

PowerWorld Simulator Integration with GICHarm in Simulator Version 24

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Overview



- The purpose of this presentation is to show how EPRI's GICHarm program is being integrated into PowerWorld Simulator to do harmonic analysis
 - This presentation is based on the July 9, 2025 patch, with more functionality coming soon; it requires PowerWorld Simulator with the Geomagnetically Induced Current (GIC) Add-on
- The motivation for this work is geomagnetically induced currents (GICs), whether due to geomagnetic disturbances (GMDs) or High Altitude Electromagnetic Pulses (HEMPs), can cause significant harmonics
- These harmonics can trip devices, such as capacitors
- These impacts need to be considered in doing GIC analysis

Acknowledgment

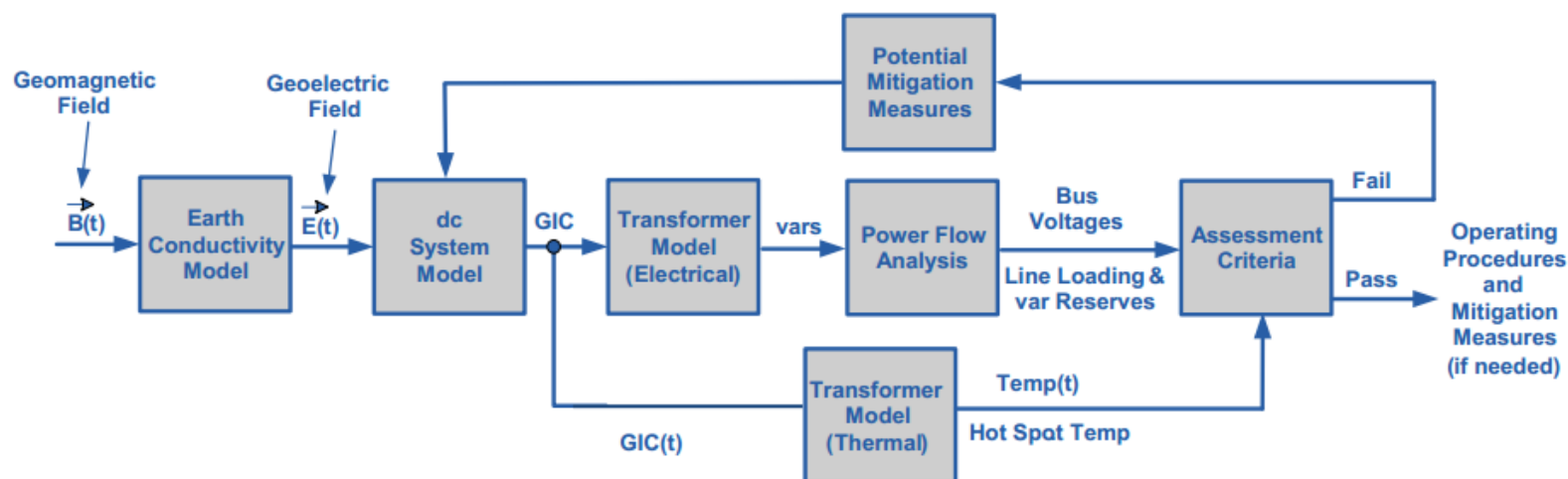


- These slides are based in part on work funded by the US Department of Energy (DoE); this support is gratefully acknowledged!
- These slides also contain contributions from my students, postdocs and staff at TAMU, from EPRI, Pacific Northwest National Laboratory (PNNL), and PowerWorld Corporation

PowerWorld Simulator GIC Analysis



- Starting in 2010 PowerWorld Simulator has gradually gained the ability to model the impacts of GICs, first in the power flow, and later its time-domain stability analysis
 - Initially this as was limited to uniform magnitude and direction electric fields, but now a variety of time and spatially varying fields are supported
 - The NERC diagram shows the overall process
- This talk will add an additional feedback loop for harmonic analysis



PowerWorld Simulator GIC Analysis, cont.



- Simulator allows for either Single Snapshot GIC Analysis or Time-Varying Analysis – the Image shows the Single Snapshot Page

The screenshot displays the 'GIC Analysis Form' window in PowerWorld Simulator. The 'Calculation Mode' is set to 'Single Snapshot'. The 'Field/Voltage Input' tab is active, showing various parameters for GIC analysis.

Calculation Mode:

- ☒ Single Snapshot
- ☐ Time Varying Electric Field Inputs
- ☐ Time Varying Series Voltage Inputs
- ☐ Spatially Uniform Time-Varying E-Field

Buttons: Calculate GIC Values, Clear GIC Values, ☒ Include GIC in Power Flow and Transient Stability, Validate Input Data for GIC, Update Line Voltages (Should be True Unless Explicitly Entered), Clear All GIC Input and Values.

Select Step:

- Field/Voltage Input
 - Options
 - DC Current Calculations
 - AC Power Flow Model
 - Tables and Results
 - Areas
 - Buses
 - Generators
 - DC Lines
 - Lines
 - Line Shunts
 - Loads
 - Switched Shunts
 - Substations
 - Transformers
 - Multi-Section Lines
 - System Summary
 - G-Matrix
 - Multi-Terminal DC Line
 - VSC DC Lines
 - Sensitivity Analysis
 - Non-Uniform Electric Field
 - Geomagnetic Latitude
 - Earth Resistivity Scaling
 - Earth Resistivity Scaling
 - Harmonic Analysis
 - Iterations with GIC
 - PFV Model Summary
 - OD Buses
 - OD Gens
 - OD Loads
 - OD Switched Shunts

Field/Voltage Input Parameters:

- Electric Field Model Parameters
 - Maximum Field: 3.00 Volts/km
 - Storm Direction: 90.0 Degrees
 - ☒ Also Calculate Maximum Direction Values
- Restrict Lines to which to model DC Voltages
 - Minimum Line Length: 1.61 km
 - ☐ Calculate Voltages for Equivalent Lines
 - ☐ Calculate Voltages for Low R Lines
- Distance Units
 - ☒ Kilometers
 - ☐ Miles

Hotspot Modeling:

- ☐ Include
 - Hotspot Field in V/km: 12.43
 - Width of Hotspot in Kilometer: 241.40
 - Height of Hotspot in Kilometer: 241.40
 - Latitude of Center: 45.000
 - Longitude of Center: -90.000
- ☐ Scale Hotspot Value with Geomagnetic Latitude
- ☒ Scale Hotspot Value with Earth Resistivity
 - Earth Resistivity Scalar Value
 - ☐ Region Scalar
 - ☒ Region Hotspot Scalar

Modeling of Scaling and Hotspots:

- ☐ Approximate with Substation Values
- ☒ Interpolate Along Line Path

Geomagnetic Latitude Scaling Function: No Scaling

Earth Resistivity Scaling Region Set: No Resistivity Scaling

Buttons: Save Setting to Aux, Load AUX, Supplemental File Options, Clear All GIC Input Fields, Close, Help.

PowerWorld Simulator GIC Analysis, cont.



- Image shows the Time-Varying Electric Field Inputs Analysis page

GIC Analysis Form

Calculation Mode
☐ Single Snapshot
☒ Time Varying Electric Field Inputs
☐ Time Varying Series Voltage Inputs
☐ Spatially Uniform Time-Varying E-Field

Calculate GIC Values Clear GIC Values ☒ Include GIC in Power Flow and Transient Stability Validate Input Data for GIC
 Current Time Offset from Reference (Seconds) 0.00 ☐ Calculate GIC on Time Change Clear All GIC Input and Values

Select Step
 Field/Voltage Input Harmonic Analysis

Modeling of Multiple Time-Varying Electric Field Events
 Event Count 1 (Active = 1) Events ott20240510_em3 ☒ Active Rename Event Delete Event Clone Event Earliest Reference Datetime 5/10/2024 3:00:00 PM (UTC) Duration 02:46:30

Non-uniform Electric Field Files (*.b3d, *.dat, *.json)
 C:\Projects_2024\EPRI_B3DFast\EPRI_Short.b3d Open File
 Clear Existing Time Points or Merging
☐ Clear Existing ☒ Merge ☐ Prompt for New Event Name
☒ Setup Time-Varying Series on Load ☐ Save Non-uniform Fields in PWB File

Options for Loading Multiple Files of Type
☒ Just selected file
☐ All after last time in Time Points List
☐ All before first time in Time Points List
☐ All files of selected type

Setup Time Series Voltage Inputs for All Active Events
 Start Time Offset (Sec.) 0.00 Setup Time Varying Series
 End Time Offset (Sec.) 0.00 ☒ Do All if Start, End Time = 0
 Sampling Rate (Sec.) 0.00

Time Varying Series Summary
 Count 0 Max. Line Volt 0.00
 First (Sec.) 0.00 Max. Sub V/km 0.00
 Last (Sec.) 0.00

Input Summary for Selected Event
 Starting Time (Seconds) 0.00 Starting Latitude 35.00 Starting Longitude -85.00
 Ending Time (Seconds) 9990.00 Ending Latitude 48.50 Ending Longitude -65.50
 Number of Time Points 1000 Number Data Points 1120
 Interpolated Offset Time 0.000 View Interpolated Offset Time (Seconds) Event Reference Datetime 5/10/2024 3:00:00 PM (UTC) Change Datetime Fractional Second 0.000 ☐ Use Local Time Zone

Save Selected Time Points in a B3D File ☒ Save All Events in B3D File B3D Save Format Version
☒ Latest (Five)
☐ Four
☐ Three

Scale or Shift All Input Points
 Latitude Shift (Degrees) 0.000 Magnitude Scalar 1.000 Stretch Scalar 1.000
 Longitude Shift (Degrees) 0.000 Shift, Scale and or Stretch all Time Point Grid Values

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
1	0.000	0.235	-77.5000	37.5000	YES	5/10/2024 3:0
2	10.000	0.272	-77.5000	37.5000	YES	5/10/2024 3:0
3	20.000	0.329	-77.5000	37.5000	YES	5/10/2024 3:0
4	30.000	0.345	-77.5000	37.5000	YES	5/10/2024 3:0
5	40.000	0.301	-77.5000	37.5000	YES	5/10/2024 3:0
6	50.000	0.285	-77.5000	37.5000	YES	5/10/2024 3:0
7	60.000	0.327	-77.5000	37.5000	YES	5/10/2024 3:0
8	70.000	0.398	-77.5000	37.5000	YES	5/10/2024 3:0
9	80.000	0.413	-77.5000	37.5000	YES	5/10/2024 3:0
10	90.000	0.361	-77.5000	37.5000	YES	5/10/2024 3:0
11	100.000	0.277	-77.5000	37.5000	YES	5/10/2024 3:0
12	110.000	0.198	-69.5000	43.0000	YES	5/10/2024 3:0
13	120.000	0.161	-69.5000	43.0000	YES	5/10/2024 3:0
14	130.000	0.169	-77.5000	37.5000	YES	5/10/2024 3:0
15	140.000	0.180	-77.5000	37.5000	YES	5/10/2024 3:0
16	150.000	0.215	-77.5000	37.5000	YES	5/10/2024 3:0
17	160.000	0.226	-77.5000	37.5000	YES	5/10/2024 3:0
18	170.000	0.192	-77.5000	37.5000	YES	5/10/2024 3:0
19	180.000	0.188	-77.5000	37.5000	YES	5/10/2024 3:0
20	190.000	0.195	-77.5000	37.5000	YES	5/10/2024 3:0
>1	200.000	0.142	-81.5000	36.5000	YES	5/10/2024 3:0

Show Interpolated Values
 Latitude -40.00 Longitude 0.00 Get Interpolated Value Eastward Northward ☐ Include All Active Events

