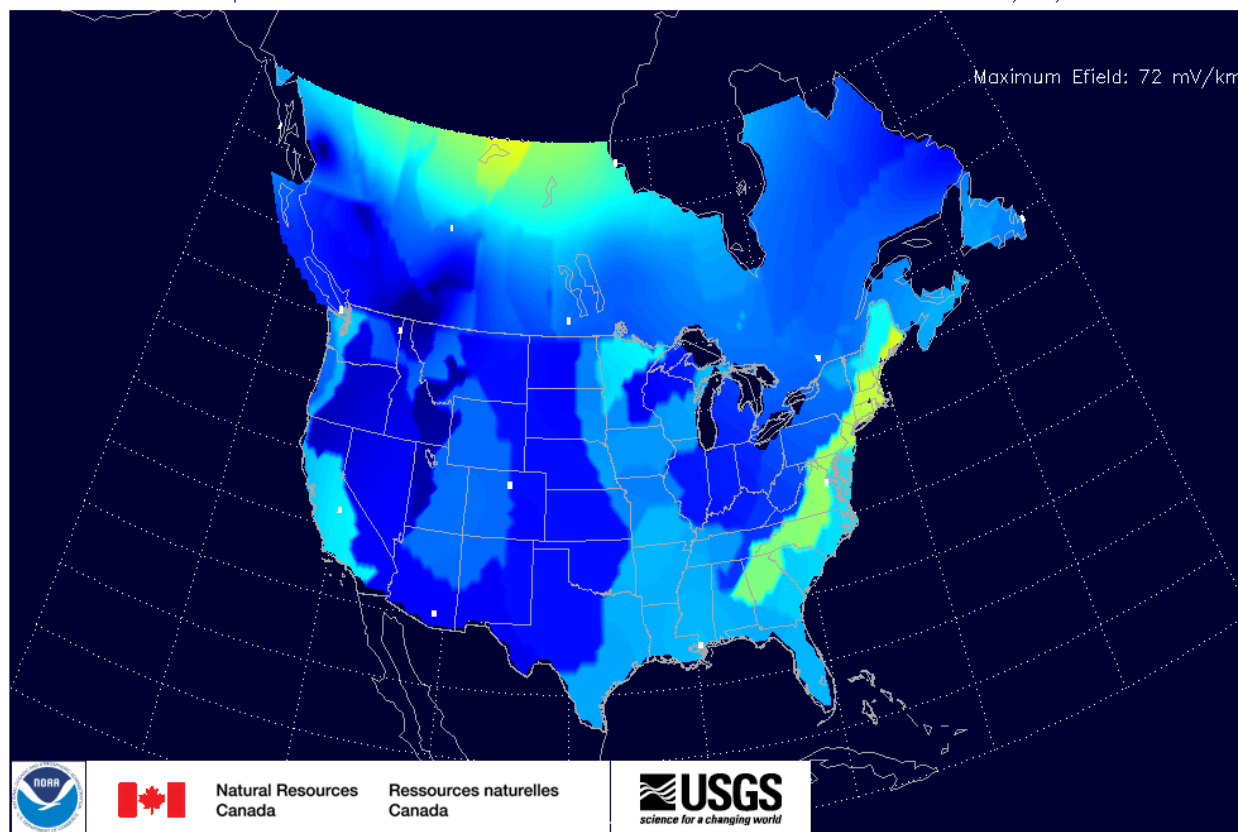
The near real-time E-field mapping project is a joint effort between NOAA/SWPC, the USGS geomagnetism group, NRCAN Space Weather, and the NASA/CCMC



# US Canada 1D Model

Geoelectric Field Map US-Canada-1D

2025/05/28 18:31:30UTC



Based on USGS and NRCAN 1D conductivity physiographic regions; includes CONUS and Canada up to 60 degrees north latitude



