

In Pursuit of Reuseable, Electric Power System Models: Breaking Down Barriers



*Time-Series, Automated
Analysis and Design with
Large Measurement Sets*

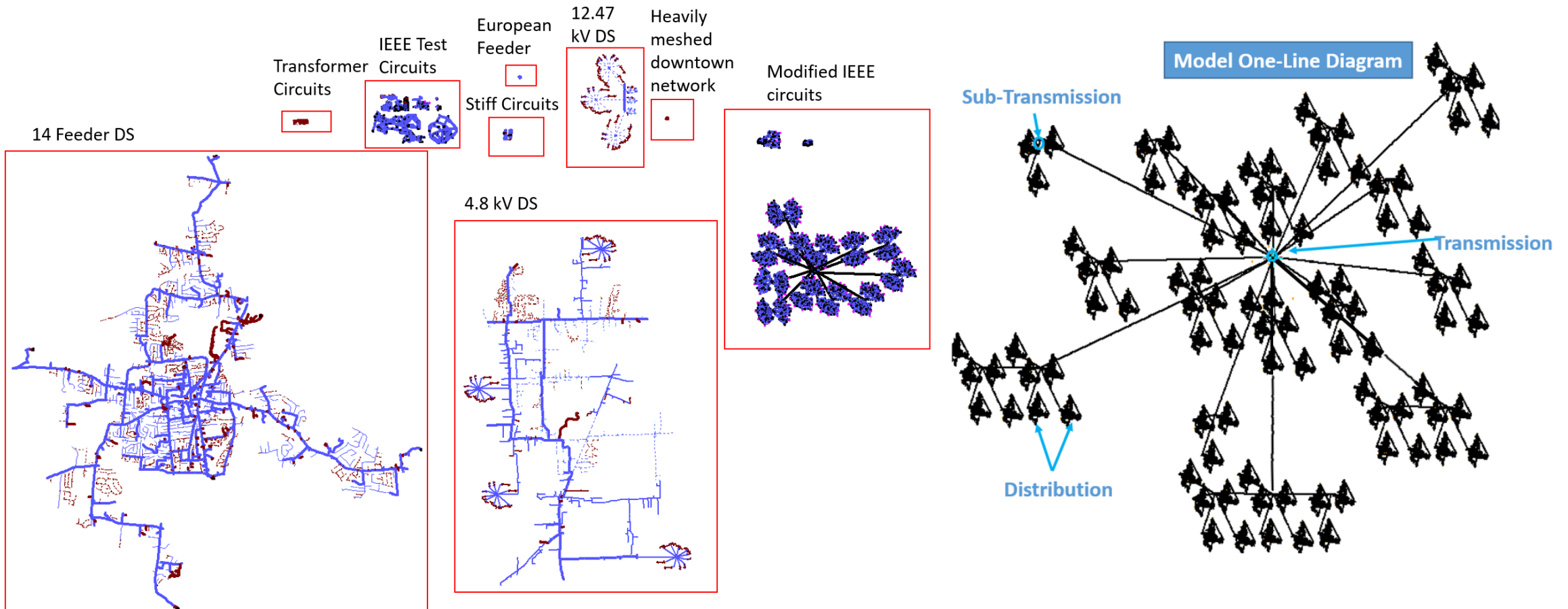


Robert Broadwater
dew@edd-us.com

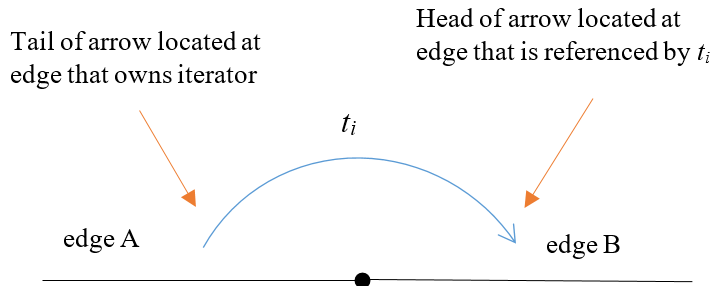
December 2, 2016



Integrated System Modeling: Research Circuits



Graph Trace Analysis: Generic Programming, Edge-Edge Graphs, Topology Iterators



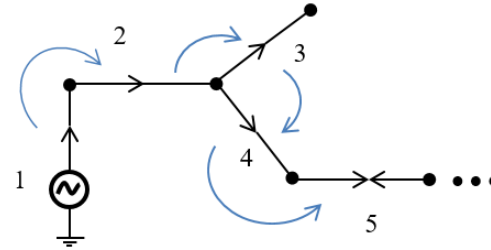
quadruply linked list $\begin{cases} p[f] \\ p[b] \end{cases}$ doubly linked list

$\begin{cases} p[fp] \\ p[ct] \end{cases}$ connectivity

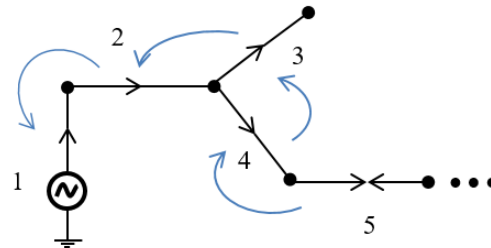
$$S \rightarrow BT_s \rightarrow \{ i[p] = 0 \mid i[p] += i_l[p] + i[p[ct]], i[p[fp]] += i[p] \}$$

$$CT \rightarrow LT_{ct} \rightarrow \{ v_{sum} = 0 \mid v_{sum} += v[p[fp]] - v[p] \}$$

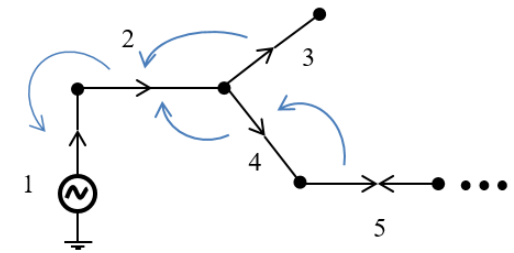
• Forward Trace



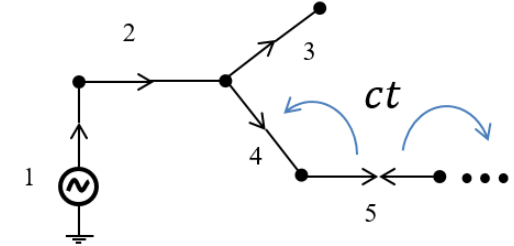
• Backward Trace



• Feeder Path Trace



• Cotree Trace



Initialize iterators: Add, connect

Update iterators: Insert, delete, operate, fail

Generic: Attach any algorithm, measurement set

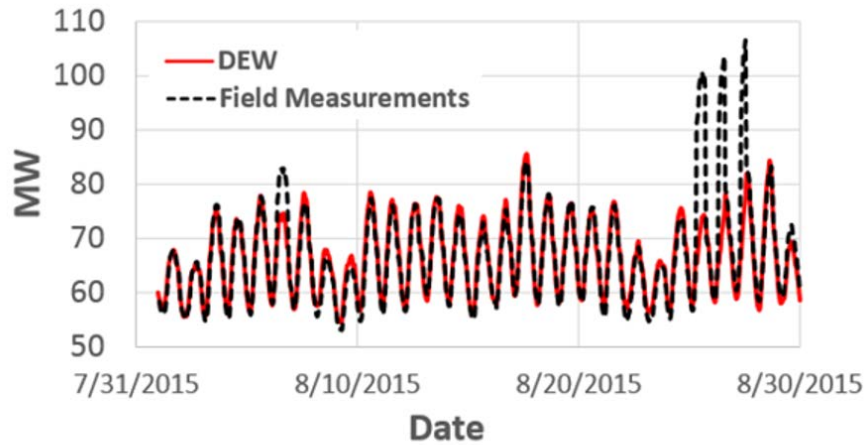
Algorithms: Sorting, continuation methods (robustness)

