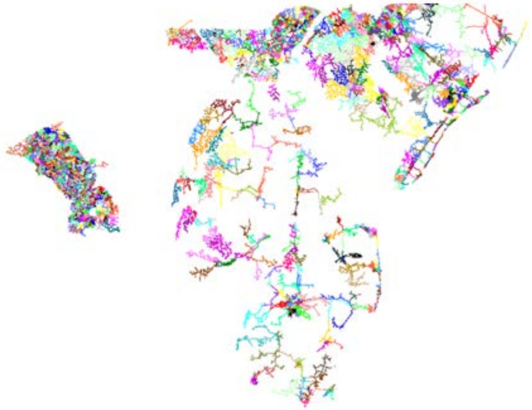
In Pursuit of Reuseable, Electric Power System Models: Breaking Down Barriers



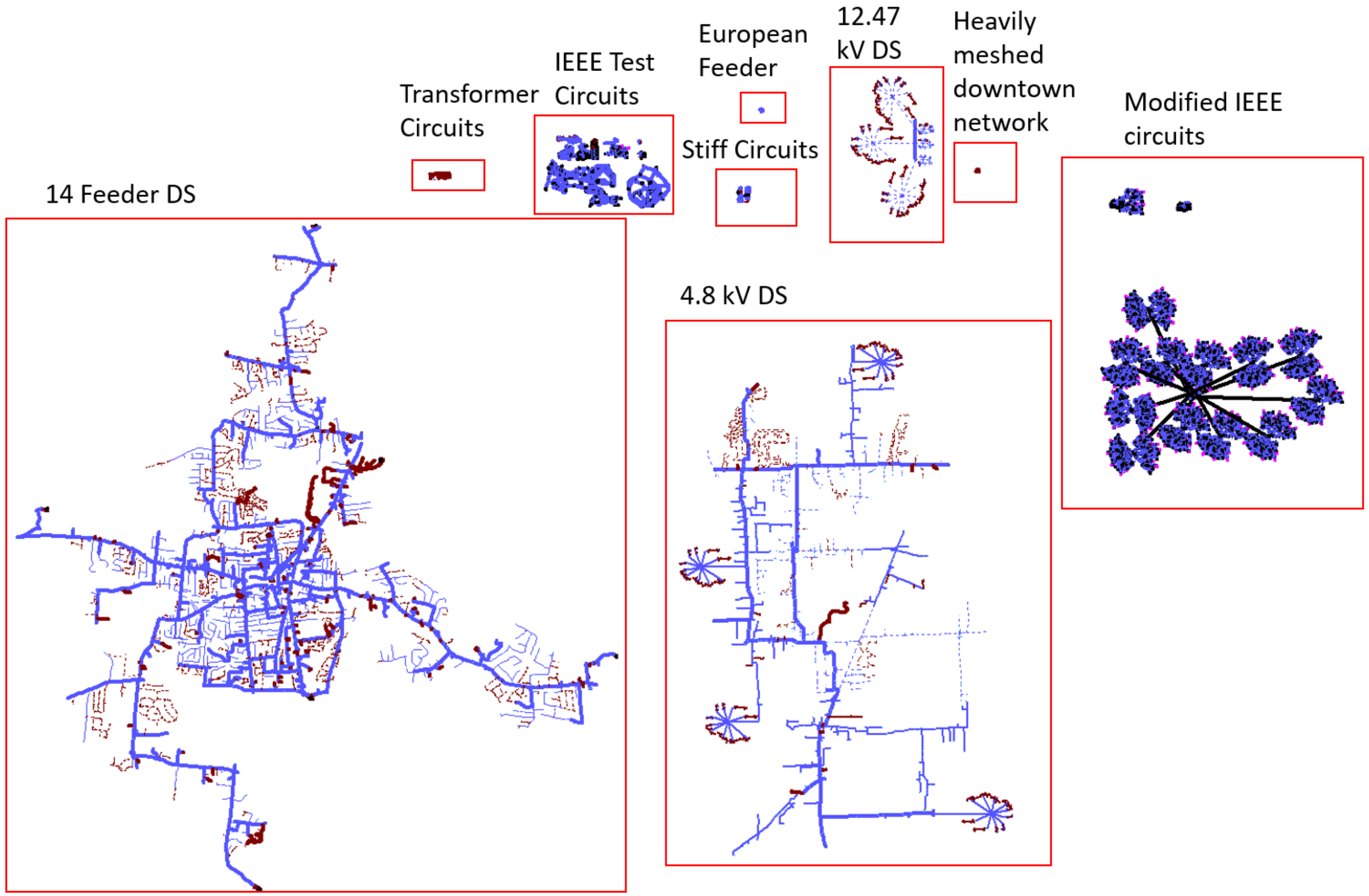
Time-Series, Automated Analysis and Design with Large Measurement Sets

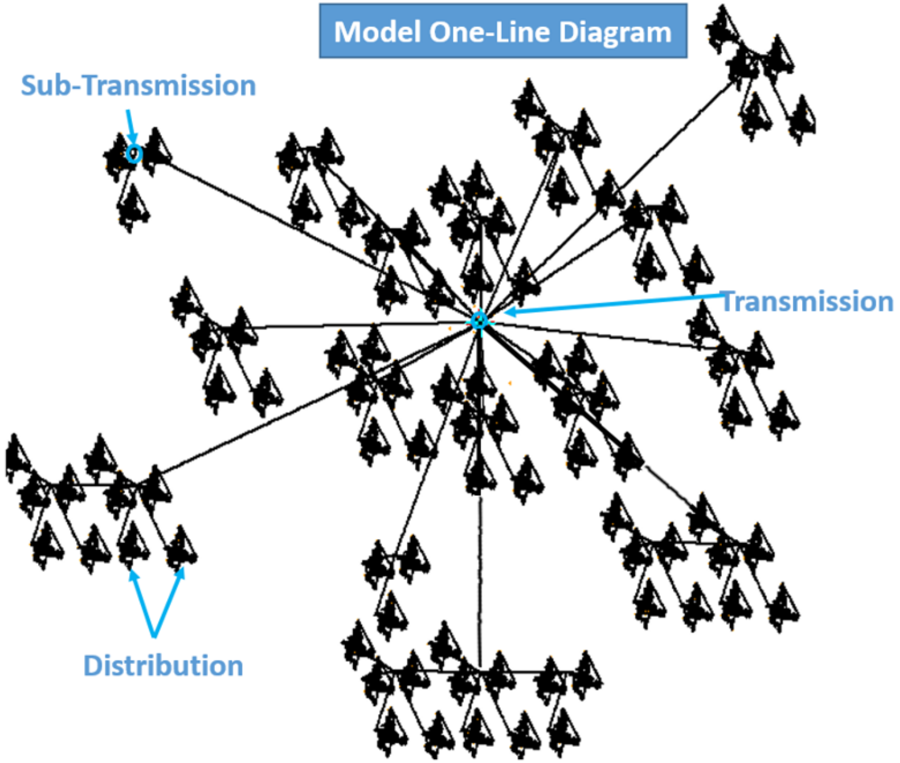
Robert Broadwater
dew@edd-us.com

December 2, 2016

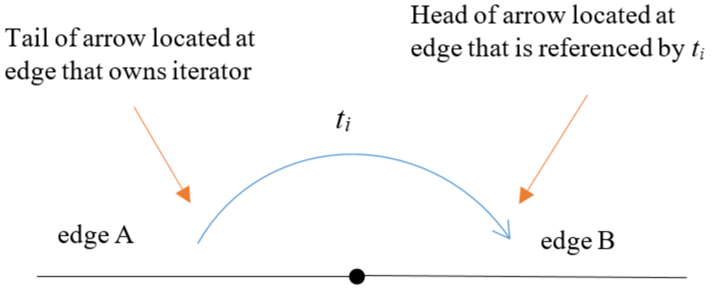
edd
Modeling a Greener World

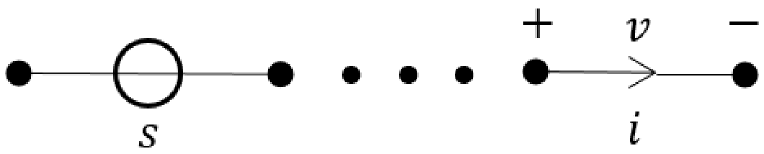
Integrated System Modeling: Research Circuits





