PowerWorld Simulator Integration with GICHarm in Simulator Version 24

Thomas J. Overbye
O'Donnell Foundation Chair III
Texas A&M University
overbye@tamu.edu, Overbye@powerworld.com

December 11, 2024

TEXAS A&M UNIVERSITY

PowerWorld Corporation

Overview

- 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

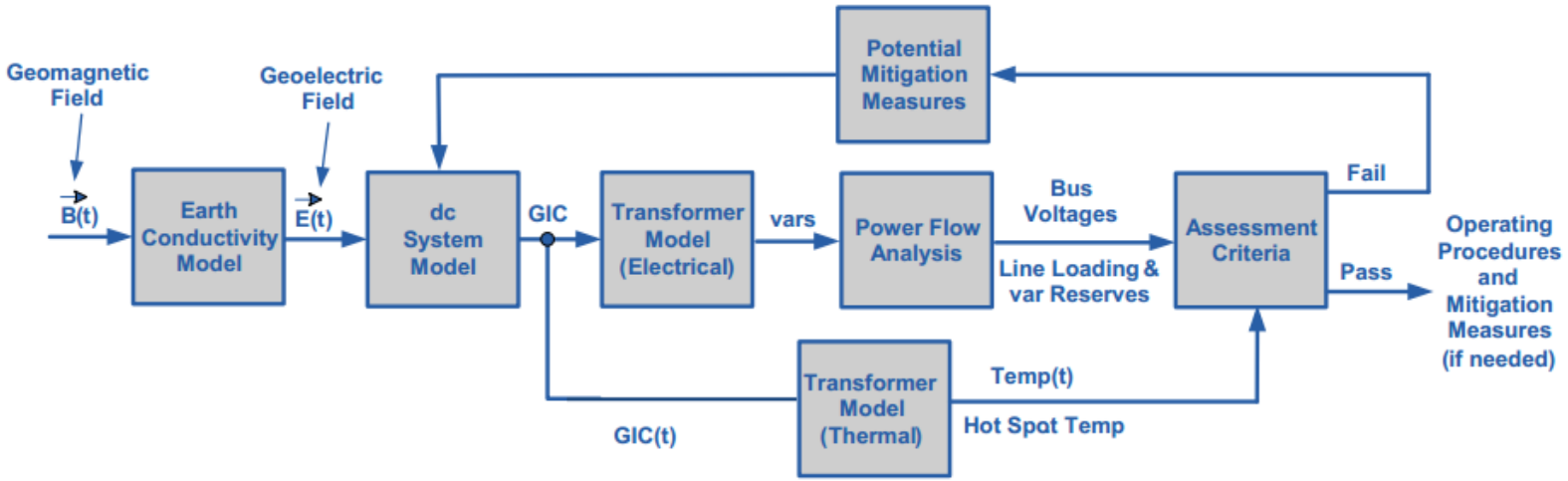
- These slides are based in part on work funded by the US Department of Energy (DoE); this support is gratefully acknowledged!
- These slides also contain contributions from my students, postdocs and staff at TAMU, from EPRI, Pacific Northwest National Laboratory (PNNL), and PowerWorld Corporation