Traditional Analysis versus GTA

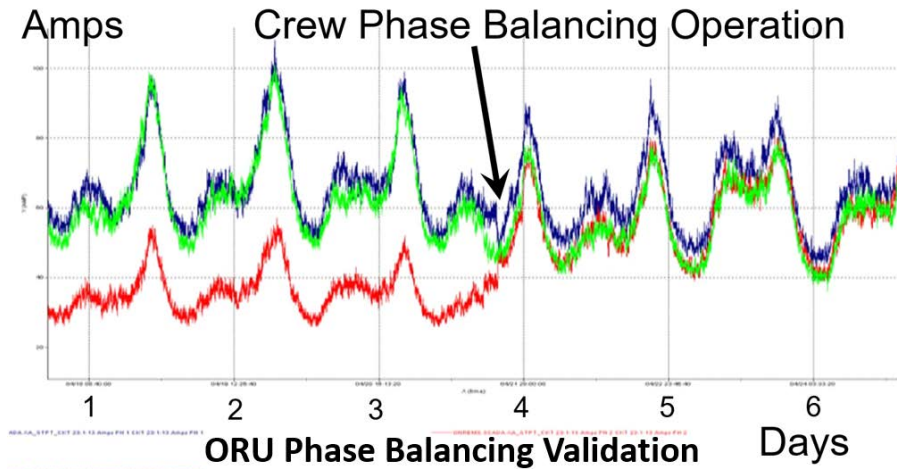


Traditional Analysis	GTA	Importance
Node-edge graph	Edge-edge graph	Rapid topology management
Uses topology up front in algorithms to create matrices	Continuously uses topology in traces throughout algorithm	Topology management enables rapid development of complex algorithms – schematics, design, weather analysis, ...
Time to manage topology changes increases as size of system grows	Time to manage topology changes is independent of system size	Configuration changes on systems with millions of components can be managed
Different analysis algorithms use different simplified models	All analysis algorithms run on same model and exchange results through the model	Algorithms can work together as a team to solve complex problems
Each analysis algorithm gets its own copy of measurements	All analysis algorithms share measurements through the same model	Do not have multitude of measurement interfaces to create and maintain
Multi-domain system analysis is complicated	Can write common algorithms that run across multi-domain systems {solves TSD together}	Do not have to write separate software for different engineering domains
Optimization suffers from curse of dimensionality	Traces are used to determine space of possible solutions	Optimization of large scale systems is practical
Special computer hardware required for parallel processing	Distribute calculations across processors by distributing model	Do not need to invest in expensive computer equipment

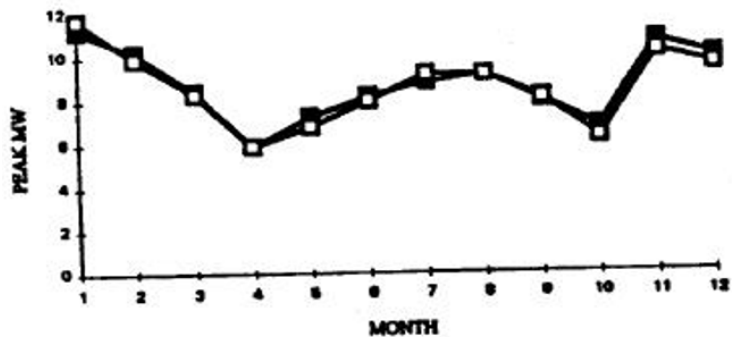
GTA-Based Time-Series Analysis Validations



SVP Transmission System Validation



ORU Phase Balancing Validation Days



Entergy Load Model Validation
Mount Valley Sub, 2977 customers



Largest voltage deviation:	1.1 %	Average:	0.5 %
Largest current deviation:	3.9 %	Average:	2.8 %
Largest pf deviation:	5.7 %	Average:	2.7 %

NREL Validation on DTE 16 MVA Feeder with 1 MW DG

DOE Sponsored ISM Survey



BARRIERS

“The technical challenges do not appear to be as great as the interpersonal challenges, which include bringing together silos of responsibility, where the silos often do not speak the same language.” **NISC**

“Very experienced personnel can be naysayers, and often an experience is needed to get their attention and change their perspective.” **NISC**

“Getting processes in place to insure ISM stays accurate and in synch with field conditions.” **ORU, CHGE, PHI**

BENEFITS

“Provides situational awareness for the whole system” **ORU**

“First line of defense in finding inaccurate meters” **ORU**

“Allows utility to become proactive in problem solutions” **CHGE**

“Once an ISM is achieved model maintenance is more efficient” **NISC**

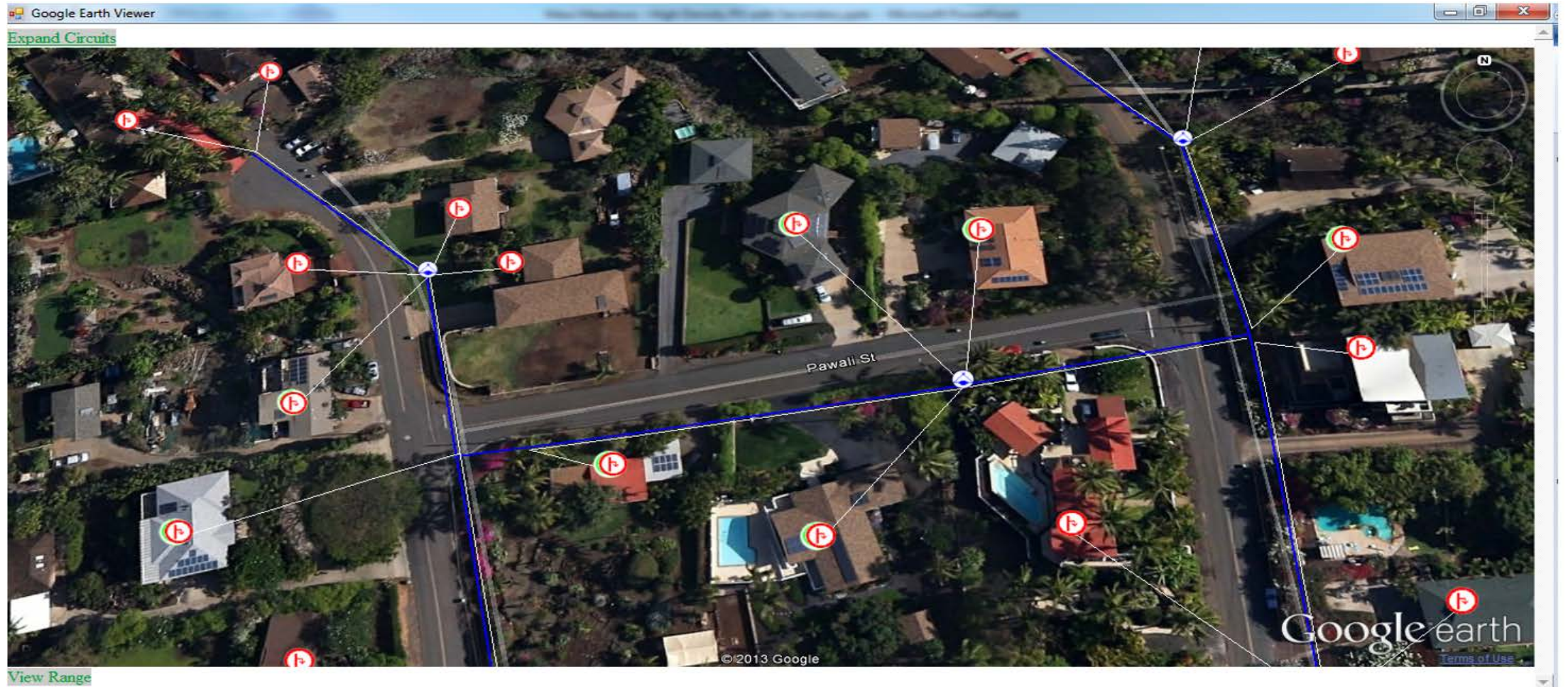
“Without an ISM the understanding of system behavior is limited to a few operators and engineers” **SVP**