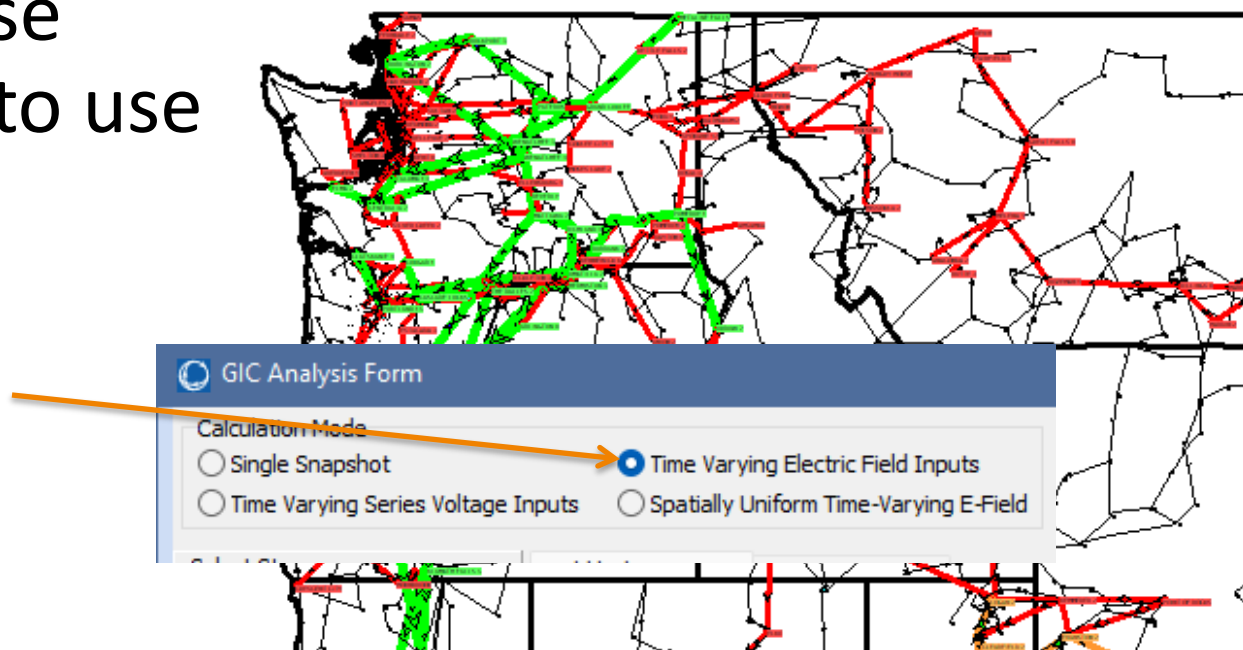
# Knowledge Base Reference

- Historic Events based on NOAA SWPC EMTF 3D Model data are available for use in PowerWorld Simulator at <https://www.powerworld.com/knowledge-base/historic-gmd>
  - March 1989 solar storm (March 13-14, 1989)
  - Bastille Day solar storm (July 14-16, 2000)
  - Halloween solar storms (October 30 – November 2, 2003) – **download this for the example**
  - September 2017 X8.2 class solar flare (September 6-8)
  - May 12, 2021
  - April 9-10, 2022
  - March 23-24, 2023
  - Gannon Storm (May 10-12, 2024)



# Time Varying Electric Field Inputs

- Binary (B3D) or text (GeoJSON or dat) file formats
- Include time points and geo-spatial (longitude, latitude) points with Eastward and Northward E-field at each point
- Demonstrated here with case **ACTIVSg10k.pwb** (feel free to use ANY case)
- On the *GIC Analysis Form*, set **Calculation Mode** to “Time Varying Electric Field Inputs”





# Halloween 2003 Solar Storm Example

- By *Non-uniform Electric Field Files* click the *Open File* button and load the Halloween Storm file  
**20031030-31-Efield-empirical-EMTF.2022.12-0.5x0.5**
- File is loaded as a new “Event”
- *Setup Time Varying Series on Load* will create corresponding inputs in “Time Varying Series Voltage Inputs” **Calculation Mode** (needed for Power Flow and Transient Stability Calculations)
  - De-check prior to opening files if you need to manipulate data or load multiple events first
  - If de-checked, use the *Setup Time Varying Series* button after all other operations are finished

Field/Voltage Input

Modeling of Multiple Time-Varying Electric Field Events

Event Count 1 (Active = 1) Events 20031027T000030-19-Efield-empir ☒ Active Rename Event Delete Event

Non-uniform Electric Field Files (\*.b3d, \*.dat, \*.json)

Open File

Open File New Event

Clear Existing Time Points or Merging

☒ Clear Existing ☐ Merge ☐ Prompt for New Event Name ☐ Save Non-uniform Fields in PWB File

☒ Setup Time-Varying Series on Load

Options for Loading Multiple Files of Type

☒ Just selected file

☐ All after last time in Time Points List

☐ All before first time in TimePoints List

☐ All files of selected type





# Halloween 2003 Solar Storm Example

- 5040 time points loaded, spanning Oct 30-Nov 2, 2003 with 60-second time resolution; bottom panes show time point data
- With sorting, we can quickly identify the time and coordinates of the peak E-Field of the Event
- But what are the most significant time periods for GIC in our power system?