Aside: Upcoming Short Courses

- 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/**

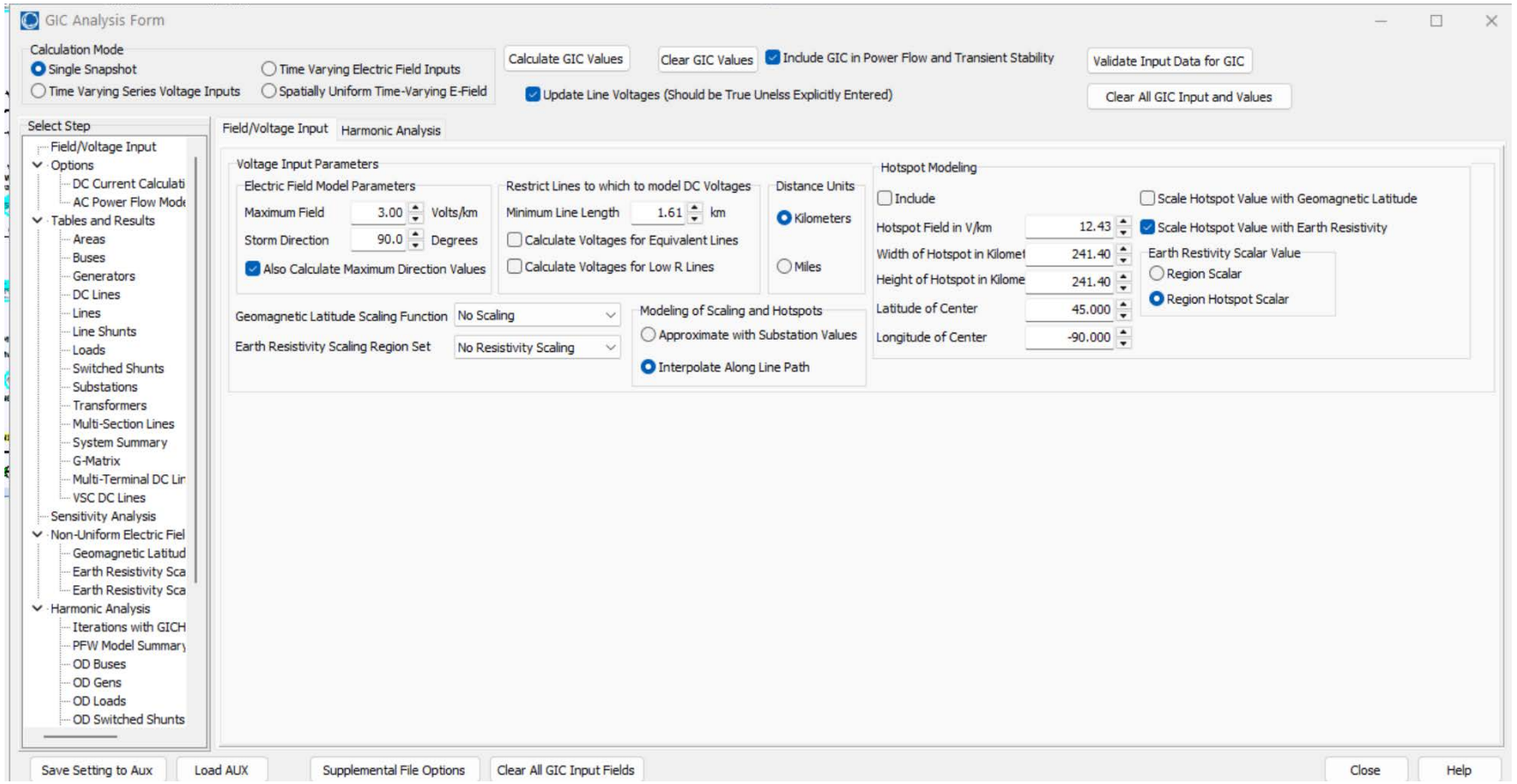
PowerWorld Simulator GIC Analysis

- 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