“With an ISM Automated analysis becomes possible” **PHI**

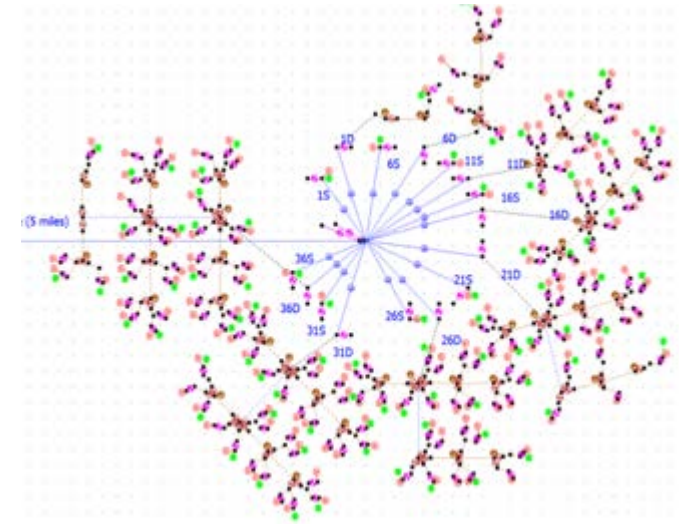
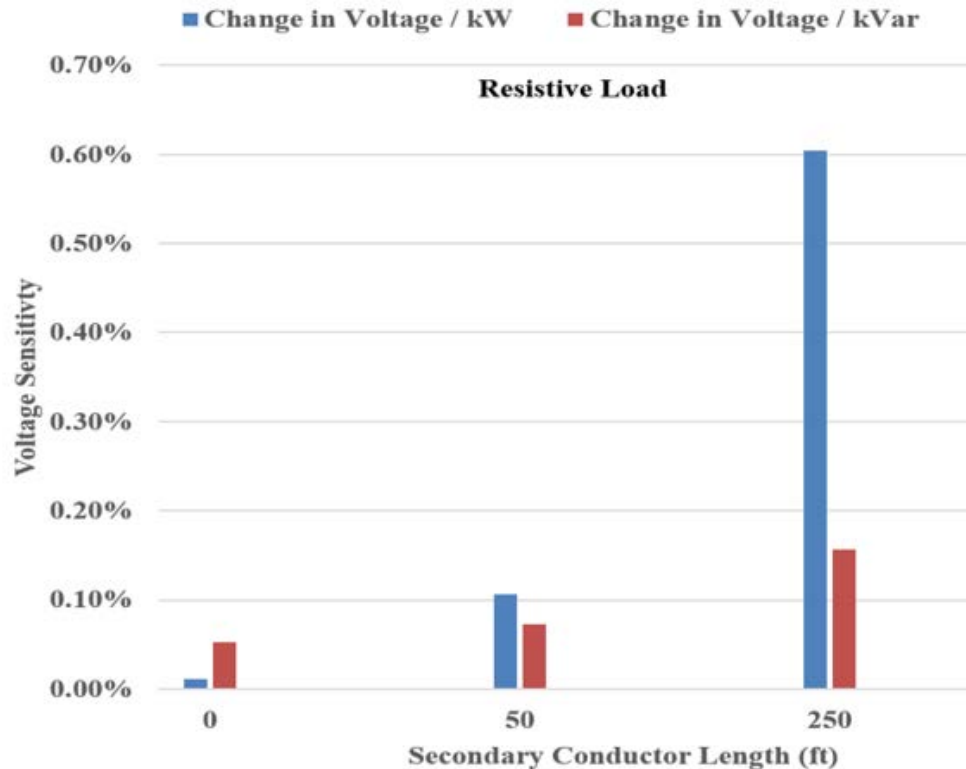
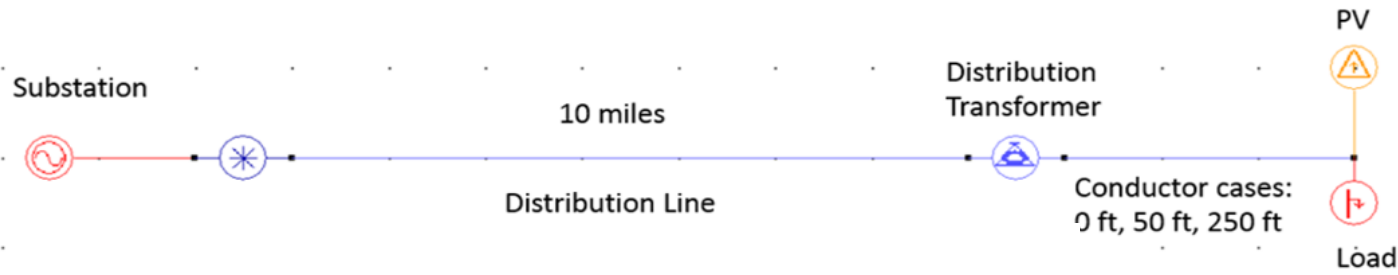
“As opposed to data analytics, ISM solutions cover the entire range of operations” **OSIsoft**

Model-Centric Life-Cycle Process using a Generic, Manufactured, Living Model providing Proactive, Holistic Solutions

ISM Over Google Earth Showing Secondary Circuits, Loads, and PV



Simplified Versus Detailed Secondary Circuit Models



PV Penetration Analysis Approach Comparisons		Max PV Penetration (% of load)
Simple Secondary	Using Step Change and IEEE 1453-1992	23
Detailed Secondary	Using Step Change and IEEE 1453-1992	18

Is the secondary circuit just a load on the distribution transformer bus?



