

# PowerWorld Simulator Integration with GICHarm in Simulator Version 24

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# Overview

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- The purpose of this presentation is to show how EPRI's GICHarm program has been integrated into PowerWorld Simulator to do harmonic analysis
  - This feature will be available in Version 24, but is not yet available in the Version 24 beta
- 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

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- 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

# Aside: Upcoming Short Courses

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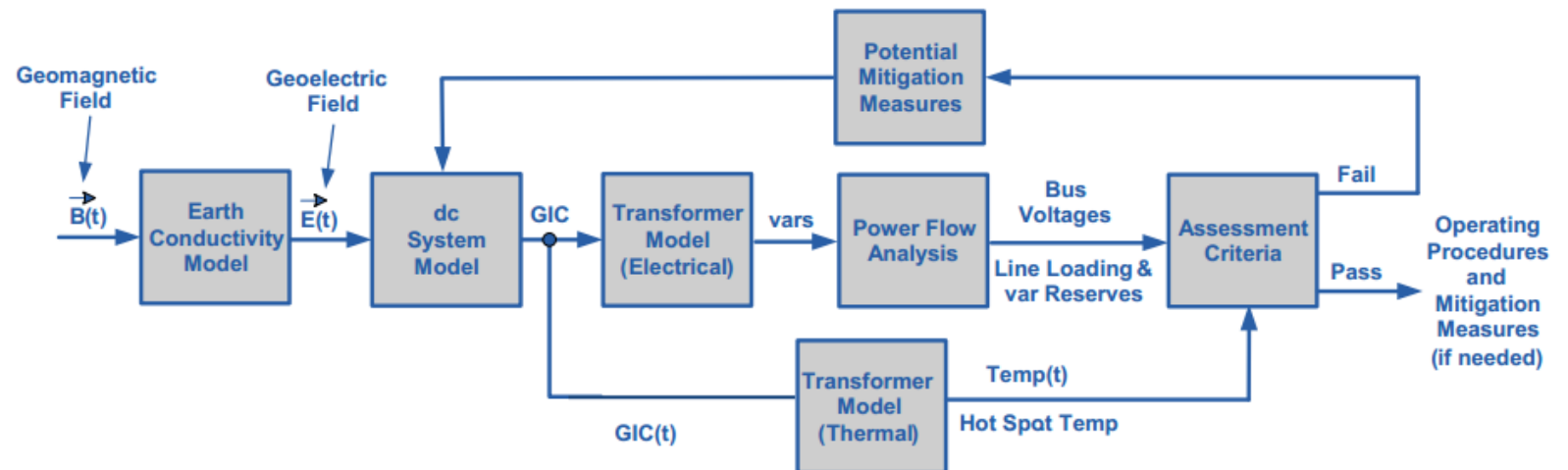
- Texas A&M has several upcoming short courses that relate to this presentation in Spring 2025
  - Primer on the Planning and Operation of Large-Scale Electric Grids (Feb 4-6)
    - Covers an overview of electric grid planning and operations for non-power engineers
  - Fundamentals of Electric Transmission System Planning (Feb 18-20)
    - Covers power system planning for power engineers including some GMD coverage
  - Electric Grid Impacts of Geomagnetic Disturbances (March 18-19)
    - Full GMD coverage including harmonics with GICHarm; co-taught with EPRI
- More details and registration information is at [epg.engr.tamu.edu/short-courses-main/](http://epg.engr.tamu.edu/short-courses-main/)

# 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 – Image shows the Single Snapshot 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

Update Line Voltages (Should be True Unless Explicitly Entered)    Clear All GIC Input and Values

Select Step

- Field/Voltage Input
  - Options
    - DC Current Calculati
    - AC Power Flow Mod
  - 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 Lir
    - VSC DC Lines
  - Sensitivity Analysis
  - Non-Uniform Electric Fiel
    - 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

Field/Voltage Input    Harmonic Analysis

Voltage Input Parameters

Electric Field Model Parameters  
 Maximum Field  Volts/km  
 Storm Direction  Degrees  
 Also Calculate Maximum Direction Values

Restrict Lines to which to model DC Voltages  
 Minimum Line Length  km  
 Calculate Voltages for Equivalent Lines  
 Calculate Voltages for Low R Lines

Distance Units  
 Kilometers  
 Miles

Geomagnetic Latitude Scaling Function   
 Earth Resistivity Scaling Region Set

Hotspot Modeling  
 Include  
 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