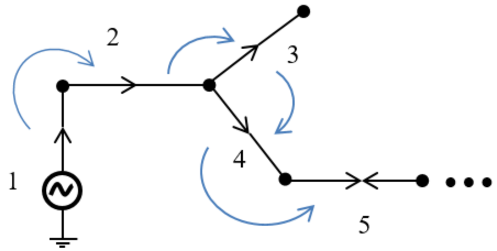
Graph Trace Analysis: Generic Programming, Edge-Edge Graphs, Topology Iterators



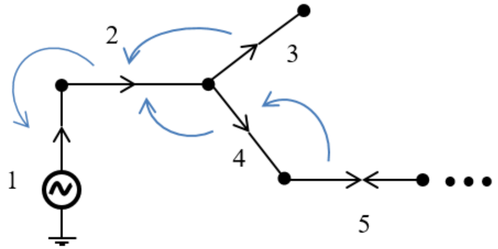


quadruply linked list { $p[f]$, $p[b]$ } *doubly linked list*; { $p[fp]$, $p[ct]$ } connectivity

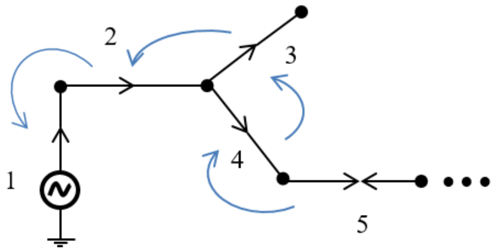
- Forward Trace



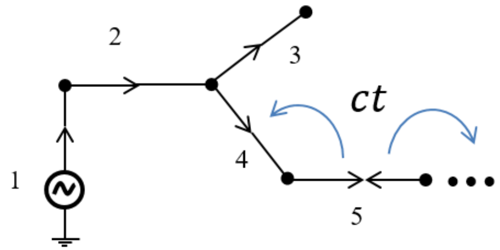
- Feeder Path Trace



- Backward Trace



- Cotree Trace



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

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

Initialize iterators: Add, connect

Update iterators: Insert, delete, operate, fail

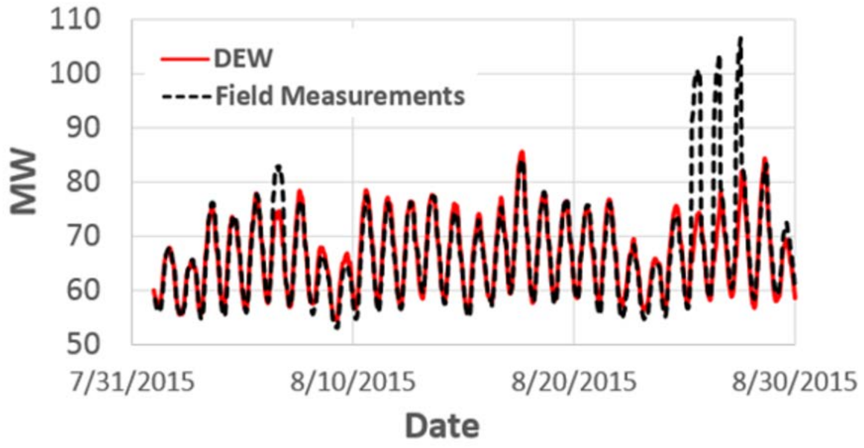
Generic: Attach any algorithm, measurement set

Algorithms: Sorting, continuation methods (robustness)

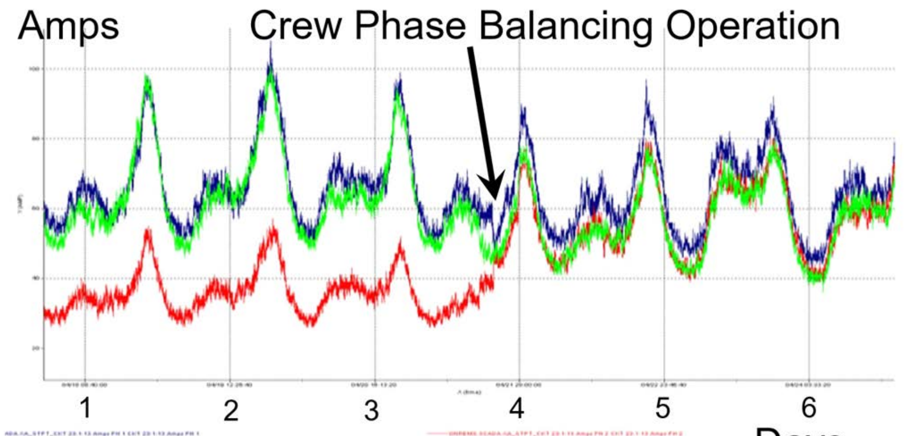
Traditional Analysis versus GTA

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

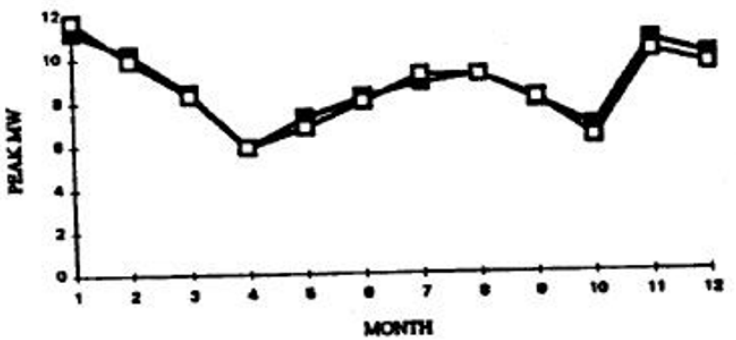
GTA-Based Time-Series Analysis Validations