Selected Time Point

Corresponding E-field at each geolocation

Time Points (Select Point to Preview)						
	Time Offset, Seconds	Maximum Electric Field V/km	Maximum Electric Field Longitude	Maximum Electric Field Latitude	Save in File	Date/Time String
1	132000.000	7.662	-70.0000	43.5000	YES	10/31/2003 12:40:30 PM (UTC)
2	132060.000	7.271	-70.0000	43.5000	YES	10/31/2003 12:41:30 PM (UTC)
3	217740.000	6.089	-70.0000	43.5000	YES	11/1/2003 12:29:30 PM (UTC)
4	131940.000	6.000	-73.5000	42.0000	YES	10/31/2003 12:39:30 PM (UTC)
5	217680.000	5.605	-77.5000	37.5000	YES	11/1/2003 12:28:30 PM (UTC)
6	132120.000	5.184	-70.0000	43.5000	YES	10/31/2003 12:42:30 PM (UTC)
7	201360.000	4.898	-70.0000	43.5000	YES	11/1/2003 7:56:30 AM (UTC)
8	201300.000	4.860	-70.0000	43.5000	YES	11/1/2003 7:55:30 AM (UTC)

Show Interpolated Values							
Latitude	40.00	Longitude	0.00	Get Interpolated Value	Eastward	Northward	<input type="checkbox"/> Include A
Time Point Grid Preview (First Entry is the Eastward Value, the Second the Northward)							
	Longitude	Latitude	Distance to Station (km)	Electric Field East, V/km	Electric Field North, V/km	Electric Field Magnitude, V	Electric Field Angle, Compass Degrees
1	-70.0000	43.5000	488.4400	-3.8571	-6.6199	7.662	210.2272
2	-73.5000	42.0000	412.3800	6.3408	-4.1825	7.596	123.4094
3	-73.5000	41.5000	464.1200	6.0720	-3.8647	7.198	122.4763
4	-70.5000	43.5000	453.0100	-2.0502	-6.2868	6.613	198.0619
5	-73.0000	41.5000	479.9700	5.5675	-3.4969	6.575	122.1329



# Calculating Results for the Entire Time Series

- The **Transient Stability** tool is well-suited for quickly computing GIC reactive power losses and screening time points for closer analysis
- The **Time Step Simulation** tool can perform multi-period power flow solutions to examine non-linear voltage response
- Return to **Field/Voltage Input** page
- Switch the **Calculation Mode** to “Time Varying Series Voltage Inputs”
- Verify that DC input voltages are populated for branches across timepoints (0 to 302340)

Field/Voltage Input															
AC Line Input Voltages															
Substation EField V/km (Display Only) Substation EField Direction Degrees (Display Only)															
	Branch ID	From Number	To Number	Circuit	From Latitude	To Latitude	From Longitude	To Longitude	Distance Between Substations (km)	Timepoint_1	Timepoint_2	Timepoint_3	Timepoint_4	Timepoint_5	Timepoint_6
1	Time in Seconds									0.000	60.000	120.000	180.000	240.000	300.000
2	Branch '10002' '10001' '1'	10002	10001	1	47.6956	48.2414	-124.1836	124.5778	67.45	0.000	0.000	0.000	0.000	0.000	0
3	Branch '10011' '10001' '1'	10011	10001	1	48.0025	48.2414	-123.7620	124.5778	66.29	-0.018	-0.018	-0.009	0.000	0.000	-0
4	Branch '10014' '10002' '1'	10014	10002	1	47.1889	47.6956	-123.6860	124.1836	67.69	-0.002	0.001	0.004	-0.001	-0.012	-0
5	Branch '10004' '10003' '1'	10004	10003	1	46.9275	47.0400	-124.1719	124.0570	15.26	0.000	0.000	0.000	0.000	0.000	0



# GIC in Transient Stability

- Open **Transient Stability** dialog and go to **Options → Power System Model → Common** page
- Check “Just Calculate GIC with No Network Solution” (allows fast computation of time-varying GIC quantities without transient stability numeric integration)

—Geomagnetic Induced Current Options—

Include GIC Effects (Option Set on GIC Form)

☒ Just Calculate GIC with No Network Solution

GIC XF Time Constant (Sec)



# GIC in Transient Stability

- Go to **Simulation** → **Control** page
- Set the Start Time, End Time, and Time Step to correspond to the GIC input data (or any desired subset)
- Especially for GIC-only simulations (no network solution), it usually works best to store every time point for plots
- Go to **Result Storage** → **Store to RAM Options**

Simulation Add...