Largest voltage variation is always at service point with PV

PV and customer information part of simple secondary model

Secondary Circuit Model Tool

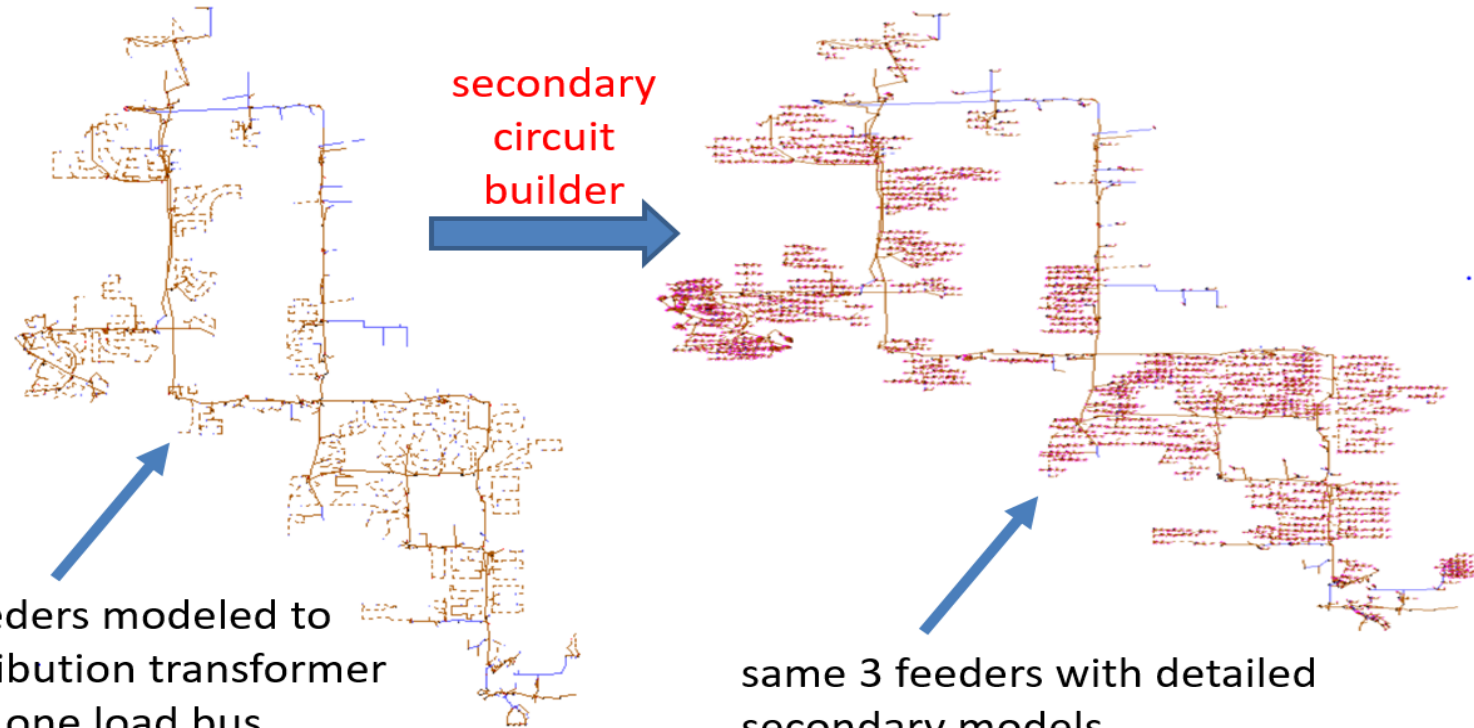
Select Secondary Circuit System
SecondaryCircuit

Select Secondary Information
 Use Primary System Customer Class Load Information
 Use Current DSW Database
 Specify Secondary Database

DSW:
Username:
Password:

Add Secondary Model to Current System

PV and customer information contained in database tables

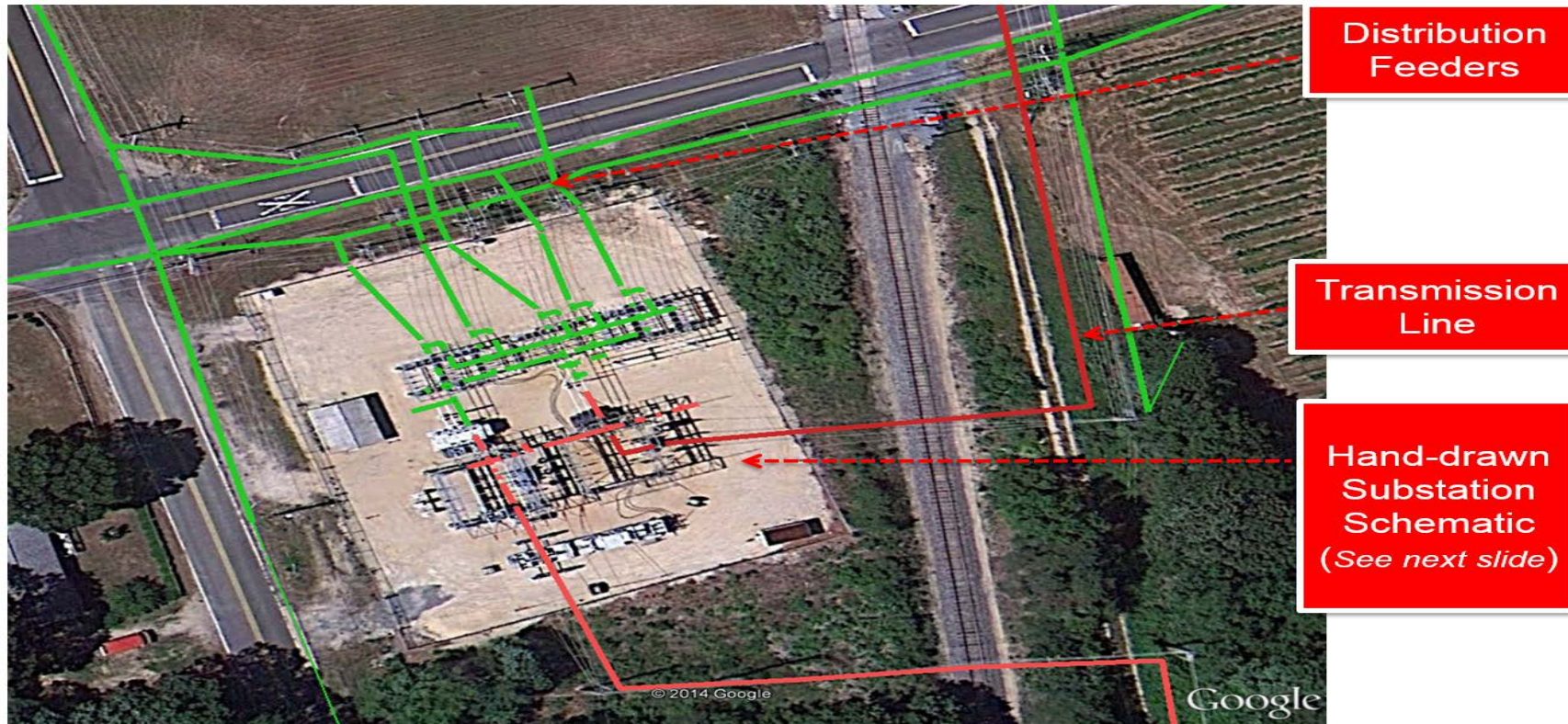


3 feeders modeled to distribution transformer with one load bus, ~3500 components, 633 load busses, 74 PV

same 3 feeders with detailed secondary models, ~35000 components, 6912 load busses, 812 PV

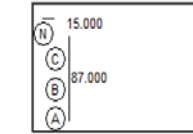
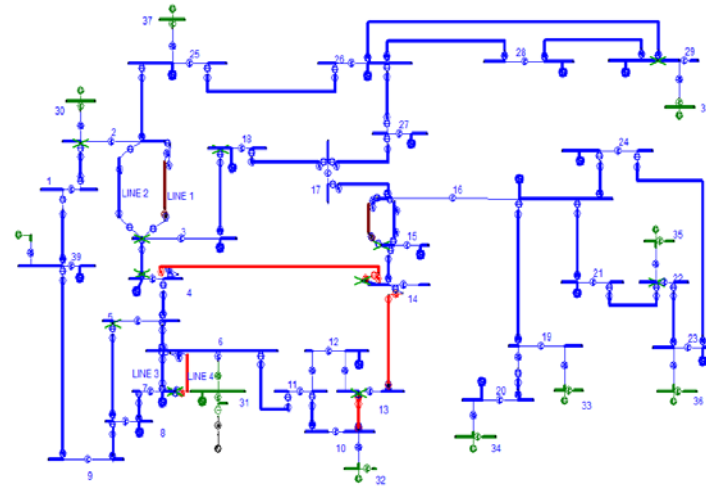
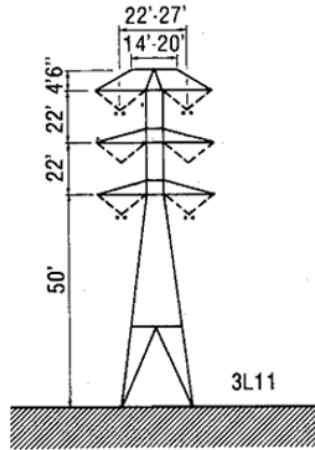
Secondary voltage variations can trump primary voltage variations

