Historic Event GMD Analysis

PowerWorld Simulator Users Group

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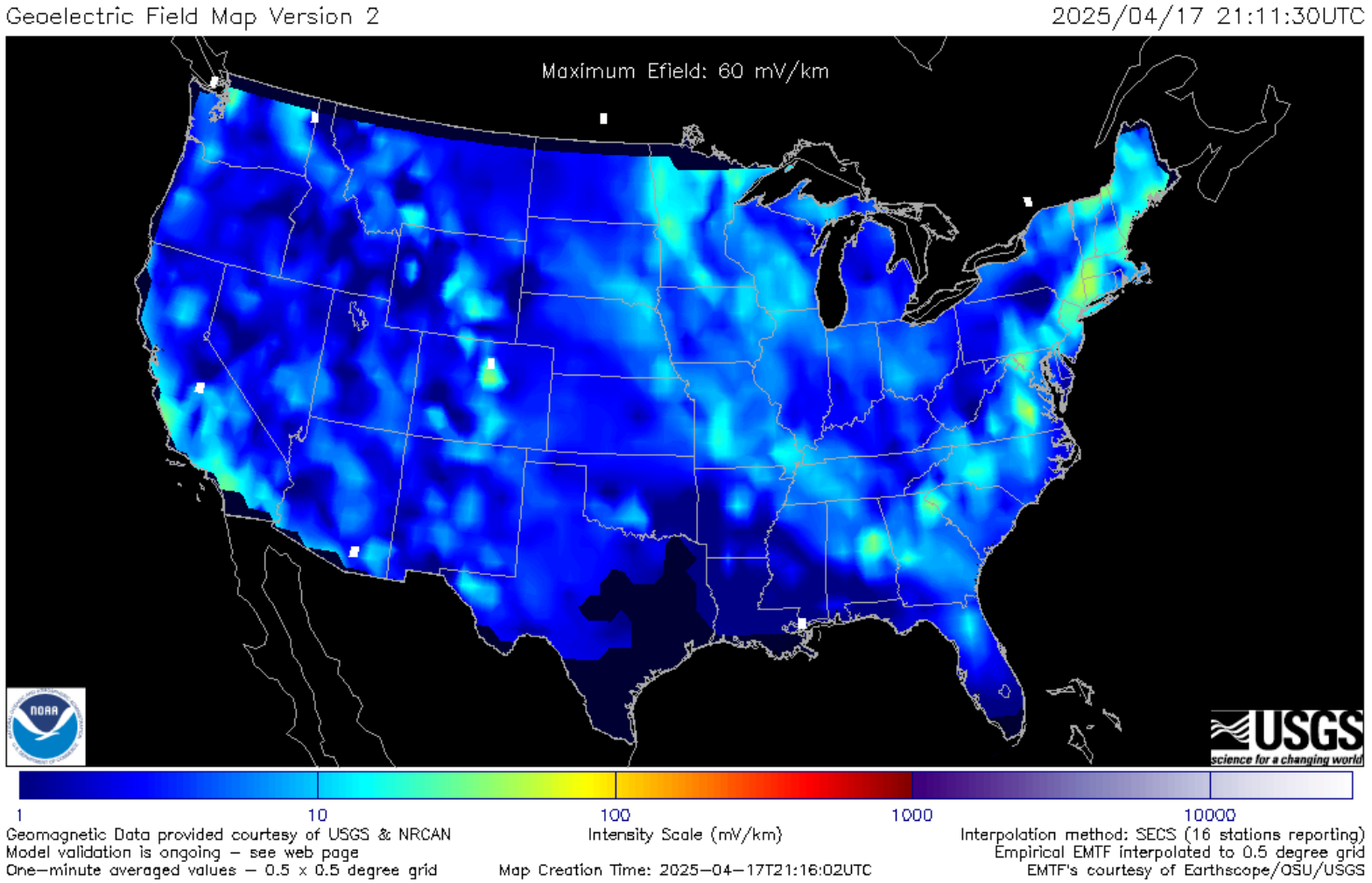
Non-Uniform Field Modeling and Historic Event Files