Control Definitions Violations

Simulation Time Values

Start Time (seconds) 0.000

End Time (seconds) 302340.000

Time Step (seconds) 60.000000

Specify Time Step in

☒ Seconds

☐ Cycles

Result Storage

Where to Save/Store Results

☒ Store Results to RAM

☐ Save Results to Hard Drive

☐ Save the Results stored to RAM in the PWB file

Save Results Every n Timestep

1

☐ Do Not C

☒ Save the



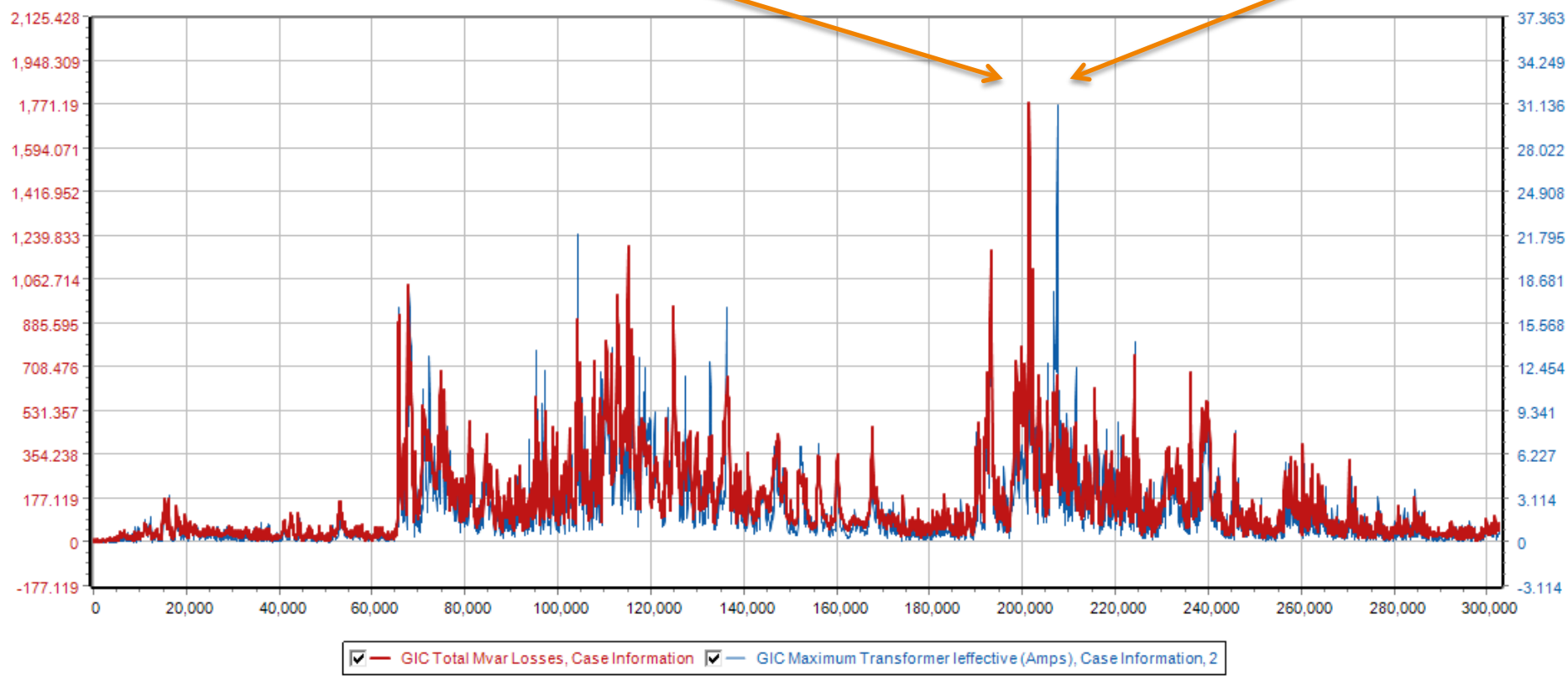
# Plot Definitions

- Go to **Plots** → **Plot Designer** page and create plots
  - For overall system response
    - *Device Type* “Case Information” and *Field* “GIC Total Mvar Losses”
    - *Device Type* “Case Information” and *Field* “GIC Maximum Transformer Ieffective (Amps)”
  - Other device quantities that may be of interest
- Click “Run Transient Stability”



