Computationally Intense PV Generation Analysis for Accurate Decisions

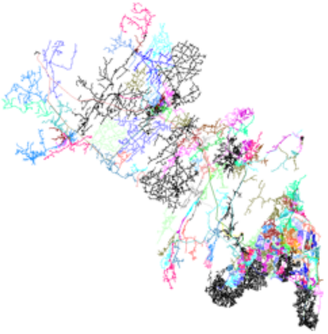
Co-op

127693 Nodes

Municipal

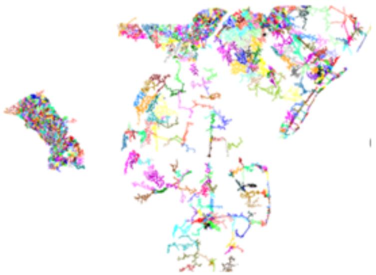
103108 Nodes
17 Loops

Medium Size IOU



1091931 Nodes
90 Loops

Large IOU

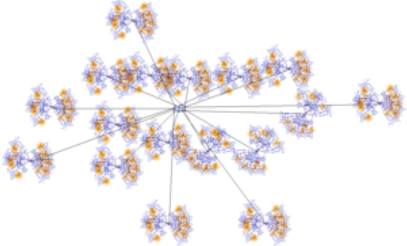


3931104 Nodes
1372 Loops

All Topologies

250501 Nodes
570 Loops
207 Lightly meshed

The Future ?
99% generation in D



98651 Nodes
23 Loops

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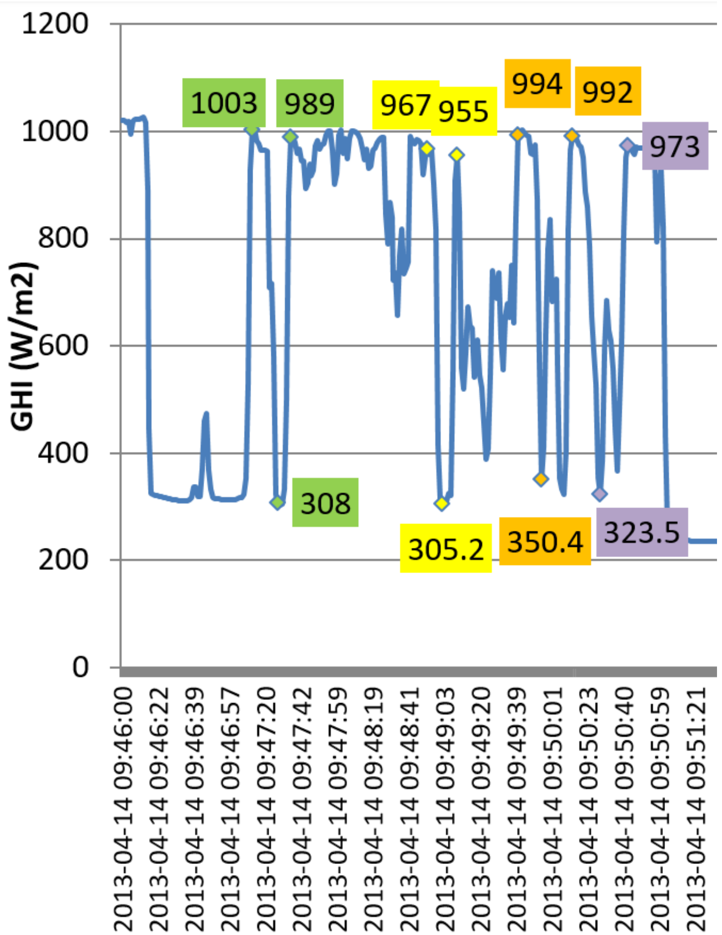
March 28, 2018

edd
Modeling a Greener World

Factors Affecting Computational Intensity

- Cloud and wind statistics and a Cloud Simulator
  - Simulates motion of many clouds moving over electrical circuits
- Power flow, time series analysis with one-second step sizes
- Modeling secondary circuits
  - Can increase model size by a factor of 10
- Calculations for IEEE 1453-2015 standard
  - Requires 600 power flows to calculate one flicker intensity value
- Modeling geographically distributed PV generators

One Second PV Data, NWS Data, and Statistical Parameters



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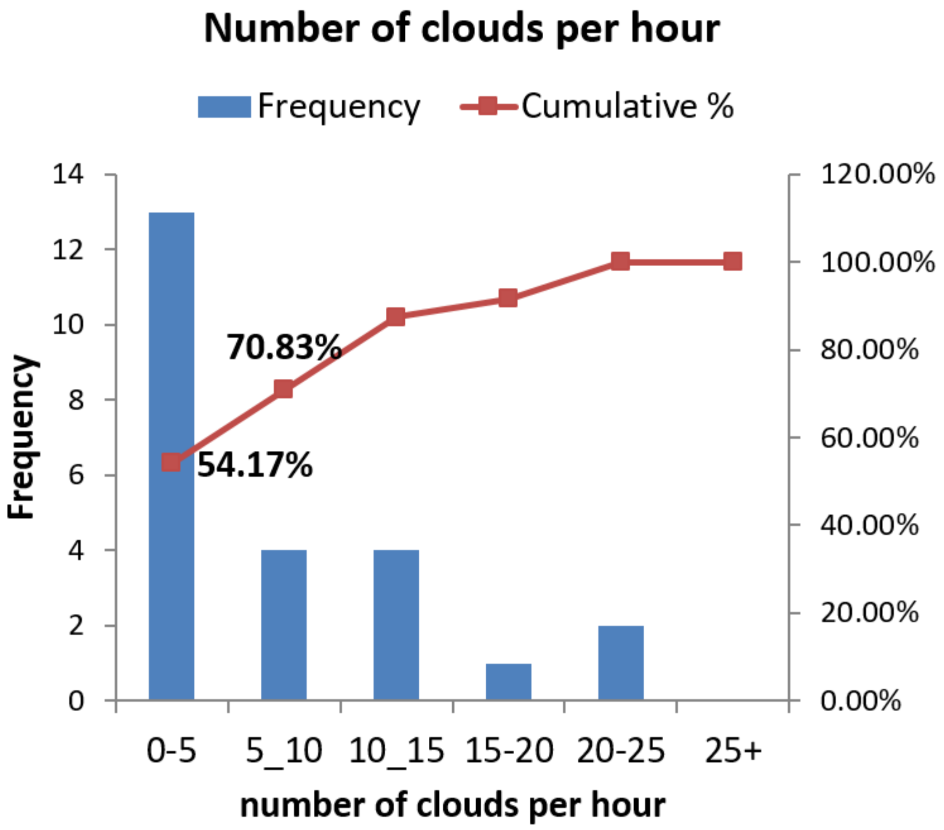
NWS Wind Speeds and Direction