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

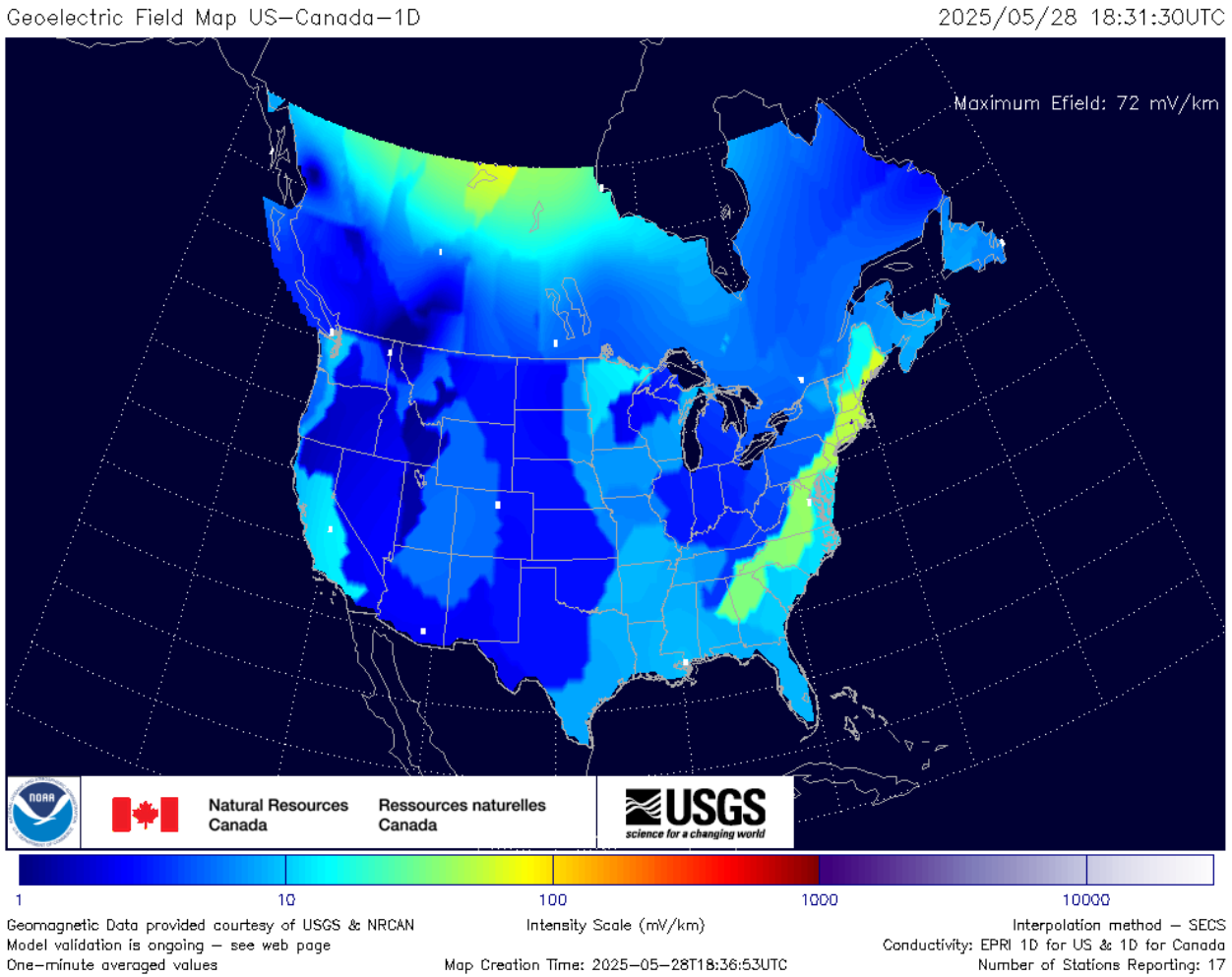
Emprical EMTF – 3D Model (CONUS)



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



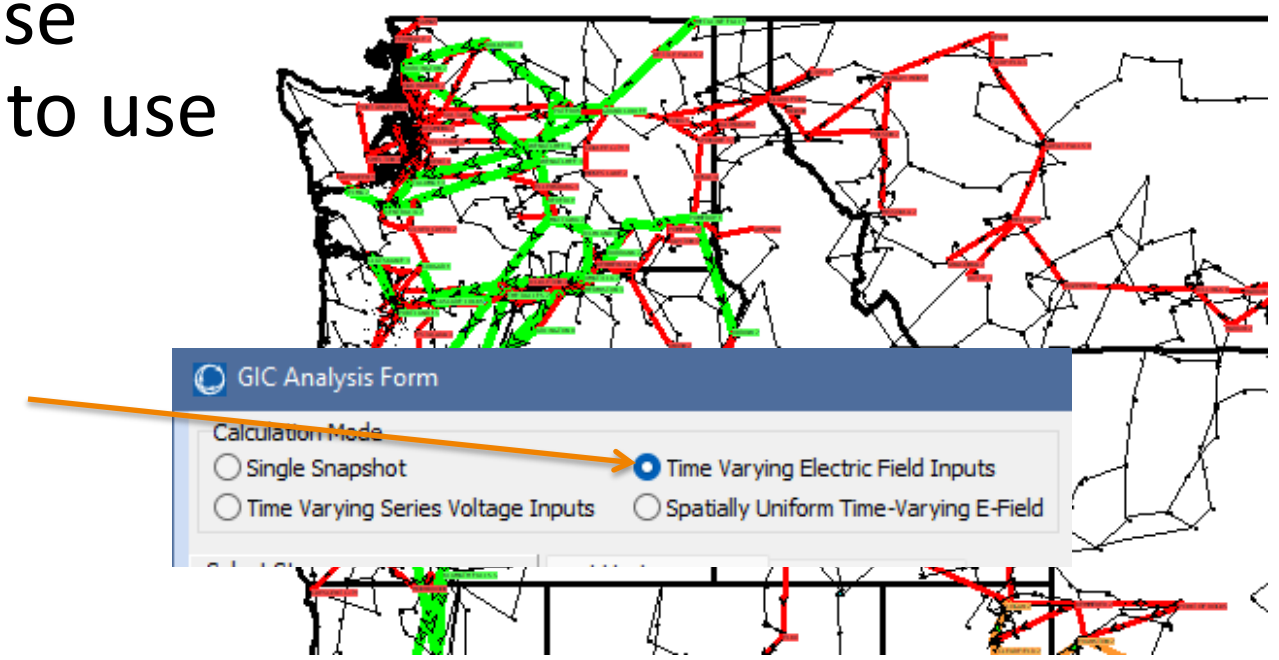
Based on USGS and NRCan 1D conductivity physiographic regions; includes CONUS and Canada up to 60 degrees north latitude

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)

