OpenDSS Training Workshop

Advanced Topics

Jeremiah Deboever, Andres Ovalle
EPRI Knoxville, TN

August 27, 2020

ELECTRIC POWER RESEARCH INSTITUTE

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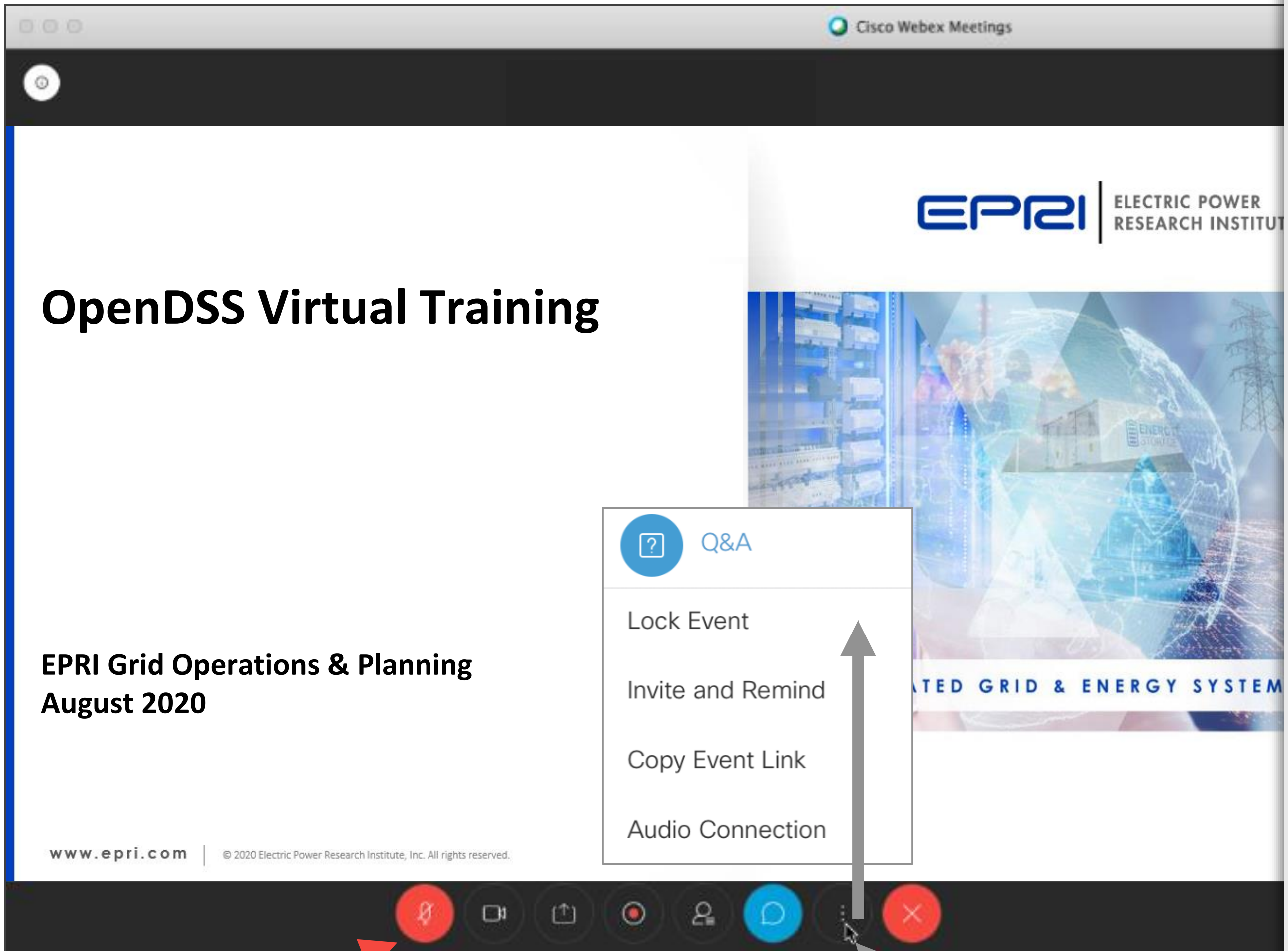


Red Means Muted

Polling, Q&A

Meeting Logistics

- **Audio Options:**
  1. Connect via computer audio
  2. Call local dial number and use participant code
- **You are Muted on Entry**
  - **Use Q&A to ask panelist questions**
- **Q&A window**
  - Panelist will either answer in the Q&A, or
  - Panelist will voice the question
- **We are Recording**
- **Polling window**
  - Polling questions will be active throughout

OpenDSS Virtual Training 2020

Date	Time (NY time)	Session Topic
August 24	11:30 am – 12:00 pm	Distribution System Basics
	12:00 pm – 12:30 pm	Intro to OpenDSS
	12:30 pm – 1:00 pm	OpenDSS Basics and Scripting
August 25	11:30 am – 12:00 pm	Intro to OpenDSS-G
	12:00 pm – 12:30 pm	APIs, COM interface, etc.
August 26	11:30 am – 12:30 pm	PVSystem, InvControl, Storage, Storagecontroller
August 27	11:30 am – 12:30 pm	Advanced Topics
	12:30 pm – 1:00 pm	Applying OpenDSS in R&D