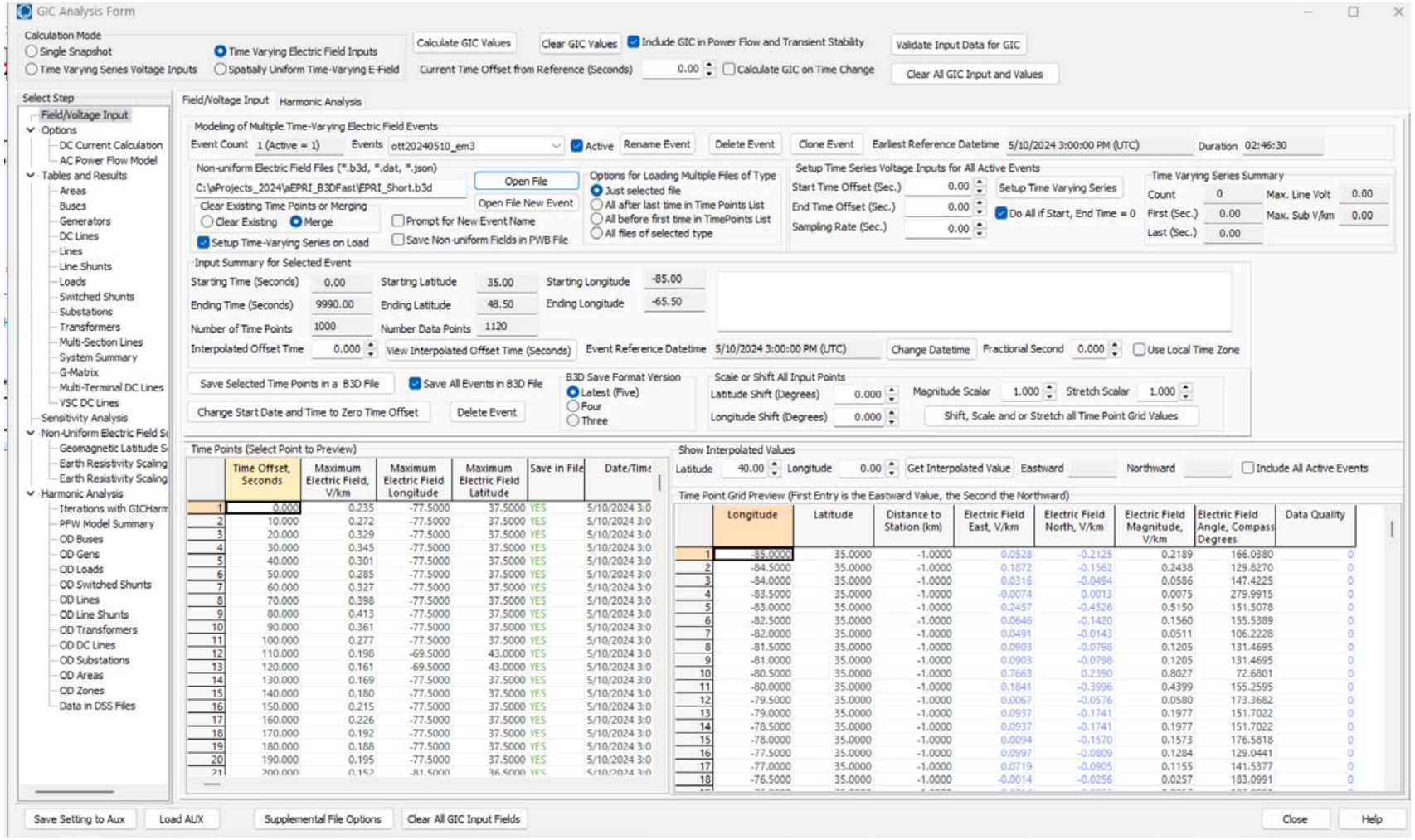
PowerWorld Simulator GIC Analysis, cont.

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



PowerWorld Simulator GIC Analysis, cont.