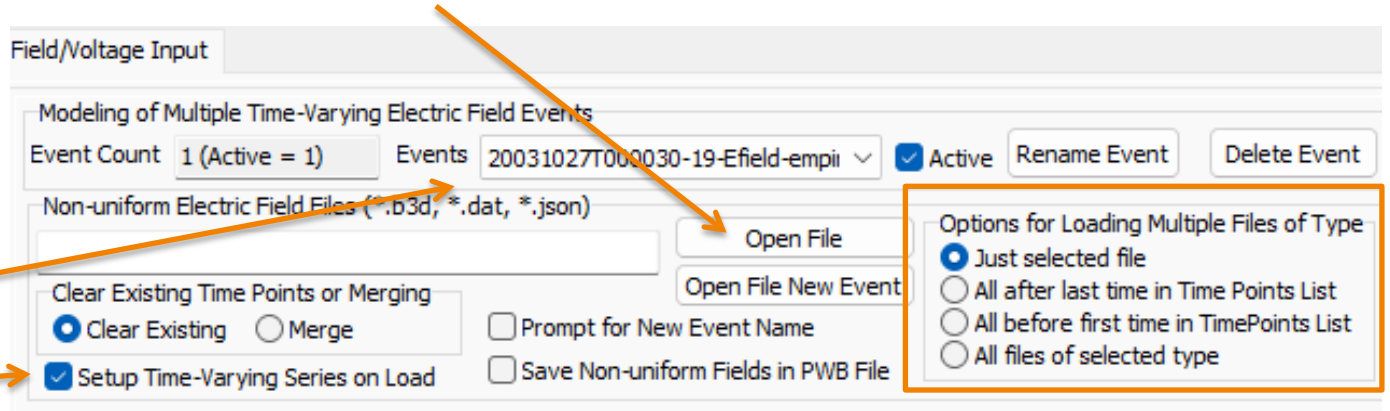
Time Varying Electric Field Inputs

- 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

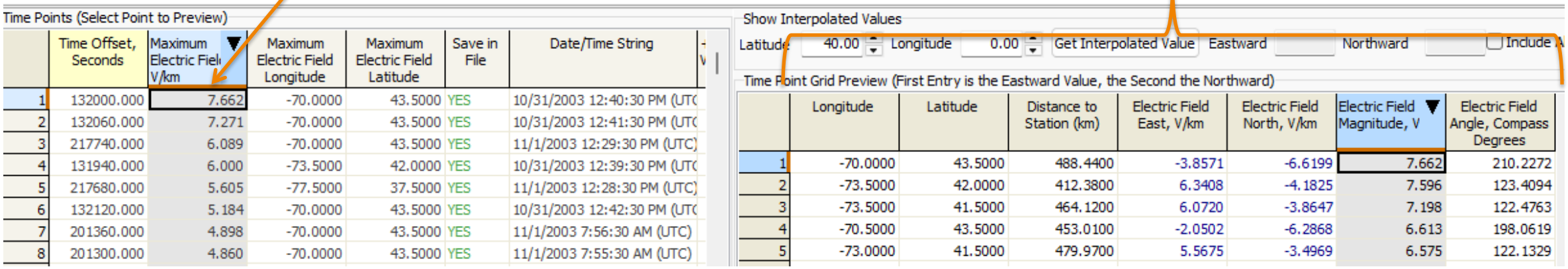


Halloween 2003 Solar Storm Example

- 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 Include

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)

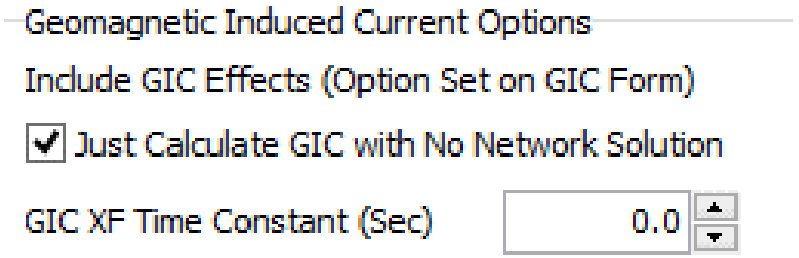
ld/Voltage Input

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	Timepo
1	Time in Seconds									0.000	60.000	120.000	180.000	240.000	300
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

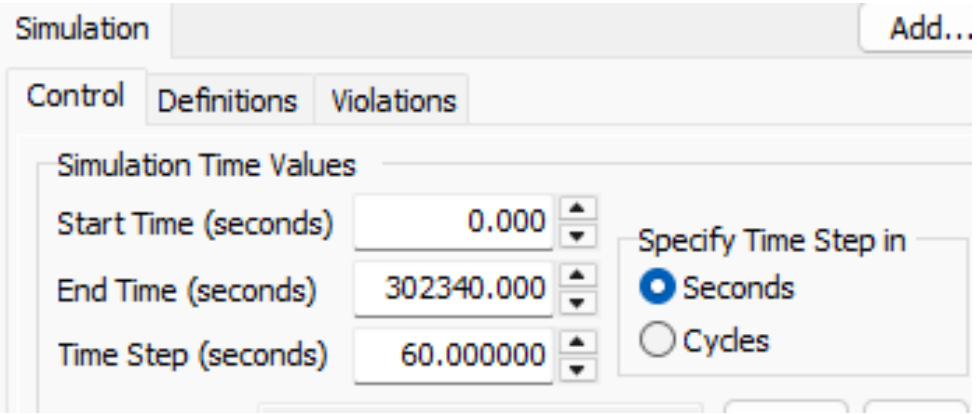
GIC in Transient Stability

- 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)