SVP Transmission System Validation



ORU Phase Balancing Validation



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**

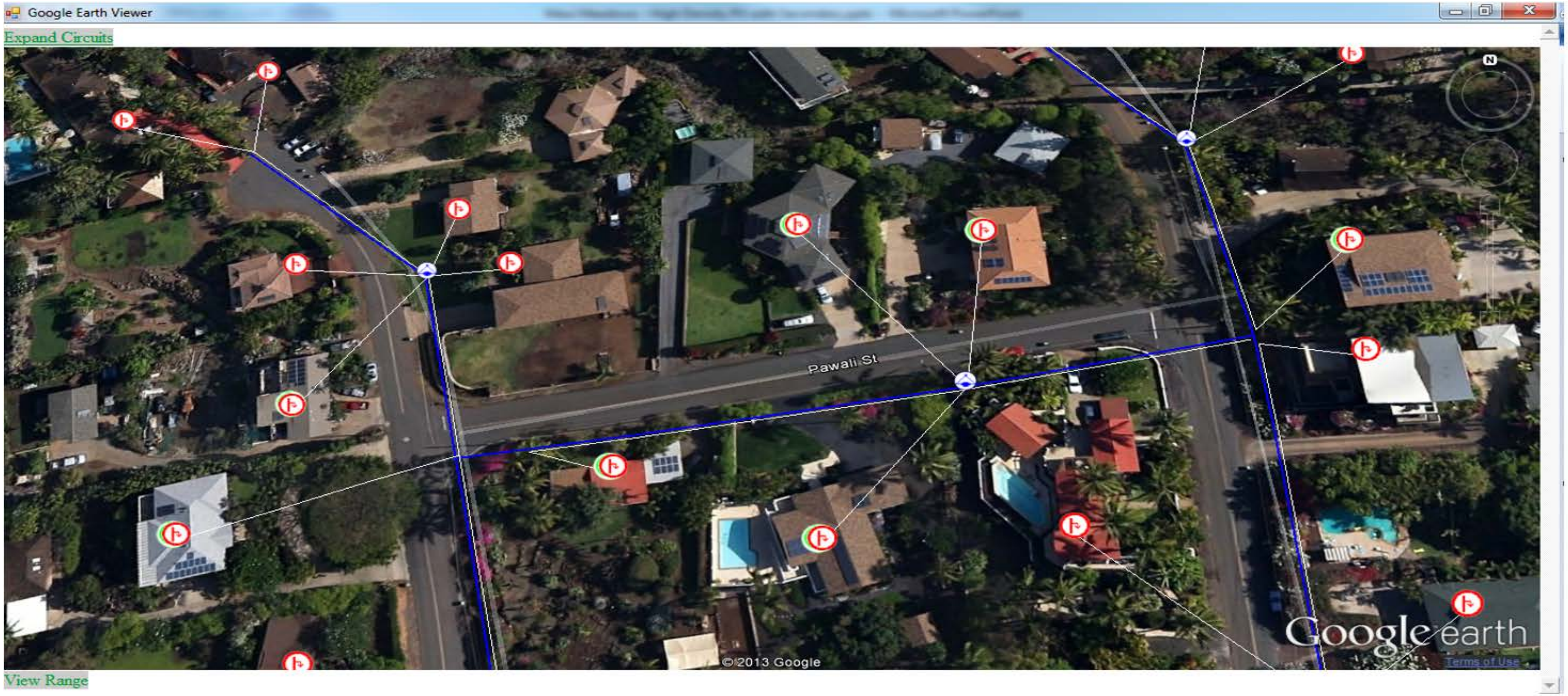
"Without an ISM the understanding of system behavior is limited to a few operators and engineers" ***SVP***

"With an ISM Automated analysis becomes possible" **PHI**

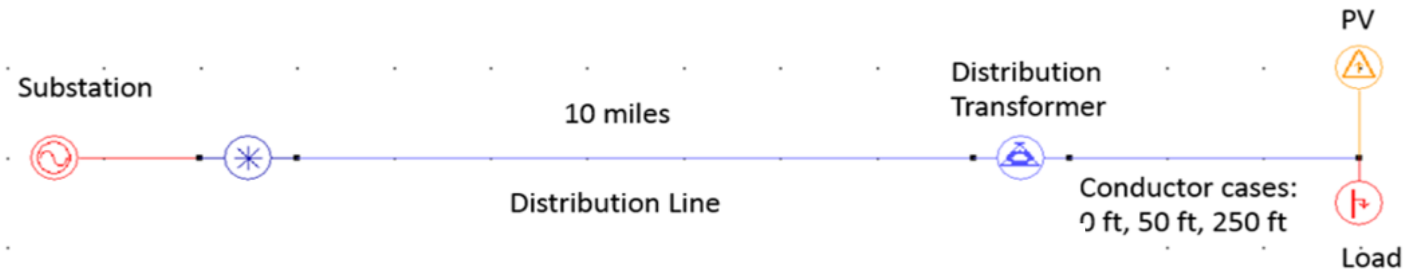
"As opposed to data analytics, ISM solutions cover the entire range of operations" **OSIsoft**

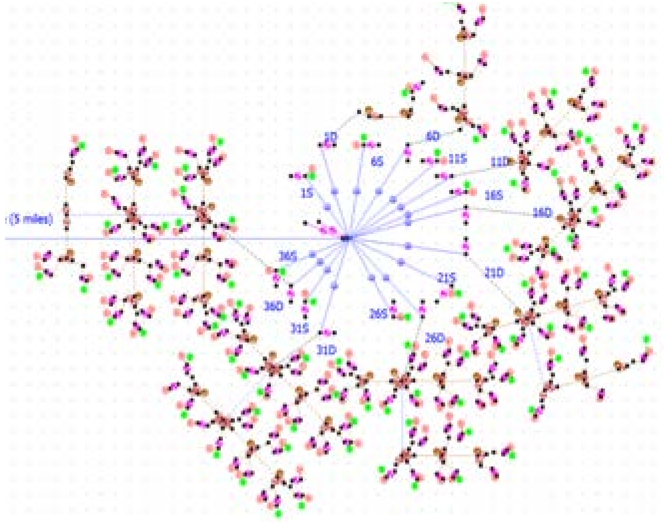
Model-Centric Life-Cycle Process using a Generic, Manufactured, Living Model providing Proactive, Holistic Solutions

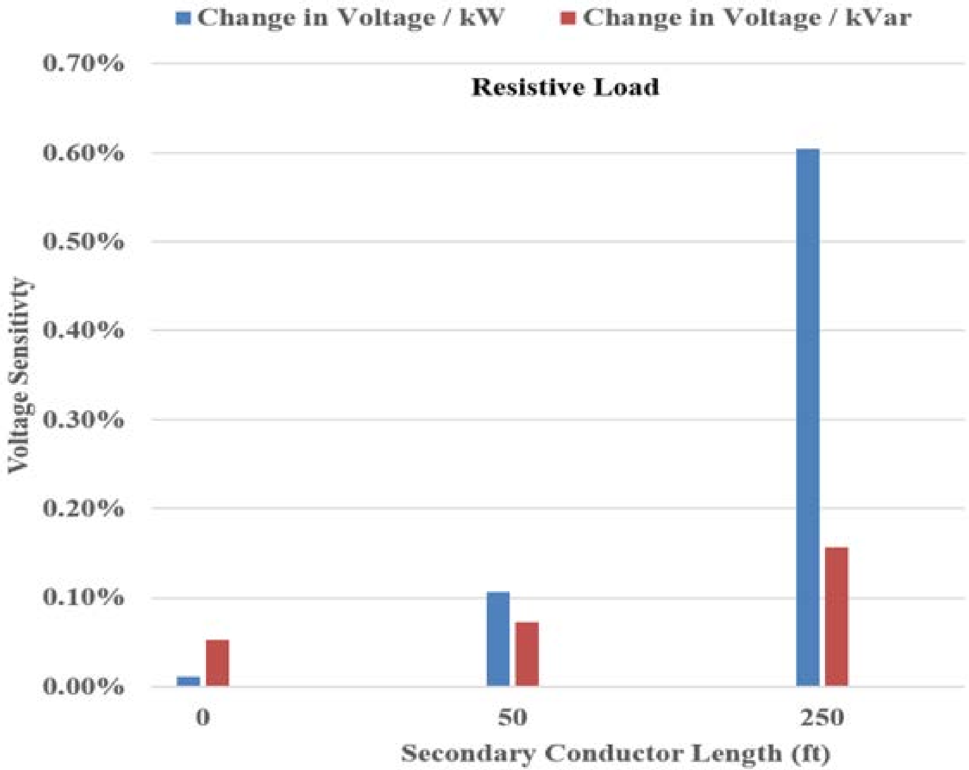
ISM Over Google Earth Showing Secondary Circuits, Loads, and PV



Simplified Versus Detailed Secondary Circuit Models





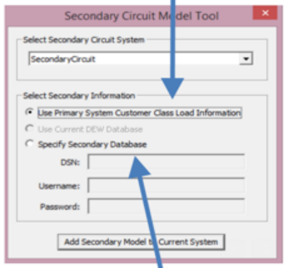


PV Penetration Analysis Approach Comparisons	Max PV Penetration (% of load)
Simple Secondary Using Step Change and IEEE 1453-1992	23
Detailed Secondary Using Step Change and IEEE 1453-1992	18