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

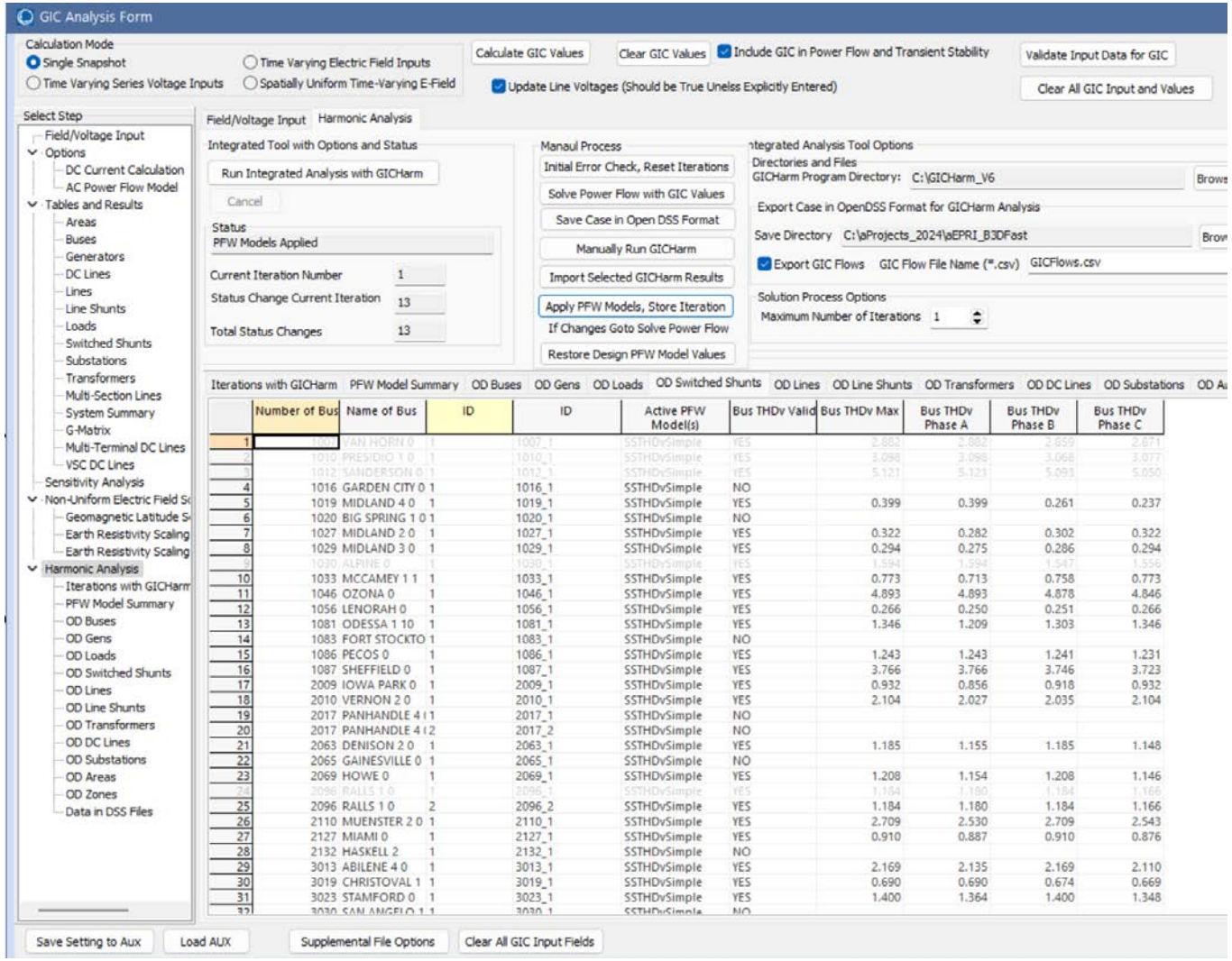


Adding Harmonic Analysis to GIC Calculations

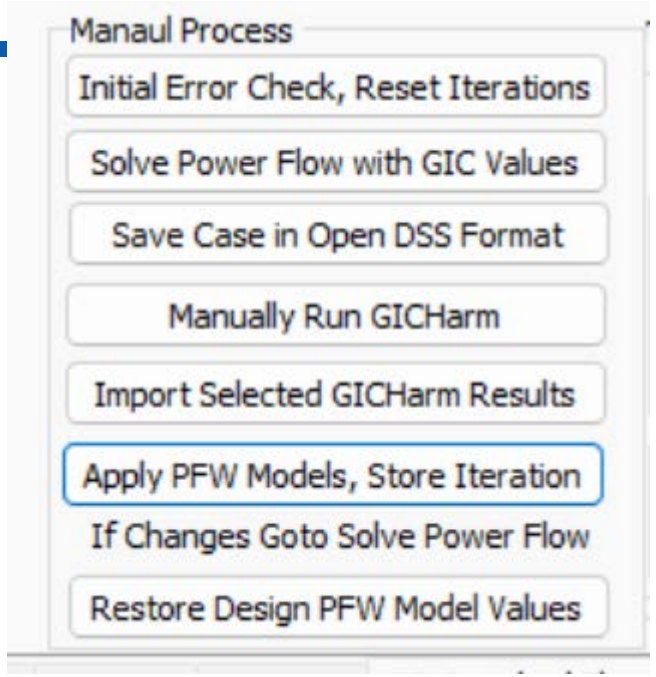
- Standard power flow GIC analysis involves
  1. Using an assumed electric field, calculate the GICs
  2. Solve a GIC-enhanced power flow in which the transformer reactive power losses include a GIC dependent component
- With harmonic analysis this becomes
  1. Using an assumed electric field, calculate 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