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/km	Electric Field Angle, Compass Degrees	Data Quality
1	-85.0000	35.0000	-1.0000	0.0528	-0.2125	0.2189	166.0380	0
2	-84.5000	35.0000	-1.0000	0.1872	-0.1562	0.2438	129.6270	0
3	-84.0000	35.0000	-1.0000	0.0316	-0.0494	0.0586	147.4225	0
4	-83.5000	35.0000	-1.0000	-0.0074	0.0013	0.0075	279.9915	0
5	-83.0000	35.0000	-1.0000	0.2457	-0.4526	0.5150	151.5078	0
6	-82.5000	35.0000	-1.0000	0.0646	-0.1420	0.1560	155.5389	0
7	-82.0000	35.0000	-1.0000	0.0491	-0.0143	0.0511	106.2228	0
8	-81.5000	35.0000	-1.0000	0.0903	-0.0798	0.1205	131.4695	0
9	-81.0000	35.0000	-1.0000	0.0903	-0.0798	0.1205	131.4695	0
10	-80.5000	35.0000	-1.0000	0.7663	0.2390	0.8027	72.6801	0
11	-80.0000	35.0000	-1.0000	0.1841	-0.3996	0.4399	155.2595	0
12	-79.5000	35.0000	-1.0000	0.0067	-0.0576	0.0580	173.3682	0
13	-79.0000	35.0000	-1.0000	0.0937	-0.1741	0.1977	151.7022	0
14	-78.5000	35.0000	-1.0000	0.0937	-0.1741	0.1977	151.7022	0
15	-78.0000	35.0000	-1.0000	0.0094	-0.1570	0.1573	176.5818	0
16	-77.5000	35.0000	-1.0000	0.0997	-0.0809	0.1284	129.0441	0
17	-77.0000	35.0000	-1.0000	0.0719	-0.0905	0.1155	141.5377	0
18	-76.5000	35.0000	-1.0000	-0.0014	-0.0256	0.0257	183.0991	0

Save Setting to Aux Load AUX Supplemental File Options Clear All GIC Input Fields Close Help

Adding Harmonic Analysis to GIC Calculations



- Standard power flow GIC analysis involves
 1. Using an assumed electric field, calculate the GICs
 2. Solve a GIC-enhanced power flow in which the transformer reactive power losses include a GIC dependent component
- With harmonic analysis this can optionally become
 1. Using an assumed electric field, calculate the GICs
 2. Solve a GIC-enhanced power flow, in which the transformer reactive power losses include a GIC dependent component
 3. Calculate the harmonics, with bus voltage total harmonic distortion (THDv) key
 4. Determine if any devices (e.g., capacitors) need to be outaged; if so, remove them and goto to 1; otherwise done

Integrated Harmonic Analysis in Simulator

- The Simulator GIC Analysis Form now has a page to make this process fully automatic
 - A manual process is also provided to help in the initial setup of a simulation
 - Scripting commands will be added in the new future
- This requires GICHarm be installed on the computer

Iterations with GICHarm	PFW Model Summary	OD Buses	OD Gens	OD Loads	OD Switched Shunts	OD Lines	OD Line Shunts	OD Transformers	OD DC Lines	OD Substations	OD Au
	Number of Bus	Name of Bus	ID	ID	Active PFW Model(s)	Bus THDr Valid	Bus THDr Max	Bus THDr Phase A	Bus THDr Phase B	Bus THDr Phase C	
1	1007	IAN HORN 0	1	1007_1	SSTHDvSimple	YES	2.883	2.883	2.859	2.871	
2	1010	PRESIDIO 1 0	1	1010_1	SSTHDvSimple	YES	3.098	3.098	3.068	3.077	
3	1012	SANDERSON 0 1	1	1012_1	SSTHDvSimple	YES	5.121	5.121	5.093	5.050	
4	1016	GARDEN CITY 0 1	1	1016_1	SSTHDvSimple	NO					
5	1019	MIDLAND 4 0	1	1019_1	SSTHDvSimple	YES	0.399	0.399	0.261	0.237	
6	1020	BIG SPRING 1 0 1	1	1020_1	SSTHDvSimple	NO					
7	1027	MIDLAND 2 0	1	1027_1	SSTHDvSimple	YES	0.322	0.282	0.302	0.322	
8	1029	MIDLAND 3 0	1	1029_1	SSTHDvSimple	YES	0.294	0.275	0.286	0.294	
9	1030	ALPINE 0	1	1030_1	SSTHDvSimple	YES	1.594	1.594	1.547	1.556	
10	1033	MCCAMEY 1 1	1	1033_1	SSTHDvSimple	YES	0.773	0.713	0.758	0.773	
11	1046	OZONA 0	1	1046_1	SSTHDvSimple	YES	4.893	4.893	4.878	4.846	
12	1056	LENORAH 0	1	1056_1	SSTHDvSimple	YES	0.266	0.250	0.251	0.266	
13	1081	ODESSA 1 10	1	1081_1	SSTHDvSimple	YES	1.346	1.209	1.303	1.346	
14	1083	FORT STOCKTO 1	1	1083_1	SSTHDvSimple	NO					
15	1086	PECOS 0	1	1086_1	SSTHDvSimple	YES	1.243	1.243	1.241	1.231	
16	1087	SHEFFIELD 0	1	1087_1	SSTHDvSimple	YES	3.766	3.766	3.746	3.723	
17	2009	IOWA PARK 0	1	2009_1	SSTHDvSimple	YES	0.932	0.856	0.918	0.932	
18	2010	VERNON 2 0	1	2010_1	SSTHDvSimple	YES	2.104	2.027	2.035	2.104	
19	2017	PANHANDLE 4 1	1	2017_1	SSTHDvSimple	NO					
20	2017	PANHANDLE 4 1 2	1	2017_2	SSTHDvSimple	NO					
21	2063	DENISON 2 0	1	2063_1	SSTHDvSimple	YES	1.185	1.155	1.185	1.148	
22	2065	GAINESVILLE 0	1	2065_1	SSTHDvSimple	NO					
23	2069	HOWE 0	1	2069_1	SSTHDvSimple	YES	1.208	1.154	1.208	1.146	
24	2096	RALLS 1 0	1	2096_1	SSTHDvSimple	YES	1.184	1.180	1.184	1.166	
25	2096	RALLS 1 0	2	2096_2	SSTHDvSimple	YES	1.184	1.180	1.184	1.166	
26	2110	MUENSTER 2 0	1	2110_1	SSTHDvSimple	YES	2.709	2.530	2.709	2.543	
27	2127	MIAMI 0	1	2127_1	SSTHDvSimple	YES	0.910	0.887	0.910	0.876	
28	2132	HASKELL 2	1	2132_1	SSTHDvSimple	NO					
29	3013	ABILENE 4 0	1	3013_1	SSTHDvSimple	YES	2.169	2.135	2.169	2.110	
30	3019	CHRISTOVAL 1	1	3019_1	SSTHDvSimple	YES	0.690	0.690	0.674	0.669	
31	3023	STAMFORD 0	1	3023_1	SSTHDvSimple	YES	1.400	1.364	1.400	1.348	
32	3030	SAN ANGELO 1 1	1	3030_1	SSTHDvSimple	NO					

Background: Electric Grid Harmonics



- Large-scale electric grids usually operate at 50 or 60 Hz for their fundamental frequency
 - Smaller systems (e.g., aircraft) operate at higher frequencies, which has advantages in for devices such as generators and motors
 - However, inductive reactance increases linearly with frequency, so higher frequencies are not practical for large-scale grids
- Integer multiples of the fundamental frequency are known as harmonics; harmonics have always been present in grids
- Harmonics can be created in different ways, including power electronics loads and by GICs causing transformer saturation (the focus here)

Two Useful References



- There are several good books on harmonics and the associated topic of power quality
- For people looking for a quick overview, a good reference is web.ecs.baylor.edu/faculty/grady/understanding_power_system_harmonics_grady_april_2012.pdf (**Grady2012**)
- A great (and free) document looking at the assessment of the harmonics caused by GMDs is EPRI's "Assessment Guide: Geomagnetic Disturbance Harmonic Impacts and Asset Withstand Capabilities" (**EPRI2019**)
 - Available at www.epri.com/research/products/000000003002017707

Periodic Signals, Fourier Series and Harmonics



- Almost any periodic signal with frequency f can be represented as a Fourier series consisting of the signal's dc value and sinusoidals with integer multiples of f
 - The fundamental frequency is f , $2f$ is the second harmonics, etc.
- A signal with half-wave symmetry will only have odd harmonics
- The image shows the Fourier components for desktop computer waveform

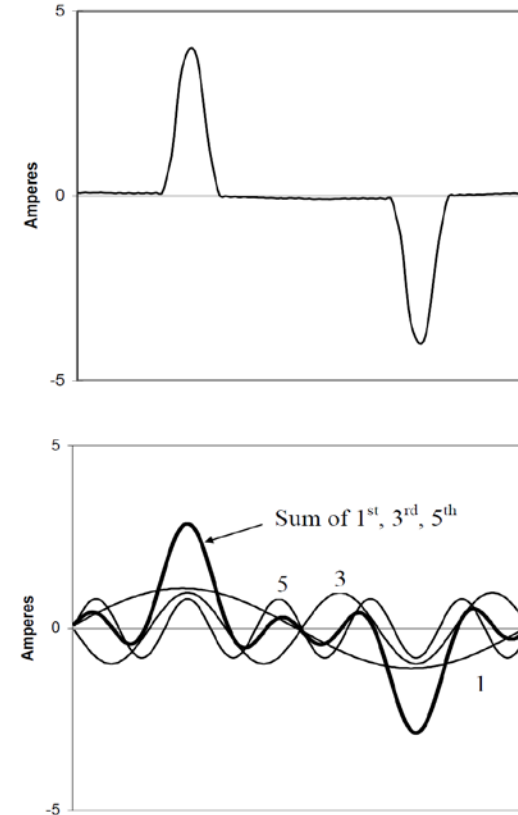


Figure 2.1. PC Current Waveform, and its 1st, 3rd, and 5th Harmonic Components
(Note – in this waveform, the harmonics are peaking at the same time as the fundamental. Most waveforms do not have this property. In fact, in many cases (e.g. a square wave), the peak of the fundamental component is actually greater than the peak of the composite wave.)

Background: Total Harmonic Distortion (THD)



- Total harmonic distortion (THD) is used to quantify the amount of harmonics in a signal; It is defined as the rms value of the harmonics above the fundamental, divided by the rms of the fundamental
 - It can be applied to currents and voltages
- If there are no harmonics then the THD is zero

$$THD_I = \frac{\sqrt{\sum_{k=2}^{\infty} \left(\frac{I_k}{\sqrt{2}} \right)^2}}{\frac{I_1}{\sqrt{2}}} = \frac{\sqrt{\frac{1}{2} \sum_{k=2}^{\infty} I_k^2}}{\frac{I_1}{\sqrt{2}}}.$$

The same equation form applies to voltage THD_V .

Background: Electric Grid Harmonics



- If a grid is balanced then each harmonic has a phase sequence:

Table 3.2. Phase Sequence of Harmonics in a Balanced Three-Phase System

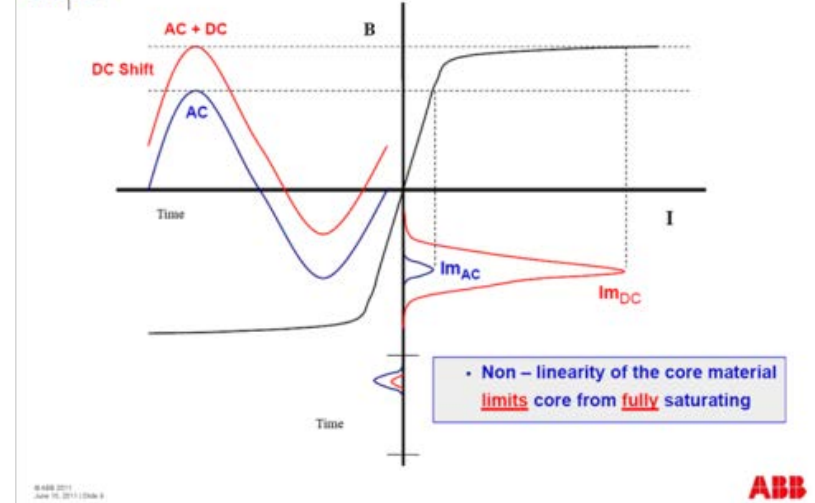
Harmonic	Phase Sequence
1	+
2	–
3	0
4	+
5	–
6	0
...	...