# GIC Time Series Plots

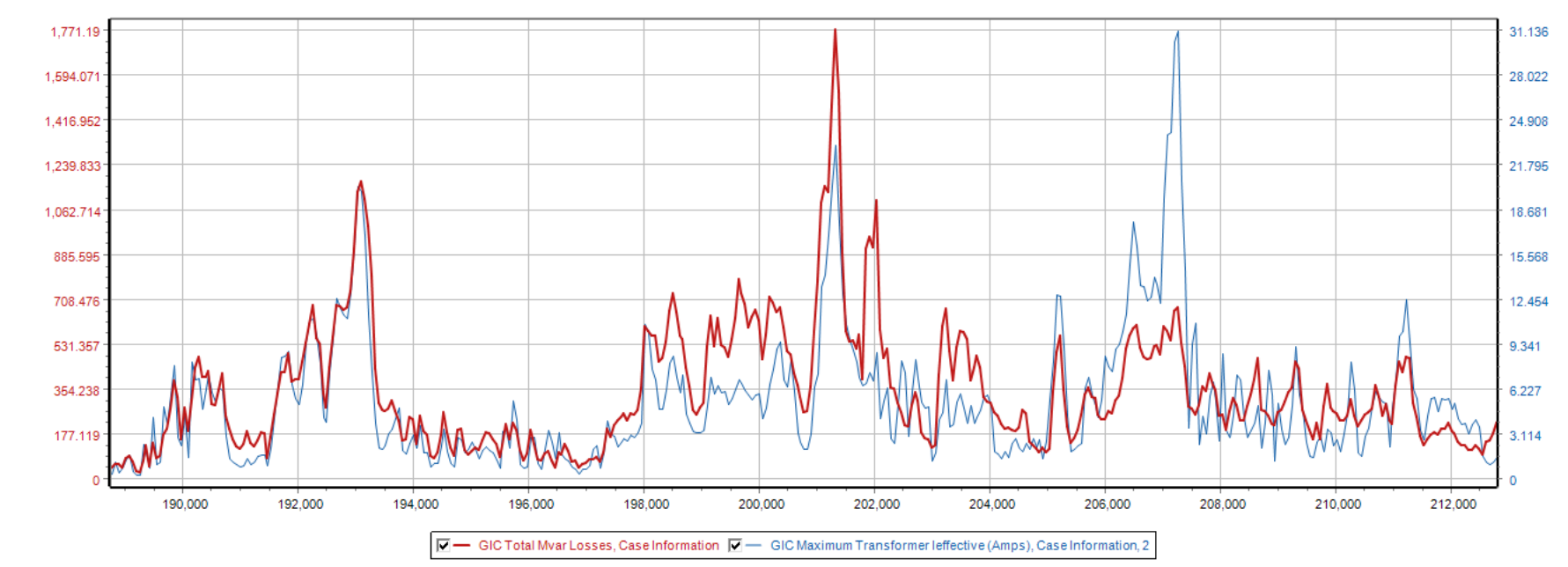
Mouse Over plot traces for details; peak transformer GIC at t=207,240;  
peak losses at t=201,300





# Period of Peak Activity

- Zoom into the plot between  $t=189,000$  to  $t=212,000$
- This is a relatively short period of peak activity for which we may wish to examine non-linear voltage response (i.e. power flow solution)





# Non-linear Power Flow Solutions with GIC

- For events with higher frequency variation, such as high-altitude electromagnetic pulse E3 (HEMP E3), it may be appropriate to also perform a transient stability dynamic simulation
- For most solar GMD, the steady-state non-linear power flow is more salient
- Transient Stability can be used for quick calculation of time-varying GIC – then you can perform a power flow on those time periods with the highest GIC or reactive power losses





# Non-linear Power Flow Solutions with GIC

- If there are just a few time periods of interest, you could set the *Current Time Offset from Reference (Seconds)* in the GIC Analysis Form, then solve the power flow for each
- Methods for *many* time periods of interest
  - Automation using *GlCTimeVaryingCalculate* script function to set the time and solve the power flow
  - Time Step Simulation (TSS) tool



# GIC with Time Step Simulation

- Open Tools – Time Step Simulation
- Click “Insert Time Points”
- For **New Timepoint Source**, choose “GIC Time Varying Electric Field Inputs” and check “For GIC Time Inputs, Use GIC UTC or Time Zone Option”
- Click “OK”

New Timepoint Dialog

New Timepoint Source

☐ Manual Entry Using Below Fields

☒ GIC Time Varying Electric Field Inputs

☐ Delete Existing Timepoints Existing Count 0

☒ For GIC Time Inputs, Use GIC UTC or Time Zone Option

Manual Entry Fields

Start Date January 30, 2025

Start Time 12 : 00 : 00 AM Milliseconds 0

Total Number of Timepoints to Enter 24

Time Zone for Above Date/Time

☒ Assumed Time Zone ☐ UTC

Time Zone UTC Offset (from Time Step Options page) -6.0

Interval for Additional Timepoints

Hours 1 Seconds 0

Minutes 0 Milliseconds 0

OK Cancel



# GIC with Time Step Simulation

- The Solution Type “GIC Only (No Power Flow)” allows calculation of GIC quantities, similar to the “Just Calculate GIC with No Network Solution” in Transient Stability (albeit slower)
- To compute AC power flow quantities, however, leave all Solution Types as “Single Solution”