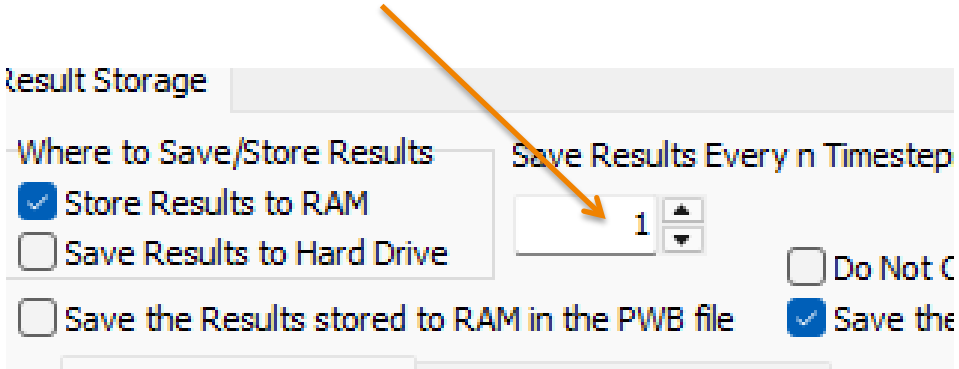


GIC in Transient Stability

- 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**

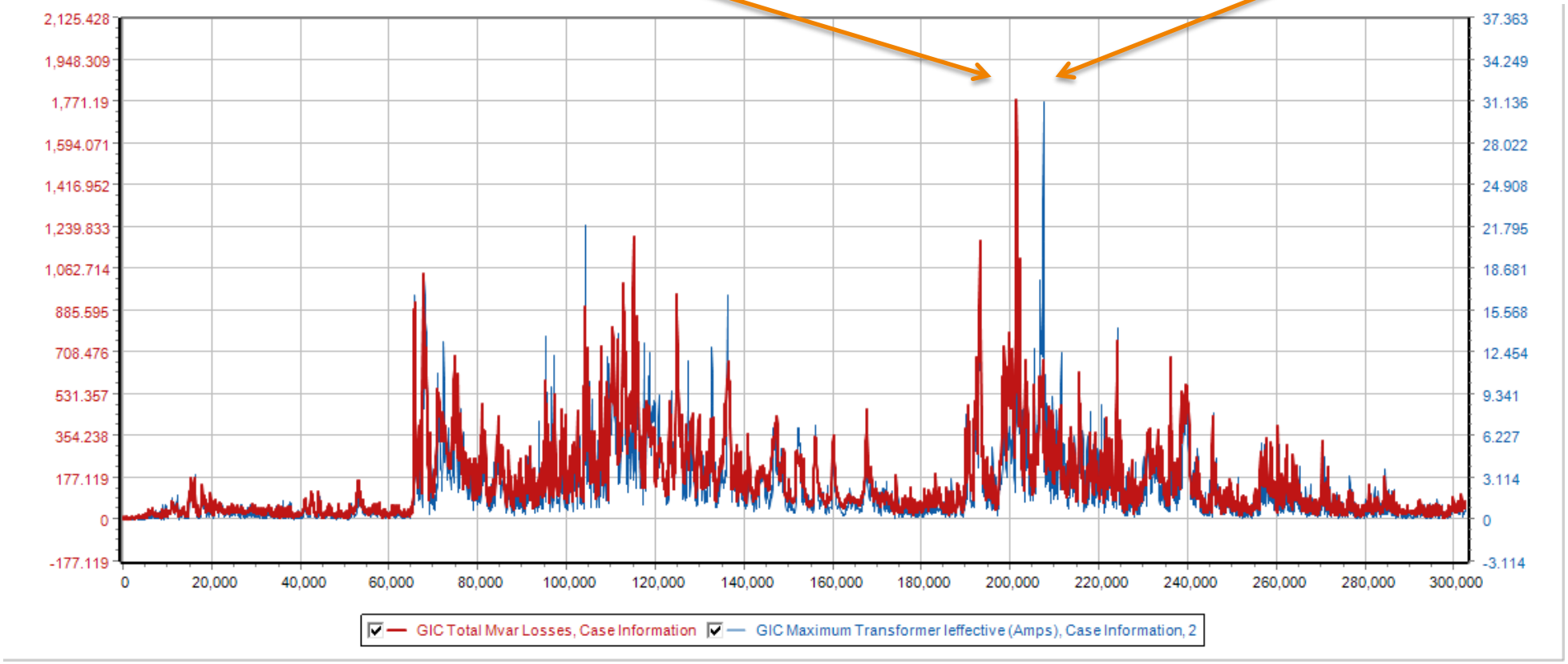


Plot Definitions

- 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”