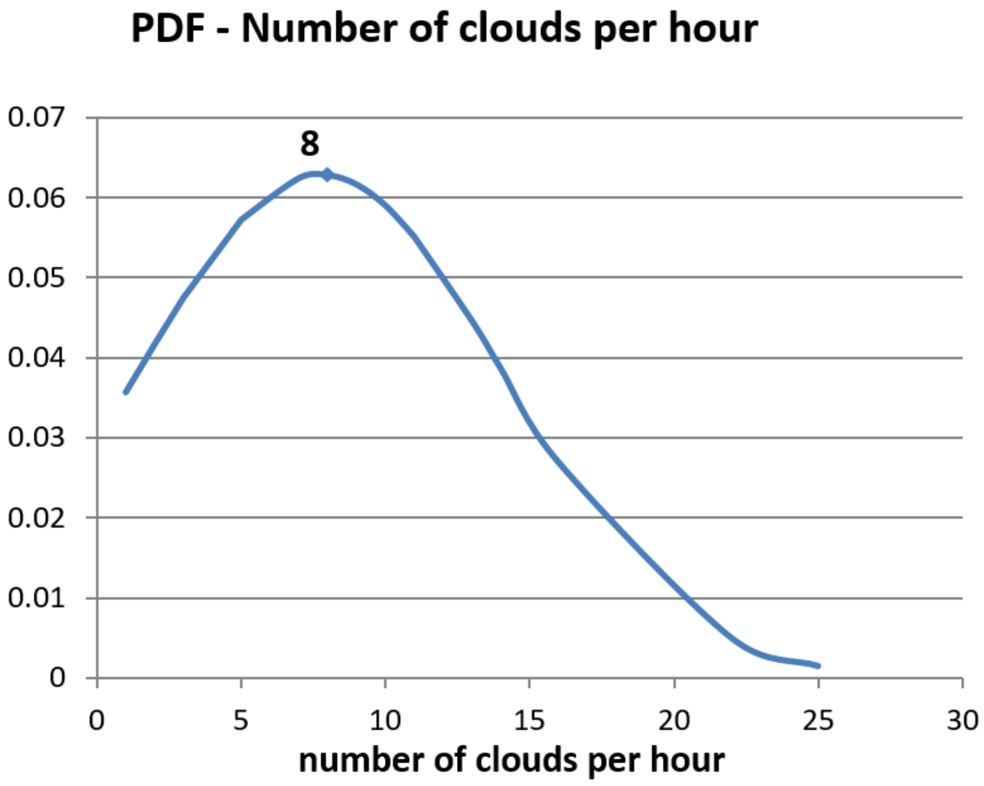
=

Cloud and PV Statistics

- Change in generation
- Generation decay/recovery time
- Speed of shadows
- Width of clouds
- Time between clouds
- Number of clouds per unit time

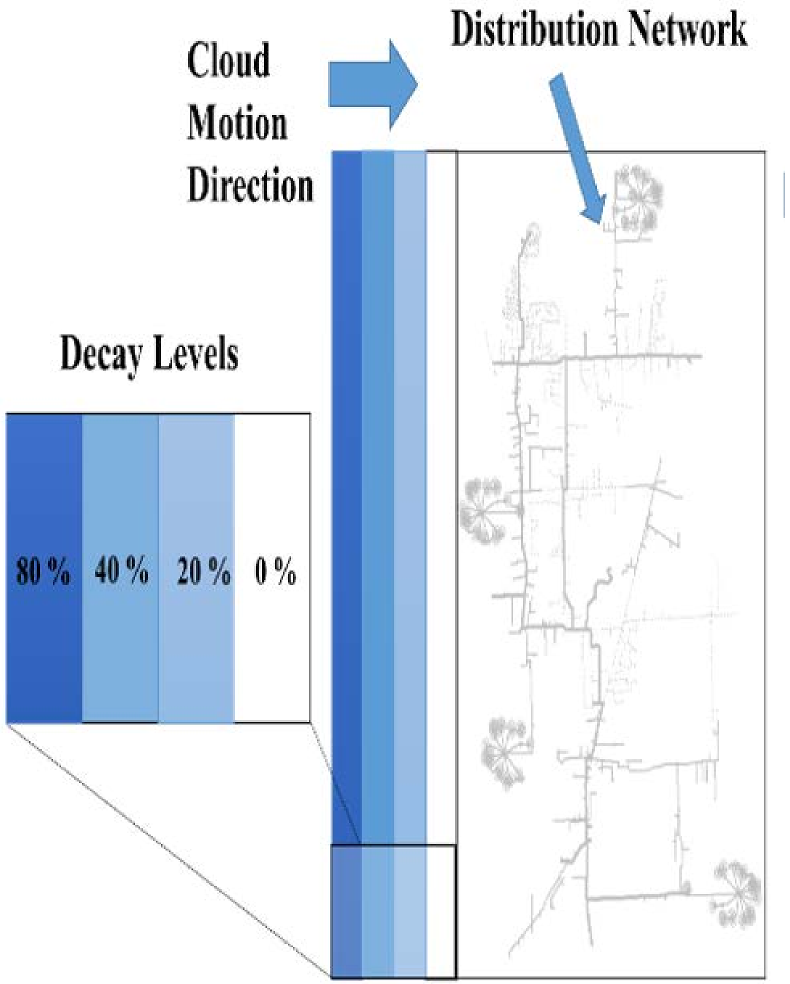
Clouds per Hour During High PV Variations