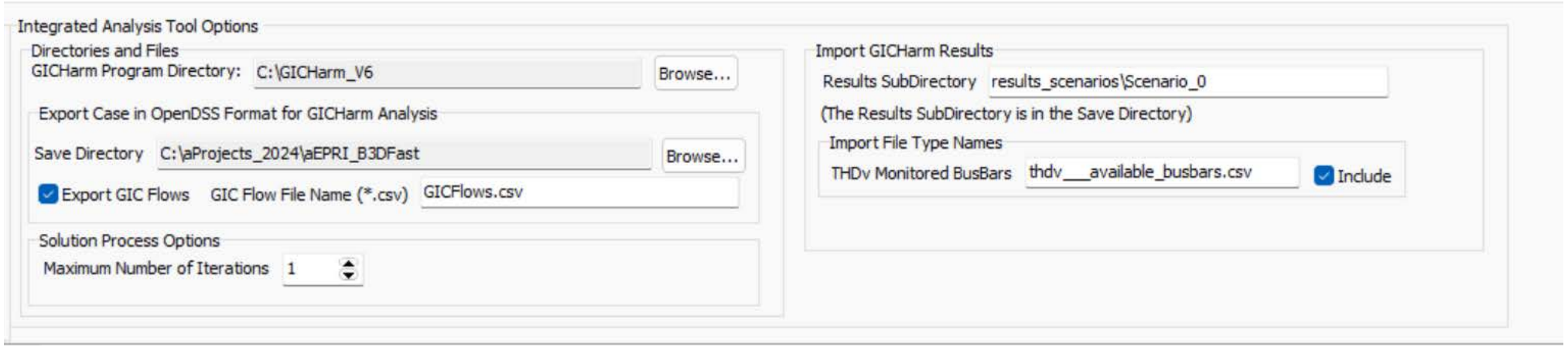
Integrated Tool Detailed Steps



- 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

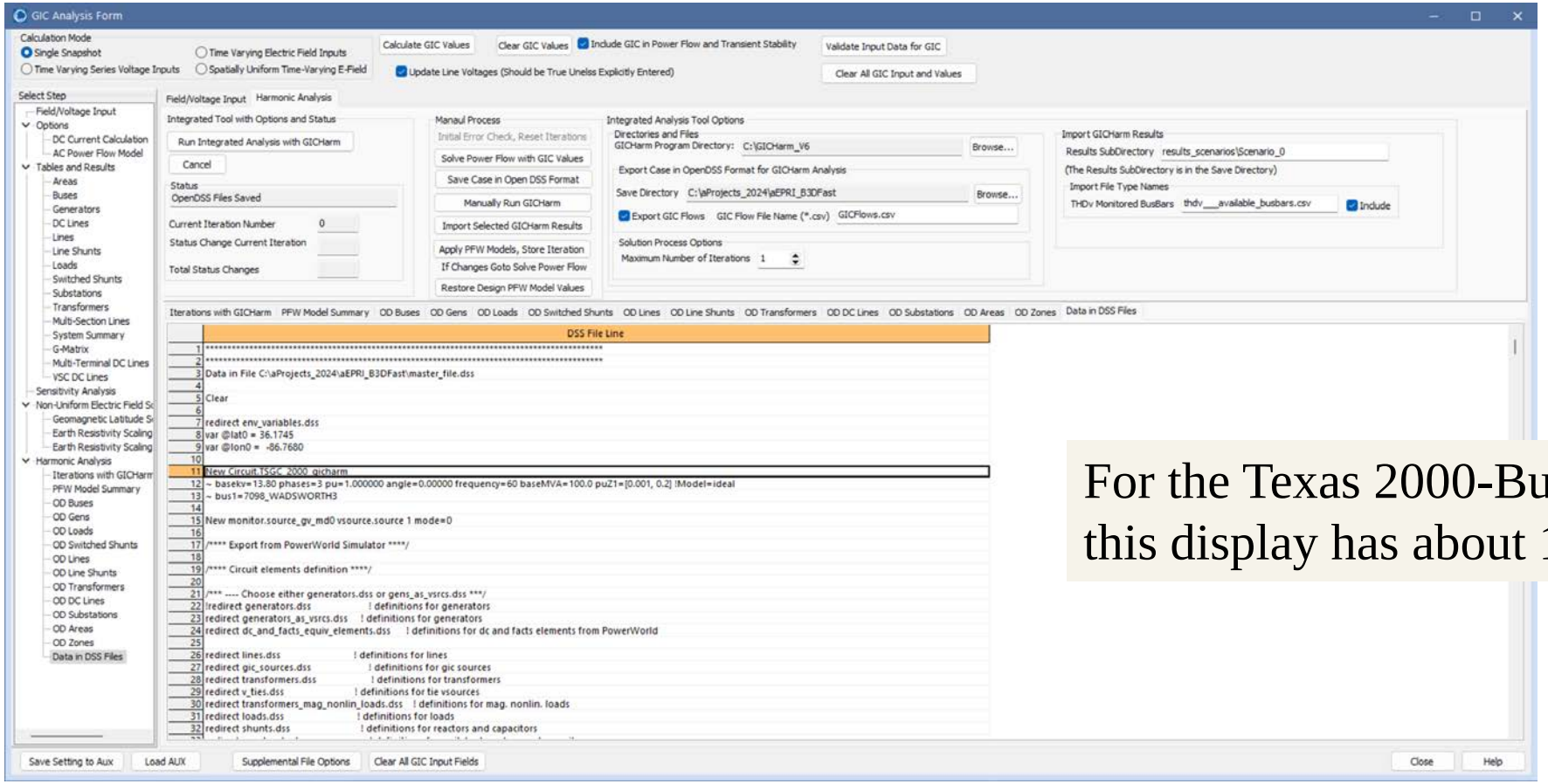
Integrated Tool Options

- 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



Listing of All the *.DSS File Contents

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



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

PowerWorld PFW Models

- 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 handing 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

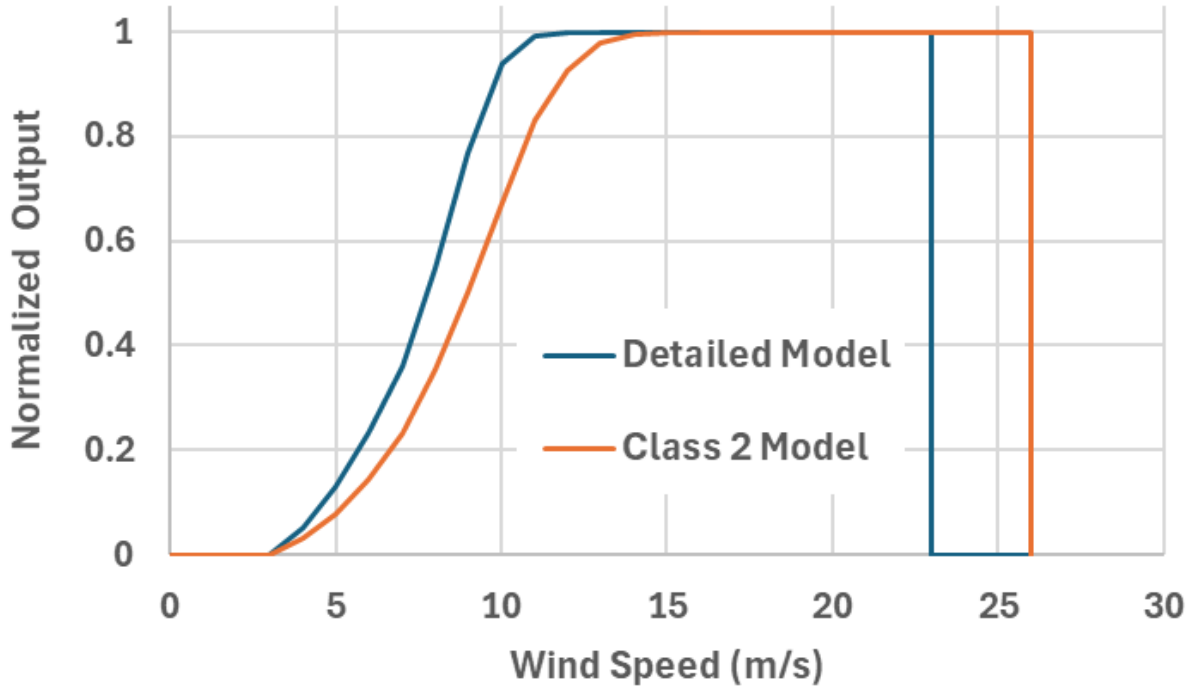
PFW Gen Object

Insert | Delete

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

Parameters

Description		Speed1	0.00000	PowerScalar5	0.05000	Speed10	
AllowTurnOff	1	PowerScalar1	0.00062	Speed6	5.0000	PowerScalar10	
AllowTurnOn	1	Speed2	1.0000	PowerScalar6	0.1599	Speed11	1
MWMax	217.0000	PowerScalar2	0.00062	Speed7	6.0000	PowerScalar11	
HubHeightScalar	1.5000	Speed3	2.0000	PowerScalar7	0.3111	Speed12	1
WindSpeedScalar	1.0500	PowerScalar3	0.00062	Speed8	7.0000	PowerScalar12	
HubHeightM	80.1624	Speed4	3.0000	PowerScalar8	0.4988	Speed13	1
CutOut1MS	26.0000	PowerScalar4	0.00062	Speed9	8.0000	PowerScalar13	
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