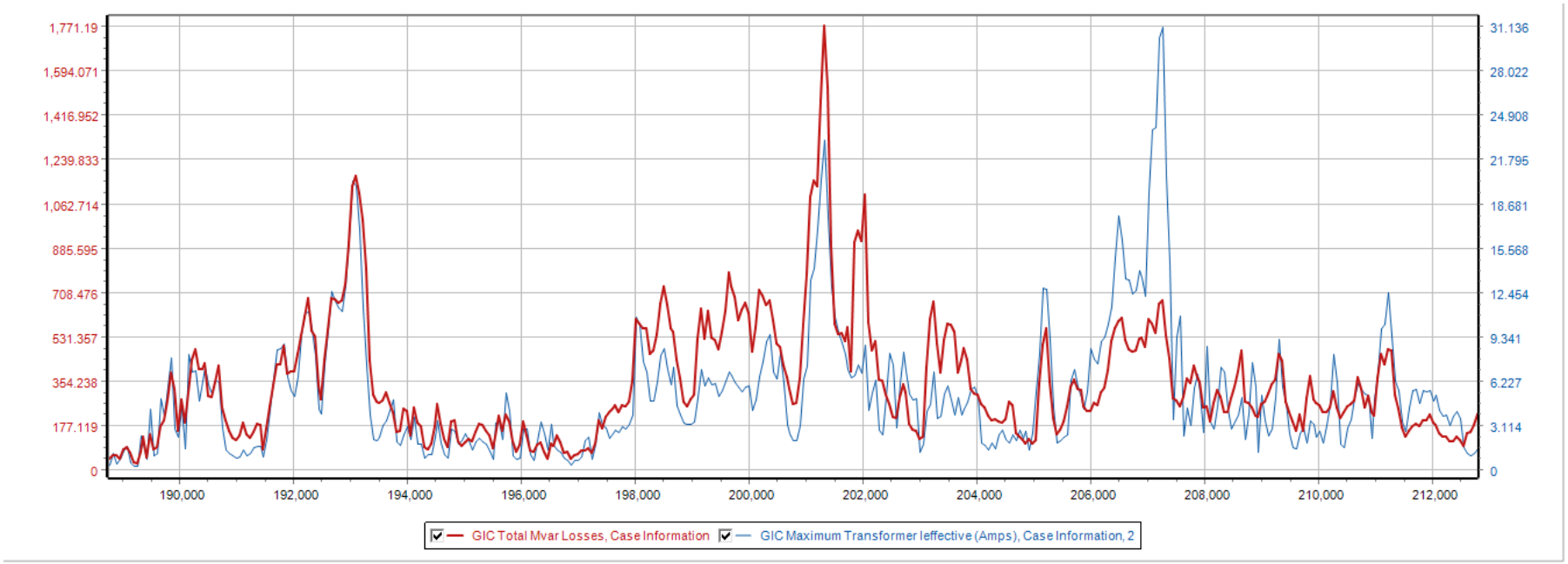
GIC Time Series Plots

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

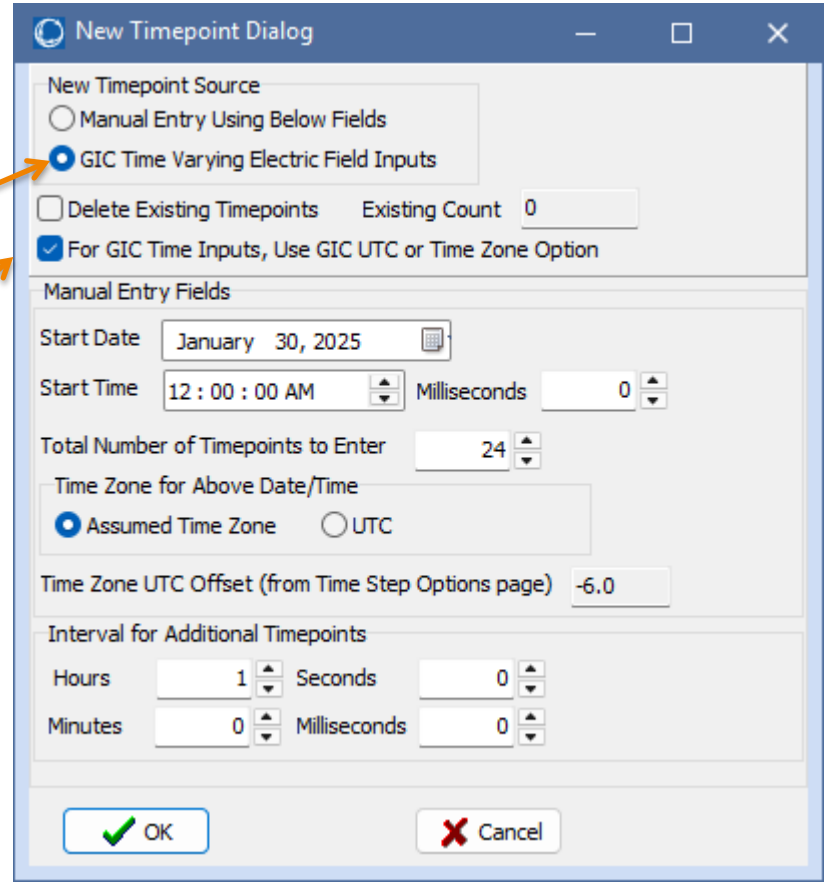
- For events with higher frequency variation, such as high-altitude electromagnetic pulse E3 (HEMP E3), it may be appropriate to also perform a transient stability dynamic simulation
- For most solar GMD, the steady-state non-linear power flow is more salient
- Transient Stability can be used for quick 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 *GICTimeVaryingCalculate* script function to set the time and solve the power flow
  - Time Step Simulation (TSS) tool