Instructors

▪ Jeremiah Deboever, PhD

Jeremiah is a Research/Scientist II with EPRI in Palo Alto, California USA. He holds a PhD in Electrical Engineering from Georgia Institute of Technology, Atlanta GA, a MS in Renewable Energy Engineering from Oregon Institute of Technology, Wilsonville OR, and a BS in Mechanical Engineering from Binghamton University, Binghamton NY. Jeremiah has worked on different projects around distribution system modeling and simulation with a focus on DER integration studies, hosting capacity analysis, DERMS modeling, distribution load modeling, and quasi-static time-series simulation. He has published over 20 publications on electric distribution modeling/simulation and won a best poster award at the World Conference on Photovoltaic Energy Conversion in 2018.

▪ Andres Ovalle, PhD

Andres Ovalle is an Engineer/Scientist II in the Power System Studies team at the Electric Power Research Institute (EPRI). His current research activities focus on modeling of power systems, system protection in distribution and transmission, and impacts geomagnetic disturbance related harmonics on power systems. Mr. Ovalle joined EPRI in 2018. Prior to joining EPRI, Mr. Ovalle was with the French National Railways Company (SNCF) and the Grenoble Electrical Engineering Laboratory (G2E-lab) for approximately 2 years where he worked as a postdoctoral research engineer in the use of energy storage for the support of electrified railways. Mr. Ovalle received the B.S.E.E. degree from the Universidad de Los Andes, Bogota, Colombia, in 2011, the M.E.E. degree from the Universidad de Los Andes in 2013, and the Ph.D. in Electrical Engineering from the Université de Grenoble Alpes, Grenoble, France, in 2016.

Advanced Topics

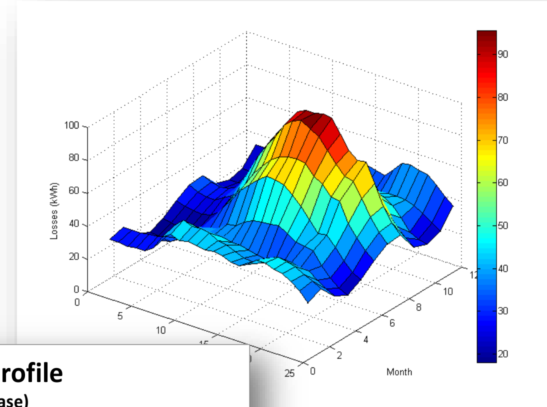
Outline for today's session

- Advanced topics:
  - Quasi-Static Time-Series (QSTS) simulation
  - OpenDSS parallel processing capabilities
  - Recloser placement
  - GIC related harmonic capabilities (GICharm)

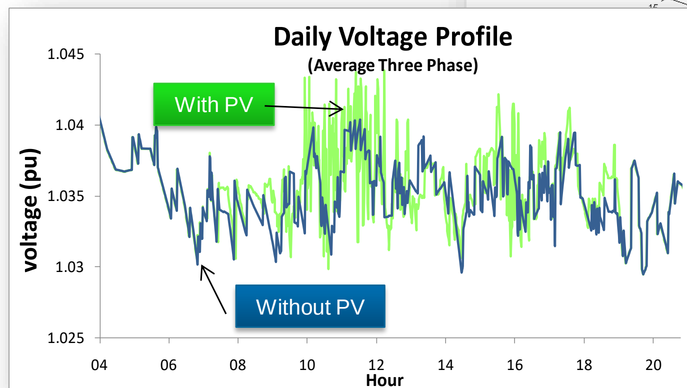
- OpenDSS in R&D:
  - Available tools
  - Available models and datasets
  - DER integration studies
  - Hosting capacity analysis
  - Other examples of OpenDSS

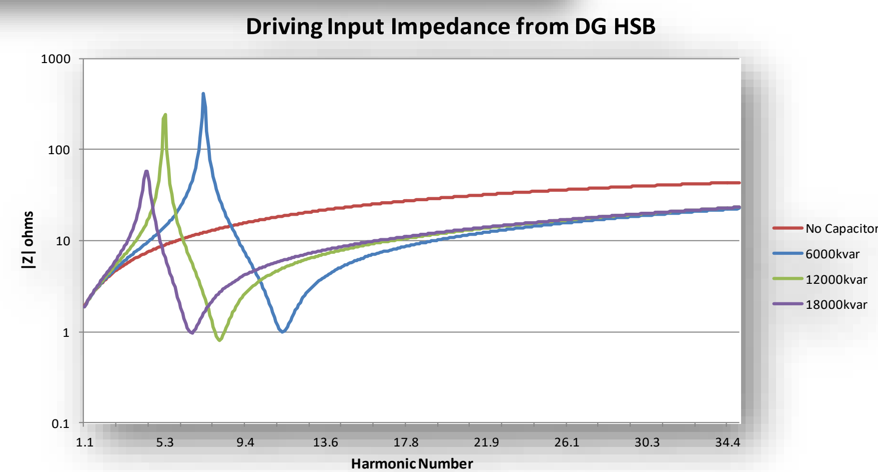
Flexible Tool Enabling a Wide Range of Analysis Types