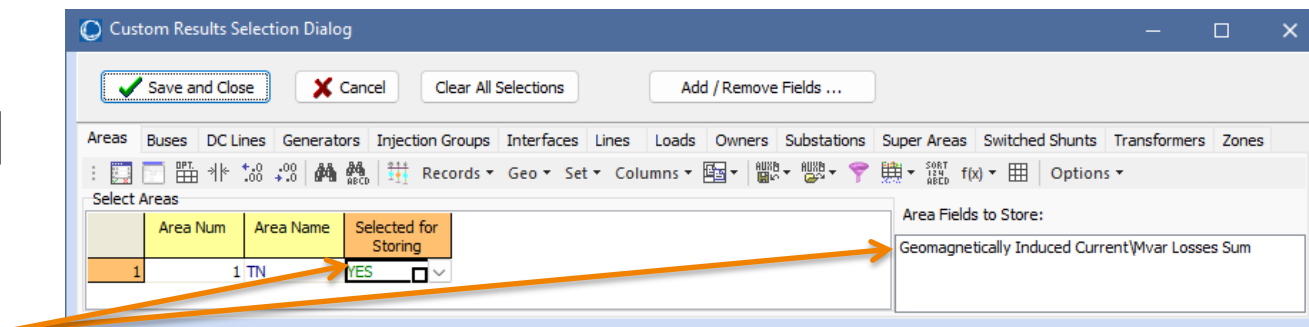
	Date	Time	Skip	Processed	Solution Type	Run Contingency	Solved
1	06/22/2015	12:00:00 AM	NO	NO	Single Solution	NO	Not Started
2	06/22/2015	12:00:10 AM	NO	NO			
3	06/22/2015	12:00:20 AM	NO	NO			
4	06/22/2015	12:00:30 AM	NO	NO			
5	06/22/2015	12:00:40 AM	NO	NO			
6	06/22/2015	12:00:50 AM	NO	NO			
7	06/22/2015	12:01:00 AM	NO	NO			
8	06/22/2015	12:01:10 AM	NO	NO			
9	06/22/2015	12:01:20 AM	NO	NO			
10	06/22/2015	12:01:30 AM	NO	NO			

- Single Solution
- Unconstrained OPF
- OPF
- SCOPF
- GIC Only (No Power Flow)
- Apply Only [With Weather]
- Toggle All



# GIC with Time Step Simulation

- Go to the **Results** page and choose the “View/Modify” button under the Results Definition group
- Click “Add/Remove Fields” and choose
  - “Geomagnetically Induced Current\Mvar Losses Sum” for SuperArea 1 (FullCase)
  - Geomagnetically Induced Current\Transformer Per Phase Effective GIC” for all transformers
  - “Voltage\Per Unit Magnitude” for load buses (hint: use Quick Filter)
  - Any other desired quantities
- Click “Save and Close”





# GIC with Time Step Simulation

- To run just the peak period, set the Starting Time to 11/1/2023 4:30:30 AM and the Ending Time to 11/1/2023 10:53:30 AM
- Click the “Do Run” button

☐ Time Step Simulation

Starting Time:	11/ 1/2003	4:30:30 AM	<input type="button" value="Do Run"/>
Ending Time:	11/ 1/2003	10:53:30 AM	