ISM Over Google Earth



Common approach is distribution feeders are analyzed one-by-one, transmission system is analyzed separately, and substation is not included in analysis at all*

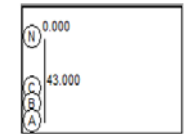
Pretending Transmission Lines are Transposed



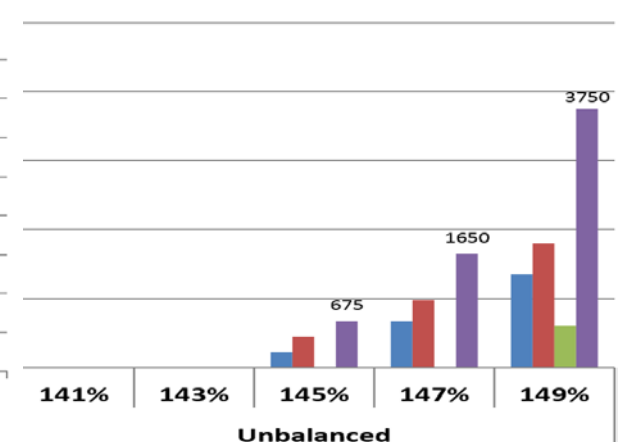
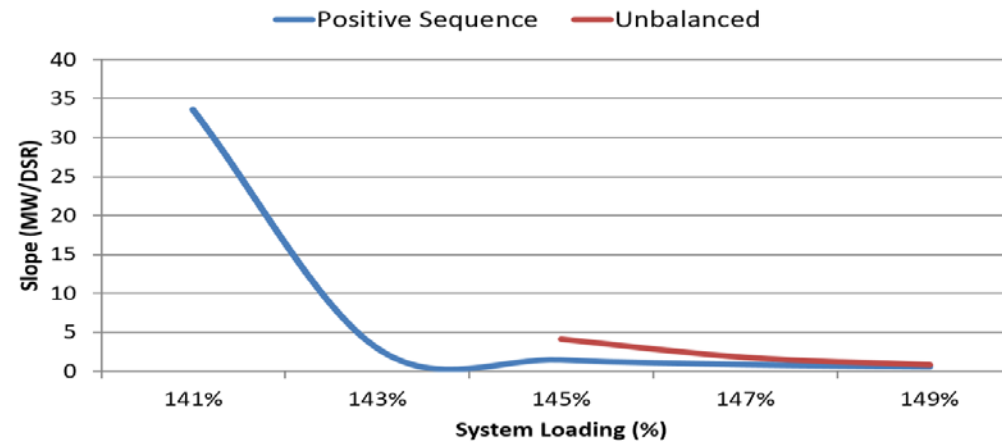
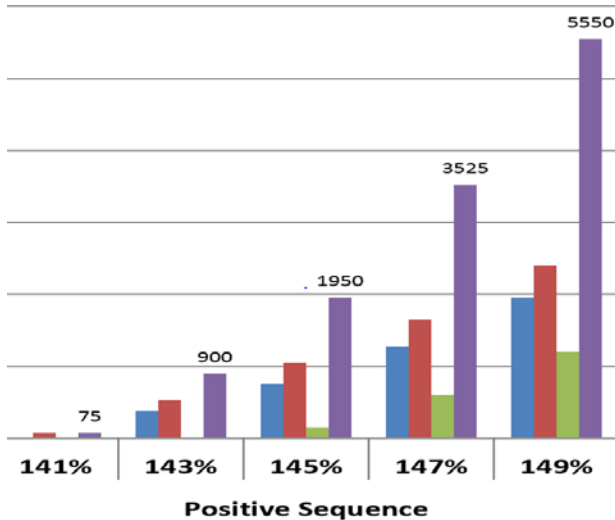
500 kV line spacing



345 kV line spacing



230 kV line spacing

$$= \begin{bmatrix} 0.18 + j 1.27 & 0.13 + j 0.53 & 0.14 + j 0.44 \\ 0.13 + j 0.53 & 0.19 + j 1.26 & 0.14 + j 0.52 \\ 0.14 + j 0.44 & 0.14 + j 0.52 & 0.21 + j 1.24 \\ 0.054 + j 0.75 & 0 & 0 \\ 0 & 0.054 + j 0.75 & 0 \\ 0 & 0 & 0.054 + j 0.75 \end{bmatrix}$$


IEEE 1453-2015 Standard: Formula



P_x = for a 10 minute interval, voltage change level that is exceeded X% of the time

$$P_{st} = \sqrt{0.0314P_{0.1} + 0.0525P_{1s} + 0.0657P_{3s} + 0.28P_{10s} + 0.08P_{50s}}$$

Short term flicker factor

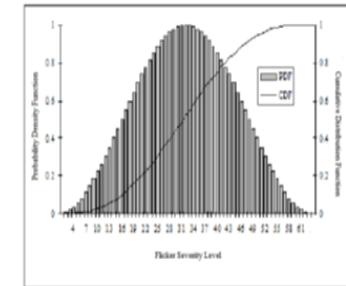
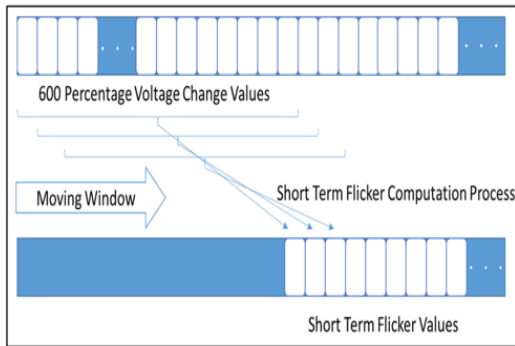
Smoothed values

$$P_{1s} = \frac{P_{0.7} + P_1 + P_{1.5}}{3}$$

$$P_{3s} = \frac{P_{2.2} + P_3 + P_4}{3}$$

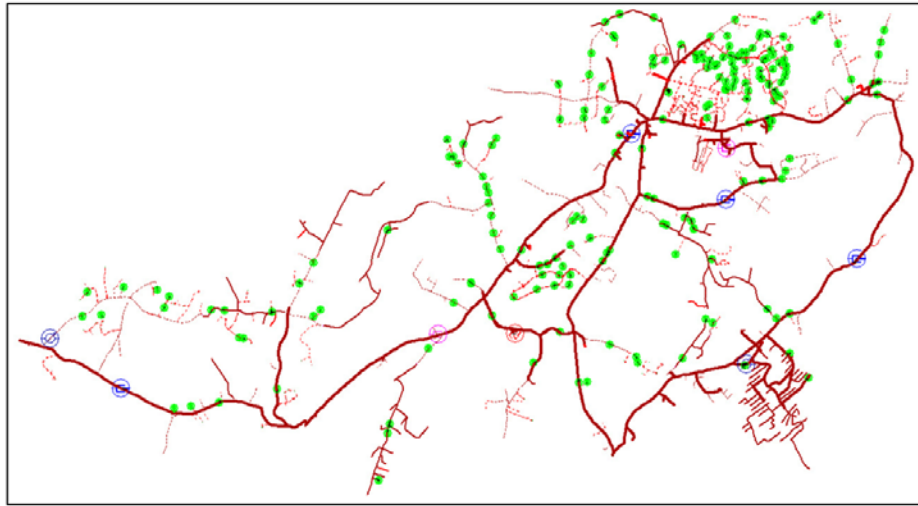
$$P_{10s} = \frac{P_6 + P_8 + P_{10} + P_{14} + P_{17}}{5}$$

$$P_{50s} = \frac{P_{30} + P_{50} + P_{80}}{3}$$



Flicker severity level	Compatibility Limits - LV	Planning—MV	Planning—HV and EHV
P_{st} [10-min]	1.0	0.9	0.8
P_{lt} [120-min]	0.8	0.7	0.6