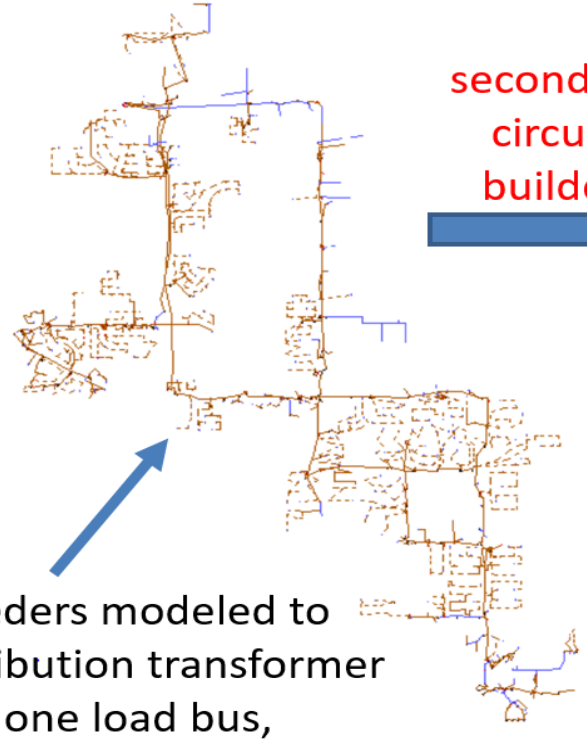
Is the secondary circuit just a load on the distribution transformer bus?

Largest voltage variation is always at service point with PV

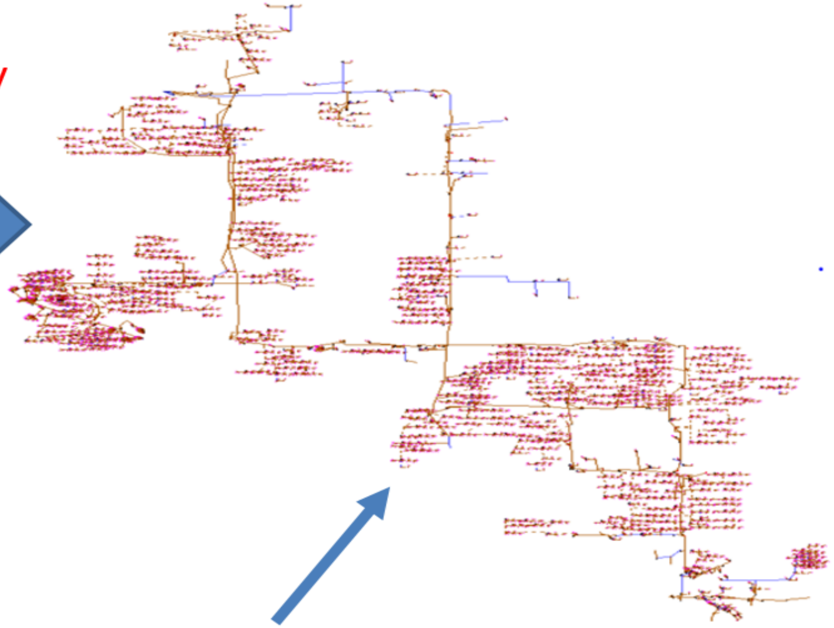
PV and customer information part of simple secondary model



PV and customer information contained in database tables



secondary circuit builder

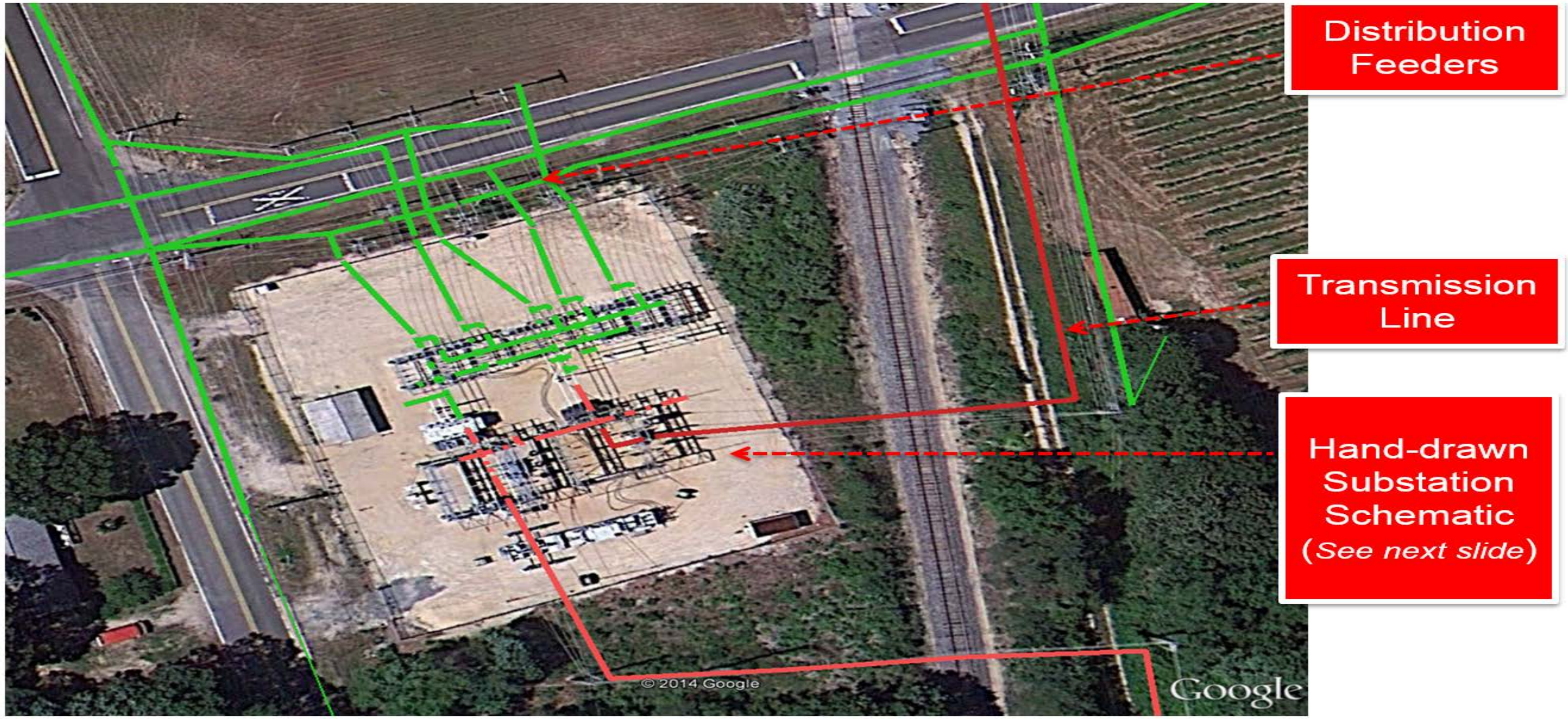


3 feeders modeled to distribution transformer with one load bus,
~3500 components,
633 load busses,
74 PV

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

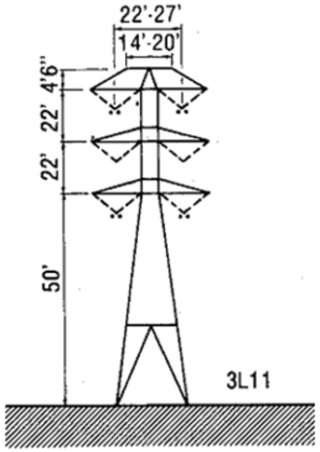
Secondary voltage variations can trump primary voltage variations