- DER Interconnection studies
- Locational value studies
- Hosting capacity studies
- DA/FLISR scheme evaluation
- VVO (w/ DER)
- Energy impact analysis
- DER protection impacts
- Power quality (harmonics/flicker)
- Long-range planning studies
- Smart inverter control optimization



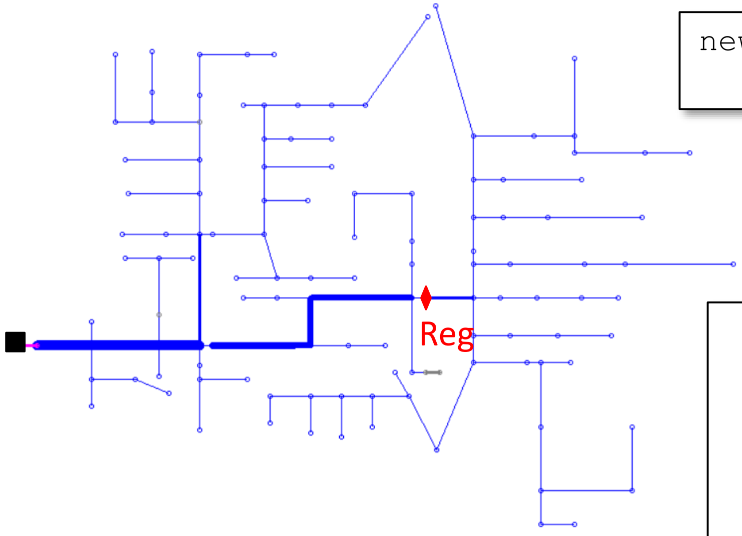
Mid-Feeder





Quasi-Static Time-Series (QSTS) simulation

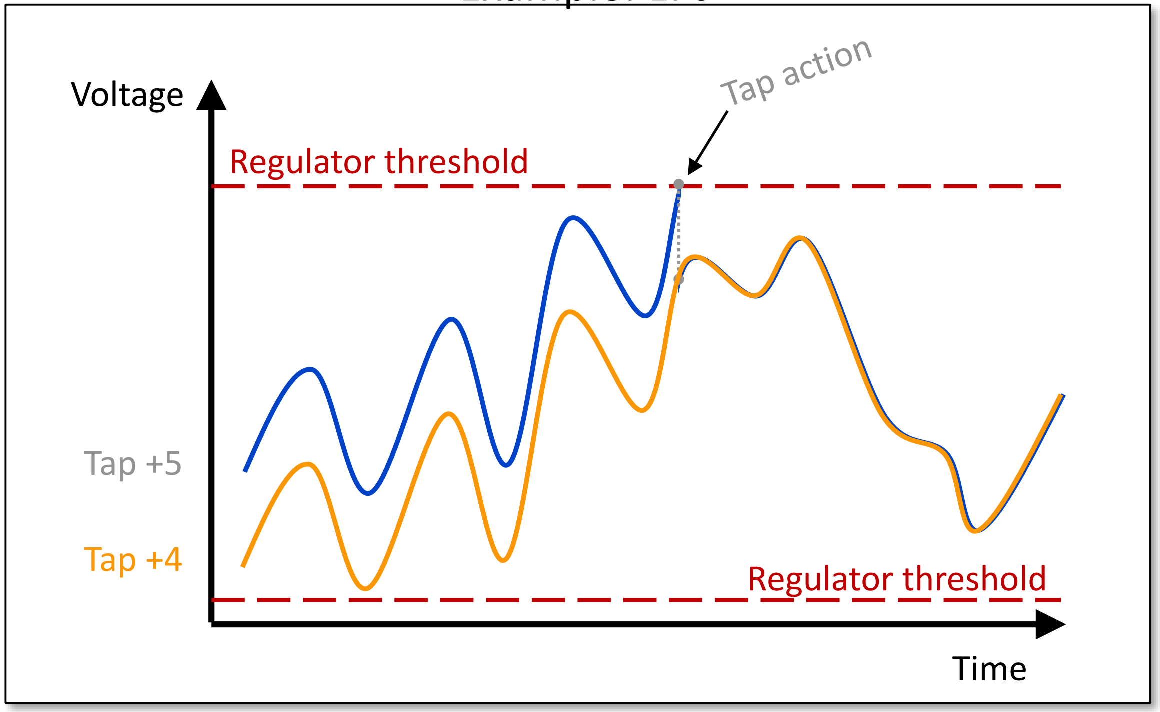
- The operation of discrete controls from autonomous controllers can be modeled with a QSTS simulation.