Hotspot Field in V/km   
 Width of Hotspot in Kilomet   
 Height of Hotspot in Kilome   
 Latitude of Center   
 Longitude of Center

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  Open File New Event

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

Change Start Date and Time to Zero Time Offset  Delete Event

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 becomes
  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

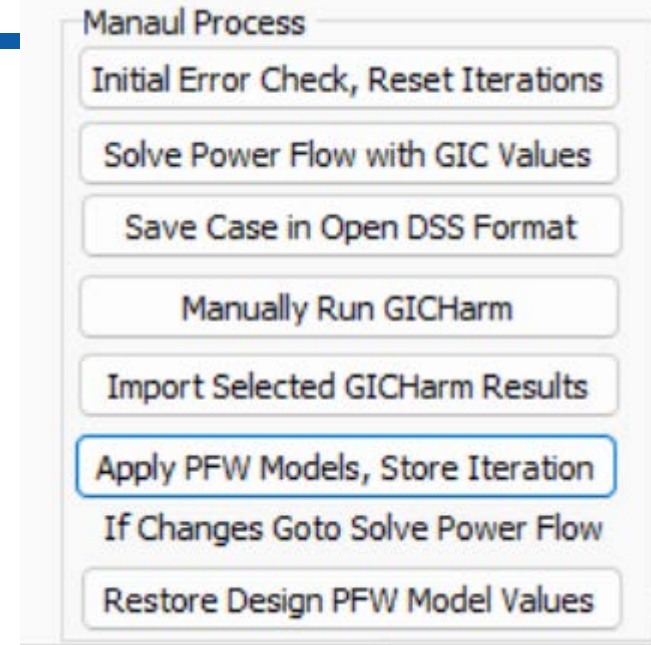
- The Simulator GIC Analysis Form now has a page to make this process fully automatic
  - A manual process is also provided to help in the initial setup of a simulation
  - Scripting commands will be added in the new future
- This requires GICHarm be installed on the computer

The screenshot displays the 'GIC Analysis Form' software interface. The 'Calculation Mode' section has 'Single Snapshot' selected. The 'Field/Voltage Input' section has 'Harmonic Analysis' selected. The 'Manual Process' section includes a 'Run Integrated Analysis with GICHarm' button. The 'Integrated Analysis Tool Options' section shows the 'GICHarm Program Directory' set to 'C:\GICHarm\_V6' and 'Export GIC Flows' checked. The bottom section contains a table with the following data:

| Iterations with GICHarm | Number of Bus | Name of Bus     | ID | ID     | Active PFW Model(s) | Bus THDv Valid | Bus THDv Max | Bus THDv Phase A | Bus THDv Phase B | Bus THDv Phase C |
|-------------------------|---------------|-----------------|----|--------|---------------------|----------------|--------------|------------------|------------------|------------------|
| 1                       | 1007          | PAN 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  | 1012_1 | SSTHDvSimple        | YES            | 5.121        | 5.121            | 5.093            | 5.050            |
| 4                       | 1016          | GARDEN CITY 0   | 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  | 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          | LENDRAH 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  | 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             |              |                  |                  |                  |

# Integrated Tool Detailed Steps

- When run either automatically or manually the following steps occur
  1. Initial error checking and resetting the iterations
  2. Solving the power flow with the GIC values; how this is done depends on the GIC Calculation Mode
  3. Exporting the PowerWorld data in OpenDSS format; this also exports a \*.csv file with the GIC values
  4. Running GICHarm to calculate the harmonics
  5. Importing the GICHarm results; currently the bus THDv values
  6. Using PFW Models (covered next) to update the power flow values based on the GICHarm results
  7. Repeating until there are no power flow changes or the power flow does not converge



# Integrated Tool 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

Integrated 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)

Solution Process Options

Maximum Number of Iterations

Import GICHarm Results

Results SubDirectory

(The Results SubDirectory is in the Save Directory)

Import File Type Names

THDv Monitored BusBars   Include

# Listing of All the \*.DSS File Contents



- For convenience the contents of all the \*.dss files are shown in a single Case Information display