☐ Run Time Backwards (End to Start) ☒ Automatically Pause on

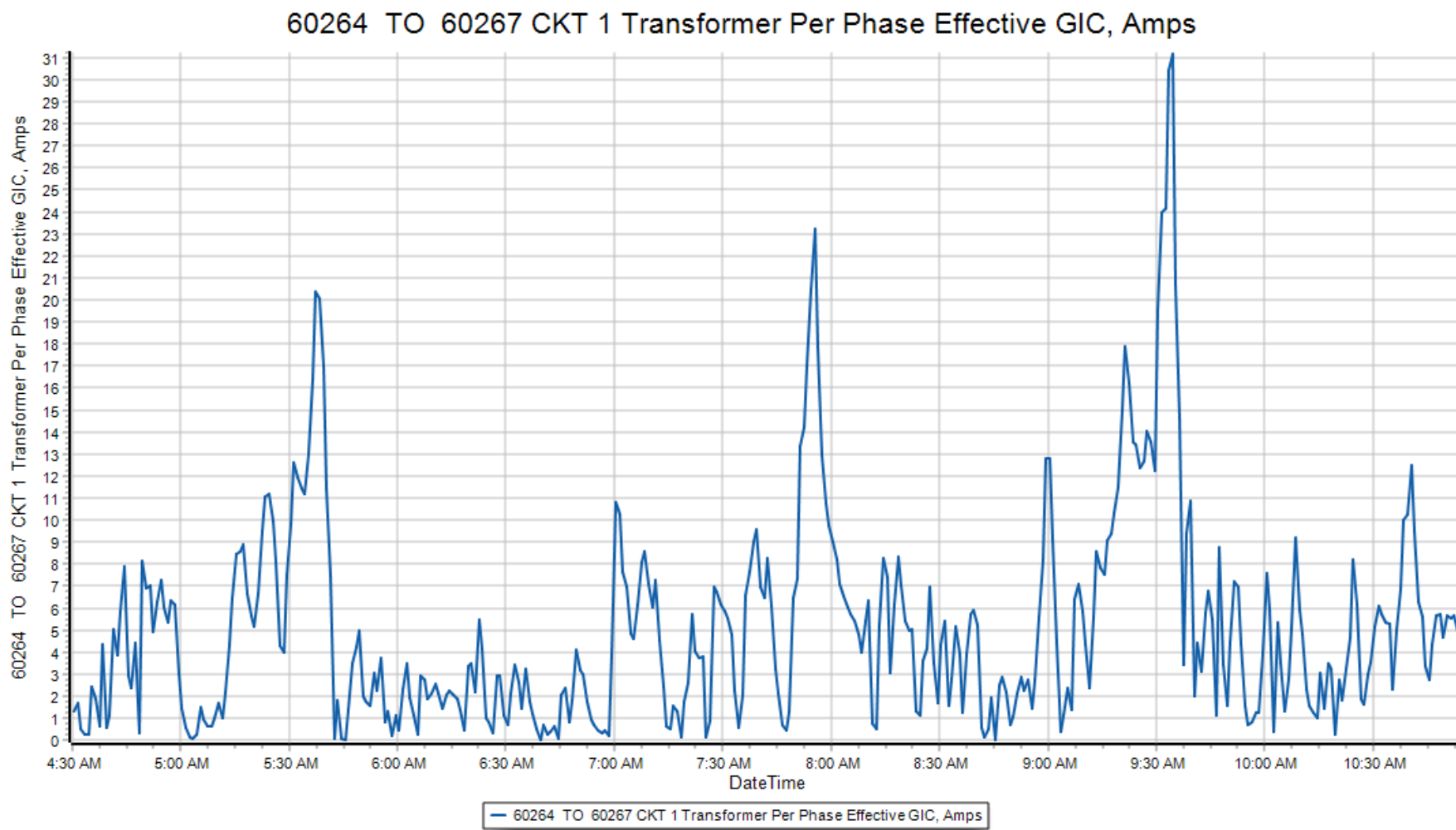


# Time Step Simulation Results

- TIP: If you have a large number of results, as in this example, it may be best to Send All Results to Excel to perform analysis and decide what is worth plotting
- Examine Results in Tables and/or Plot Columns (**Columns → Plot Column(s)** from the Case Information Toolbar)