IEEE 123 bus feeder

```
new regcontrol.creg4a transformer=reg4a winding=2
     vreg=124  band=2  ptratio=20 ctprim=300 R=0.6 X=1.3
```

Example: LTC



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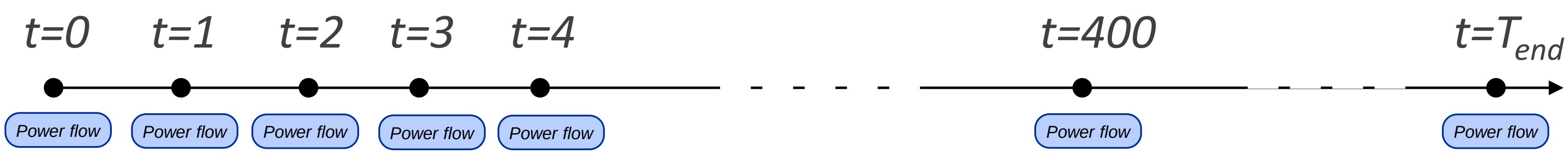
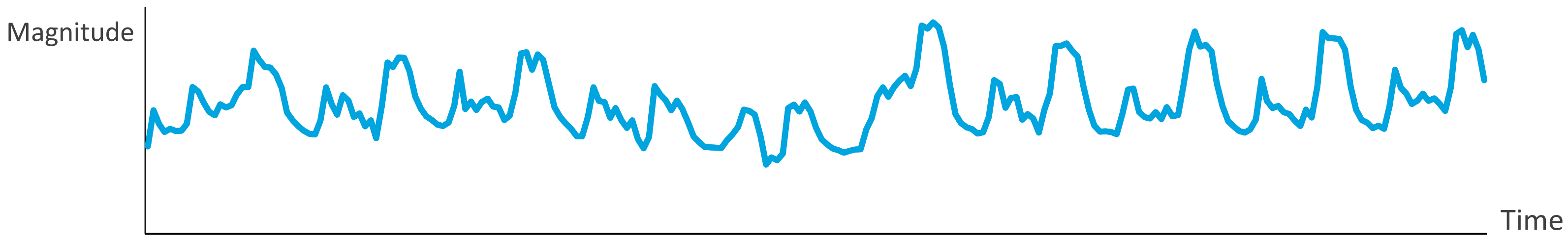
QSTS Applications

The IEEE Std[1] defines a Quasi-Static Time-Series simulation as:

Quasi-static time-series (QSTS) simulation *– "Quasi-static simulation refers to a sequence of steady-state power flow, conducted at a time step of no less than 1 second but that can use a time step of up to one hour. Discrete controls, such as capacitor switch controllers, transformer tap changers, automatic switches, and relays, may change their state from one step to the next. However, there is no numerical integration of differential equations between time steps."* [IEEE Std 1547.7-2013]



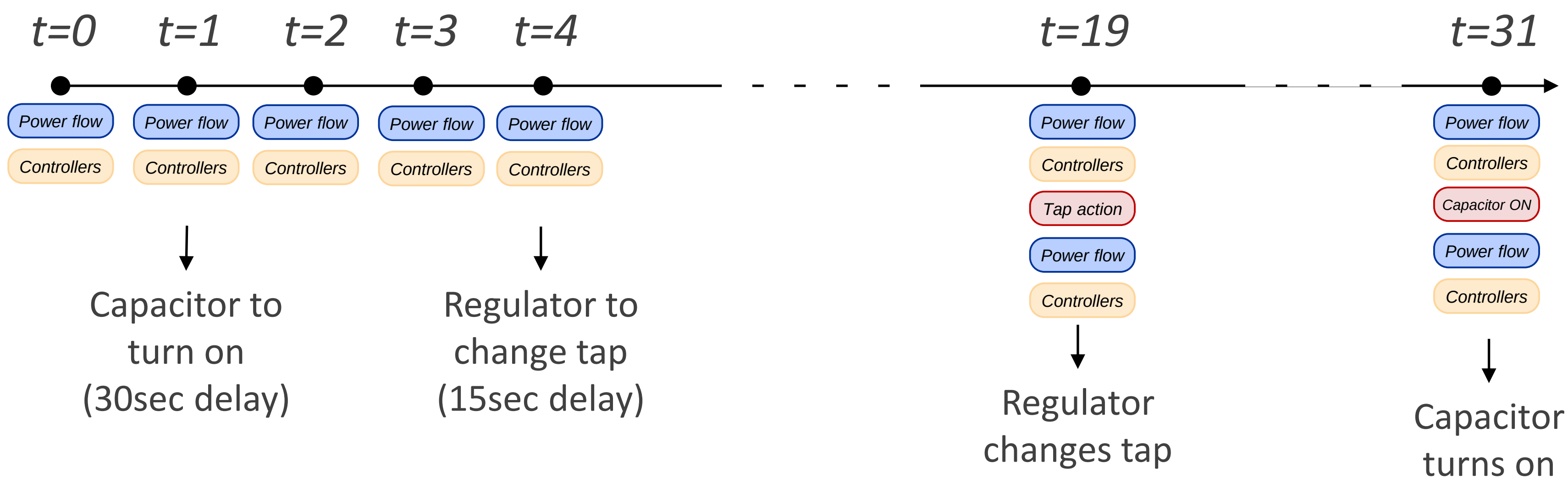


[1] IEEE Std 1547.7-2013. '*IEEE Guide for Conducting Distribution Impact Studies for Distributed Resource Interconnection*'. *2016.*