The screenshot shows the 'GIC Analysis Form' software interface. The 'Calculation Mode' is set to 'Single Snapshot'. The 'Select Step' tree on the left is expanded to 'Data in DSS Files'. The main display area shows a list of DSS file lines, including:

```

1 .....
2 .....
3 Data in File C:\a\Projects_2024\EPRI_B3DFast\master_file.dss
4 .....
5 Clear
6 .....
7 redirect env_variables.dss
8 var @lat0 = 36.1745
9 var @lon0 = -96.7680
10 .....
11 New Circuit 15GIC_2000 gicarm
12 ~ baseky=13.80 phases=3 pu=1.000000 angle=0.00000 frequency=60 baseMVA=100.0 puZ1=[0.001, 0.2] lmodel=ideal
13 ~ bus1=7098_WADSWORTHS
14 .....
15 New monitor.source_gv_md0 vsource.source 1 mode=0
16 .....
17 ***** Export from PowerWorld Simulator *****
18 .....
19 ***** Circuit elements definition *****
20 .....
21 *** ---- Choose either generators.dss or gens_as_vsrcs.dss ***
22 redirect generators.dss ! definitions for generators
23 redirect generators_as_vsrcs.dss ! definitions for generators
24 redirect dc_and_facts_equiv_elements.dss ! definitions for dc and facts elements from PowerWorld
25 .....
26 redirect lines.dss ! definitions for lines
27 redirect gic_sources.dss ! definitions for gic sources
28 redirect transformers.dss ! definitions for transformers
29 redirect v_ties.dss ! definitions for tie resources
30 redirect transformers_mag_nonlin_loads.dss ! definitions for mag. nonlin. loads
31 redirect loads.dss ! definitions for loads
32 redirect shunts.dss ! definitions for reactors and capacitors

```

For the Texas 2000-Bus synthetic grid this display has about 19,500 lines



# PowerWorld PFW Models

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- Over the last two 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