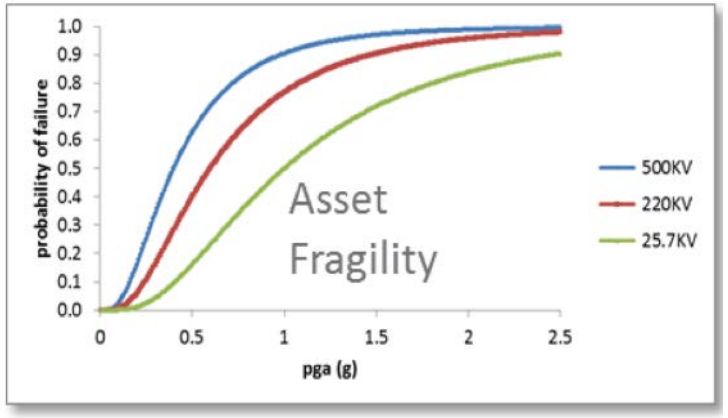
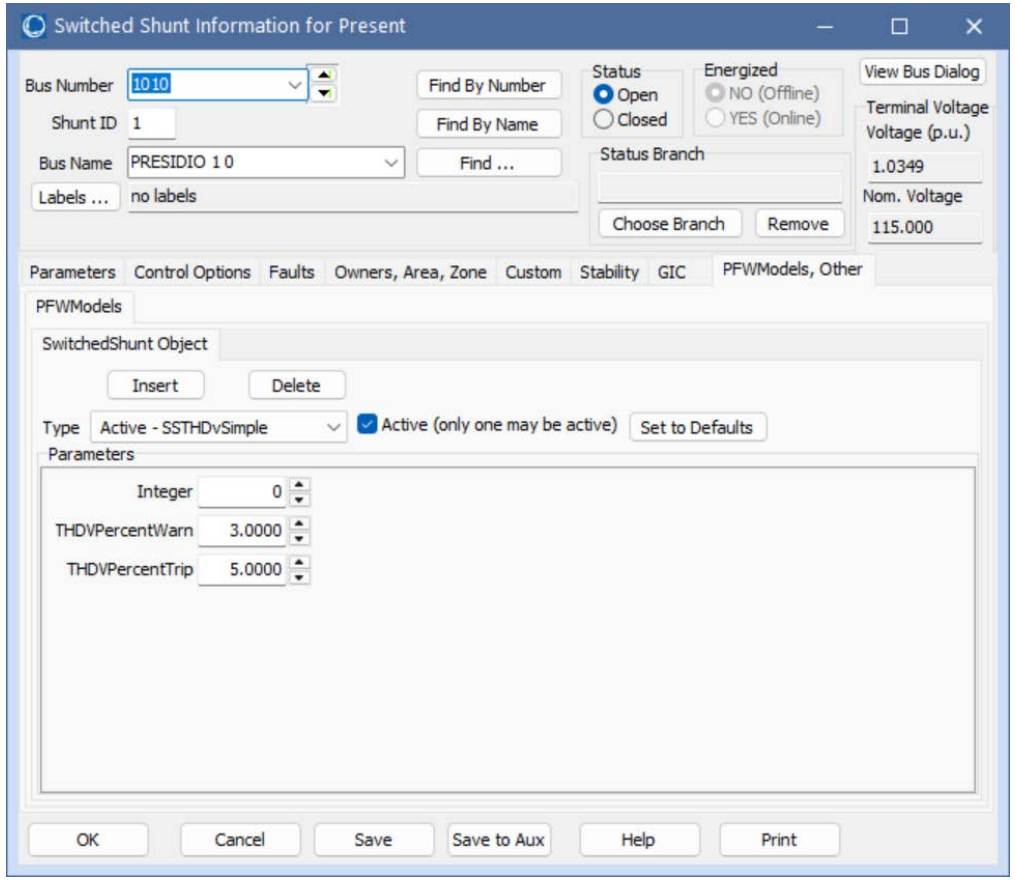


Image source: Figure 2.1 of A. Veeramany, G.A. Coles, S.D. Unwin, T.B. Nguyen, J.E Dagle, "Trial Implementation of the High Impact, Low-Frequency Power Grid Event Risk Framework to Support Informed Decision-Making," PNNL-25667, October 2016.