Dealing with multiple controllers: Control queue

What if there are a line regulator and a capacitor banks?

Which one is the first one to act?



Timestamp	Action to take
t = 31	Capacitor to turn on
-	-
-	-
-	-
-	-
-	-

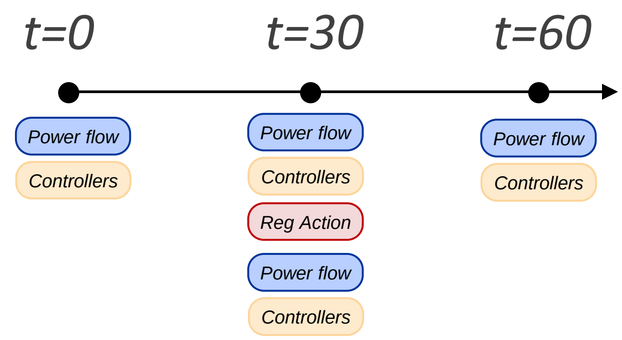
Timestamp	Action to take
t = 19	Regulator to change tap +1
t = 31	Capacitor to turn on
-	-
-	-
-	-

Timestamp	Action to take
~~t = 19~~	~~Regulator to change tap +1~~
t = 31	Capacitor to turn on
-	-
-	-
-	-

OpenDSS QSTS simulation

- `Set Controlmode={OFF | STATIC |EVENT | TIME}`
  – STATIC: time does not advance, and control actions are executed in order of shortest time to action until all actions are cleared from the queue.
  – EVENT: Time is advanced automatically to the time of the event.
  – TIME: Similar to the last slide, the control actions are driven by time.

- A control action in the queue will be removed if the control signal comes back within the controller limits and the timestamp isn't reach.



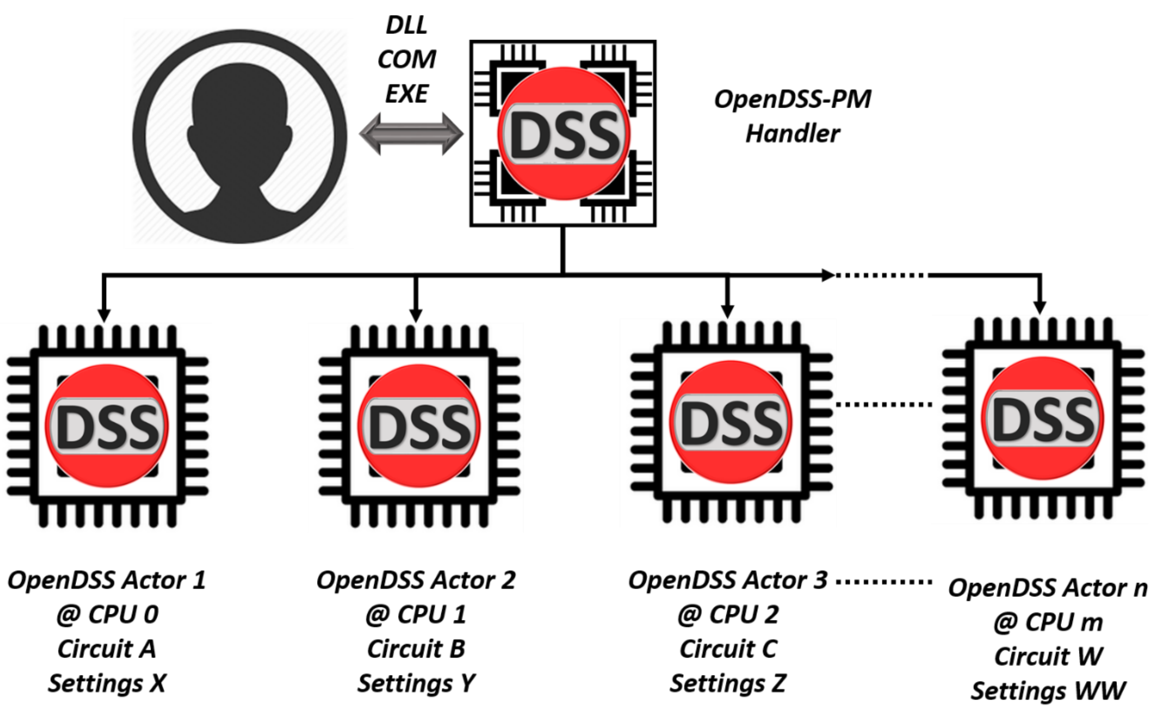
Control queue

Timestamp	Action to take
t = 15	Regulator to change tap +1
t = 30	Capacitor to turn on
-	-
-	-
-	-
-	-
-	-

- OpenDSS command lines:
  – '`Show controlled`' will show controlled equipment.
  – '`Show controlqueue`' will show the current control queue.
  – '`Show eventlog`' will show the past controller actions.