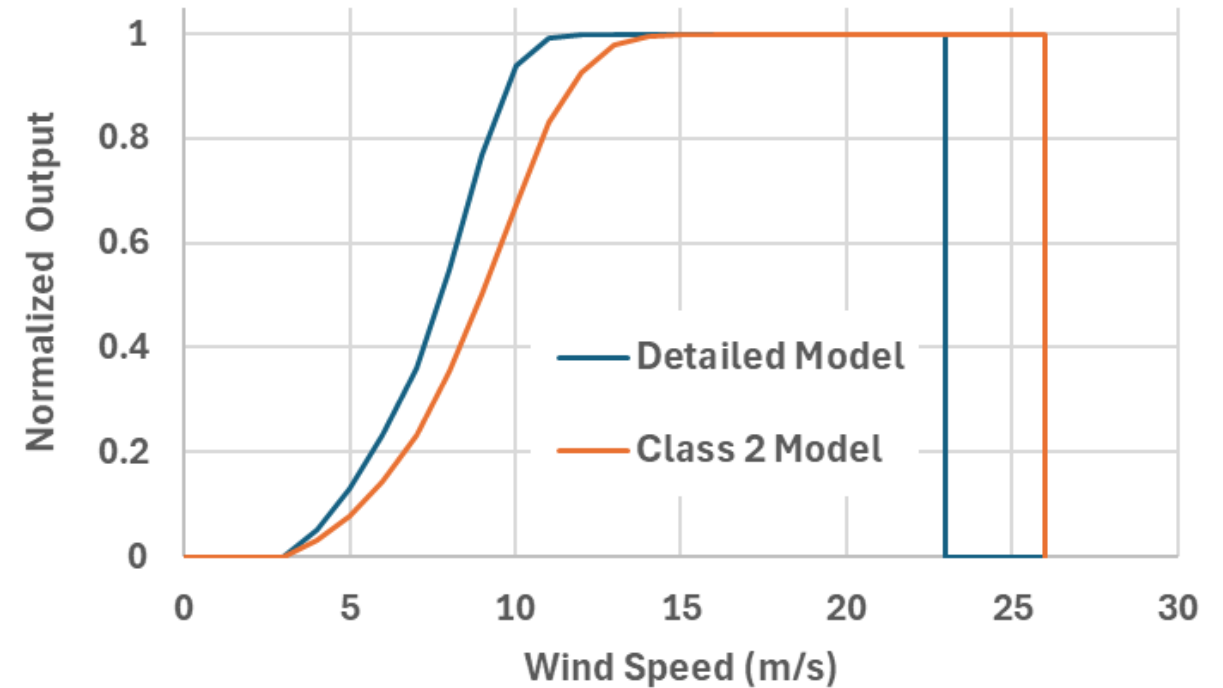
PFW Gen Object

Insert Delete

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

Parameters

|                 |          |              |              |              |         |
|-----------------|----------|--------------|--------------|--------------|---------|
| Description     | Speed1   | 0.0000       | PowerScalar5 | 0.0500       | Speed10 |
| AllowTurnOff    | 1        | PowerScalar1 | 0.00062      | Speed6       | 5.0000  |
| AllowTurnOn     | 1        | Speed2       | 1.0000       | PowerScalar6 | 0.1599  |
| MWMax           | 217.0000 | PowerScalar2 | 0.00062      | Speed7       | 6.0000  |
| HubHeightScalar | 1.5000   | Speed3       | 2.0000       | PowerScalar7 | 0.3111  |
| WindSpeedScalar | 1.0500   | PowerScalar3 | 0.00062      | Speed8       | 7.0000  |
| HubHeightM      | 80.1624  | Speed4       | 3.0000       | PowerScalar8 | 0.4988  |
| CutOut1MS       | 26.0000  | PowerScalar4 | 0.00062      | Speed9       | 8.0000  |
| CutOut2MS       | 26.0000  | Speed5       | 4.0000       | PowerScalar9 | 0.7154  |
|                 |          |              |              | Speed14      | 1       |

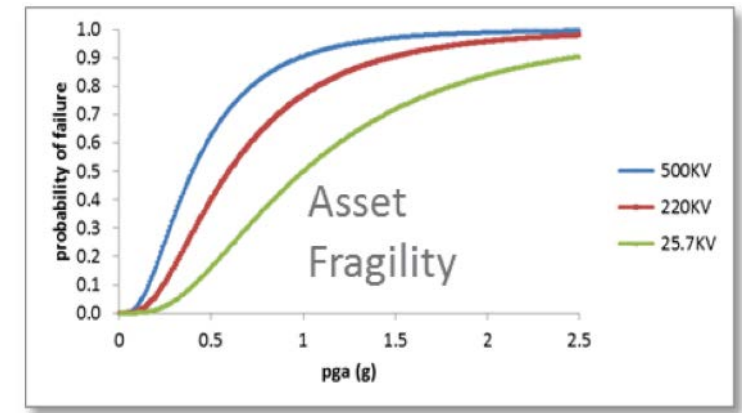




# Additional PFWs, Including Harmonic Impacts



- 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 bus THDv just required creating a new, quite simple PFW model



# Switched Shunt SSTHDvSimple Model



- This PFW model only has two parameters: a THDv percentage to issue a warning, and a THDv percentage to trip the object;

Switched Shunt Information for Present

Bus Number: 1010  
Shunt ID: 1  
Bus Name: PRESIDIO 10  
Labels: no labels

Status:  Open  
Energized:  NO (Offline)  YES (Online)

Terminal Voltage (p.u.): 1.0349  
Nom. Voltage: 115.000

Parameters: Control Options, Faults, Owners, Area, Zone, Custom, Stability, GIC, PFWModels, Other

PFWModels

SwitchedShunt Object

Insert Delete

Type: Active - SSTHDvSimple  Active (only one may be active) Set to Defaults

Parameters

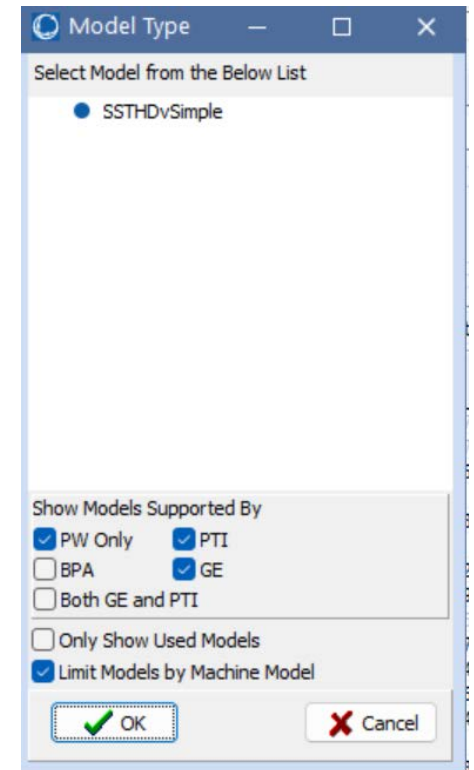
|                 |        |
|-----------------|--------|
| Integer         | 0      |
| THDVPercentWarn | 3.0000 |
| THDVPercentTrip | 5.0000 |