- Switching devices generate odd harmonics, whereas GLCs can also cause even harmonics

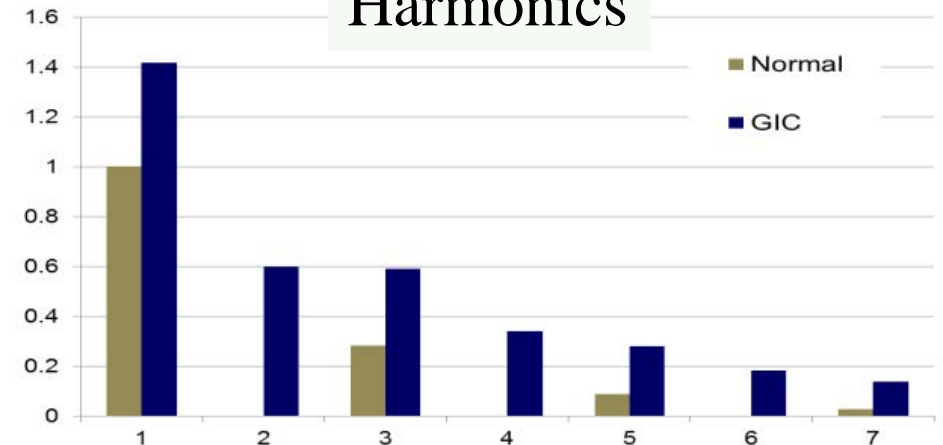
GIC-Induced Transformer Harmonics

- GMDs and HEMPs cause the quasi-dc GICs. The superimposed dc GICs can push transformers into saturation for part of the ac cycle
- This can cause large harmonics; in the positive sequence (e.g., power flow) these harmonics can be represented by increased reactive power losses in the transformer
- However, sometimes they to be explicitly considered, the focus here

DC causes Part – Cycle, Semi – Saturation of the core



Harmonics



Impact of Harmonics



- In general harmonics can cause a variety of problems both on the utility side and the customer side. Grady2012 notes 1) resonance, 2) tripping of sensitive loads, 3) blown fuses/device failures, 4) transformer overheating, 5) motor heating, 6) overloaded neutrals, 7) telephone interference
- EPRI2019 notes impacts on transformers, shunt capacitors, surge arresters, transmission cables, overhead ac lines, HVDC, SVCs, voltage-source converters (VSCs), wind/solar generation, loads
 - “Although capacitors are reasonably robust to harmonics, the tendency for capacitors to amplify harmonic currents and voltages, combined with relatively short thermal time constants, make capacitors arguably the most vulnerable to GMD of the major power system components”

Resonance in LC Circuits

- An LC circuit has a resonance frequency which can amplify the voltages and currents

$$f_{res} = \frac{\omega_{res}}{2\pi} = \frac{1}{2\pi \sqrt{L_{sys} C_{cap}}}$$

GIC-Induced Transformer Harmo.

The inductive reactance of the system at the fundamental frequency is

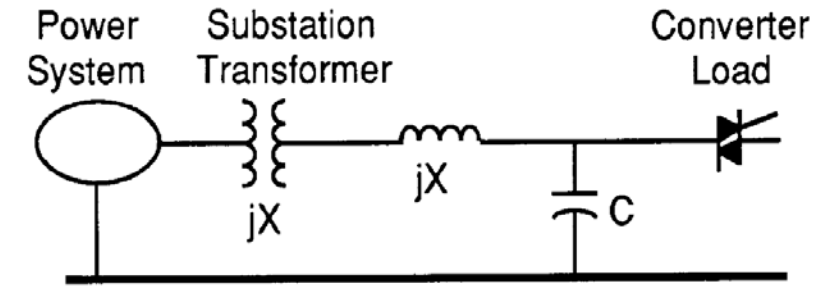
$$X_{sys} = \omega_1 L_{sys}, \text{ so } L_{sys} = \frac{X_{sys}}{\omega_1}$$

The reactance of the capacitor at the fundamental frequency is

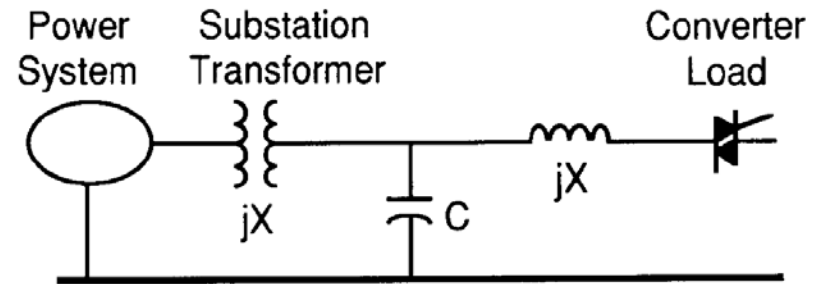
$$X_{cap} = \frac{1}{\omega_1 C_{cap}}, \text{ so } C_{cap} = \frac{1}{\omega_1 X_{cap}}$$

Substituting into the f_{res} equation yields

$$f_{res} = \frac{1}{2\pi} \sqrt{\frac{\omega_1}{X_{sys}}} \sqrt{\omega_1 X_{cap}} = \frac{\omega_1}{2\pi} \sqrt{\frac{X_{cap}}{X_{sys}}} = f_1 \sqrt{\frac{X_{cap}}{X_{sys}}}$$



Parallel Resonance (high voltage distortion at converter load, low voltage distortion at points down the feeder)



Series Resonance (low voltage distortion at converter load, high voltage distortion at points down the feeder)

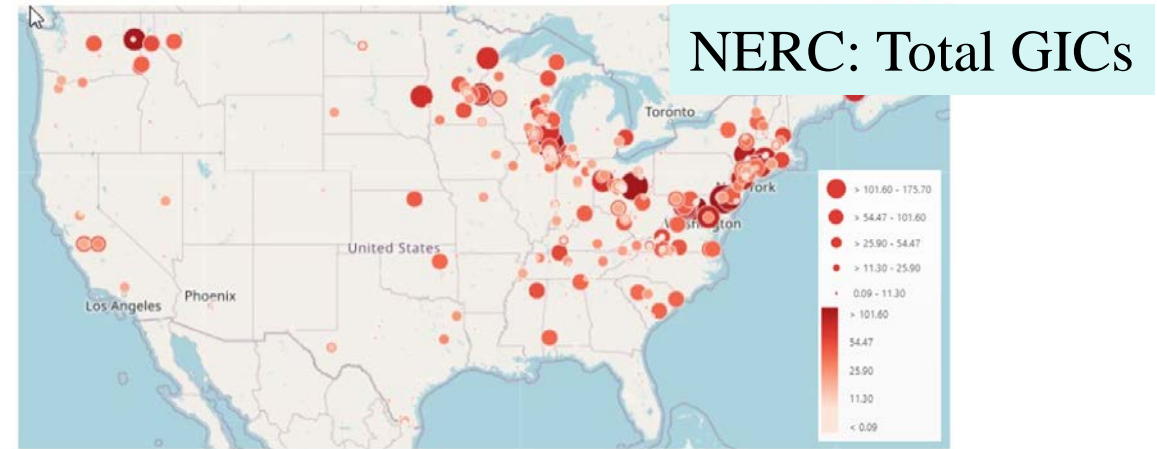
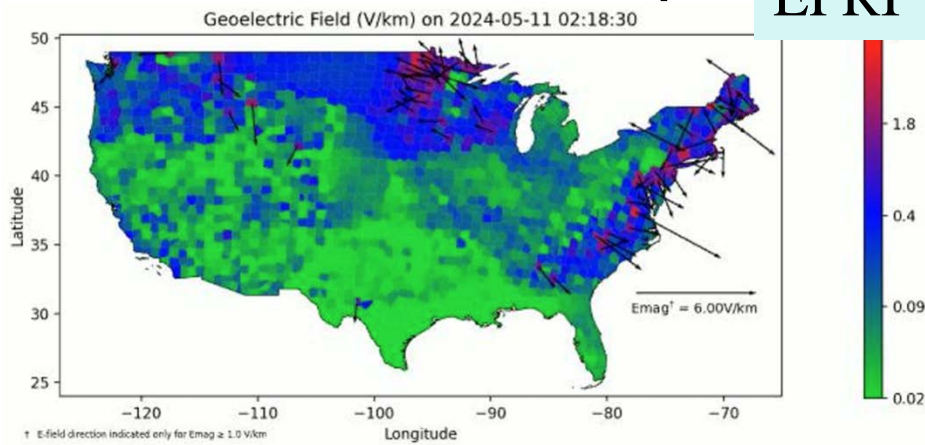
Figure 5.2. Simple Examples of Parallel and Series Resonance

Images: Grady2012

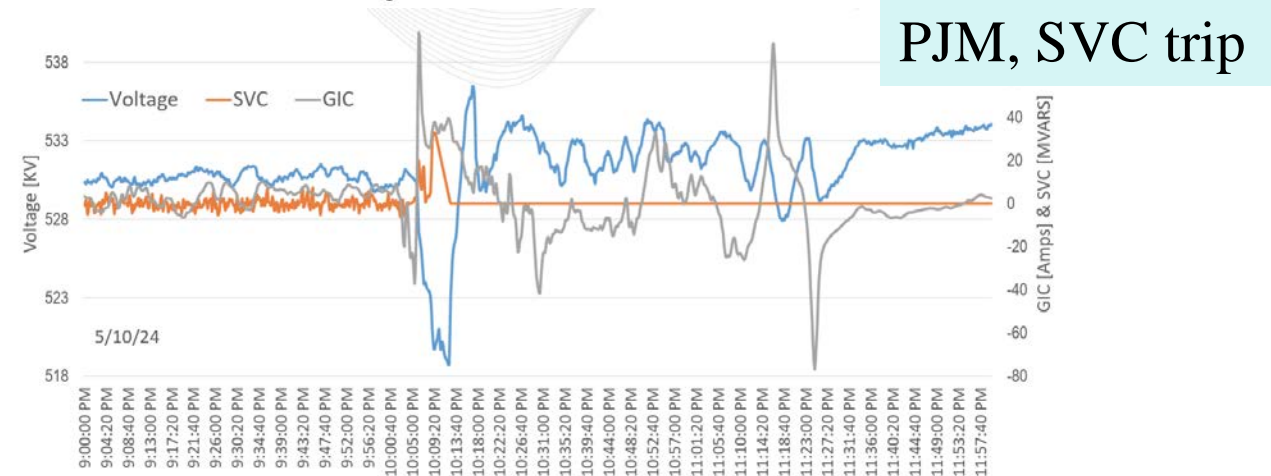
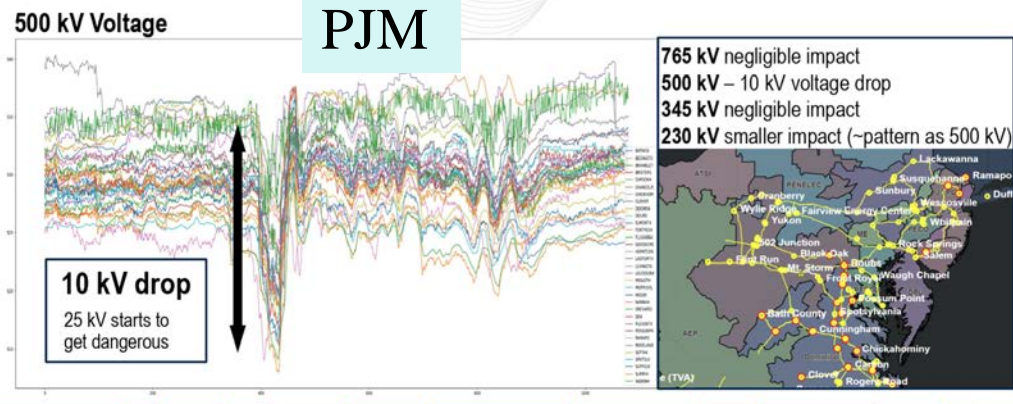
Some Values from the May 2024 GMD