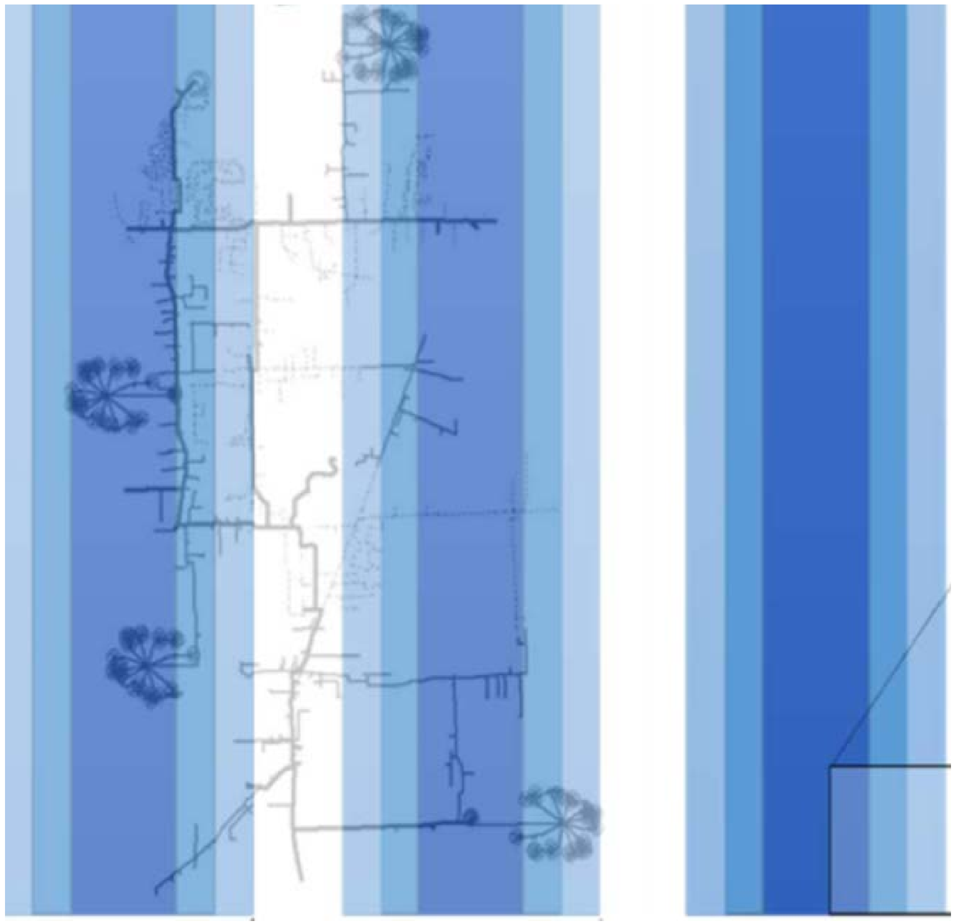




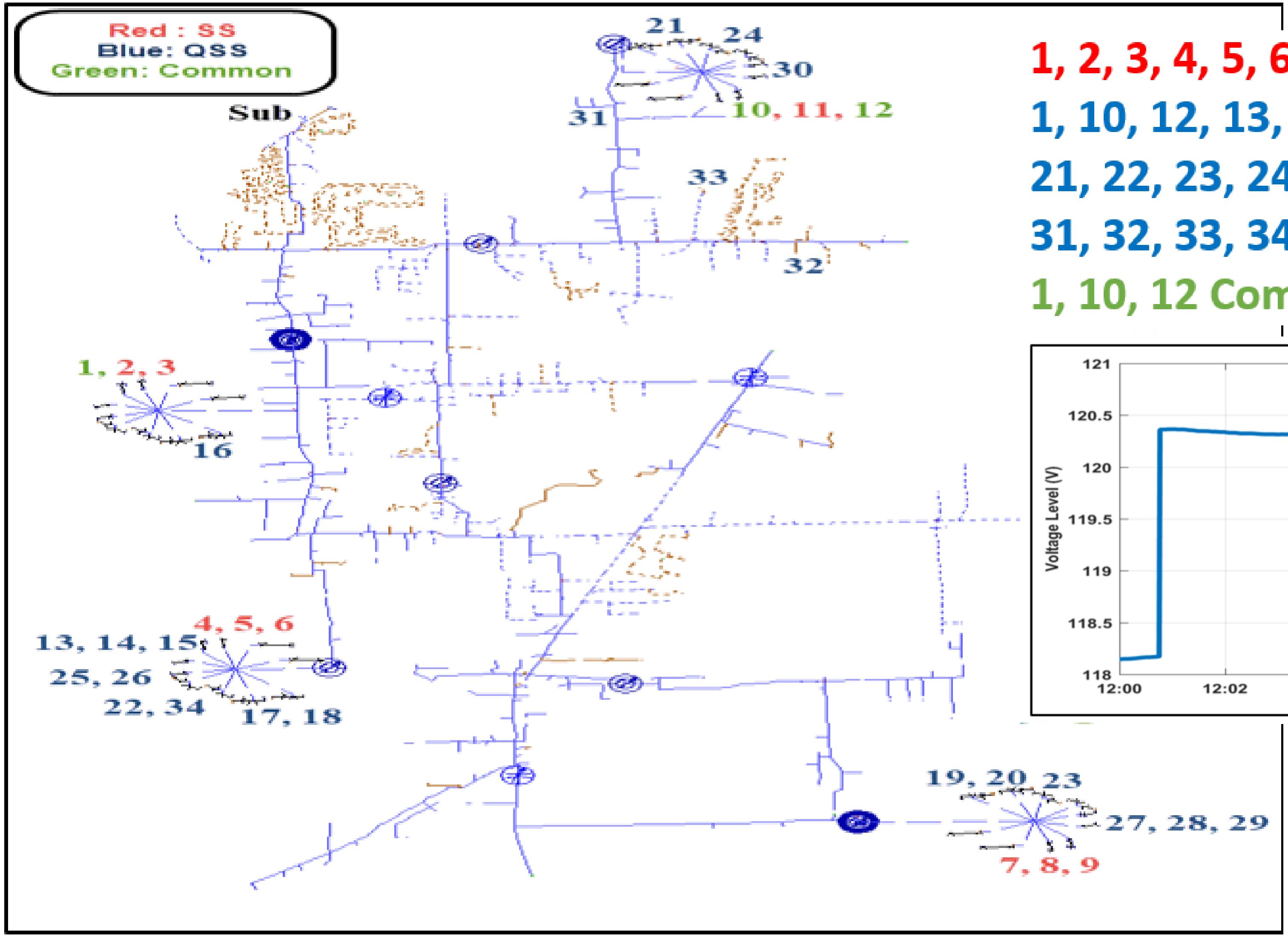
Reference: "Computation of Voltage Flicker with Cloud Motion Simulator," …, accepted for publication in IEEE Transaction on Industry Applications.

Cloud Simulator and One-Second Step Size, Time Series Power Flow





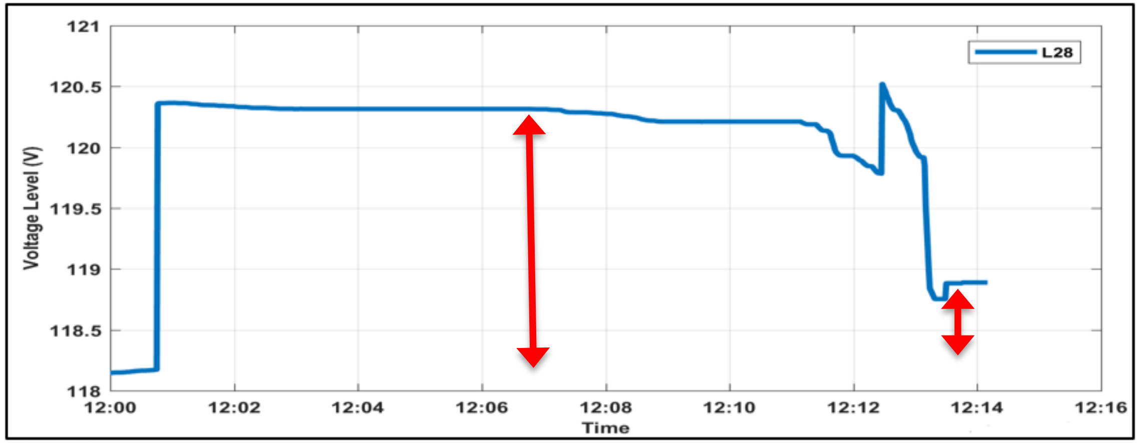
Power Flow Step Change versus One Second, Time Series Analysis