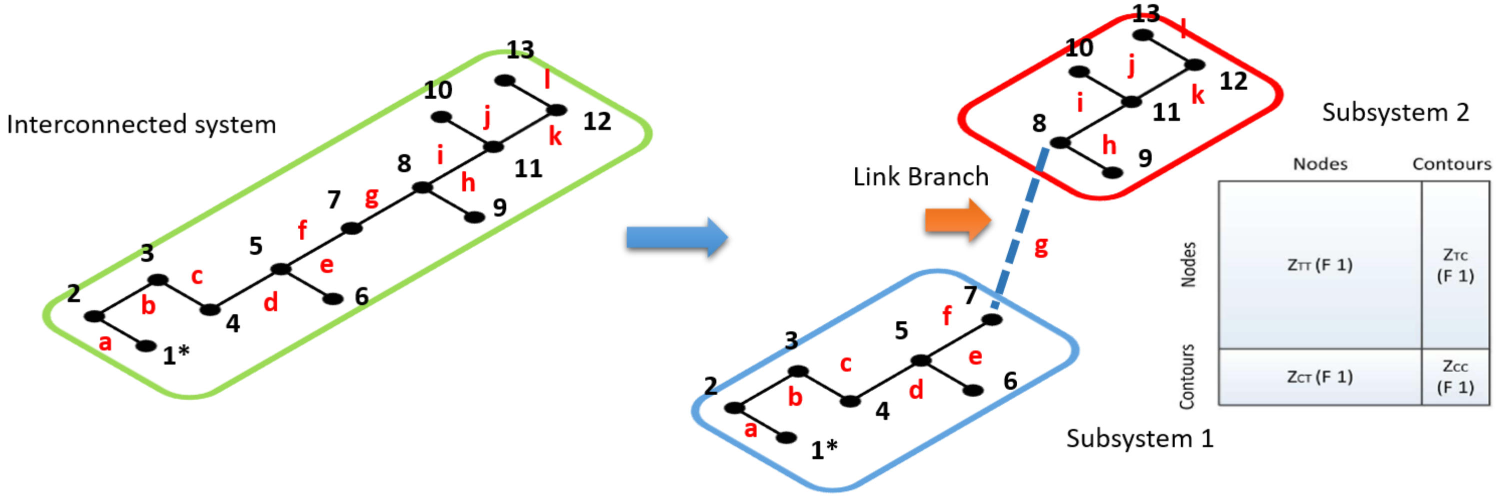
Parallel computing in OpenDSS

- To further increase the computational speed on large feeder models, a parallel processing is used with OpenDSS **using the actor model**.
- Each actor is created by OpenDSS, runs on a separate processor using separate threads and has its own assigned core and priority (real-time priority for the process and time critical for the thread)

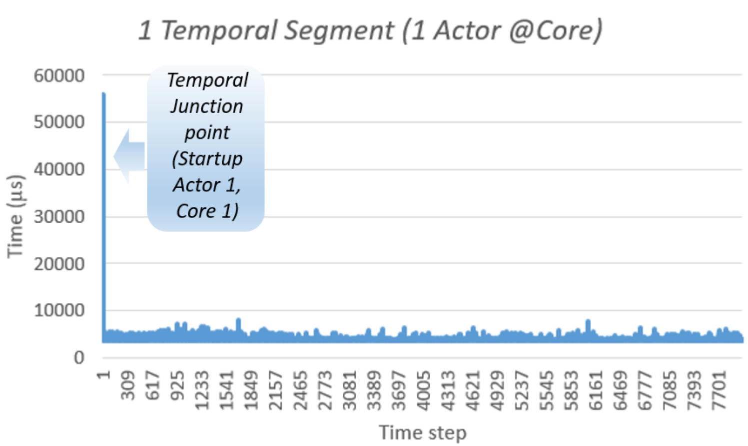


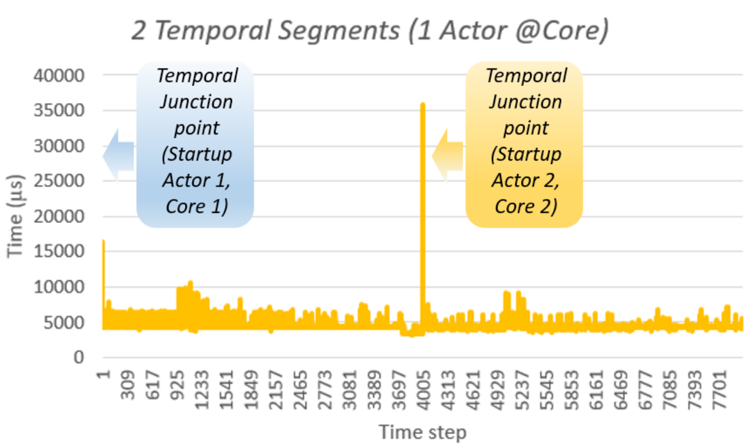
What can be done with parallel processing in OpenDSS?