- Last year the May 2024 GMD (Gannon Storm) caused GICs of more than 100 amps



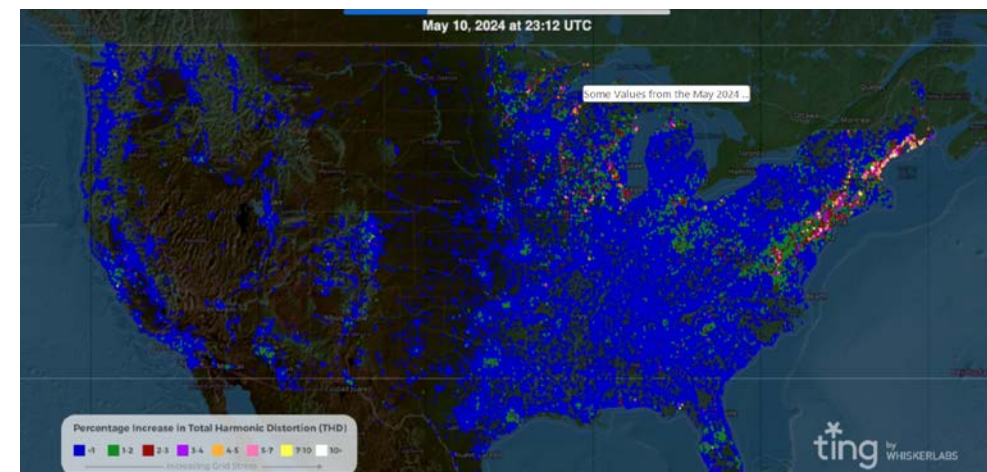
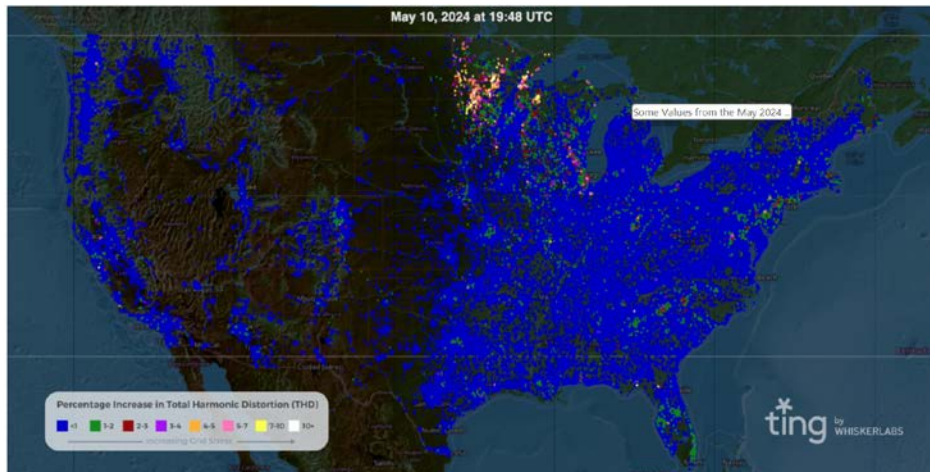
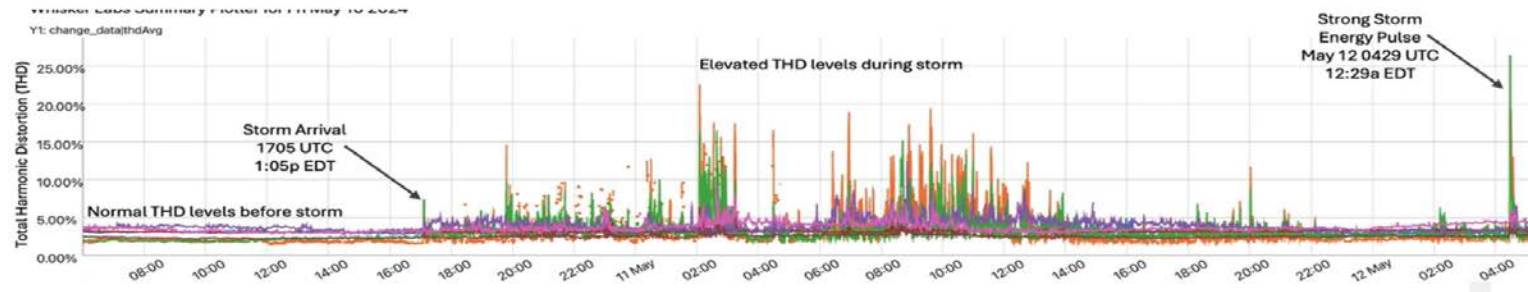
Bubble Size Indicates Size of Maximum Reading



Some Values from the May 2024 GMD, cont.



- Various measurements of THDs during the 05/2024 GMD both from utilities and from the Whisker Lab's Tin Sensor Network



GIC Harmonic Analysis in PowerWorld Simulator



- The first step is to install GICHarm (v6), which is available open source from EPRI at epri.com/research/products/000000003002029748
- GICHarm requires EPRI's OpenDSS (also open source); just use the version of OpenDSS that is included with the GICHarm download

The screenshot shows the EPRI website interface for the product 'PRE-SW: GICHarm v6.0 Beta'. The page is titled 'Energy Delivery and Customer Solutions'. It includes a navigation bar with links to Research, Portfolio, Thought Leadership, Events, Training, Journal, About, and Careers. The main content area is divided into several sections:

- Details:** Product ID 3002029748, Date Published Oct 01, 2024, Document Type PRE PRODUCTION SOFTWARE.
- Abstract:** GMD-related harmonics are caused by the part-cycle saturation of transformers. These harmonic currents and voltages resulting from transformer saturation have had major impact on system operations and security during severe GMD events in the past. Harmonics studies are an integral part of any GMD vulnerability assessment, and as such, are a key component of related reliability and planning assessments and associated regulatory requirements. This is a tool needed by the industry to perform an adequate assessment of GMD-related distortion impacts.
- Benefits & Values:** The objective of this research is to advance the industry's ability to perform an adequate assessment of GMD-related distortion impacts.
- Platform Requirements:** Windows 10.
- Program:** 2024 40 Transmission Planning.
- Report:** 000000003002029748.
- Price:** \$ 0 (US Dollars). This product is available at no cost to funding members only. If you are a member, you must log in to access. If you are a non-funding individual or entity and wish to purchase this document, please contact the EPRI Order Center at 1-800-313-3774 Option 2 or 650-855-2121. You may also send an email to orders@epri.com.
- Keywords:** Harmonics, Geomagnetic disturbance (GMD), Geomagnetic-induced current (GIC), Geomagnetic storm scenario.
- Notes:** For further information about EPRI, call the EPRI Customer Assistance Center at (800) 313-3774 or email askepri@epri.com.
- Having Trouble Downloading?** (dropdown menu).

GIC Harmonic Analysis



- Adding harmonic analysis requires performing the following steps
 1. Solve the power flow with the desired GMD (or HEMP) electric field; the power flow should include models representing the sensitivity of components (e.g., shunt capacitors) to harmonics (e.g., THDv), and should have the ability to store at least the bus THDv values
 2. Save the power flow model in OpenDSS format
 3. Use GICHarm to solve for the harmonics
 4. Load the harmonic information (e.g., bus THDv) into the power flow
 5. If harmonics are below trip values then done; others trip the associated devices and go to 1.
- The PowerWorld GICHarm integration automates this, but first we'll step through it manually

Analysis Using PowerWorld and GIC Harm Separately



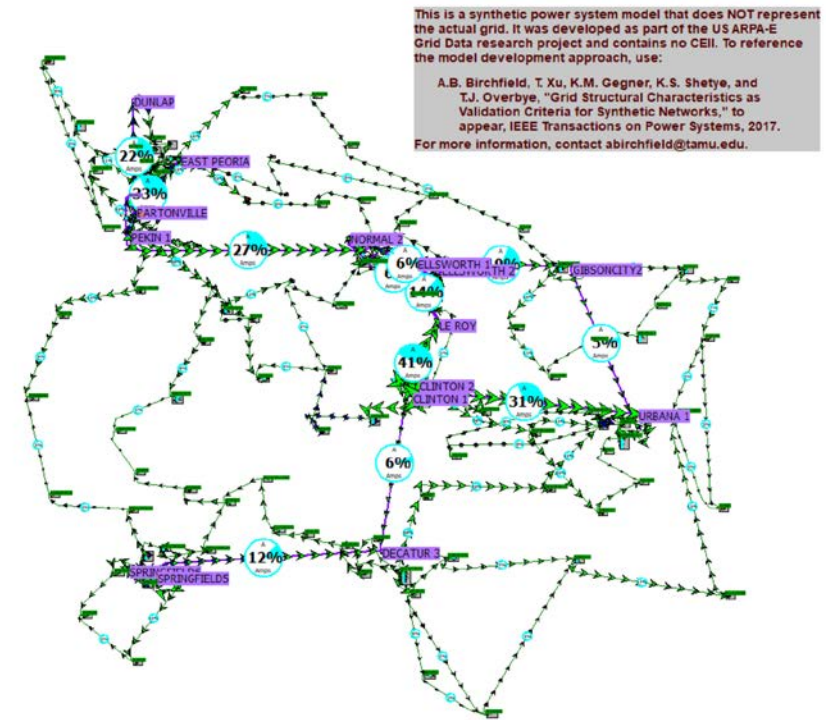
- Load a case in PowerWorld and save it in the *.raw format (version 33) and save a *.gic file (version 4)
- This example uses the 200 bus available at electricgrids.engr.tamu.edu/electric-grid-test-cases/

Synthetic Cases from ARPA-E GridData Program

Synthetic electric grid models are fictitious representations that are designed to be statistically and functionally similar to actual electric grids while containing no confidential critical energy infrastructure information (CEII). Some of these cases were developed with the support of the [U.S. DOE ARPA-E Grid Data program](http://www.electricgrids.engr.tamu.edu/arpa-e-grid-data-program/); their support is gratefully acknowledged. Specific references for the creation and validation of these cases [here](http://www.electricgrids.engr.tamu.edu/arpa-e-grid-data-program/).

ACTIVSg200: 200 bus synthetic grid on footprint of Central Illinois – TS GMD OPF
 ACTIVSg500: 500 bus synthetic grid on footprint of South Carolina – TS GMD OPF
 ACTIVSg2000: 2000 bus synthetic grid on footprint of Texas – TS GMD OPF MOV PMU
 ACTIVSg10k: 10,000 bus synthetic grid on footprint of western United States – TS GMD OPF MOV
 ACTIVSg25k: 25,000 bus synthetic grid on footprint of northeastern United States – TS GMD OPF
 ACTIVSg70k: 70,000 bus synthetic grid on footprint of eastern United States – GMD OPF

Synthetic PMU Data for the 2000-bus case



Separate Analysis: Solve for the GICs and Export



- After loading the case, select **Add Ons, GIC**; go to the Single Snapshot page, set the Maximum Electric Field to 1.14 Volts/mile and set the Storm Direction to 45 degrees; make sure **Include GIC in Power Flow and Transient Stability** is checked; solve the power flow, and then save the results as a 1) *.raw file (version 33), and 2) on the GIC Analysis Form select Supplemental File Options to save the *.gic (version 4)