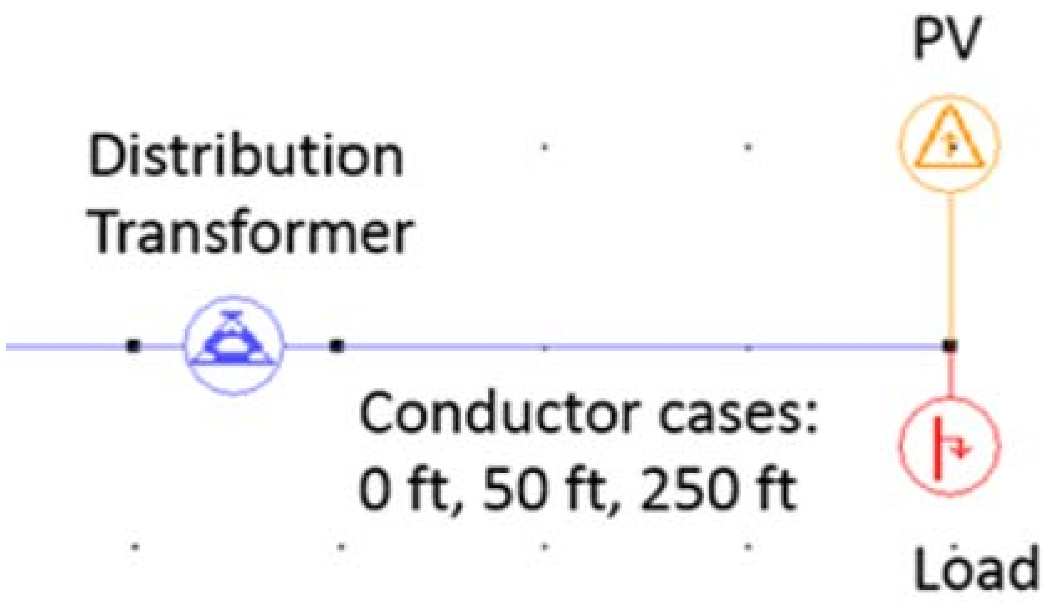
1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 Step Change

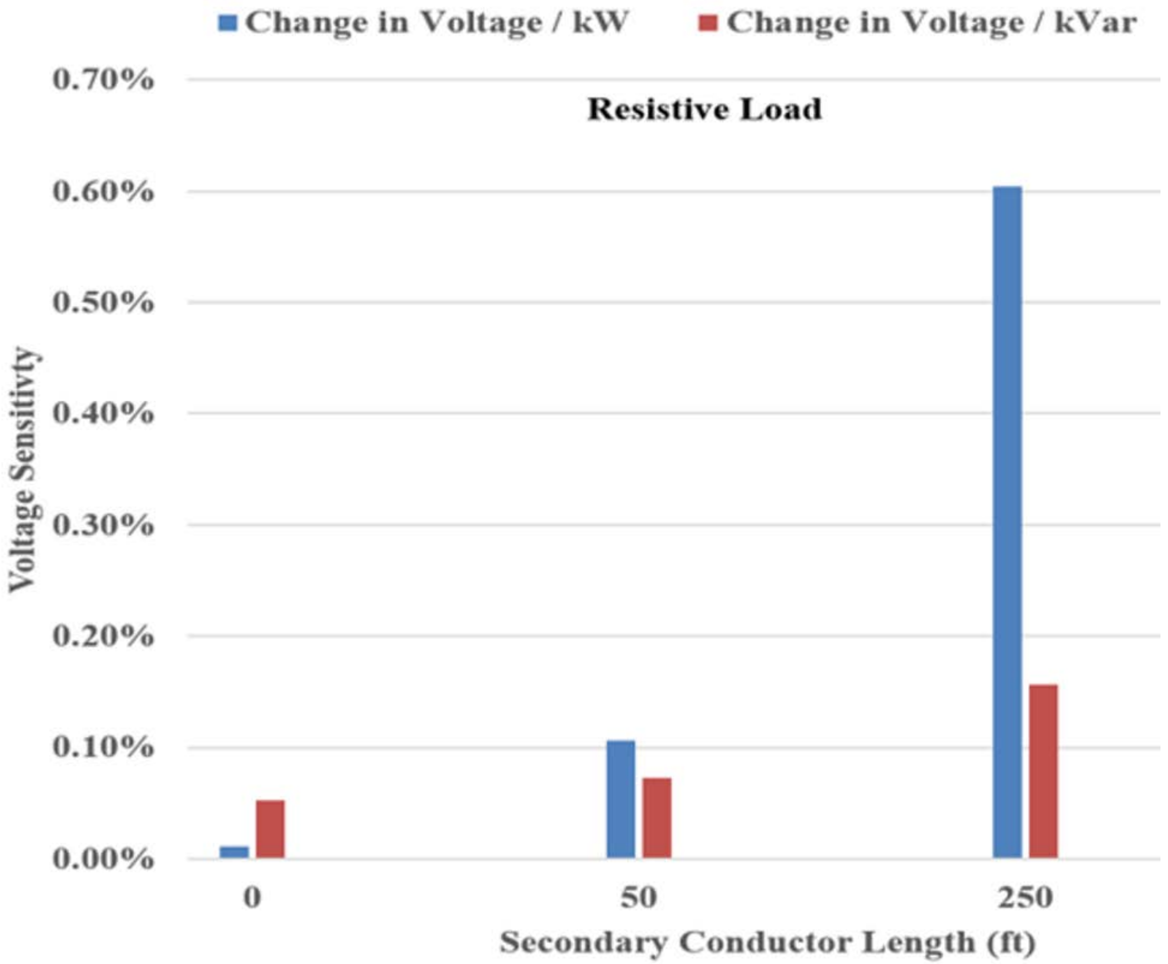
1, 10, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34 Time Series