OK Cancel Save Save to Aux Help Print

# Entering Large Number of PFW Models

- A large number of PFW models can be entered by going to the **GIC Analysis Form, Harmonics, OD Switched Shunts** page, right-clicking and selecting **Insert New PFW Model**
- The PFW models inherit all the support for Simulator's stability models, so they can be easily modified (e.g., by using aux files or spreadsheets)

|    | Number of Bus | Name of Bus    | ID | ID     | Active PFW Model(s) | Bus THDv Valid | Bus THDv Max | Bus THDv Phase A | Bus THDv Phase B | Bus THDv Phase C |
|----|---------------|----------------|----|--------|---------------------|----------------|--------------|------------------|------------------|------------------|
| 1  | 1007          | VAN HORN 0     | 1  | 1007_1 | SSTHDvSimple        | YES            | 2.882        | 2.882            | 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  | 1012_1 | SSTHDvSimple        | YES            | 5.121        | 5.121            | 5.093            | 5.050            |
| 4  | 1016          | GARDEN CITY 0  | 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  | 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  | 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            |

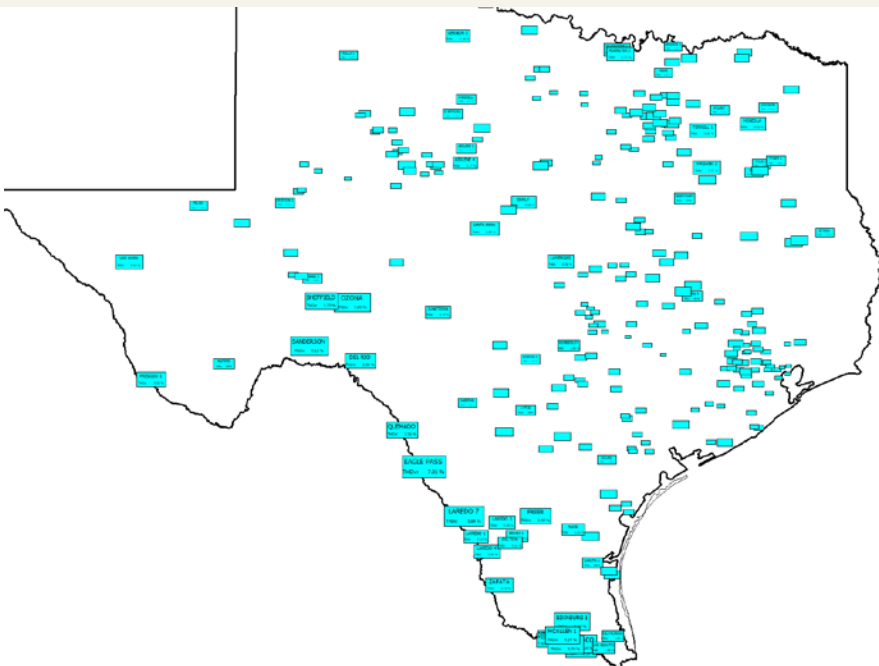


# Full Simulator Support of Harmonic Information



- 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 THD<sub>v</sub>



Simulator Case Info Display Showing GICHarm Bus THD<sub>v</sub>

| Number of Bus | Name of Bus         | ID | Reg Bus Num | Bus THD <sub>v</sub> Max | Status | Status Branch | Control Mode | Auto Control | Regulates | Actual Mvar | Volt High |
|---------------|---------------------|----|-------------|--------------------------|--------|---------------|--------------|--------------|-----------|-------------|-----------|
| 1             | 1007 VAN HORN 0     | 1  | 1007        | 2.882                    | 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 C 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  | 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  | 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  | 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 C 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            | 3010 CHRISTOVA 1    | 1  | 3010        | 0.600                    | Closed |               | Fixed        | YES          | Volt      | 20.56       | 1.000     |

# Summary and Future Directions

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- PowerWorld Simulator is being integrated with EPRI's GICHarm program, allowing for the calculation and application of harmonics without leaving Simulator
- This functionality should be available in Version 24
- Currently the focus is on uses 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?