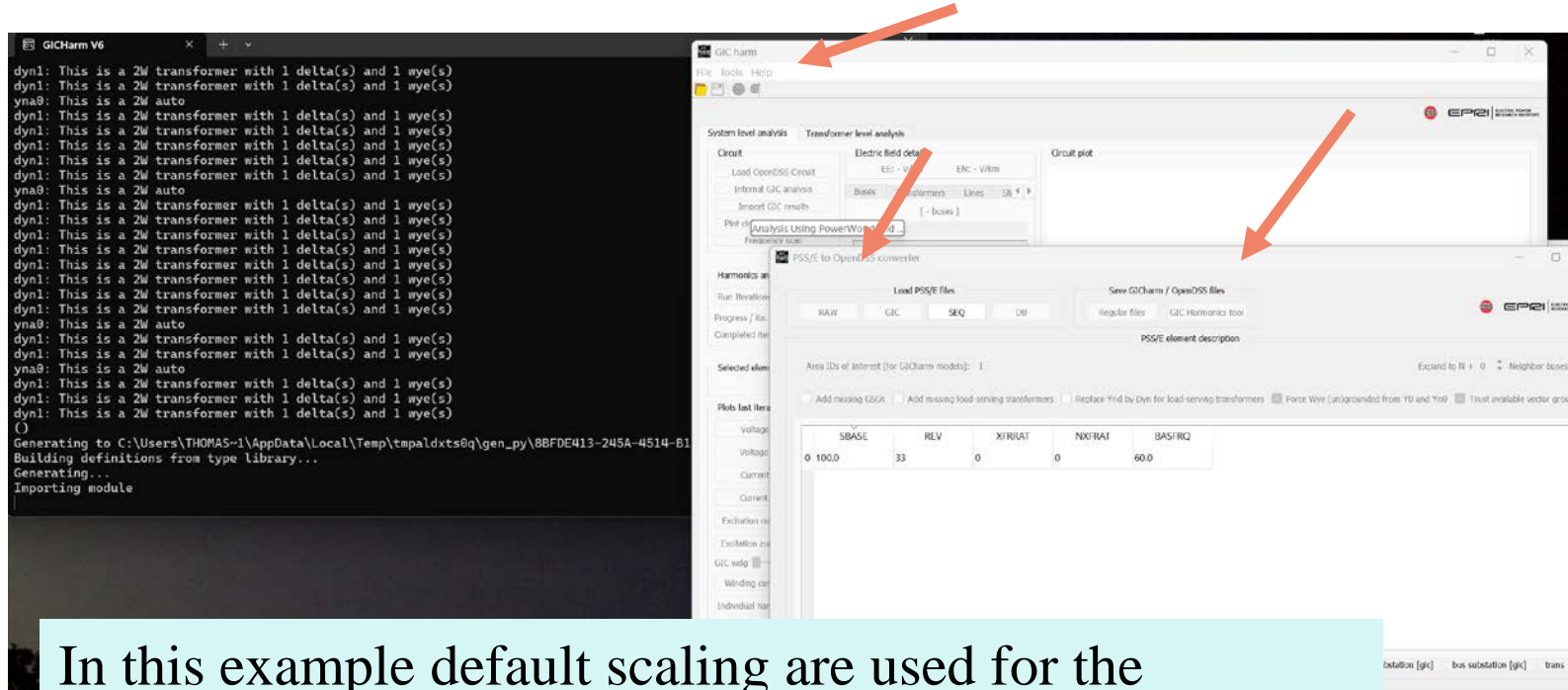
The screenshot shows the 'GIC Analysis Form' window. Red arrows point to the following elements:

- Calculation Mode:** 'Single Snapshot' is selected.
- Field/Voltage Input:** 'Maximum Field' is set to 1.14 Volts/mile and 'Storm Direction' is set to 45.0 Degrees.
- Buttons:** 'Calculate GIC Values' and 'Update Line Voltages (Should be True Unless Explicitly Entered)' are checked.
- Distance Units:** 'Miles' is selected.
- Hotspot Modeling:** 'Include' is checked, and 'Interpolate Along Line Path' is selected under 'Modeling of Scaling and Hotspots'.
- Supplemental File Options:** This button is located at the bottom of the window.

Separate Analysis: GICHarm, Creating *.dss Files



- Start GICHarm and select **Tools, PSS/E to OpenDSS Converter**
- Load the RAW and GIC files, then select **GIC Harmonics Tool** to produce the set of *.dss files; the file name should be master_file



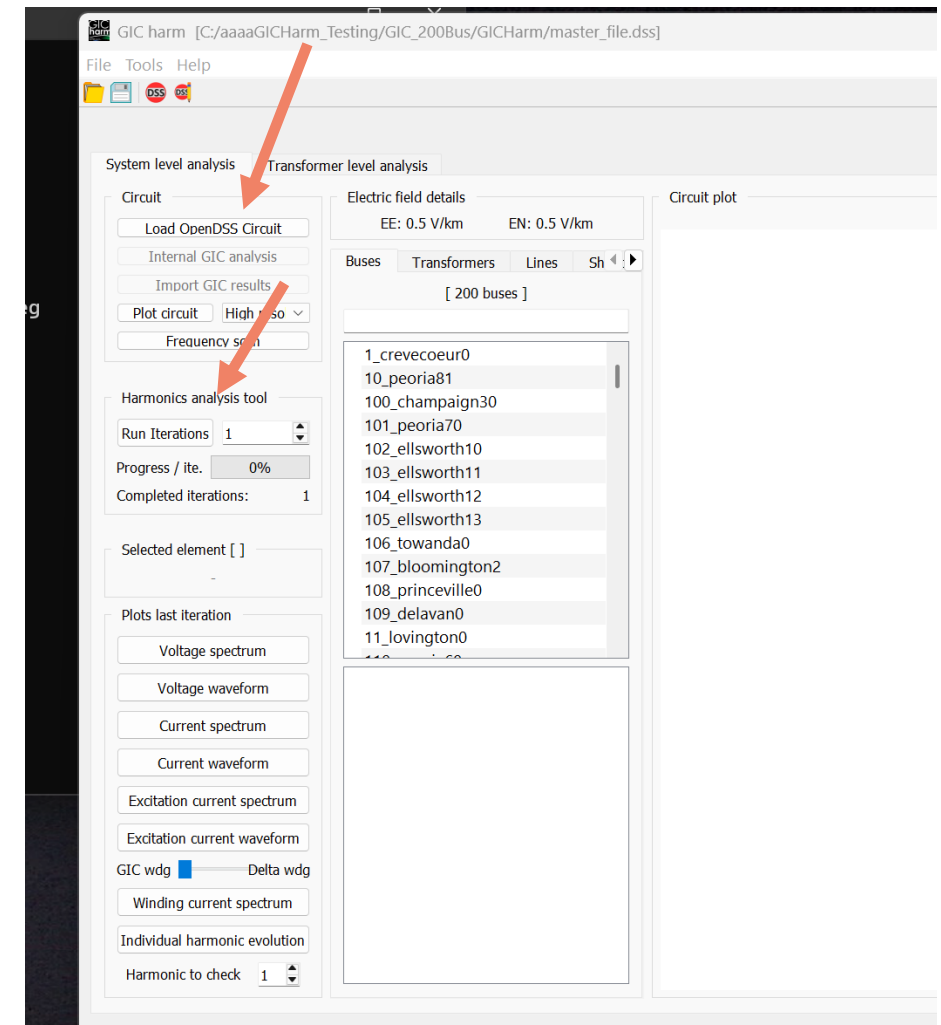
In this example default scaling are used for the sequence values, but they could be loaded as well

history	7/5/2025 10:22 AM	File folder	
recovery	7/5/2025 4:00 PM	File folder	
pickle_xmrs	7/5/2025 11:47 AM	File folder	
commands_file.dss	7/5/2025 11:47 AM	DSS File	2 KB
confirm_kv_bases.dss	7/9/2025 8:35 AM	DSS File	11 KB
dc_and_facts_equiv_elements.dss	7/9/2025 8:35 AM	DSS File	1 KB
dc_equiv_gsu_mag_nonlin_load.dss	7/9/2025 8:35 AM	DSS File	1 KB
dc_equiv_step_ups.dss	7/9/2025 8:35 AM	DSS File	1 KB
dc_equiv_step_ups.dss	7/9/2025 8:35 AM	DSS File	1 KB
generator_step_ups.dss	7/9/2025 8:35 AM	DSS File	1 KB
generators.dss	7/9/2025 8:35 AM	DSS File	8 KB
generators_as_vsrcs.dss	7/9/2025 8:35 AM	DSS File	11 KB
gic_sources.dss	7/9/2025 8:35 AM	DSS File	19 KB
lines.dss	7/9/2025 8:35 AM	DSS File	47 KB
load_transformers.dss	7/9/2025 8:35 AM	DSS File	12 KB
loads.dss	7/9/2025 8:35 AM	DSS File	39 KB
master_file.dss	7/9/2025 8:35 AM	DSS File	3 KB
monitors.dss	7/9/2025 8:35 AM	DSS File	14 KB
monitors_dc_equiv_gsu.dss	7/9/2025 8:35 AM	DSS File	1 KB
monitors_gsu.dss	7/9/2025 8:35 AM	DSS File	1 KB
monitors_lines.dss	7/9/2025 8:35 AM	DSS File	11 KB
monitors_shunts.dss	7/9/2025 8:35 AM	DSS File	1 KB
monitors_transformers_loads.dss	7/9/2025 8:35 AM	DSS File	1 KB
shunts.dss	7/9/2025 8:35 AM	DSS File	1 KB
sw_shunts.dss	7/9/2025 8:35 AM	DSS File	1 KB
transformers.dss	7/9/2025 8:35 AM	DSS File	55 KB
transformers_mag_nonlin_loads.dss	7/9/2025 8:35 AM	DSS File	26 KB
v_file_update.dss	7/9/2025 8:35 AM	DSS File	0 KB
v_res.dss	7/9/2025 8:35 AM	DSS File	1 KB

Separate Analysis: Solving Harmonics



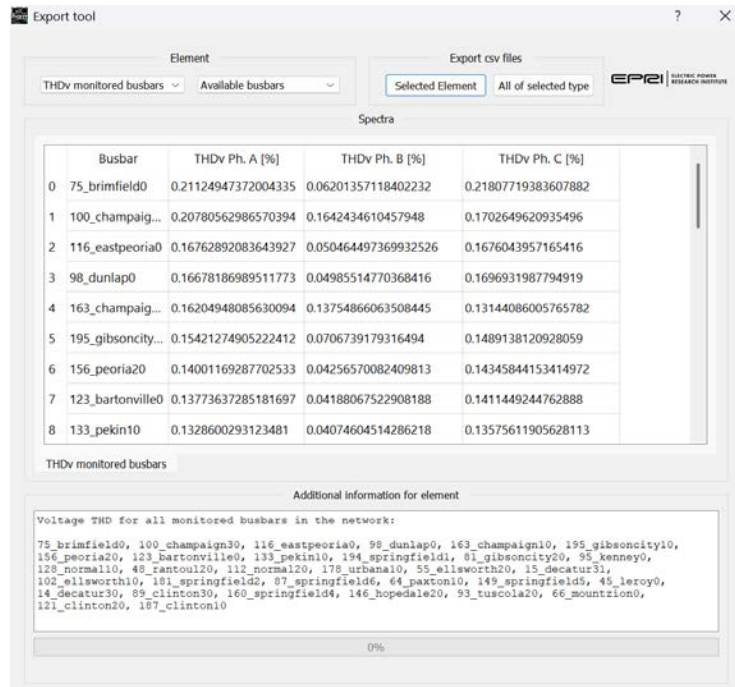
- Then, still in GIC Harm, select **File, Open** and then select the saved master_file.dss, which loads all the other files
- Select **Load OpenDSS Circuit**
- Select **Internal GIC Analysis**
- Set the number of desired internal GIC Harm iterations (I use 1 for testing)
- Select **Run Iterations**
 - It takes about 14 seconds on my computer)



Separate Analysis: Exporting Results



- To save the results select **Tools, Export Tool**, then select **THDv monitored busbars** and **Available busbars**
- Then select **Selected Element**, and give a directory to save the thdv__available_busbars file



Busbar	THDv Ph. A [%]	THDv Ph. B [%]	THDv Ph. C [%]
75_brimfie	0.211212665	0.061880077	0.218080481
100_cham	0.206758998	0.163955406	0.170482574
116_eastp	0.167578378	0.050340694	0.167606785
98_dunlap	0.166740831	0.049735227	0.169696653
163_cham	0.161113147	0.137227734	0.131586599
195_gibso	0.153975578	0.070389746	0.14888217
156_peori	0.139973429	0.042469503	0.143461074
123_barto	0.137699481	0.041786024	0.141147672
133_ekin	0.132819682	0.040655236	0.135758985
194_spring	0.130408106	0.126347771	0.120955602
81_gibson	0.124657908	0.068255718	0.112953835
95_kennedy	0.119785532	0.115429106	0.103216083
128_norma	0.116393096	0.04928657	0.111812819
48_rantoul	0.113123774	0.070709947	0.106334474
112_norma	0.112406857	0.048311083	0.108454395
55_ellswor	0.10976094	0.051230811	0.104079029
178_urban	0.109553468	0.088365237	0.090825766
15_decatu	0.103933411	0.110794091	0.080015328
102_ellsw	0.103310512	0.048422955	0.098865679
181_spring	0.100428668	0.1010782	0.09489046
87_springf	0.099821454	0.098269067	0.090725505
64_paxton	0.099079687	0.065691636	0.08758406
149_spring	0.093183936	0.092235954	0.08492414
45_leroy0	0.092807985	0.049590348	0.08690565
14_decatu	0.089910161	0.094649492	0.067664489
89_clinton	0.086542646	0.095050901	0.067364586
160_spring	0.084575286	0.086421077	0.080432754
146_hopec	0.076268732	0.054673511	0.069610438
93_tuscol	0.074788434	0.089991648	0.058326302
66_mount	0.064910908	0.074332077	0.050413983
121_clinto	0.059743056	0.056114017	0.049716216
187_clinto	0.053588428	0.048353469	0.045039209