1, 10, 12 Common



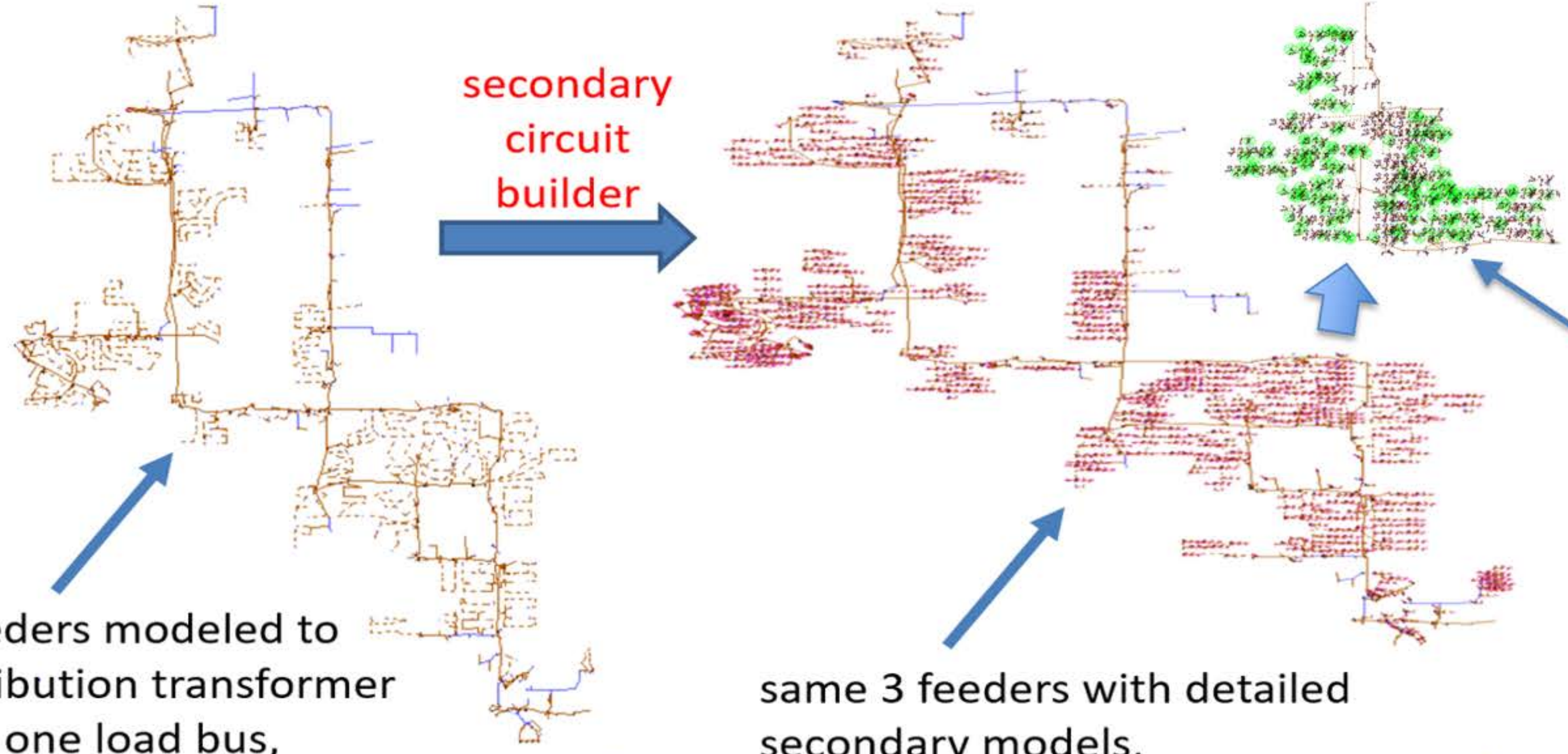
Simplified Versus Detailed Secondary Circuit Models





Reference: "Investigating PV Generation Induced Voltage Volatility for Customers Sharing a Distribution Service Transformer," … IEEE Transactions on Industry Applications, Vol. 53, No. 1, pp. 71-79, Jan./Feb. 2017.

Modeling Secondary Circuits: Model Size

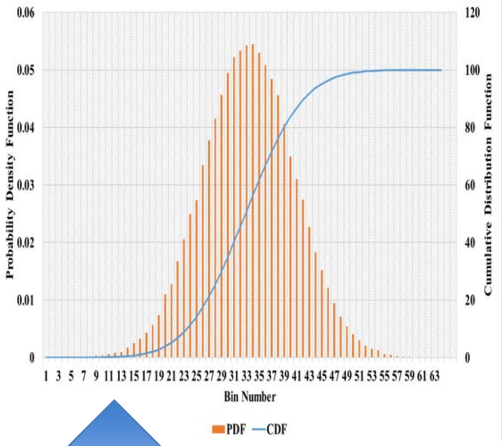


3 feeders modeled to distribution transformer with one load bus, ~3500 components, 633 load busses, 74 PV

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

high pen PV, with PV represented by green symbols on secondary load busses

IEEE 1453-2015 Standard and One Second Time Series Power Flow



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

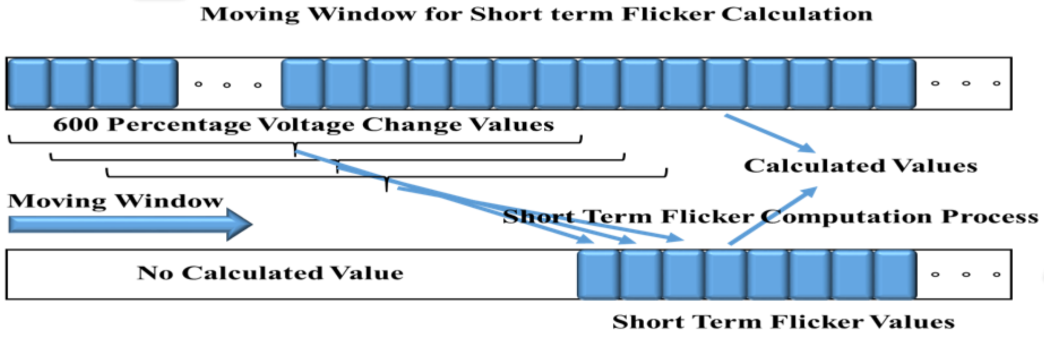
Smoothed values

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

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

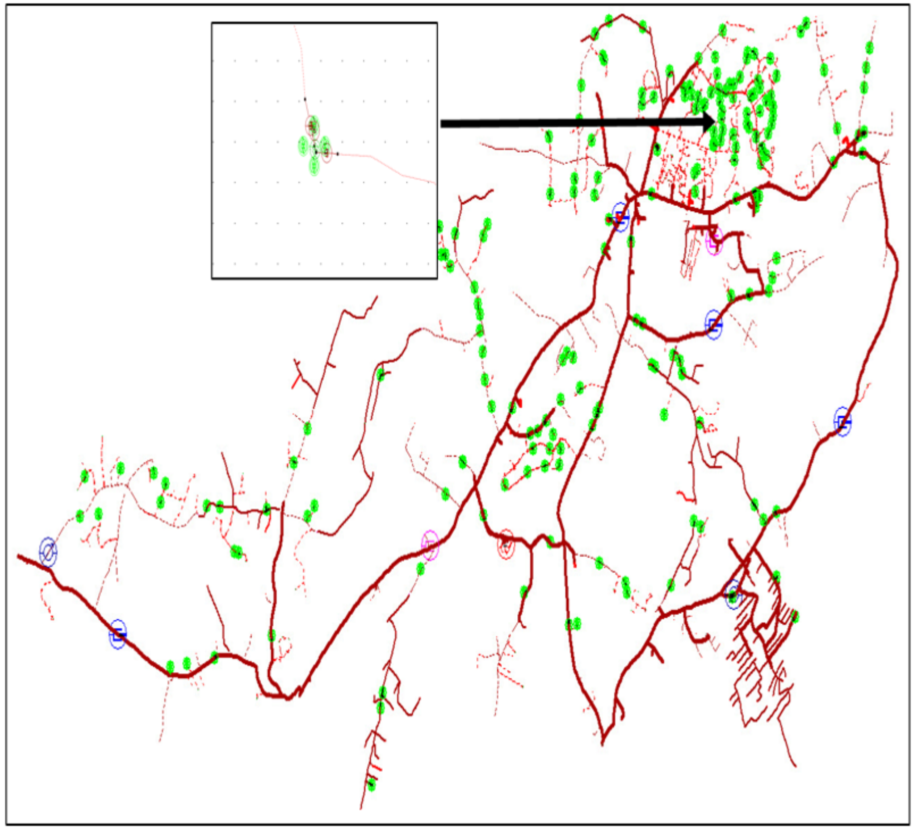
$$P_{10s} = \frac{P_6 + P_8 + P_{10} + P_{14} + P_{17}}{5}$$