Spatial Parallelization

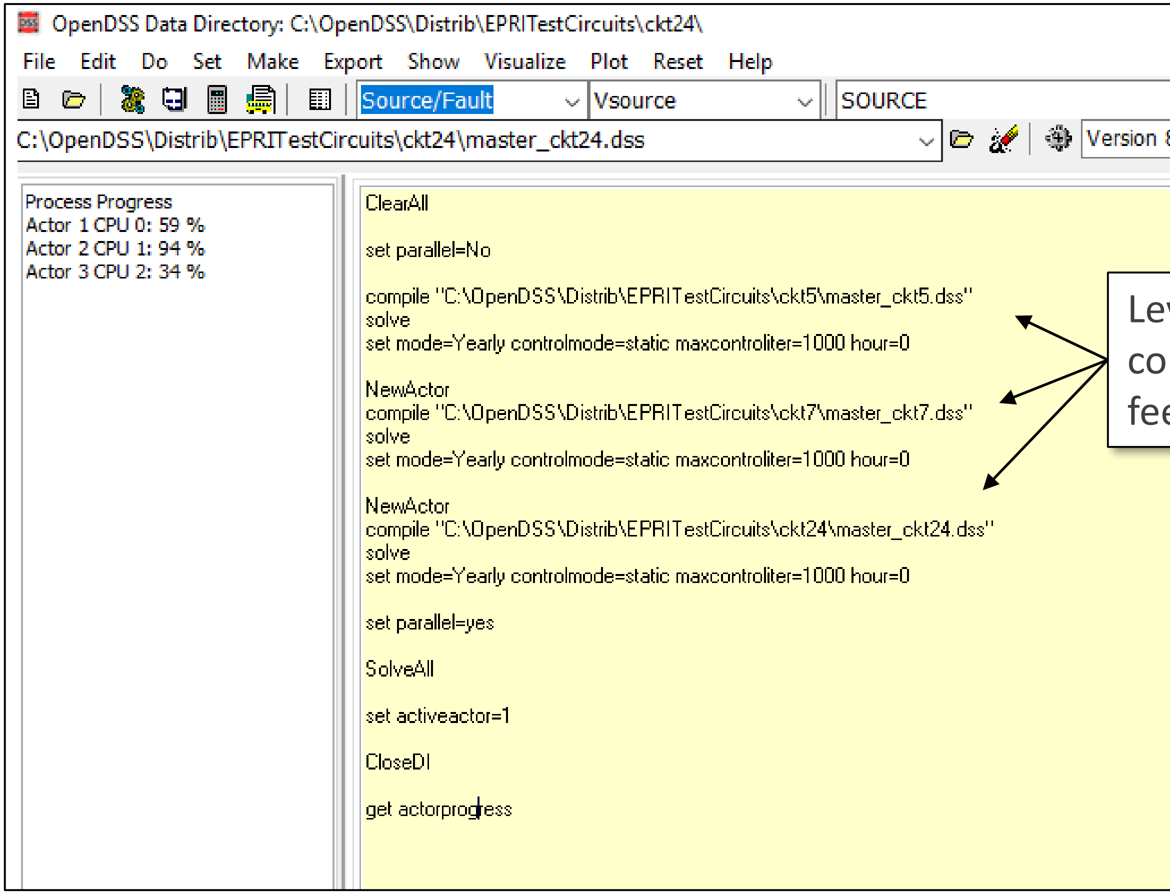


Temporal Parallelization





Using parallel processing in OpenDSS



Leveraging parallel processing to concurrently analyzing 3 different feeder models.

The examples for parallel processing (MATLAB and python) can be downloaded from: https://sourceforge.net/p/electricdss/code/HEAD/tree/trunk/Version8/Distrib/Examples/Parallel_Processing/

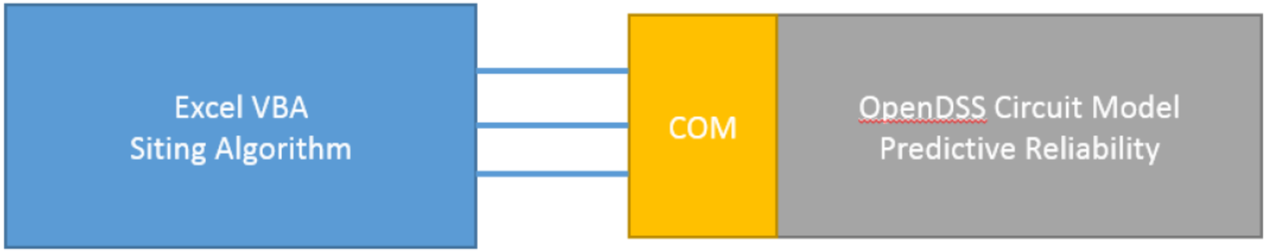
Other examples for LabVIEW are available through the VI Package Manager.