Separate Analysis: Loading Results into Simulator



- Simulator now has fields to store and use the bus THDv values
- These can be loaded using the new **Harmonic Analysis** page on the GIC Analysis Form
- This page is used for automatic and manual analysis

Here the values are manually loaded from the *.csv file

Number of Bus	Name of Bus	ID	OpenDSS ID	Included in GIC	Neutral Node Number	Active PFW Model(s)	Bus THDv Valid	Bus THDv Max	Bus THDv Phase A	Bus THDv Phase B	Bus THDv Phase C	Actual Mvar	From Multiple
1	DECATUR 3 1	1	15_1	YES	5	YES	YES	0.111	0.104	0.111	0.080	32.33	NO
2	95 KENNEY 0	1	95_1	YES	7	YES	YES	0.120	0.120	0.115	0.103	31.43	NO
3	100 CHAMPAIGN30	1	100_1	YES	5	YES	YES	0.207	0.207	0.164	0.170	84.43	NO
4	194 SPRINGFIELD1	1	194_1	YES	5	YES	YES	0.130	0.130	0.126	0.121	53.07	NO

Showing results

Separate Analysis: Loading Results into Simulator



- The THDv fields are regular Simulator fields, though they are read only
 - GIC Harm doesn't calculate the values at all buses

Model Explorer: Buses

Explore Fields

- Recent
- Network
 - Branches By Type
 - Branches Input (246)
 - Branches State (246)
 - Buses (200)
 - DC Transmission Lines
 - Generators (49)
 - Impedance Correction Tables
 - Line D-FACTS Devices
 - Line Shunts
 - Loads (160)
 - Mismatches (200)
 - Multi-Terminal DC
 - Switched Shunts (4)
 - Three-Winding Transformers
 - Transformer Controls (66)
 - Voltage Control Groups
 - Voltage Droop Controls
 - VSC DC Transmission Lines
 - Aggregations
 - Other Aggregations
 - Case Summary (1)
 - Injection Groups
 - Interfaces
 - Islands (1)
 - Multi-Section Lines
 - MW Transactions
 - Owners (1)
 - Substations (111)
 - Super Areas
 - Transfer Directions
 - Zones (7)
 - Case Information and Auxiliary
 - Conditions, Filter, and Exceptions

Buses

Number	Name	THDv Valid	THDv Phase A	THDv Phase B	THDv Phase C	THDv Max	Sub Name	Sub Num	Zone Name	Zone Num
1	75 BRIMFIELD 0	YES	0.211	0.062	0.218	0.218	BRIMFIELD	36	Peoria	
2	100 CHAMPAIGN3	YES	0.207	0.164	0.170	0.207	CHAMPAIGN 3	50	Champaign-U	
3	98 DUNLAP 0	YES	0.167	0.050	0.170	0.170	DUNLAP	49	Peoria	
4	116 EASTPEORIA0	YES	0.168	0.050	0.168	0.168	EAST PEORIA	60	Peoria	
5	163 CHAMPAIGN11	YES	0.161	0.137	0.132	0.161	CHAMPAIGN 1	88	Champaign-U	
6	195 GIBSONCITY1C	YES	0.154	0.070	0.149	0.154	GIBSONCITY1	108	Rural NE	
7	156 PEORIA 2 0	YES	0.140	0.042	0.143	0.143	PEORIA 2	83	Peoria	
8	123 BARTONVILLE	YES	0.138	0.042	0.141	0.141	BARTONVILLE	65	Peoria	
9	133 PEKIN 1 0	YES	0.133	0.041	0.136	0.136	PEKIN 1	70	Peoria	
10	194 SPRINGFIELD1	YES	0.130	0.126	0.121	0.130	SPRINGFIELD1	107	Springfield	
11	81 GIBSONCITY2C	YES	0.125	0.068	0.113	0.125	GIBSONCITY2	38	Rural NE	
12	95 KENNEY 0	YES	0.120	0.115	0.103	0.120	KENNEY	46	Bloomington-	
13	128 NORMAL 1 0	YES	0.116	0.049	0.112	0.116	NORMAL 1	66	Bloomington-	
14	48 RANTOUL 2 0	YES	0.113	0.071	0.106	0.113	RANTOUL 2	23	Rural NE	
15	112 NORMAL 2 0	YES	0.112	0.048	0.108	0.112	NORMAL 2	59	Bloomington-	
16	15 DECATUR 3 1	YES	0.104	0.111	0.080	0.111	DECATUR 3	7	Rural SW	
17	55 ELLSWORTH2	YES	0.110	0.051	0.104	0.110	ELLSWORTH 2	25	Bloomington-	
18	178 URBANA 1 0	YES	0.110	0.088	0.091	0.110	URBANA 1	96	Champaign-U	
19	102 ELLSWORTH1C	YES	0.103	0.048	0.099	0.103	ELLSWORTH 1	52	Bloomington-	
20	181 SPRINGFIELD2	YES	0.100	0.101	0.095	0.101	SPRINGFIELD2	98	Rural SW	
21	87 SPRINGFIELD6	YES	0.100	0.098	0.091	0.100	SPRINGFIELD6	43	Springfield	
22	64 PAXTON 1 0	YES	0.099	0.066	0.088	0.099	PAXTON 1	33	Rural NE	
23	89 CLINTON 3 0	YES	0.087	0.095	0.067	0.095	CLINTON 3	44	Bloomington-	
24	14 DECATUR 3 0	YES	0.090	0.095	0.068	0.095	DECATUR 3	7	Rural SW	
25	149 SPRINGFIELD5	YES	0.093	0.092	0.085	0.093	SPRINGFIELD5	82	Springfield	
26	45 LE ROY 0	YES	0.093	0.050	0.087	0.093	LE ROY	21	Bloomington-	
27	93 TUSCOLA 2 0	YES	0.075	0.050	0.058	0.090	TUSCOLA 2	45	Rural SW	
28	160 SPRINGFIELD4	YES	0.085	0.086	0.080	0.086	SPRINGFIELD4	86	Rural SW	
29	146 HOPEDALE 2 C	YES	0.076	0.055	0.070	0.076	HOPEDALE 2	80	Bloomington-	
30	66 MOUNT ZION	YES	0.065	0.074	0.050	0.074	MOUNT ZION	34	Rural SW	
31	121 CLINTON 2 0	YES	0.060	0.056	0.050	0.060	CLINTON 2	64	Bloomington-	
32	187 CLINTON 1 0	YES	0.054	0.048	0.045	0.054	CLINTON 1	102	Bloomington-	
33	197 GIBSONCITY12	NO					GIBSONCITY1	108	Rural NE	
34	31 HEYWORTH 0	NO					HEYWORTH	13	Bloomington-	
35	190 MAHOMET 0	NO					MAHOMET	103	Rural NE	
36	188 CLINTON 1 1	NO					CLINTON 1	102	Bloomington-	
37	196 GIBSONCITY11	NO					GIBSONCITY1	108	Rural NE	

Display/Column Options: Bus

Column Options: Display Options: Data View Layouts

Available Fields: Custom, Data Check, Data Maintainer, Difference Case, Dummy Bus, EPCole, Equalizing, Fault Analysis, Fixed Bus, Fixed Bus, Generators, Generators Type Unit Fuel, Geography, Geomagnetically Induced Current, Harmonics

THDv Valid, THDvA, THDvB, THDvC, THDvMax

String, Integer, Floating Point, Field is Shown

Reset to Factory Defaults, Save Custom Settings, Non Default Values

OK, Save, Cancel, Help

Show these fields in this order: Number, Name, Harmonics\THDv Valid, Harmonics\THDvA, Harmonics\THDvB, Harmonics\THDvC, Harmonics\THDvMax, Substation\Name, Substation\Number, Zone\Name, Zone\Number, Area\Name, Area\Number, Geography\Substation Latitude, Geography\Substation Longitude, Voltage\kV Nominal, Voltage\Per Unit Magnitude, Voltage\kV Actual, Voltage\Angle (degrees), Loads\WW

Col Width: 75, Total Digits: 8, Dec Places: 3

Remove trailing zeros after decimal point

Contour Column

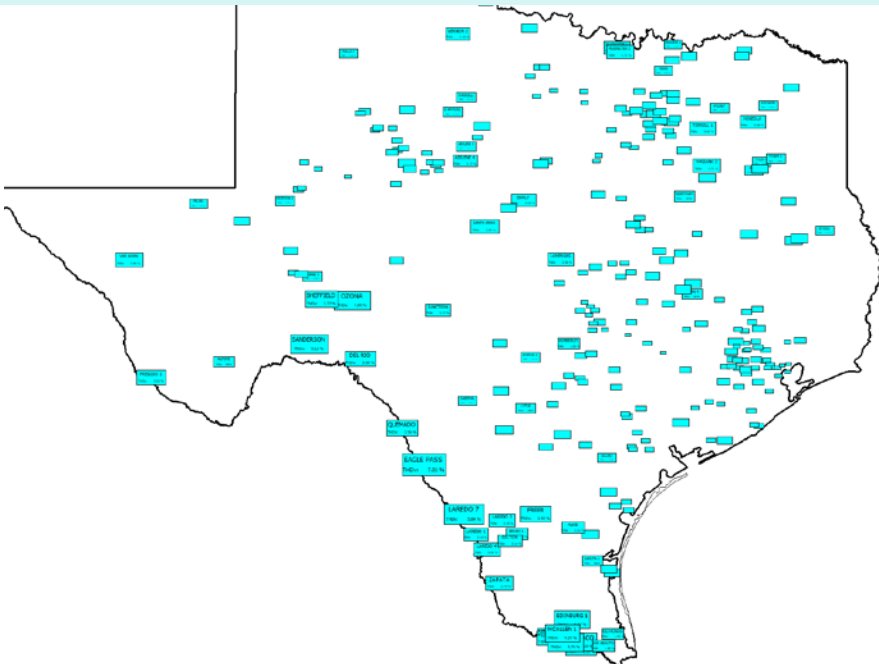
Frozen Columns: 1

Full Simulator Support of Harmonic Information



- Since harmonics is fully integrated into Simulator, all of Simulator's capabilities are available for the display of the associated information; e.g., case information displays, dialogs, onelines including full geographic data view (GDV) support