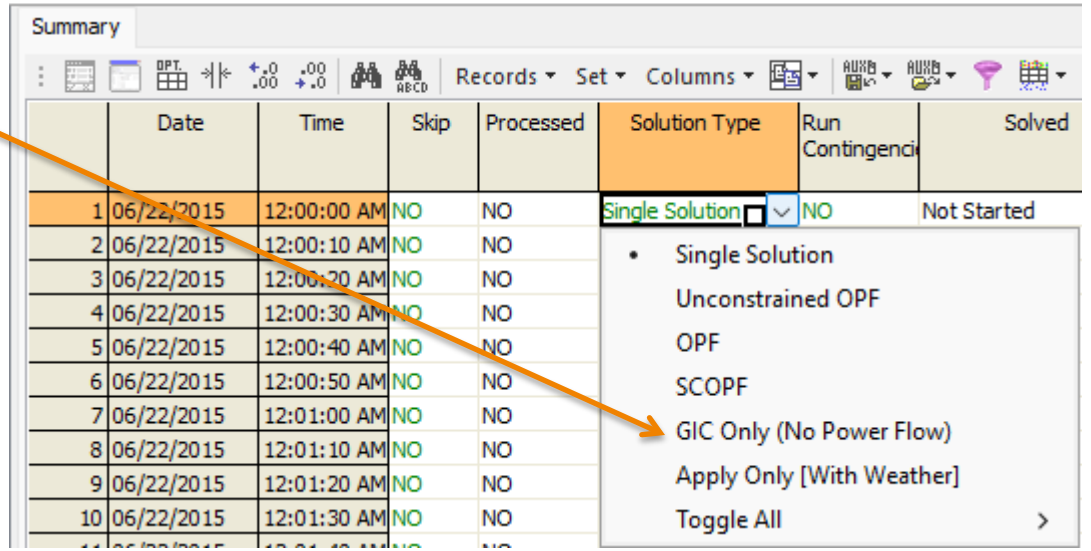
GIC with Time Step Simulation

- 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”



GIC with Time Step Simulation

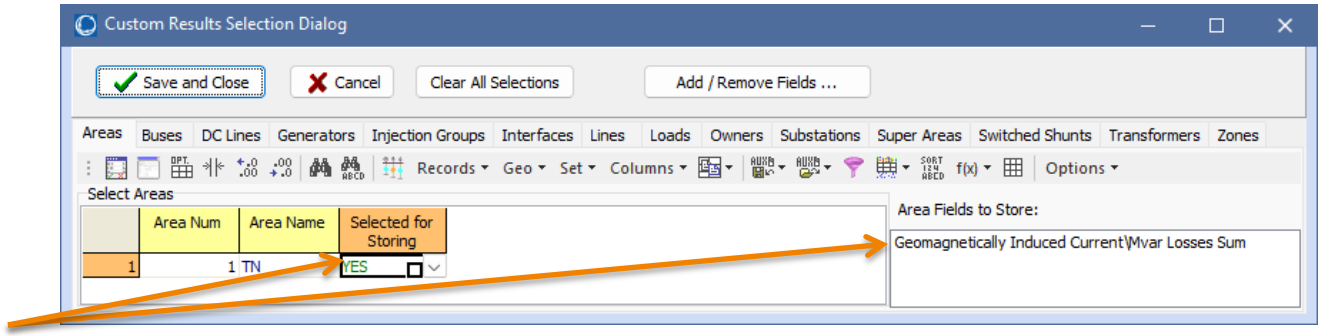
- The Solution Type “GIC Only (No Power Flow)” allows calculation of GIC quantities, similar to the “Just Calculate GIC with No Network Solution” in Transient Stability (albeit slower)



- To compute AC power flow quantities, however, leave all Solution Types as “Single Solution”

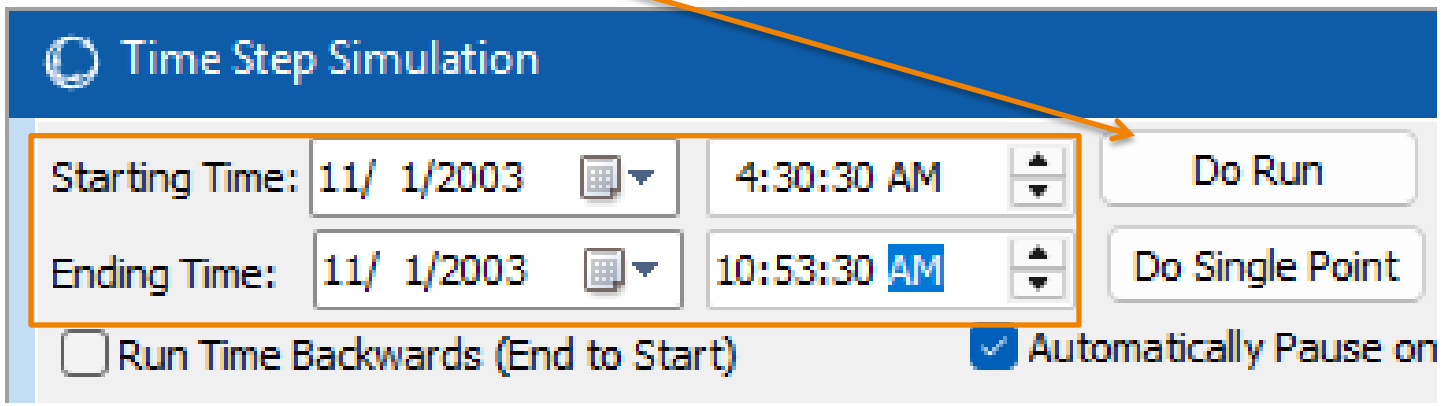
GIC with Time Step Simulation

- 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 Fliter)
  - Any other desired quantities
- Click “Save and Close”