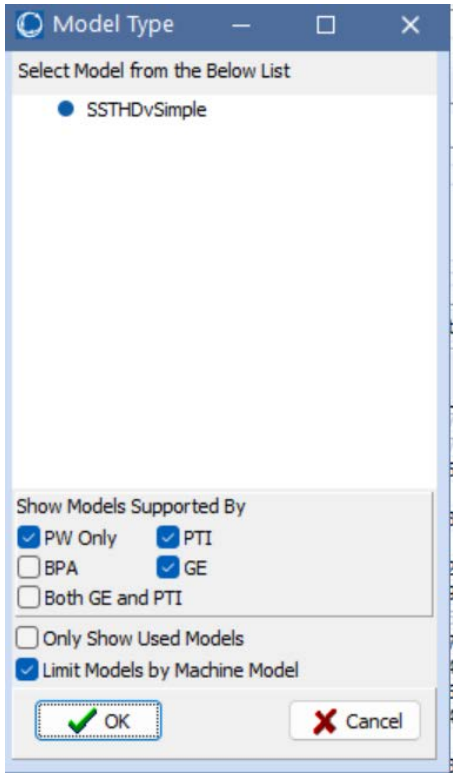
Switched Shunt SSTHDvSimple Model

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



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)



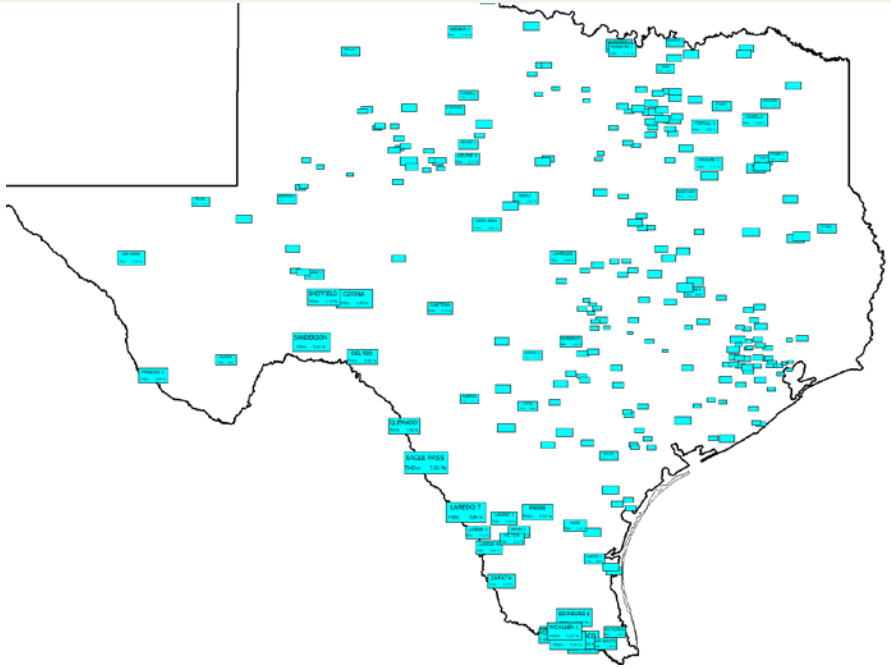
Iterations with GICHarm | PFW Model Summary | OD Buses | OD Gens | OD Loads | OD Switched Shunts | OD Lines | OD Line Shunts | OD Transformers | OD DC Lines | OD Substations | OD Ar

	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 THDv



Simulator Case Info Display Showing GICHarm Bus THDv

Switched Shunts

Filter: Advanced

	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	2.832	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	1012	5.121	Closed		Fixed	YES	Volt	9.90	0.000
4	1016	GARDEN CITY (	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 STOCKT(	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	2017		Closed		Fixed	YES	Volt	-105.76	1.000
20	2017	PANHANDLE 4	2	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 (	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	3019	CHRISTOVAL 1	1	3019	0.690	Closed		Fixed	YES	Volt	20.65	1.000

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
- 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?