2000 Bus Case, Substation GDV of THDv



Simulator Case Info Display Showing GICHarm Bus THDv

Number of Bus	Name of Bus	ID	Reg Bus Num	Bus THDv Max	Status	Status Branch	Control Mode	Auto Control	Regulates	Actual Mvar	Volt High
1	1007 VAN HORN 0	1	1007	2.883	Open		Fixed	YES	Volt	0.00	1.000
2	1010 PRESIDIO 1 0	1	1010	3.098	Open		Fixed	YES	Volt	0.00	0.000
3	1012 SANDERSON 1	1	1012	5.121	Closed		Fixed	YES	Volt	9.90	0.000
4	1016 GARDEN CITY 1	1	1016		Closed		Fixed	YES	Volt	31.09	0.000
5	1019 MIDLAND 4 0	1	1019	0.399	Closed		Fixed	YES	Volt	140.21	0.000
6	1020 BIG SPRING 1 1	1	1020		Closed		Fixed	YES	Volt	79.83	0.000
7	1027 MIDLAND 2 0	1	1027	0.322	Closed		Fixed	YES	Volt	76.33	1.000
8	1029 MIDLAND 3 0	1	1029	0.294	Closed		Fixed	YES	Volt	40.27	0.000
9	1030 ALPINE 0	1	1030	1.594	Open		Fixed	YES	Volt	0.00	1.000
10	1033 MCCAMEY 1 1	1	1033	0.773	Closed		Fixed	YES	Volt	20.56	1.000
11	1046 OZONA 0	1	1046	4.893	Closed		Fixed	YES	Volt	12.51	0.000
12	1056 LENORAH 0	1	1056	0.266	Closed		Fixed	YES	Volt	84.55	0.000
13	1081 ODESSA 1 10	1	1081	1.346	Closed		Fixed	YES	Volt	146.35	1.000
14	1083 FORT STOCKTON 1	1	1083		Closed		Fixed	YES	Volt	27.29	0.000
15	1086 PECOS 0	1	1086	1.243	Closed		Fixed	YES	Volt	30.95	0.000
16	1087 SHEFFIELD 0	1	1087	3.766	Closed		Fixed	YES	Volt	32.12	1.000
17	2009 IOWA PARK 0	1	2009	0.932	Closed		Fixed	YES	Volt	124.74	1.000
18	2010 VERNON 2 0	1	2010	2.104	Closed		Fixed	YES	Volt	20.57	1.000
19	2017 PANHANDLE 4 1	1	2017		Closed		Fixed	YES	Volt	-105.76	1.000
20	2017 PANHANDLE 4 2	1	2017		Closed		Fixed	YES	Volt	-105.76	1.000
21	2063 DENISON 2 0	1	2063	1.185	Closed		Fixed	YES	Volt	40.95	1.000
22	2065 GAINESVILLE 0 1	1	2065		Closed		Fixed	YES	Volt	105.02	1.000
23	2069 HOWE 0	1	2069	1.208	Closed		Fixed	YES	Volt	126.60	0.000
24	2096 RALLS 1 0	1	2096	1.184	Open		Fixed	YES	Volt	0.00	1.000
25	2096 RALLS 1 0	2	2096	1.184	Closed		Fixed	YES	Volt	-104.26	1.000
26	2110 MUENSTER 2 1	1	2110	2.709	Closed		Fixed	YES	Volt	52.46	0.000
27	2127 MIAMI 0	1	2127	0.910	Closed		Fixed	YES	Volt	-162.24	1.000
28	2132 HASKELL 2	1	2132		Closed		Fixed	YES	Volt	9.98	0.000
29	3013 ABILENE 4 0	1	3013	2.169	Closed		Fixed	YES	Volt	66.57	0.000
30	3013 ABILENE 4 0	2	3013	2.169	Closed		Fixed	YES	Volt	66.57	0.000

Separate Analysis: Using THDv Values in Simulator



- The next step is to use the THDv models to determine which switched shunts to outage
- This could be done manually, but that would get quite tedious and could not be automated
- The solution is to define and use PFW models

PowerWorld Simulator PFW Models



- Over the last three years PowerWorld has been developing a growing library of models to represent the impact of weather and other external events on the electric grid; these are known as PFW models
 - The first PFW models were developed to model the impact of weather on grid values, such as the maximum output values for wind and solar, or temperature on transmission line limits
- PFW originally stood for Power Flow Weather, but now it has been generalized to Power Flow Whatever models
- The approach (and actually the code itself) is similar to what is done for handling the large number of models used with power system stability; hence it is a very versatile and expandable approach
- New models are easy to implement

PFW Example: Customized Wind Power Curve



- Customized wind power curve models can also be defined; this only needs to be done once per wind generator

PFW Models Weather Details Apply Time-Varying Weather to PFW Model Weather Interpolation Details

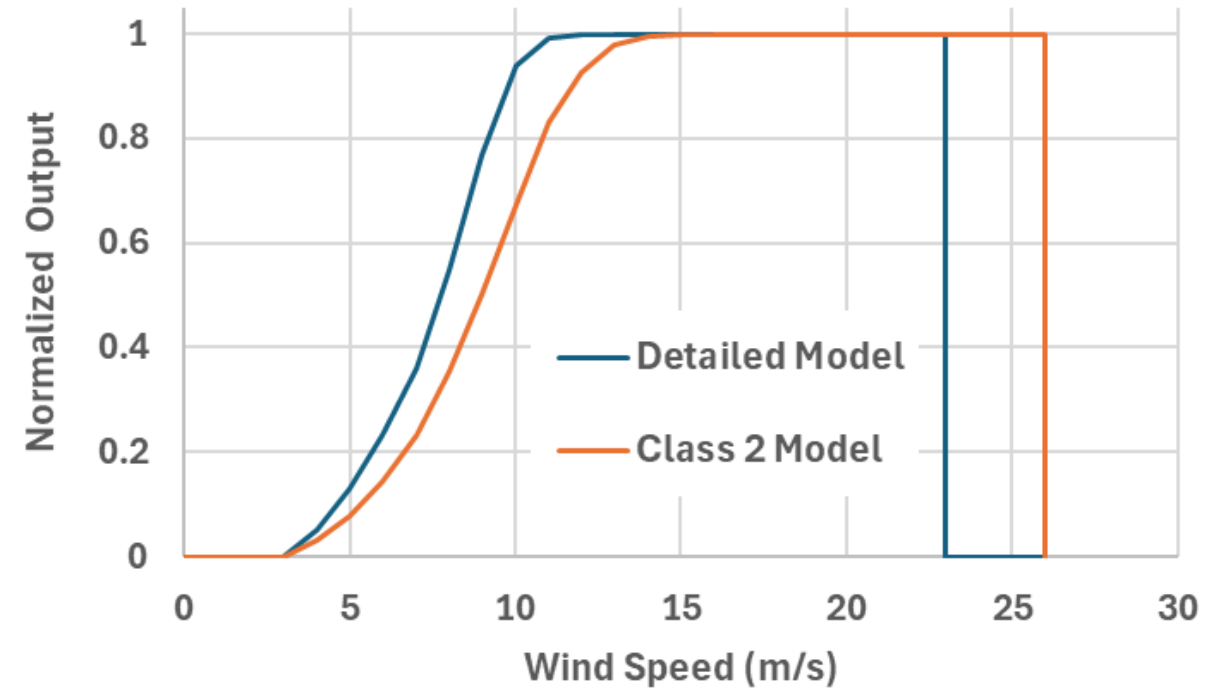
PFW Gen Object

Insert Delete

Type Active - WindGeneral ☒ Active (only one may be active) Set to Defaults

Parameters

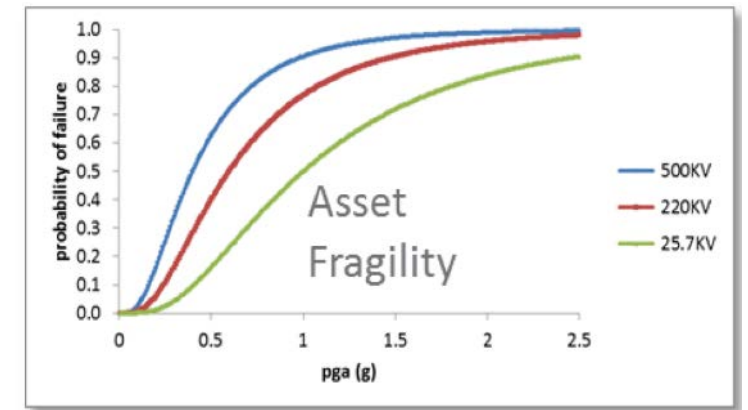
Description	Speed1	PowerScalar5	Speed10
AllowTurnOff	1	PowerScalar1 0.00062	Speed6 5.0000
AllowTurnOn	1	PowerScalar2 0.00062	Speed7 6.0000
MWMax	217.0000	PowerScalar3 0.00062	Speed8 7.0000
HubHeightScalar	1.5000	PowerScalar4 0.00062	Speed9 8.0000
WindSpeedScalar	1.0500	PowerScalar5 0.05000	Speed10
HubHeightM	80.1624	PowerScalar6 0.1599	Speed11 1
CutOut1MS	26.0000	PowerScalar7 0.3111	Speed12 1
CutOut2MS	26.0000	PowerScalar8 0.4988	Speed13 1
	Speed5 4.0000	PowerScalar9 0.7154	Speed14 1



Additional PFWs, Including Harmonic Impacts



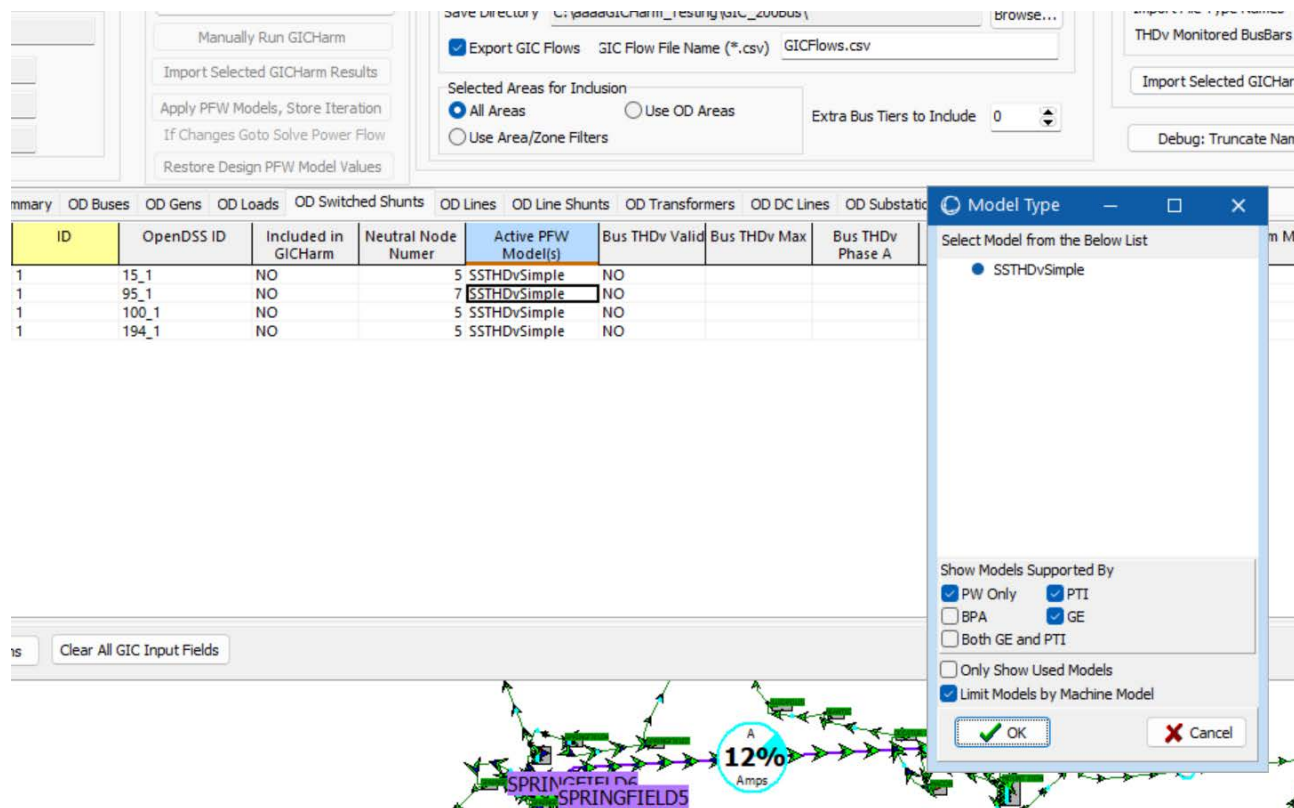
- Many different PFW models are possible, and they could certainly be stochastic
- Examples include ambient-adjusted line ratings, dynamic line ratings, thermal generator output variation with temperature, line outage due to wind gusts, asset failure during earthquakes (see figure with pga=Peak Ground Acceleration), incremental impacts of temperature on load, etc.
- The modeling of capacitors tripping due to the bus THDv just required creating a new, quite simple PFW model