GIC with Time Step Simulation

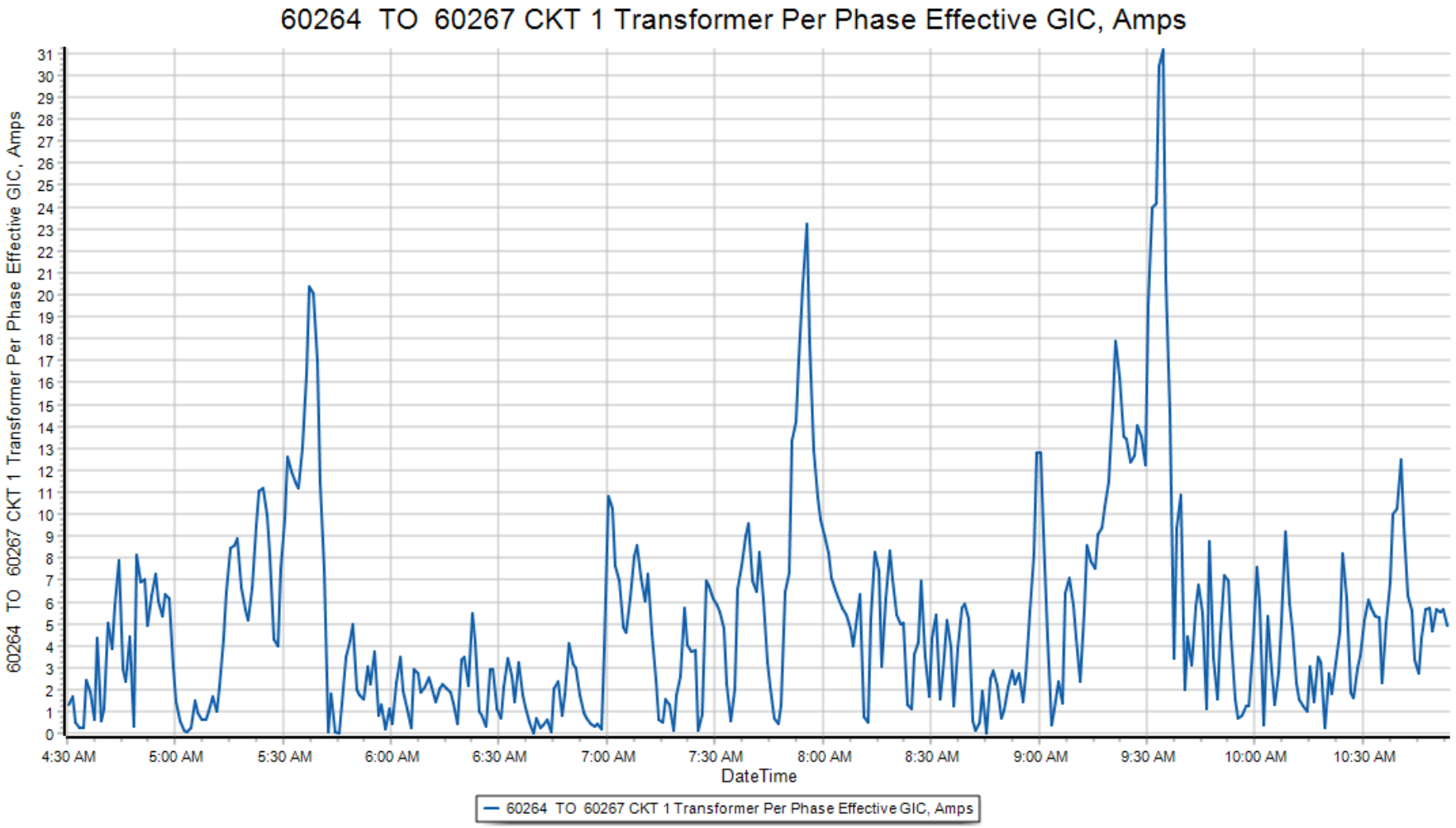
- To run just the peak period, set the Starting Time to 11/1/2023 4:30:30 AM and the Ending Time to 11/1/2023 10:53:30 AM
- Click the “Do Run” button