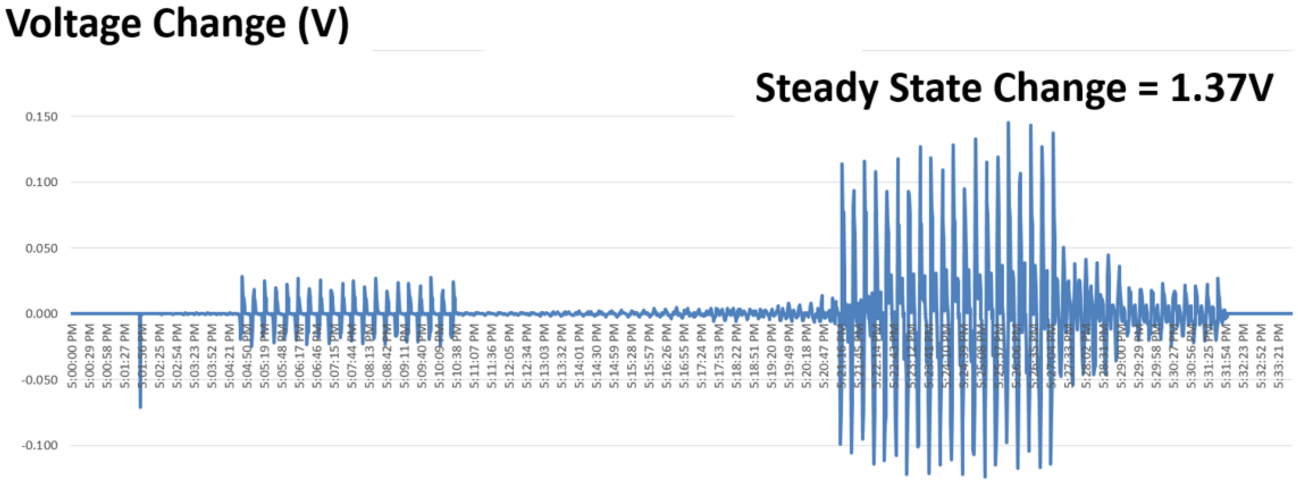
$$P_{50s} = \frac{P_{30} + P_{50} + P_{80}}{3}$$

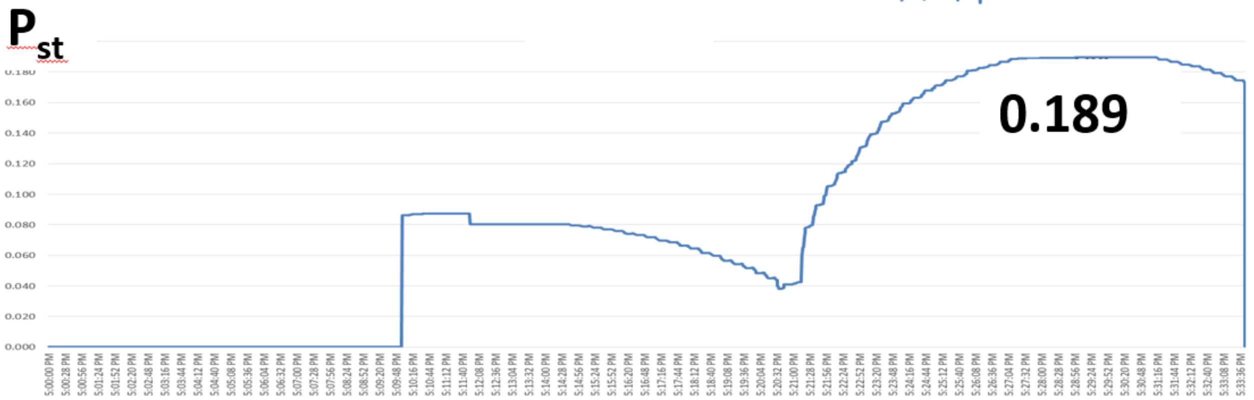


Flicker severity level	Compatibility Limits - LV	Planning—MV	Planning—HV and EHV
Pst [10-min]	1.0	0.9	0.8