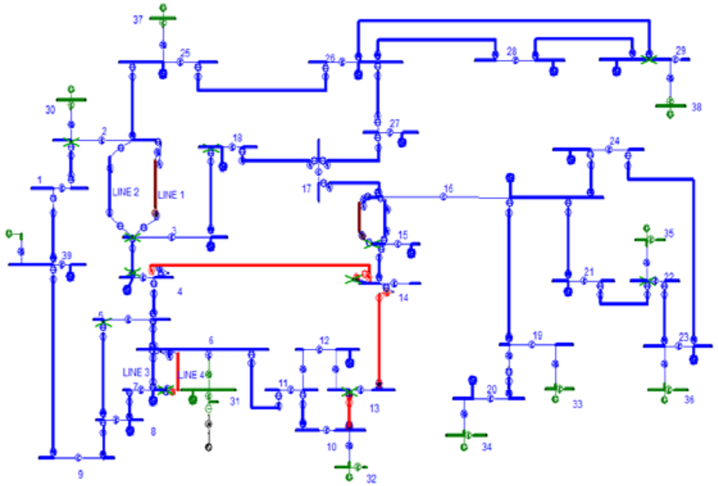
ISM Over Google Earth

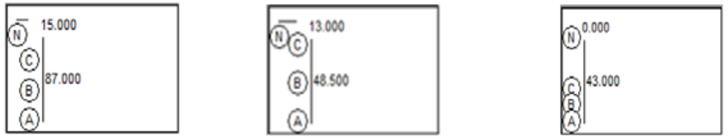


Common approach is distribution feeders are analyzed one-by-one, transmission system is analyzed separately, and substation is not included in analysis at all*

Pretending Transmission Lines are Transposed



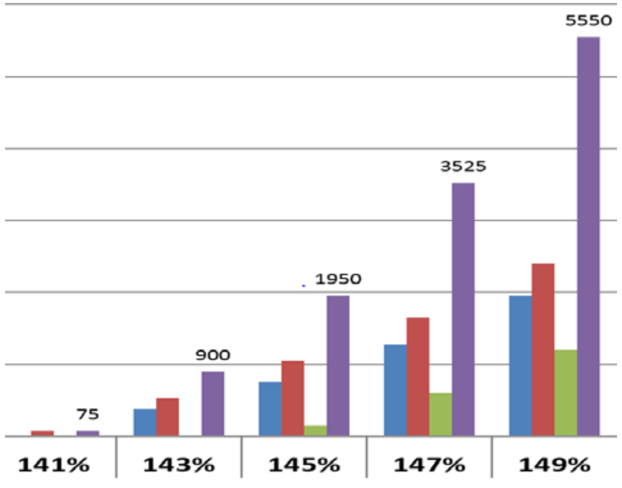


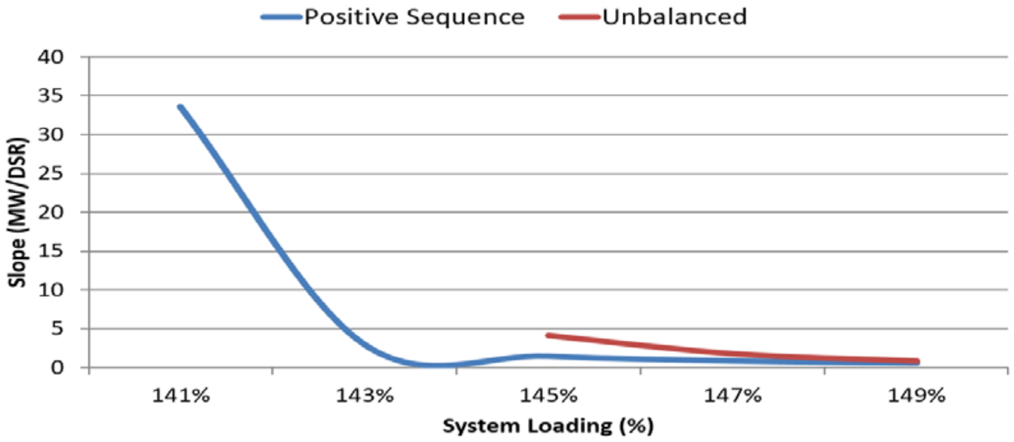


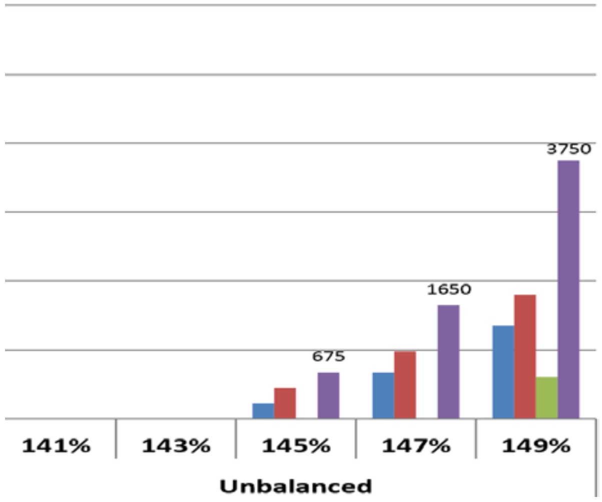
500 kV line spacing | 345 kV line spacing | 230 kV line spacing

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

$$\begin{bmatrix} 0.054 + j\,0.75 & 0 & 0 \\ 0 & 0.054 + j\,0.75 & 0 \\ 0 & 0 & 0.054 + j\,0.75 \end{bmatrix}$$







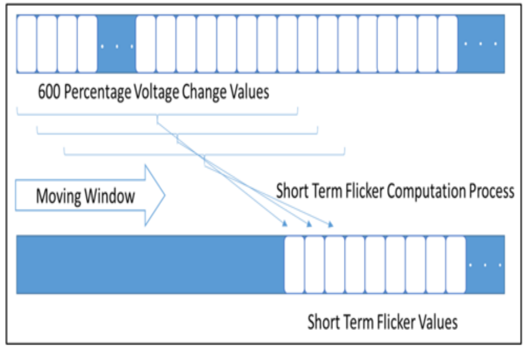
IEEE 1453-2015 Standard: Formula

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

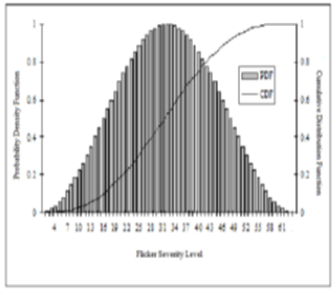


$$P_{1s} = \frac{P_{0.7} + P_1 + P_{1.5}}{3}$$

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

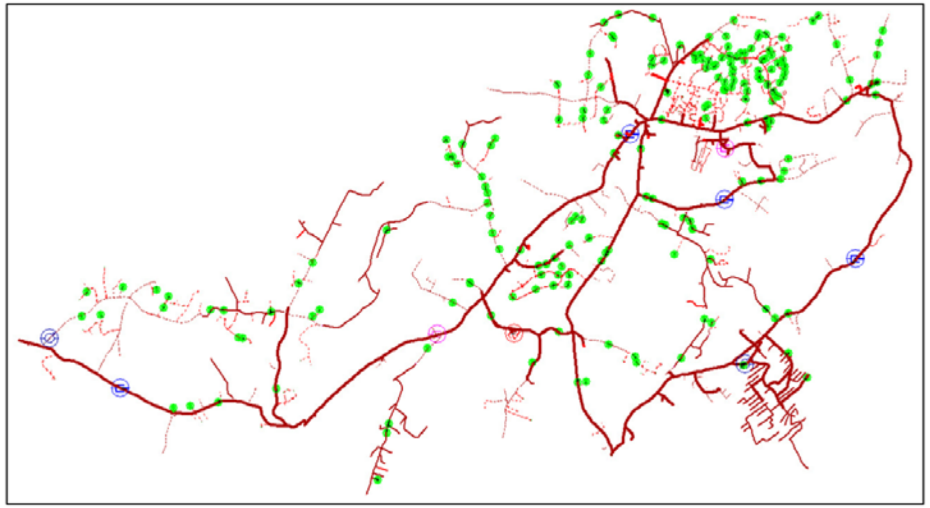
$$P_{10s} = \frac{P_6 + P_8 + P_{10} + P_{14} + P_{17}}{5}$$