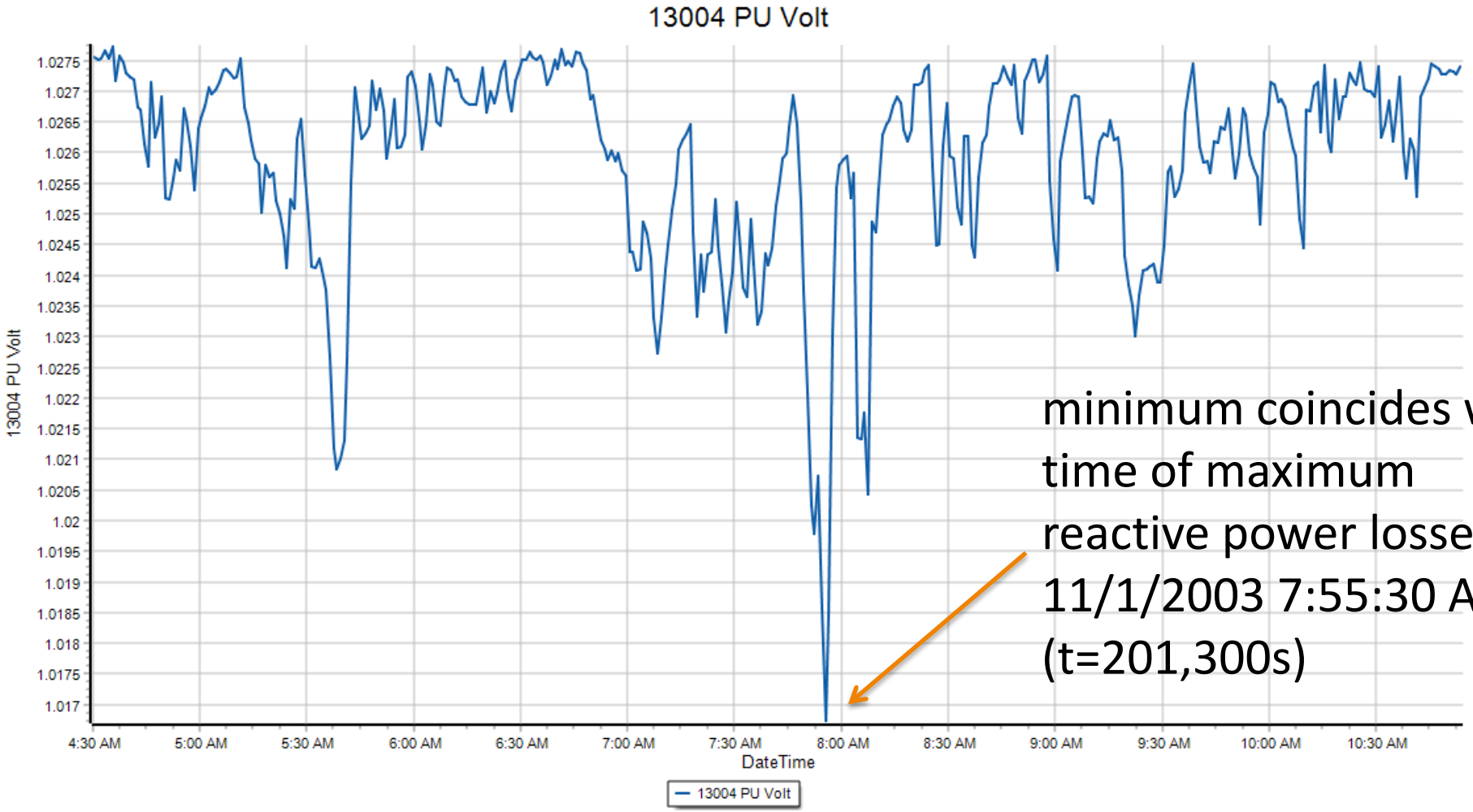
Time Step Simulation Results

- 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)

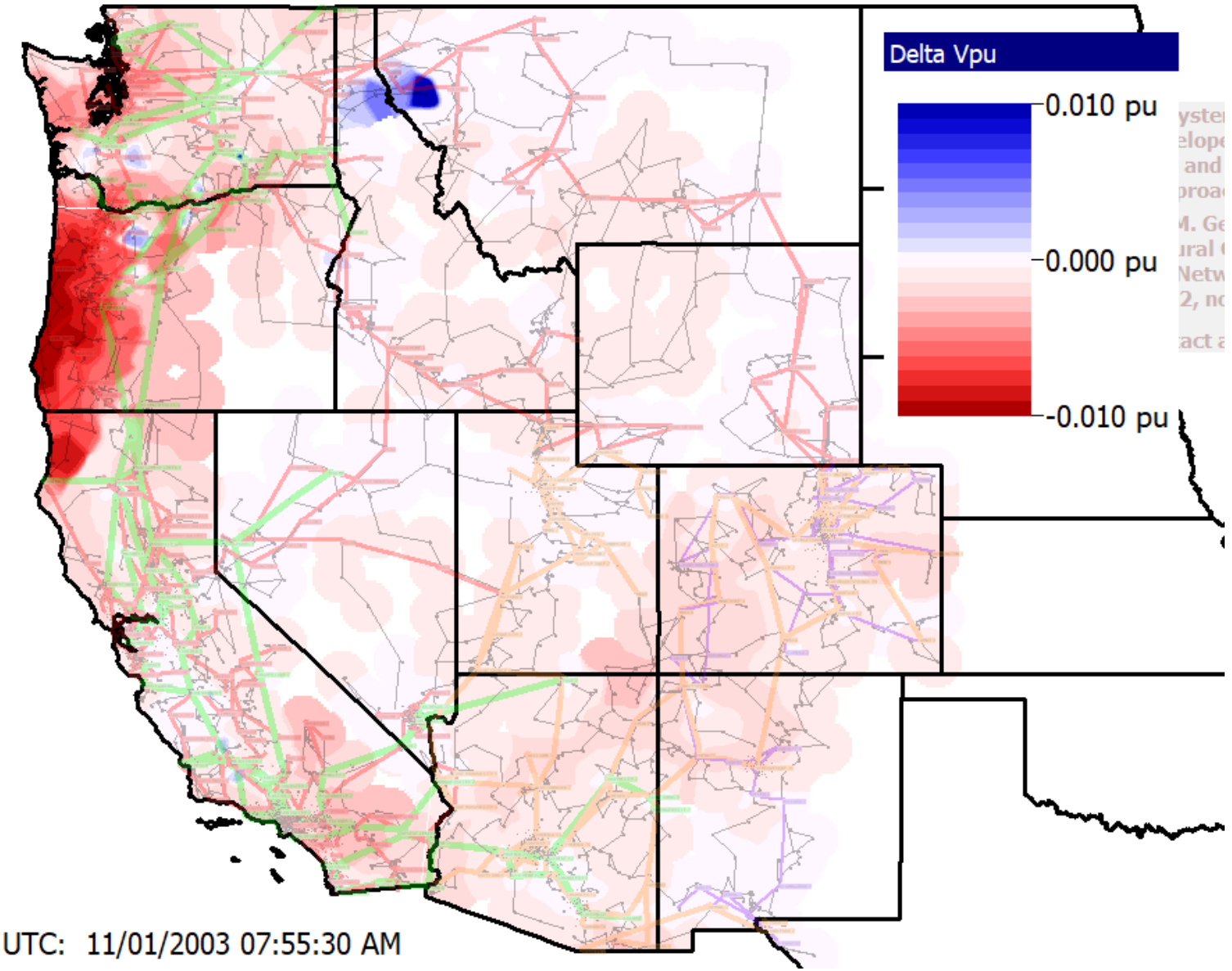


AC Bus Voltage (North Bend, OR)



minimum coincides with time of maximum reactive power losses 11/1/2003 7:55:30 AM (t=201,300s)

Voltage Difference Contour at Max GIC Mvar Loss



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