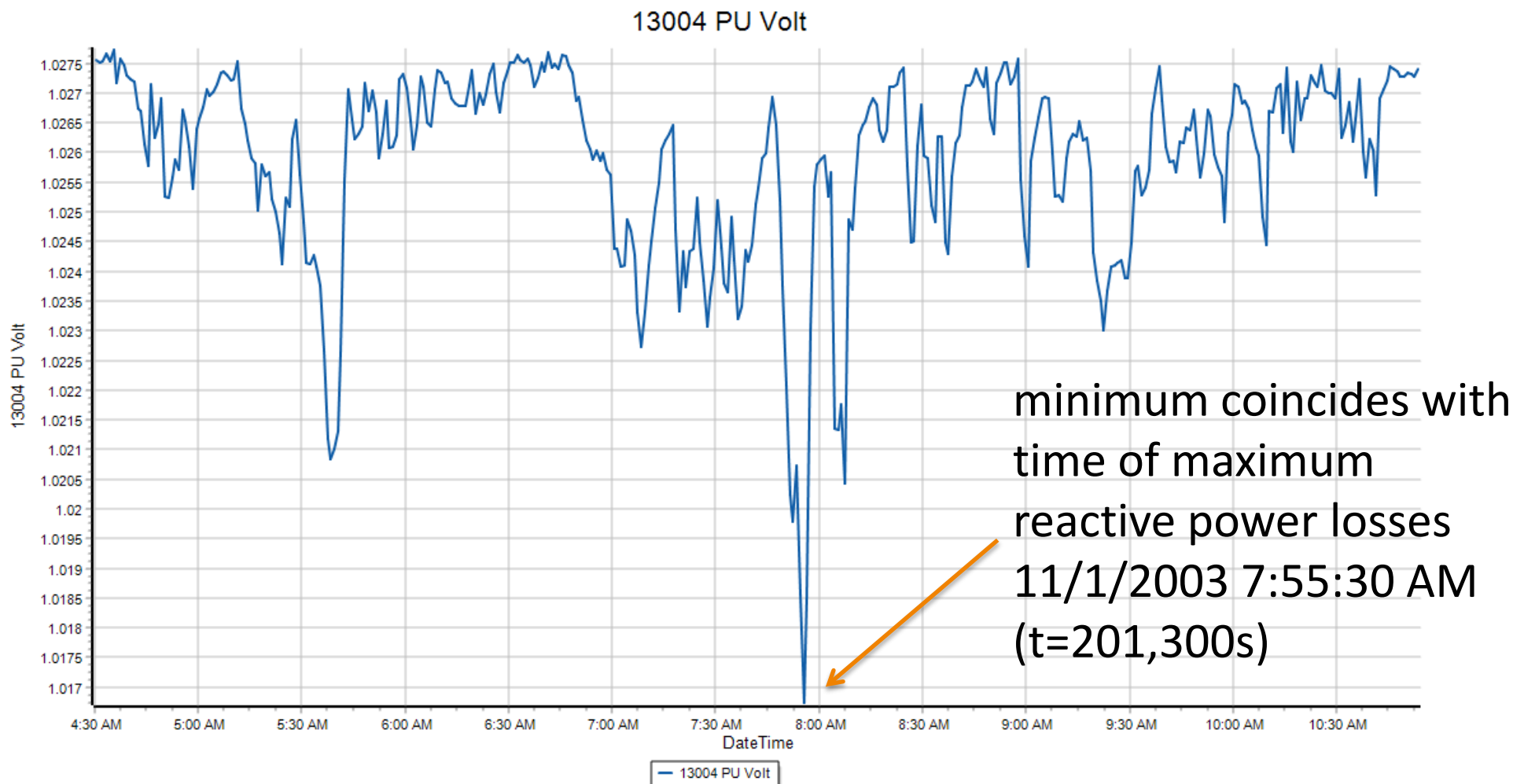


# Peak Transformer GIC Plot (Littleton, CO)





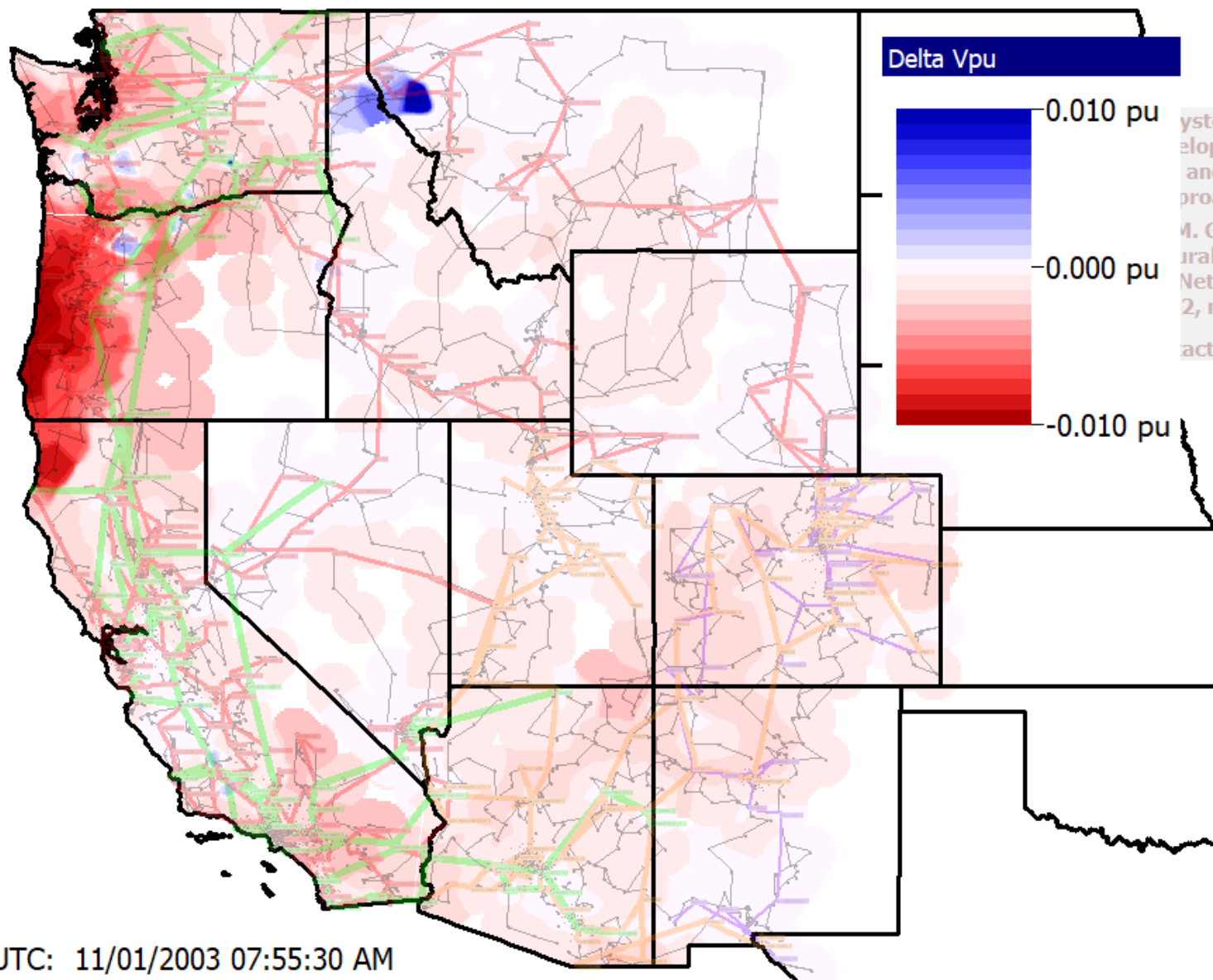
# AC Bus Voltage (North Bend, OR)







# Voltage Difference Contour at Max GIC Mvar Loss



UTC: 11/01/2003 07:55:30 AM



# More Information

- Download slides and sample files used in this example from



<https://www.powerworld.com/training/client-meetings/past-conference-materials>

- Schedule and registration links for upcoming sessions



<https://www.powerworld.com/training/client-meetings/conference-registration>