Cloud Motion PV Analysis

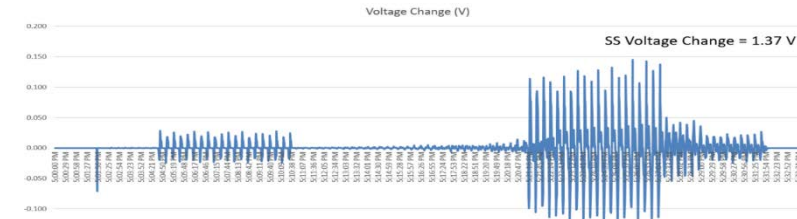


Max load ~ 14 MW, Max PV ~ 2 MW, PV Penetration ~ 14%

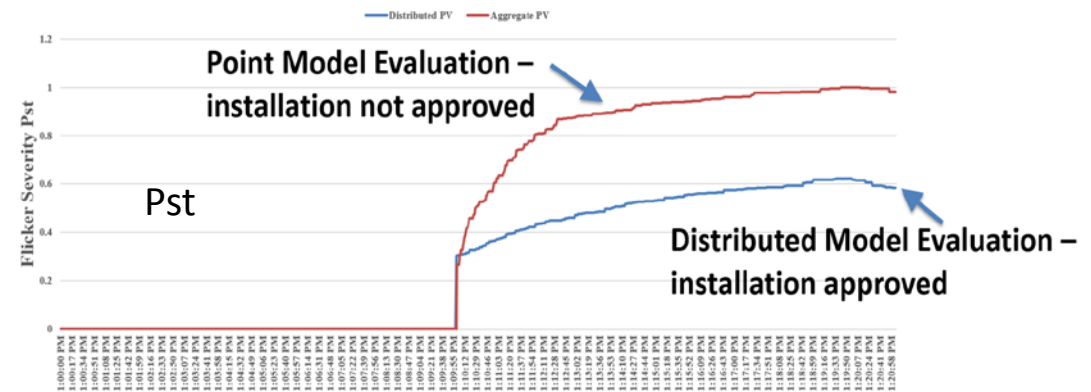
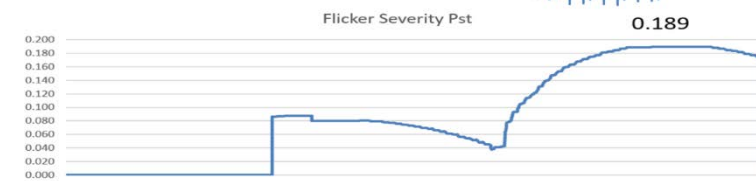
Evaluate installation of 7.3 MW PV, covering 44 acres, approximately square (about 6 acres per MW)

44 ft/sec cloud takes about 31 seconds to travel across PV generator

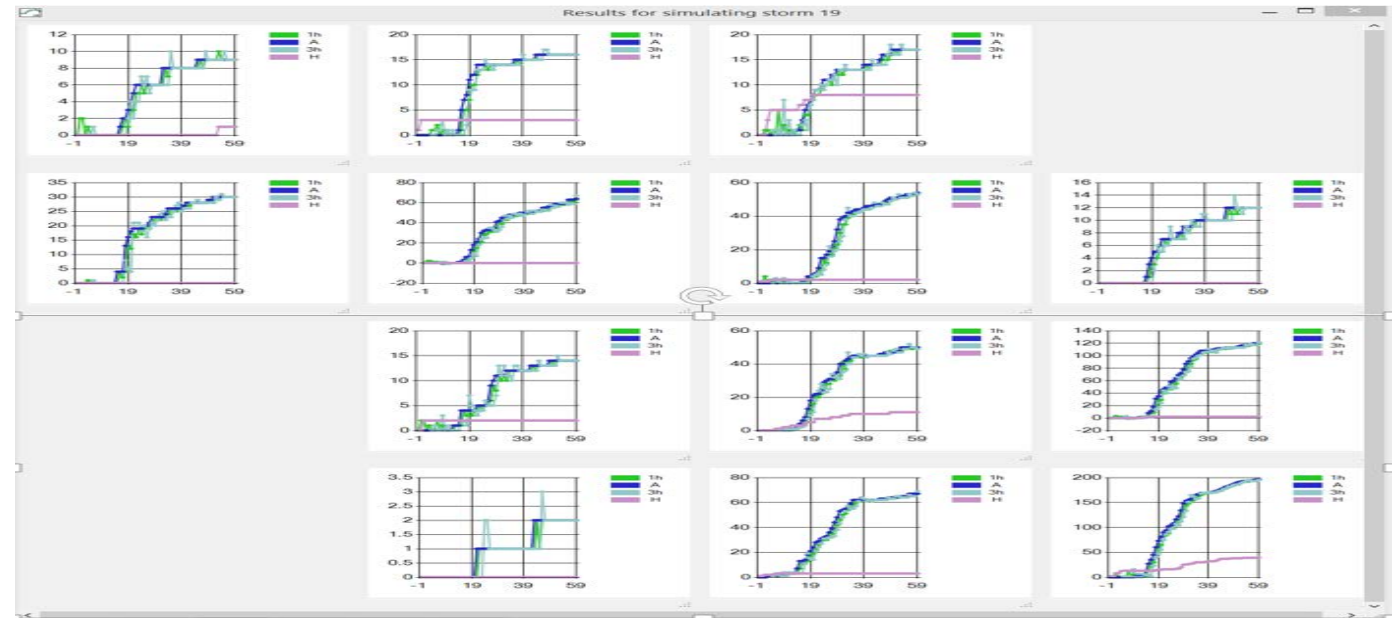
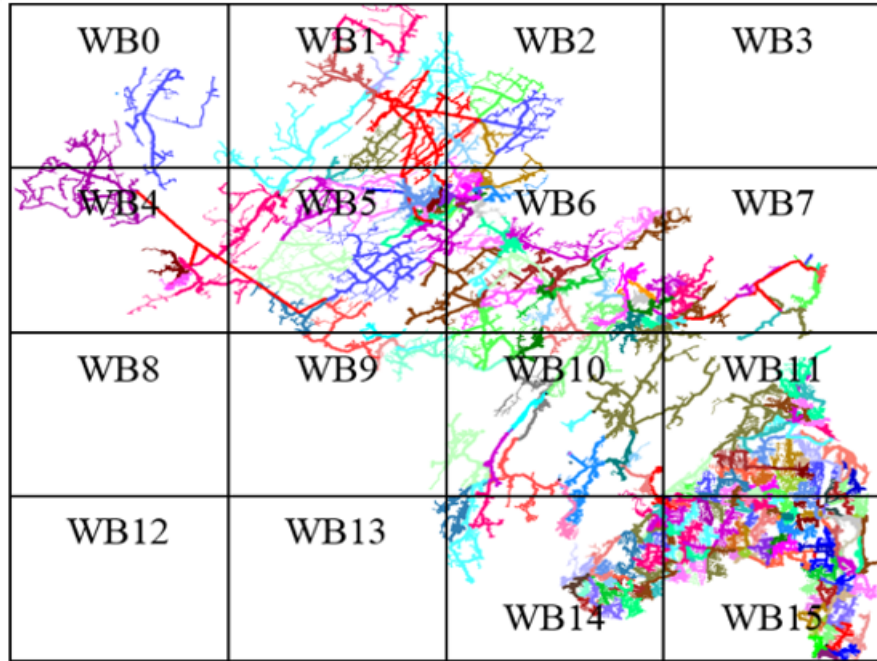
Voltage Change



Pst



Relating Radar Weather to ISM - Weather Boxes



Weather boxes and measurements:

- 1-6500 measurements per weather box per radar scan
- 2-Approximately 85000 measurements per radar scan for ORU service territory
- 3-Approximately 1,275,000 measurements per hour

For each weather box store max and average for:

- 1-Reflectivity (dbz)
- 2-Wind speed (knots)
- 3-Accumulated precipitation (inches)

GTA Analysis Embedded In or Synched with ESRI



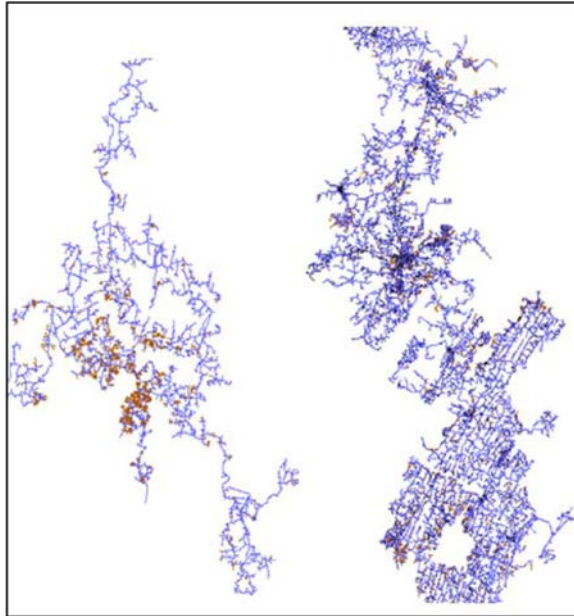
The screenshot displays the EdDD software interface, which is integrated with a GIS system. The main window shows a map with a network of power lines and nodes. On the left, there is a 'Table of Contents' pane listing various data layers. The bottom-left pane shows a 'Result' table with columns for ID, Analysis, Result, Component, Part, Time Point, Phase A, Phase B, Phase C, Desc, and Timestamp. The bottom-right pane shows a 'Model QA' table with columns for Analysis Time, Feeder, Cmp Name, Cmp UID, Component Type, Criterion Type, Criterion Value, Calculated Value, Difference, and % Vtd. The top-right pane shows a 'Solution' pane with various settings and a 'Data Directory' pane listing various data files.

ID	Analysis	Result	Component	Part	Time Point	Phase A	Phase B	Phase C	Desc	Timestamp
1	Power Flow	Voltage mag	UC_202A_0	Start of Circuit	24/02/16 9:00:00	0.00	0.00	0.00		28/02/16 9:22:22
1	Power Flow	Voltage mag	UB_202A_0	Breaker	24/02/16 9:00:00	6.33	6.33	6.33		28/02/16 9:22:22
1	Power Flow	Voltage mag	17_20A	Breaker	24/02/16 9:00:00	6.33	6.33	6.33		28/02/16 9:22:22
1	Power Flow	Voltage mag	20A21_UG	3 Phase Underg	24/02/16 9:00:00	6.33	6.33	6.33		28/02/16 9:22:22
1	Power Flow	Voltage mag	2143A_Sel	Normally Open Pt	24/02/16 9:00:00	6.33	6.33	6.33		28/02/16 9:22:22
1	Power Flow	Voltage mag	20A21_UG	3 Phase Underg	24/02/16 9:00:00	6.33	6.33	6.33		28/02/16 9:22:22
1	Power Flow	Voltage mag	3277_OH	3 Phase Line	24/02/16 9:00:00	6.33	6.33	6.33		28/02/16 9:22:22
1	Power Flow	Voltage mag	3076_Sel	CGS	24/02/16 9:00:00	6.33	6.33	6.33		28/02/16 9:22:22
1	Power Flow	Voltage mag	3277_OH	3 Phase Line	24/02/16 9:00:00	6.33	6.33	6.33		28/02/16 9:22:22
1	Power Flow	Voltage mag	3278_OH	3 Phase Line	24/02/16 9:00:00	6.34	6.34	6.34		28/02/16 9:22:22
1	Power Flow	Voltage mag	30443_OH	3 Phase Line	24/02/16 9:00:00	6.34	6.34	6.34		28/02/16 9:22:22
1	Power Flow	Voltage mag	2143A_Sel	Normally Open Pt	24/02/16 9:00:00	6.34	6.34	6.34		28/02/16 9:22:22
1	Power Flow	Voltage mag	51103_UG	3 Phase Underg	24/02/16 9:00:00	6.34	6.34	6.34		28/02/16 9:22:22

Analysis Time	Feeder	Cmp Name	Cmp UID	Component Type	Criterion Type	Criterion Value	Calculated Value	Difference	% Vtd
1/1/2016	20A	DEFAULT_BRAMA-CSG	1108A_BA	Breaker	Defaulted	1.00	1.00	0.00	0.0
1/1/2016	20A	DEFAULT_CSG TE	11071_BA	Breaker	Defaulted	1.00	1.00	0.00	0.0

Power flow runs in GIS system with towers, poles, manholes, ...

Today: NISC Cloud Automation



Example ISMs



Analyzing every measurement, every day

Automated Voltage Profile Control Design



Voltage Control Design Setup

Attach Measurements

Open Measurement Setup File: T:\DewReport\MeasLoadConfig_CH_All.xml

Run Feeder Evaluation Save result as (file name): .txt

Use Previous Results

Open Previous Result File: T:\DewLogFile\5011.txt

Design Settings

Beginning of Feeder Voltage (Volt): 122

Calculate Secondary Side Customer Voltages

Calculate Primary Side Customer Voltages

Voltage Range

Upper Limit: 124 Lower Limit: 117.5

From: 2013-01-01 00:00 To: 2013-12-31 23:00 Time Step: 1 Hours

Fixed Capacitor

Maximum # of Fixed Caps: 8 Fixed Cap Size (kVar): 200

Switched Capacitor

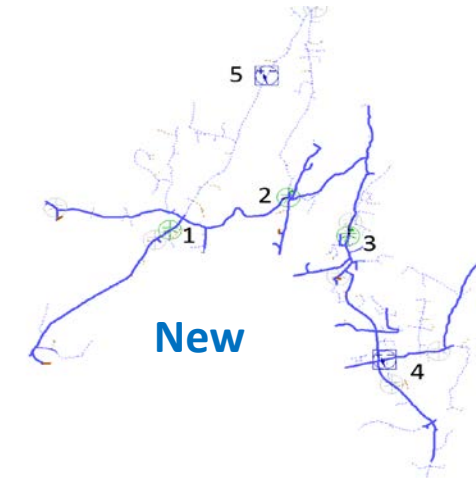
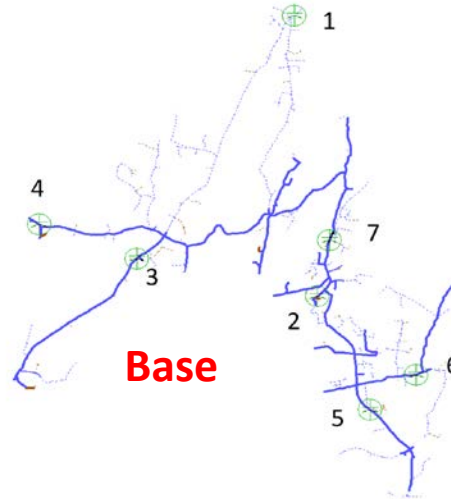
Maximum # of Switched Caps: 4 Control Bandwidth (Volt): 1.5 Switched Cap Size (kVar): 200

Voltage Regulator

Maximum # of Regulators: 2 Control Bandwidth (Volt): 1 Control Percentage (%): 5 V Drop to Lowest V (Volt): 4