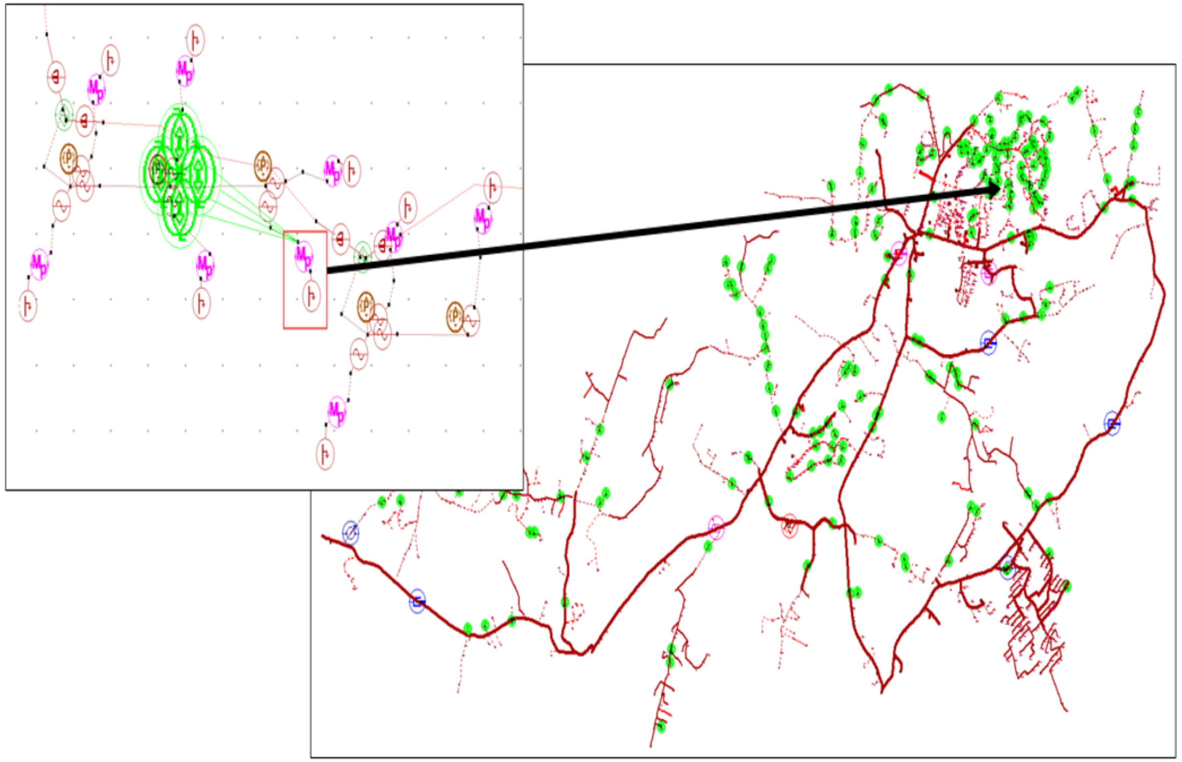
Analysis with Simple Secondary Model





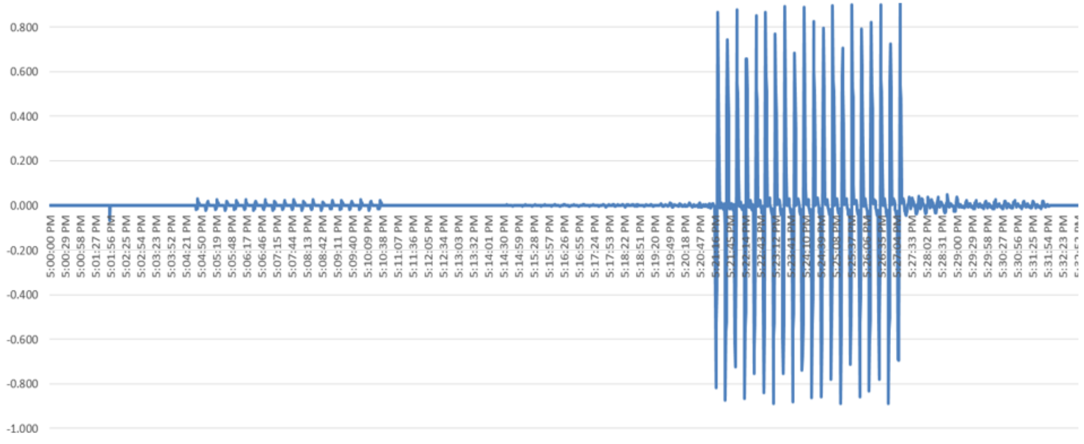


Analysis with Detailed Secondary Model



Voltage Change (V)