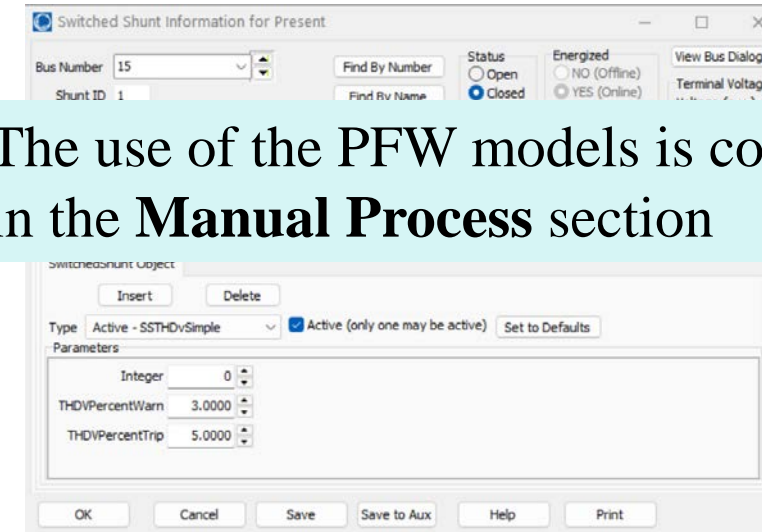
Inserting Capacitor PFW Models for Harmonics



- To quickly insert PFW models for capacitors, on the OD Switched Shunts case info display select **Insert New PFW Models**
 - Like other models, the PFW models are saved in the pwb



The use of the PFW models is covered next in the **Manual Process** section



Simulator Harmonic Analysis Manual Process



- What has been covered in the Separate Analysis section can be done more efficiently using either the step-by-step manual process or in the automated analysis
- When run either manually or automatically the following steps occur
 1. Initial error checking and resetting the iterations
 2. Solving the power flow with the GIC values (depends on GIC Calculation Mode)
 3. Exporting the PowerWorld data in OpenDSS format; this also exports a *.csv file with the GIC values
 4. Automatically running GICHarm to calculate the harmonics
 5. Importing the GICHarm results; currently the bus THDv values
 6. Using PFW Models to update the power flow values (e.g., capacitor statuses)
 7. Repeating until there are no power flow changes or power flow divergence

Simulator Harmonic Analysis Page



- On the Harmonic Analysis page the full simulation can be done either manually (a good place to start) or automatically
 - Simulator creates its own *.dss files and automatically runs GICHarm

GIC Analysis Form

Calculation Mode
☒ Single Snapshot
☐ Time Varying Electric Field Inputs
☐ Time Varying Series Voltage Inputs
☐ Spatially Uniform Time-Varying E-Field

Calculate GIC Values Clear GIC Values ☒ Include GIC in Power Flow and Transient Stability Validate Input Data for GIC
☒ Update Line Voltages (Should be True Unless Explicitly Entered) Clear All GIC Input and Values

Select Step

- Generators
- DC Lines
- Lines
- Line Shunts
- Loads
- Switched Shunts
- Substations
- Transformers
- Multi-Section Lines
- System Summary
- G-Matrix
- Multi-Terminal DC Lin
- VSC DC Lines
- Sensitivity Analysis
- Non-Uniform Electric Field
- Geomagnetic Latitud
- Earth Resistivity Sca
- Earth Resistivity Sca
- Harmonic Analysis**
 - Iterations with GICH
 - PFW Model Summary
 - OD Buses
 - OD Gens
 - OD Loads
 - OD Switched Shunts
 - OD Lines
 - OD Line Shunts
 - OD Transformers
 - OD DC Lines
 - OD Substations
 - OD Areas
 - OD Zones
 - Data in DSS Files

Harmonic Analysis

Automated Analysis with Options and Status

Run Automated Analysis with GICHarm
 Cancel Maximum Number of Iterations 5

Status
 Power Flow Solution Finished

Current Iteration Number 0
 Status Change Current Iteration
 Total Status Changes

Manual Process

Initial Error Check, Reset Iterations
 Solve Power Flow with GIC Values
 Save Case in Open DSS Format
 Manually Run GICHarm
 Import Selected GICHarm Results
 Apply PFW Models, Store Iteration
 If Changes Goto Solve Power Flow
 Restore Design PFW Model Values

Automated Analysis Tool Options

Directories and Files
 GICHarm Program Directory: C:\GICHarm_V6 Browse...
 Export Case in OpenDSS Format for GICHarm Analysis
 Save Directory C:\aaaaGICHarm_Testing\GIC_200Bus\ Browse...
☒ Export GIC Flows GIC Flow File Name (*.csv) GICFlows.csv
 Selected Areas for Inclusion
☒ All Areas ☐ Use OD Areas Extra Bus Tiers to Include 0
☐ Use Area/Zone Filters

Import GICHarm Results

Results SubDirectory results_scenarios\Scenario_0
 (The Results SubDirectory is in the Save Directory)
 Import File Type Names
 THDv Monitored BusBars thdv__available_busbars.csv ☒ Include
 Import Selected GICHarm Results
 Debug: Truncate Names to 12 for Raw Export, Unique

Iterations with GICHarm	PFW Model Summary	OD Buses	OD Gens	OD Loads	OD Switched Shunts	OD Lines	OD Line Shunts	OD Transformers	OD DC Lines	OD Substations	OD Areas	OD Zones	Data in DSS Files	
	Number of Bus	Name of Bus	ID	OpenDSS ID	Included in GICHarm	Neutral Node Numer	Active PFW Model(s)	Bus THDv Valid	Bus THDv Max	Bus THDv Phase A	Bus THDv Phase B	Bus THDv Phase C	Actual Mvar	From Multiple
1	15	DECATUR 3 1	1	15_1	NO		5 SSTDVSimple	NO					32.33 NO	
2	95	KENNEY 0	1	95_1	NO		7 SSTDVSimple	NO					31.43 NO	
3	100	CHAMPAIGN30	1	100_1	NO		5 SSTDVSimple	NO					84.43 NO	
4	194	SPRINGFIELD1	1	194_1	NO		5 SSTDVSimple	NO					53.07 NO	

Simulator Saving in OpenDSS Format



- The most challenging aspect of this process is correctly writing Simulator data in OpenDSS format
 - An OpenDSS case consist of many files (currently 24), so they are stored in their own directory
 - Simulator shows all of this data in a single case info display

Harmonic Analysis

Automated Analysis with Options and Status

Run Automated Analysis with GICHarm

Cancel Maximum Number of Iterations 5

Status

OpenDSS Files Saved

Current Iteration Number 0

Status Change Current Iteration

Total Status Changes

Manual Process

Initial Error Check, Reset Iterations

Solve Power Flow with GIC Values

Save Case in Open DSS Format

Manually Run GICHarm

Import Selected GICHarm Results

Apply PFW Models, Store Iteration

If Changes Goto Solve Power Flow

Restore Design PFW Model Values

Automated Analysis Tool Options

Directories and Files

GICHarm Program Directory: C:\GICHarm_V6 Browse...

Export Case in OpenDSS Format for GICHarm Analysis

Save Directory C:\aaaaGICHarm_Testing\GIC_200Bus\ Browse...

☒ Export GIC Flows GIC Flow File Name (*.csv) GICFlows.csv

Selected Areas for Inclusion

☒ All Areas ☐ Use OD Areas Extra Bus Tiers to Include 0

☐ Use Area/Zone Filters

Import GICHarm Results

Results SubDirectory results_scenarios\Scenario_0

(The Results SubDirectory is in the Save Directory)

Import File Type Names

THDv Monitored BusBars thdv___available_busbars.csv ☒ Include

Import Selected GICHarm Results

Debug: Truncate Names to 12 for Raw Export, Unique

Iterations with GICHarm PFW Model Summary OD Buses OD Gens OD Loads OD Switched Shunts OD Lines OD Line Shunts OD Transformers OD DC Lines OD Substations OD Areas OD Zones Data in DSS Files

DSS File Line

```

1 //*****
2 // Data in File C:\aaaaGICHarm_Testing\GIC_200Bus\master_file.dss
3
4 Clear
5
6 redirect env_variables.dss
7 New Circuit.ACTIVSg200_gicharm
8 ~ basekv=13.80 phases=3 pu=1.059569 angle=6.56194 frequency=60 baseMVA=683.0 puZ1=[0.0010, 0.1512] !Model=ideal
9 ~ bus1=189_CLINTON12
10

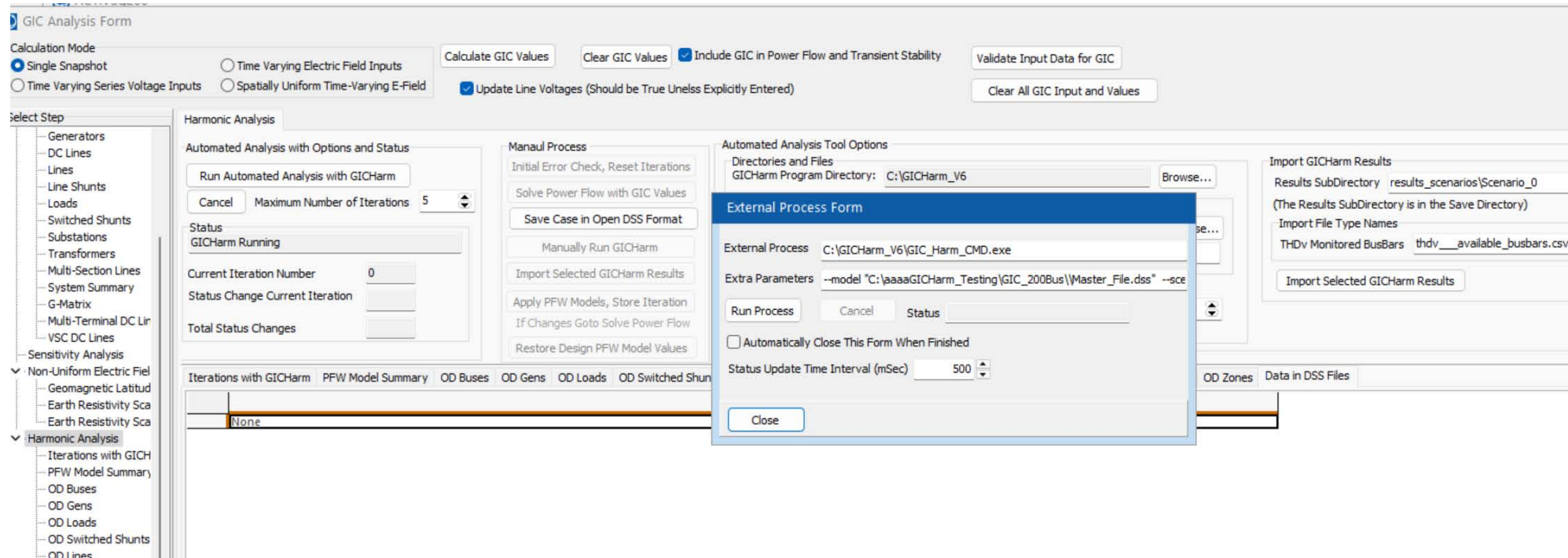
```

For the 200 bus case this file has about 2700 lines

Running the GICHarm Batch Analysis Tool



- During this solution the GICHarm Batch Analysis tool is used (GIC_Harm_CMD.exe)
- Simulator has a dialog for controlling it



Process Options



- Currently there are only a few solution options, but more will be coming soon; these include
 - The directory containing the GICHarm program
 - The directory to use for saving the OpenDSS format (*.dss) files and the GIC flows
 - The results subdirectory and the OpenDSS result files to load

Automated Analysis Tool Options

Directories and Files

GICHarm Program Directory:

Export Case in OpenDSS Format for GICHarm Analysis

Save Directory

☒ Export GIC Flows GIC Flow File Name (*.csv)

Selected Areas for Inclusion

☒ All Areas ☐ Use OD Areas ☐ Use Area/Zone Filters

Extra Bus Tiers to Include

Import GICHarm Results

Results SubDirectory

(The Results SubDirectory is in the Save Directory)

Import File Type Names

THDv Monitored BusBars ☒ Include

Summary and Future Directions



- PowerWorld Simulator is being integrated with EPRI's GICHarm program, allowing for the calculation and application of harmonics without leaving Simulator
- Beta functionality is currently available in Version 24, with development, validation and research ongoing
- Currently the focus is on using the bus THDv values, but additional values will be available in the future
- The functionality leverages the versatility of the PFW modeling methodology, which is being applied to weather and other environment inputs
- Additional options should be added in the near future

Thank You! Questions?