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



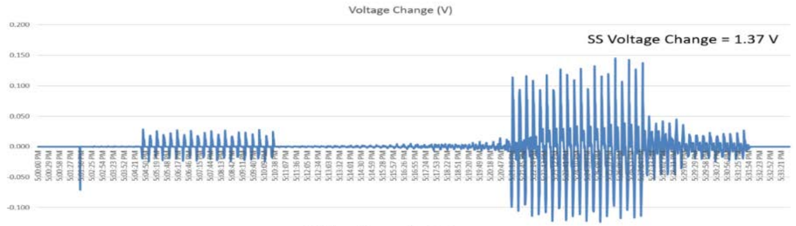
Flicker severity level	Compatibility Limits - LV	Planning—MV	Planning—HV and EHV
Pst [10-min]	1.0	0.9	0.8
Plt [120-min]	0.8	0.7	0.6

Cloud Motion PV Analysis

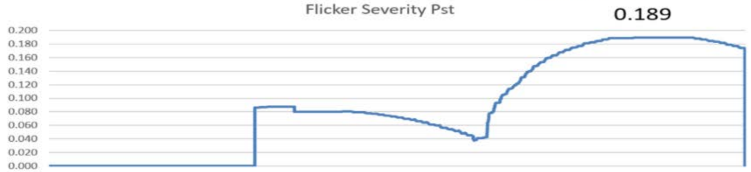


Max load ~ 14 MW, Max PV ~ 2 MW, PV Penetration ~ 14%

Voltage Change

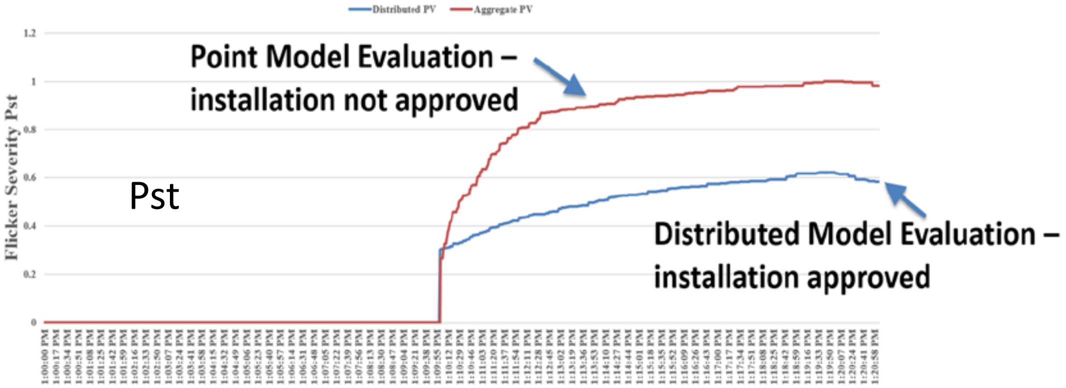


Pst

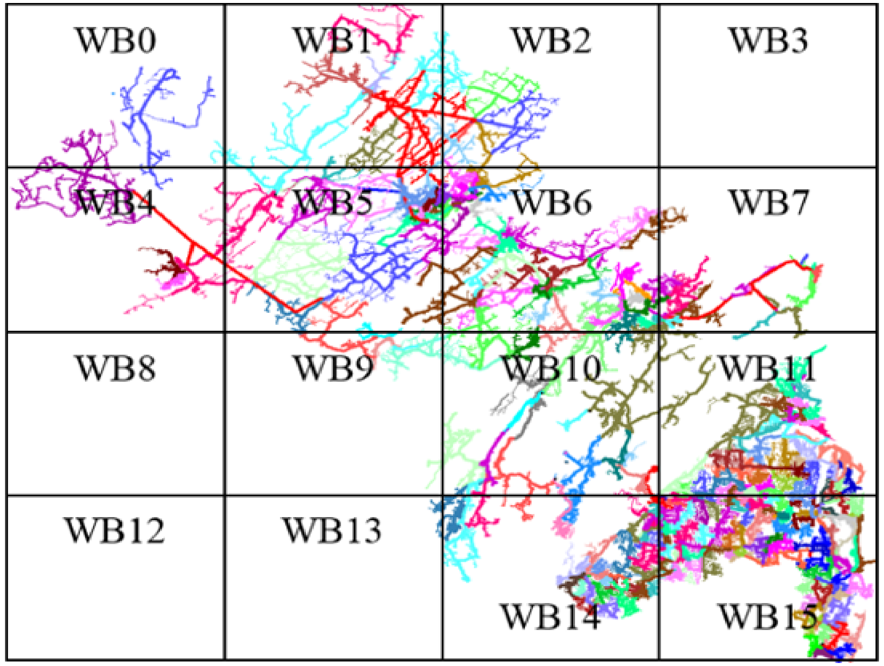


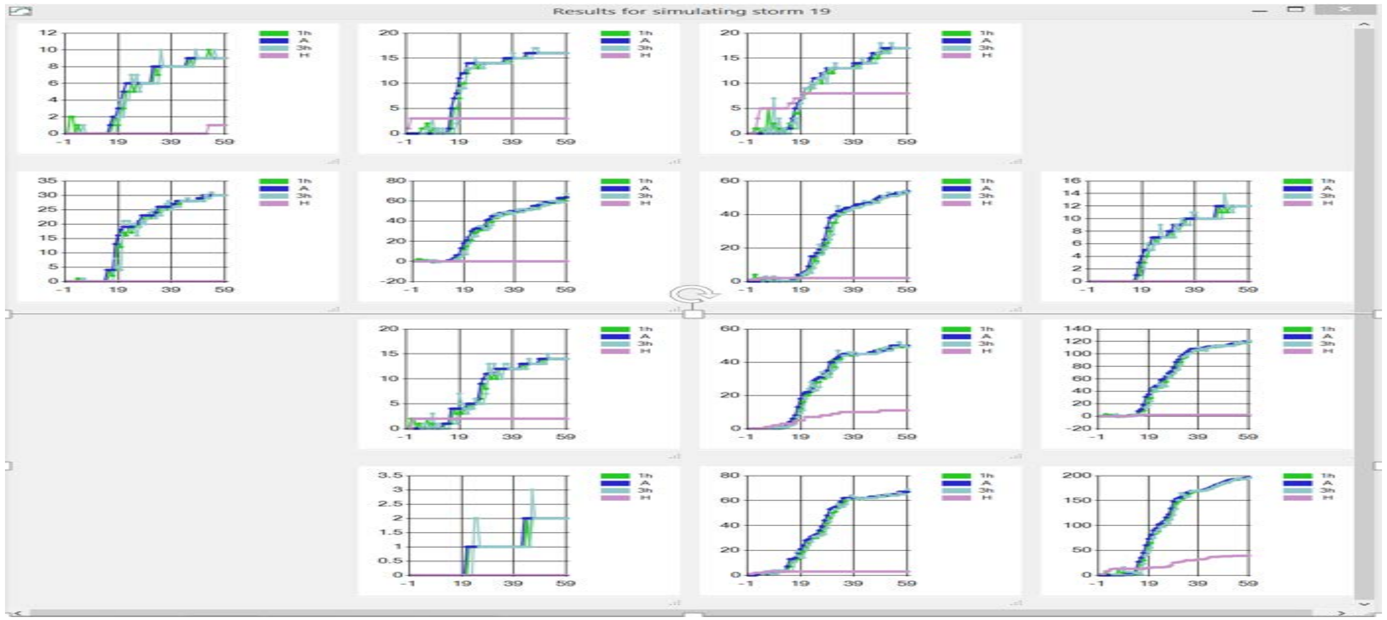
Evaluate installation of 7.3 MW PV, covering 44 acres, approximately square (about 6 acres per MW)