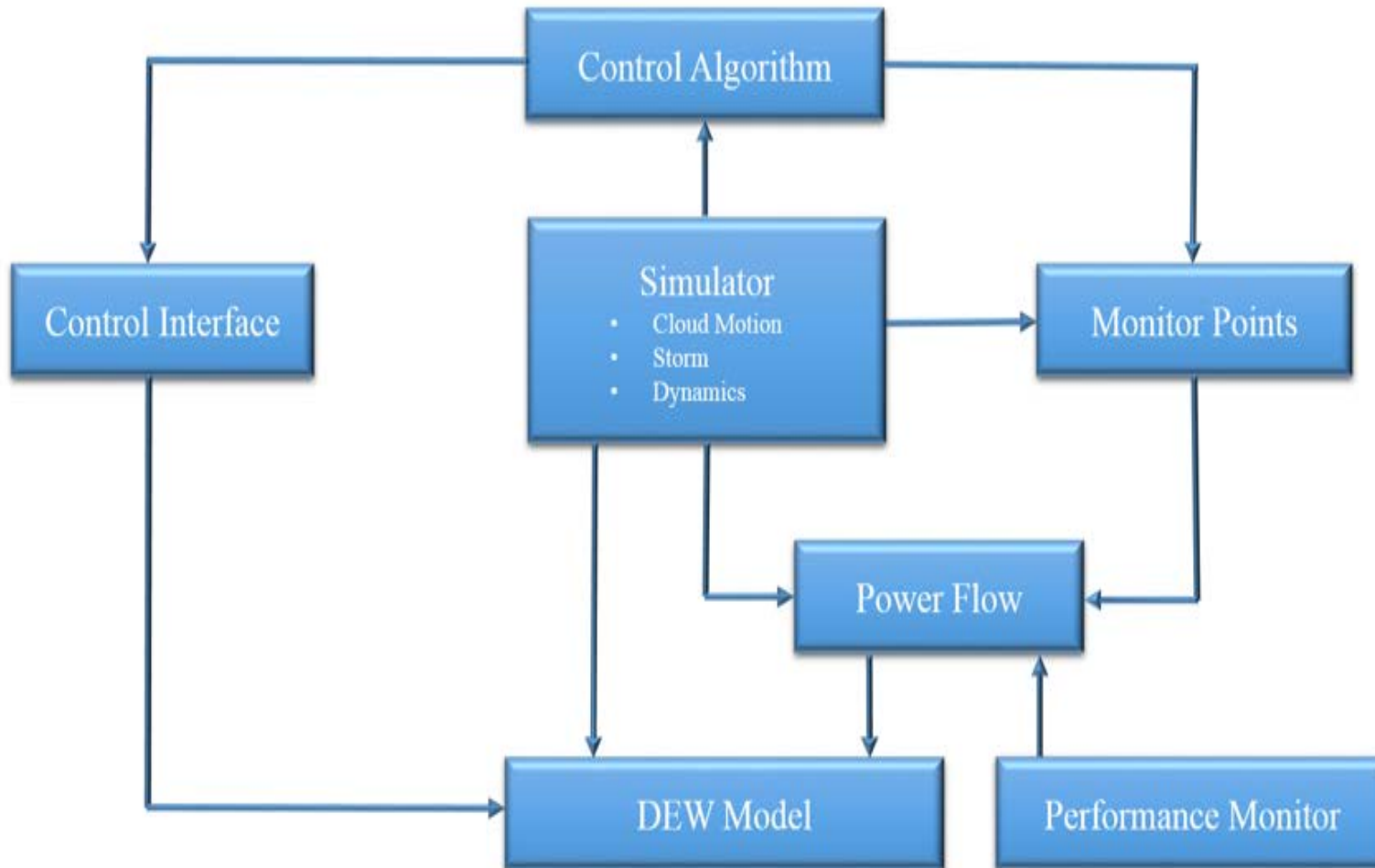
Add Secondary Capacitors

Settings OK Cancel



Average Voltage Reduction % (%Voltage Dependency Factor = -0.15)	Base/New Annual Load Mwh % Load Reduction	Annual Savings (\$0.14/kWh)	Base/New Annual Loss Mwh % Loss Decrease	Base/New Peak Kw % Peak Reduction	Increase in Hosting Capacity (kW)
-0.81	25391 24960 1.70	\$60420	662 659 0.48	4437 4337 2.27	1061

Open Source DEW Simulator



Program in four languages:

- C++
- C#
- Visual Basic
- F#

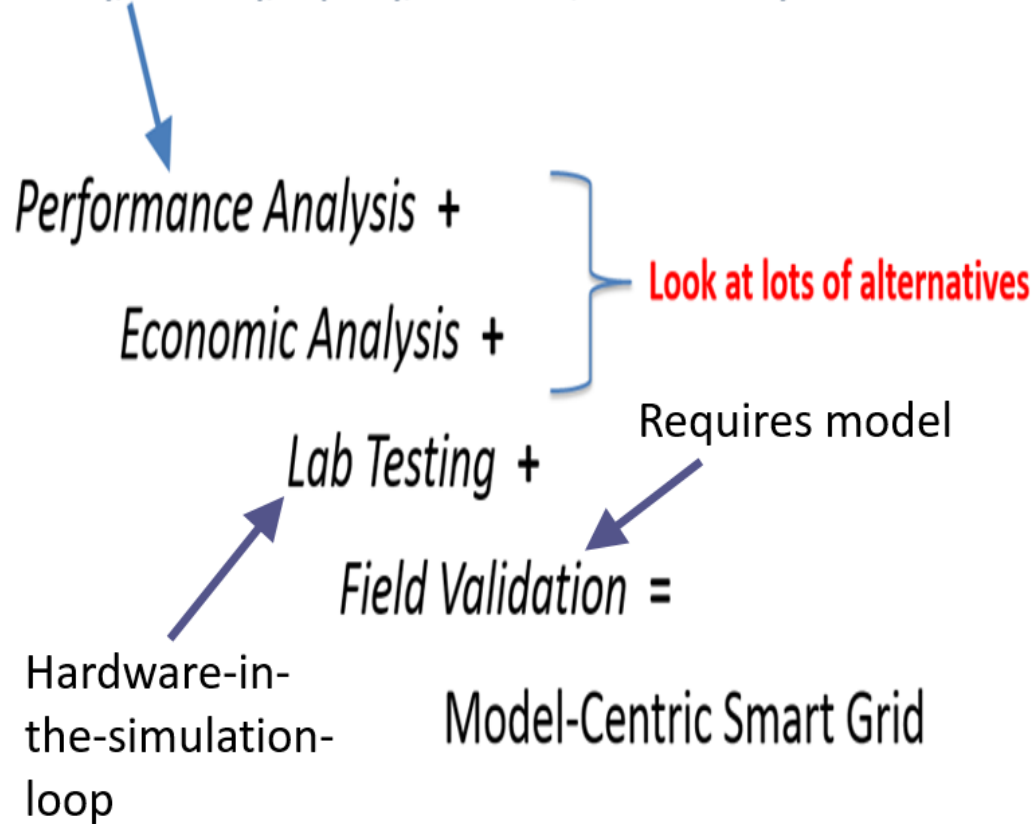
3 measurement types:

- Fixed sample rate
- Event driven
- Random sample

Summary: Modeling Philosophy



Reliability, Efficiency, Capacity, Protection, Controllability



Analysis Readiness Levels

Level 1: What happened and why did it happen?

Hindsight – reactive, diagnostic, operating seat-of-the-pants, no architecture for performance

Level 2: What will happen?

Insight – predictive, scenario driven

Level 3: What is a good way to make it happen?

Foresight – proactive, operating with analysis based decisions, architecture for performance

Model-Centric Life-Cycle Process with a Generic, Manufactured, Living Model providing Proactive, Holistic Solutions