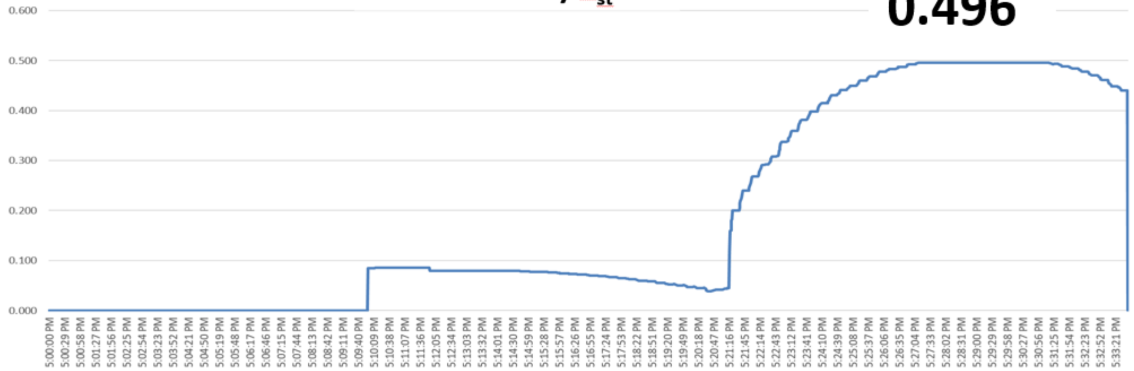
Steady State Change = 4.28 V



P_{st}

Flicker Severity P_{st}

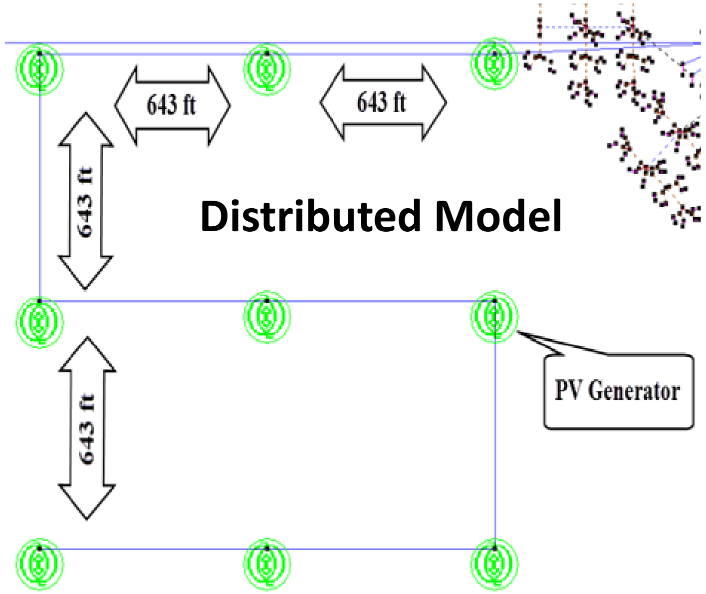
0.496

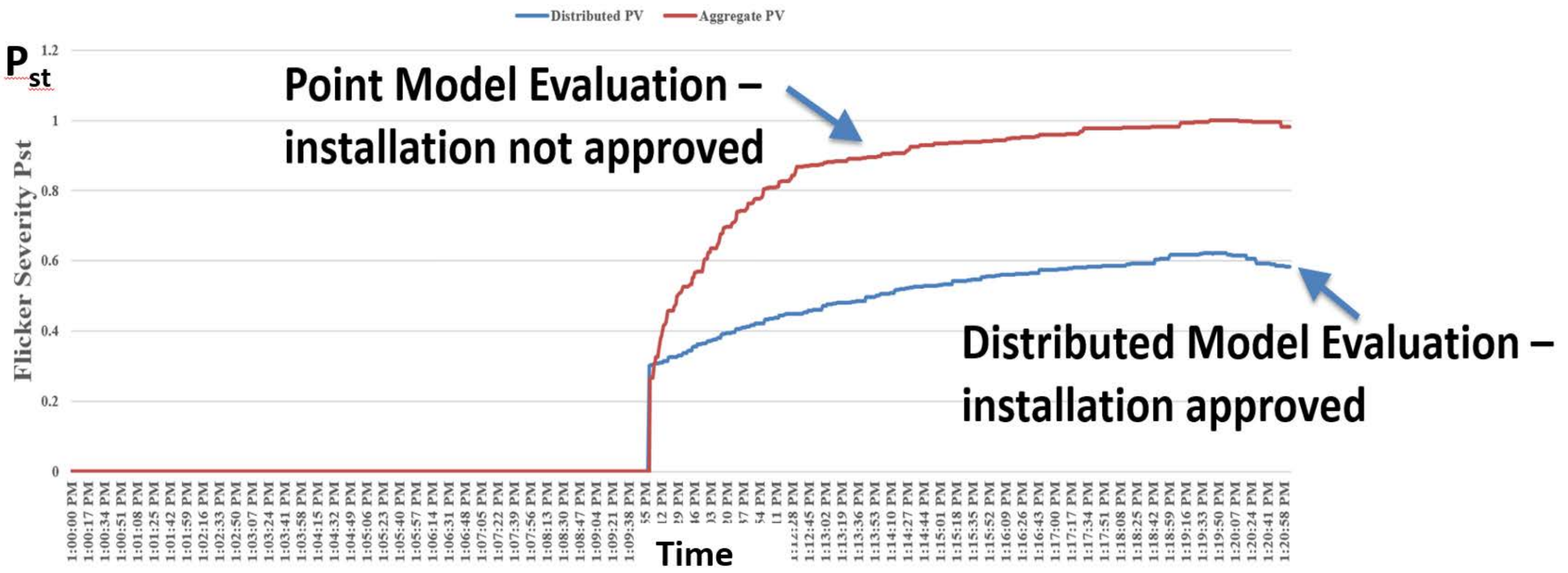


Geographically Distributed PV
Point Model versus Distributed Model

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

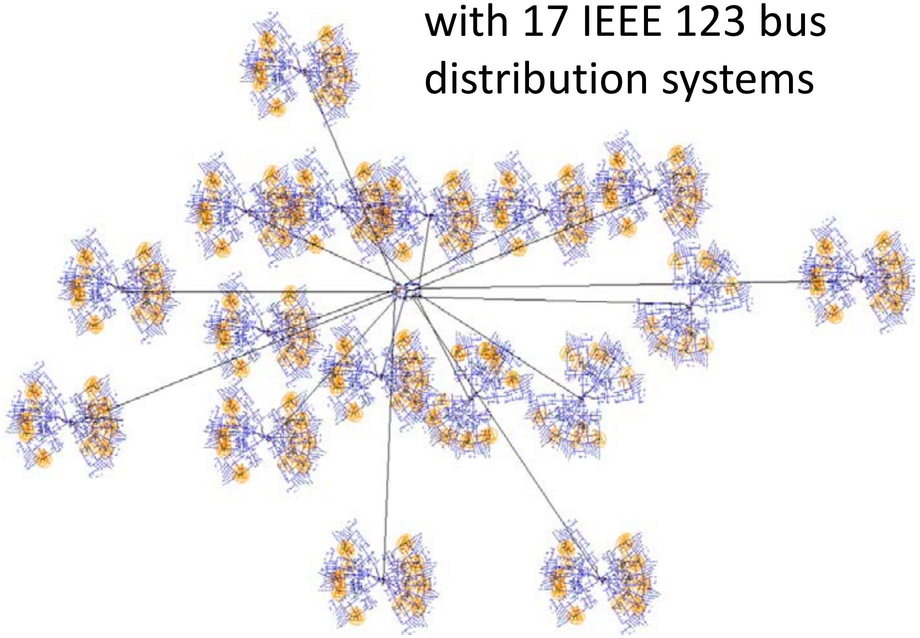


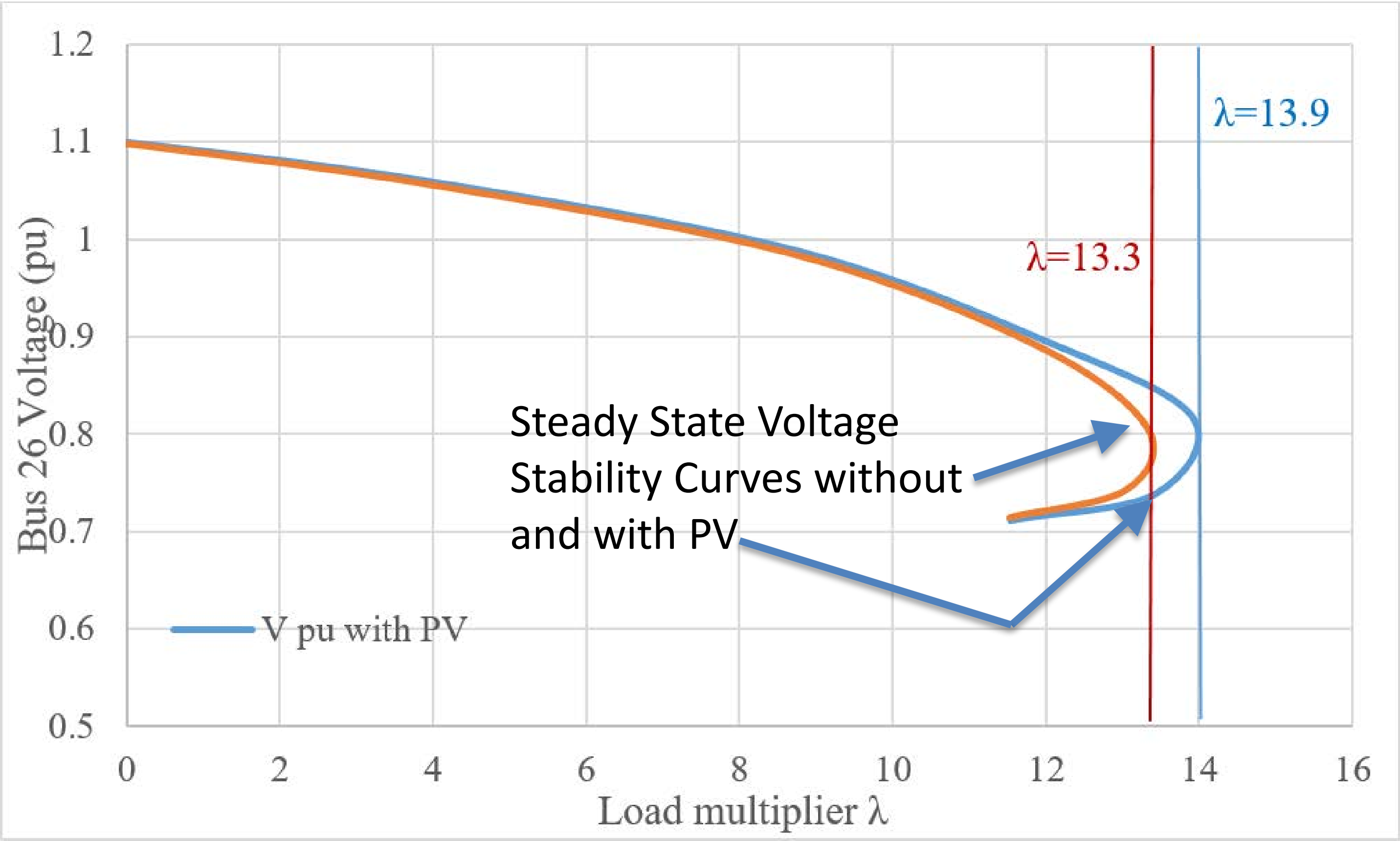


Steady-State Voltage Stability Calculation and PVs

331 PVs representing 680 MWs in distribution
20 MW synchronous generation in transmission
129 MW flow from distribution to transmission
15% transmission flow imbalance

IEEE 39 bus transmission with 17 IEEE 123 bus distribution systems





Summary: Accurate PV Analysis

- Modeling causes of generation variations
  - Cloud statistics
  - Wind statistics
- Modeling characteristics of secondary circuits
- Modeling geographically distributed PVs
- Time series, power flow analysis
- Enables analysis for IEEE 1453-2015
- Analysis of combined TS&D is important