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



Relating Radar Weather to ISM - Weather Boxes

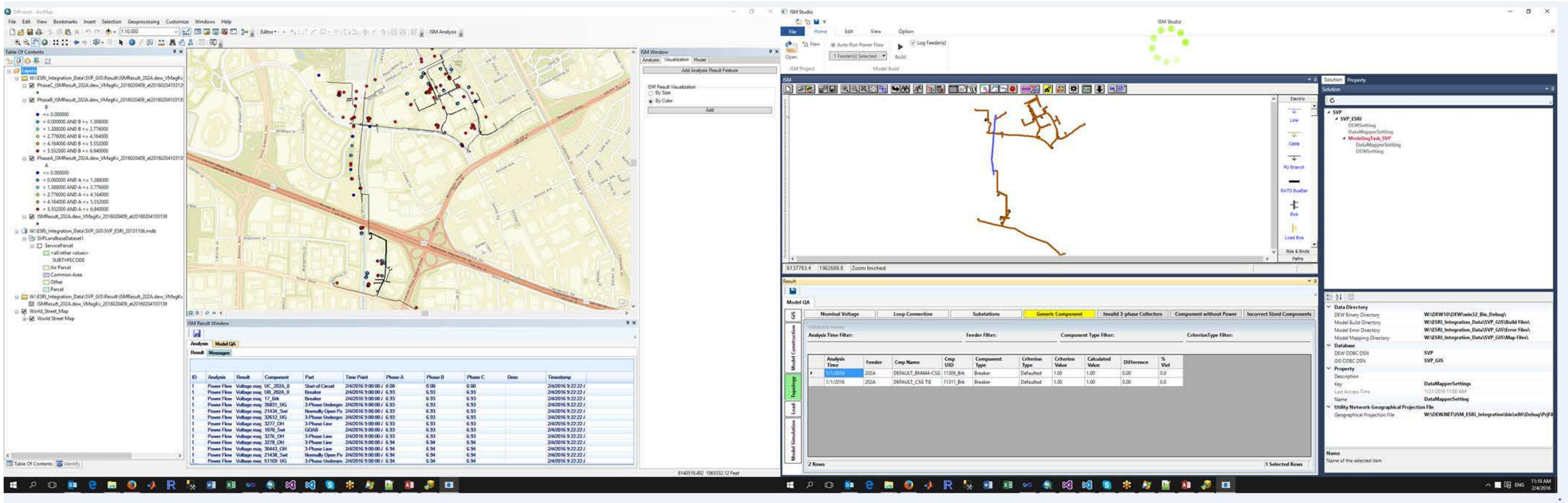




Weather boxes and measurements:
1-6500 measurements per weather box per radar scan
2-Approimately 85000 measurements per radar scan for ORU service territory
3-Approximately 1,275,000 measurements per hour

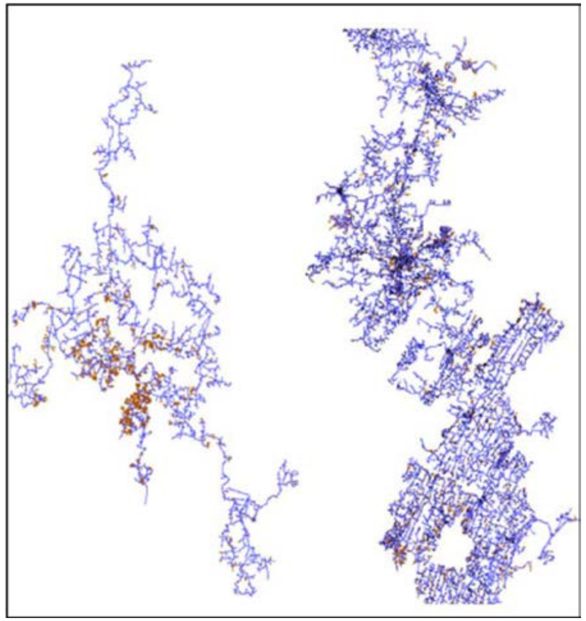
For each weather box store max and average for:
1-Reflectivity (dbz)
2-Wind speed (knots)
3-Accumlated precipitation (inches)

GTA Analysis Embedded In or Synched with ESRI



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

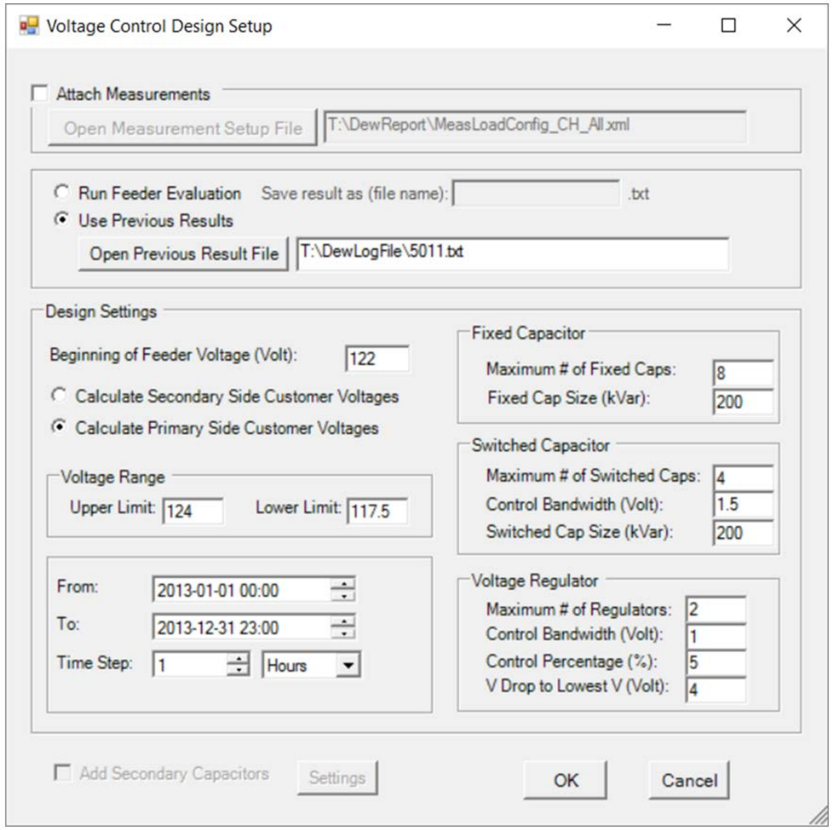
Today: NISC Cloud Automation

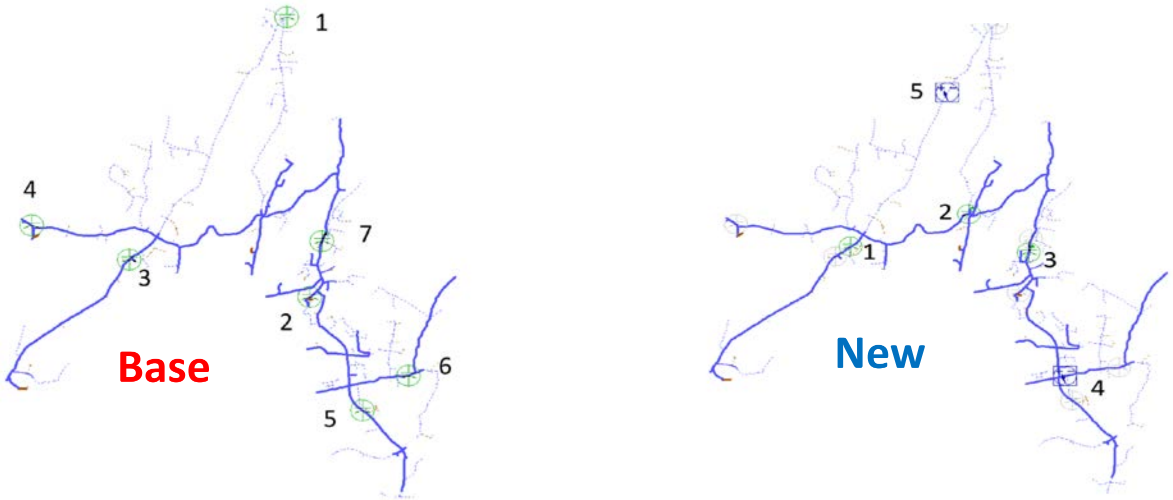


Example ISMs

Analyzing every measurement, every day

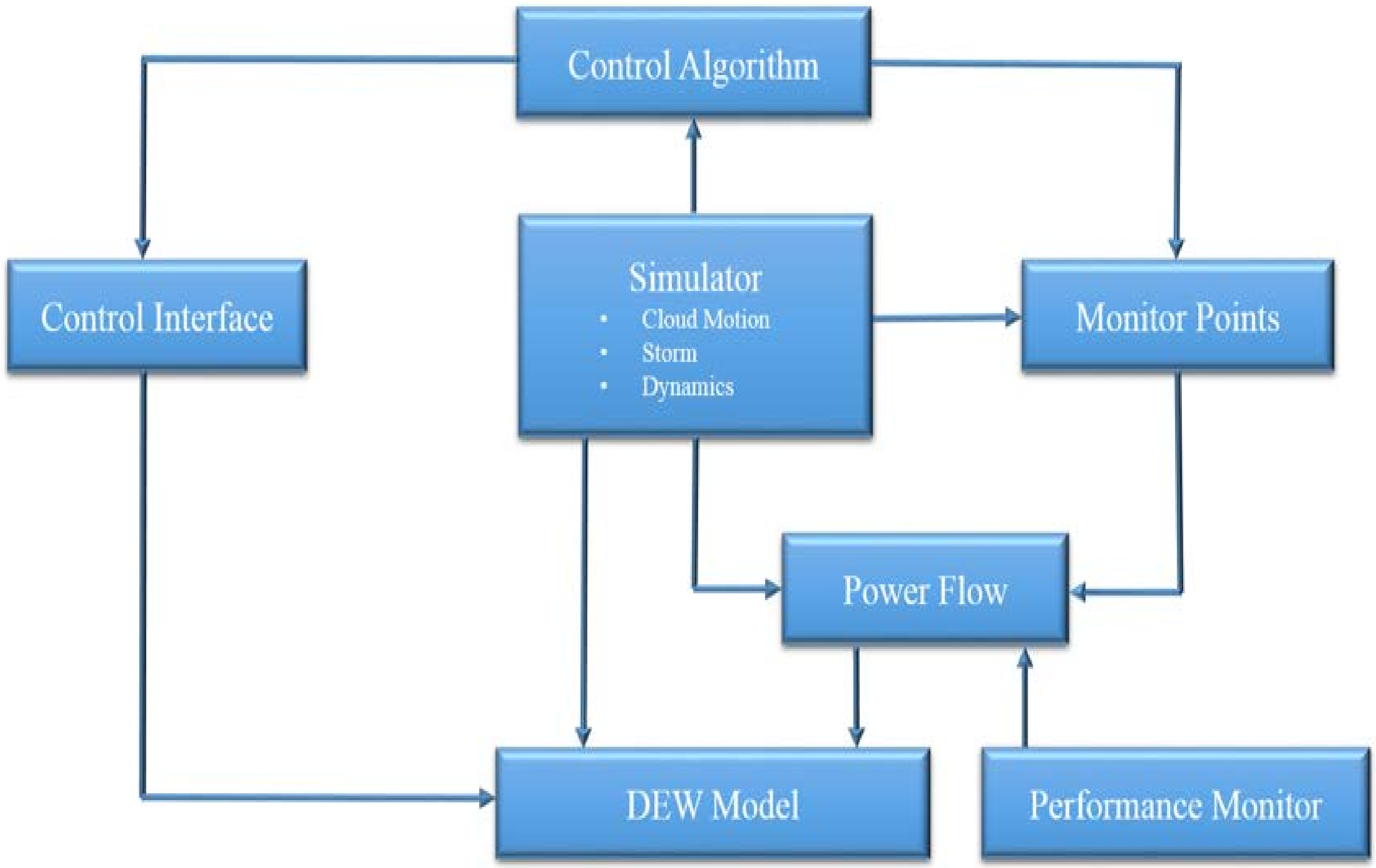
Automated Voltage Profile Control Design





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



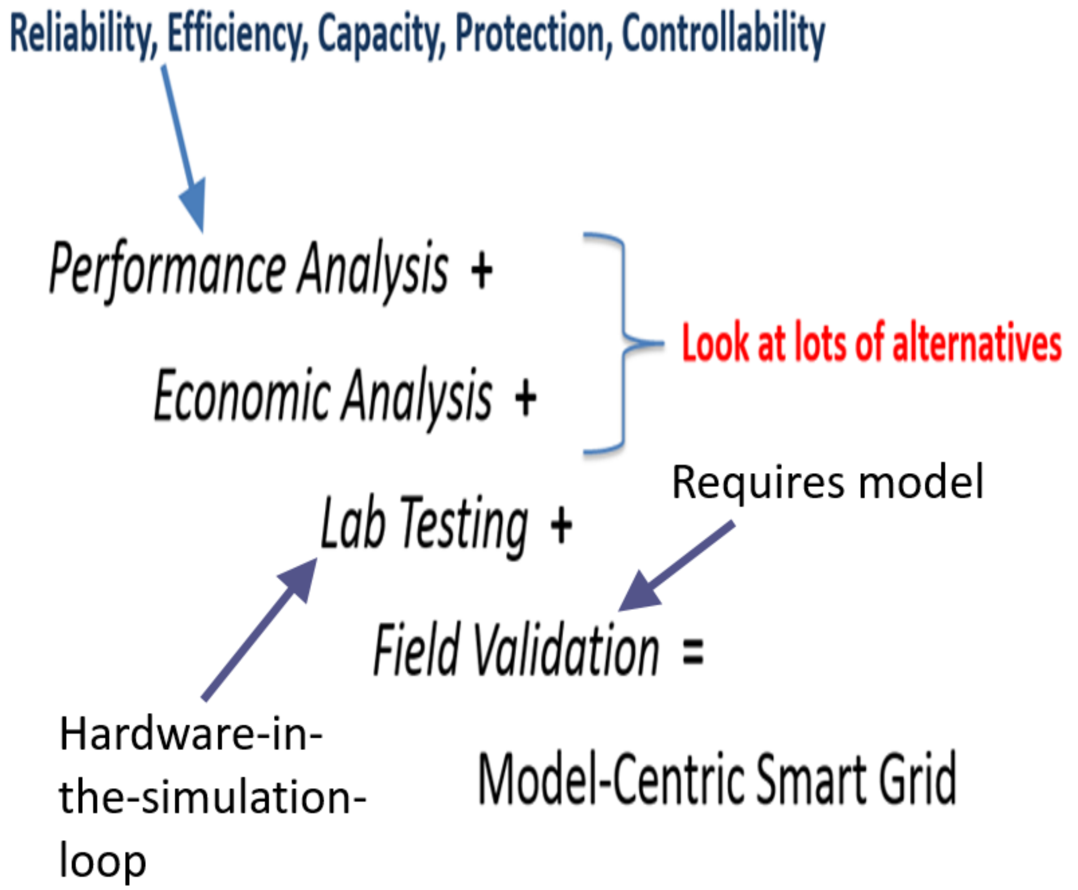
Program in four languages:

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

3 measurement types:

- Fixed sample rate
- Event driven
- Random sample

Summary: Modeling Philosophy



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