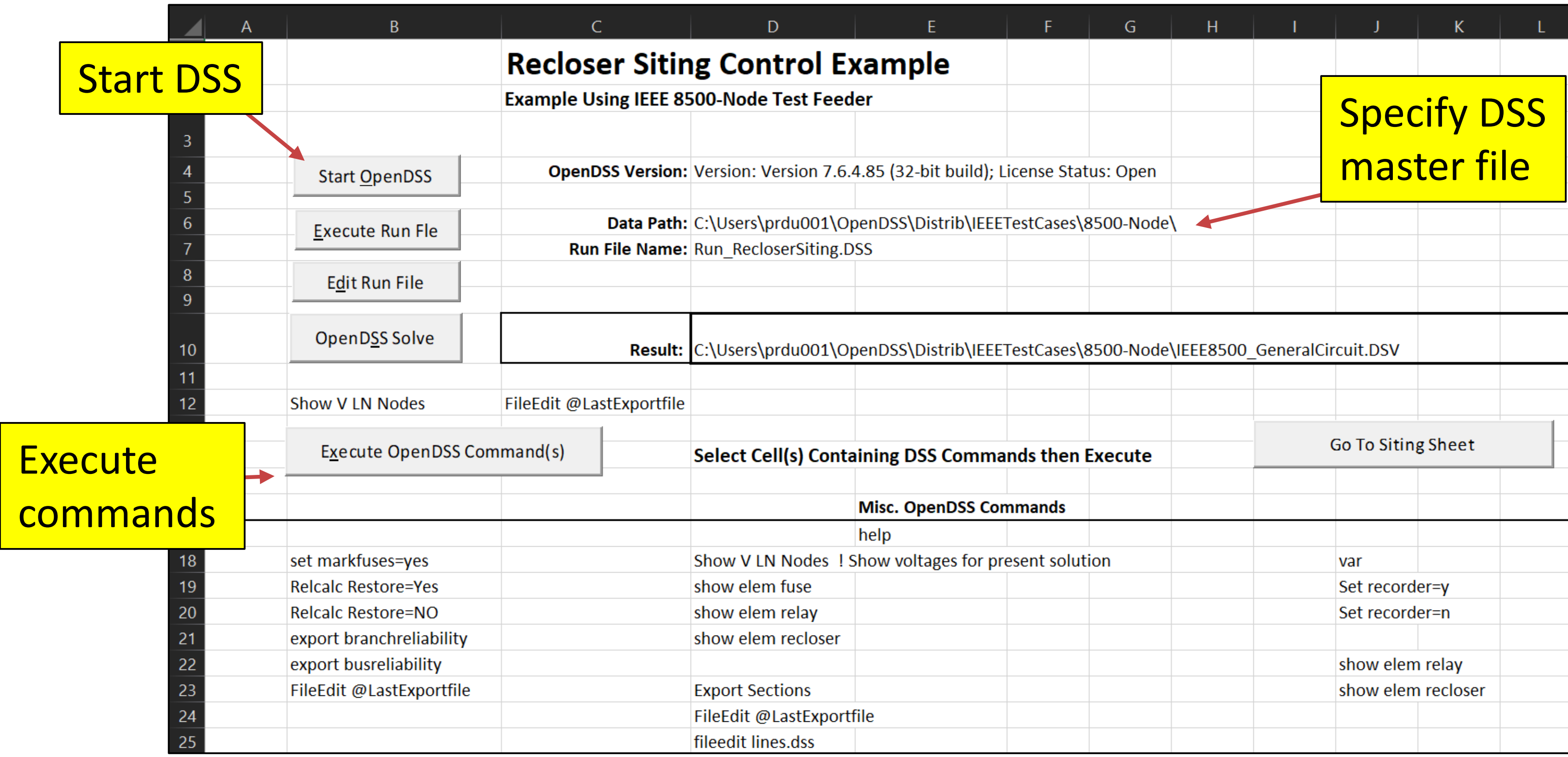
The evolution of OpenDSS into a parallel computing machine

There is a new set of functions and instructions related with parallel processing, topology analysis and more that can be used using the same DSS command environment

NumCPUs	ClearAll	Tear_Circuit
NumCores	Wait	Export IncMatrix
NewActor	Parallel	Export IncMatrixRows
NumActors	SolveAll	Export IncMatrixCols
ActiveActor	ConcatenateReports	Export BusLevels
CPU	CalcIncMatrix	Init_Diakoptics
ActorProgress	CalcIncMatrix_o	Refine_BusLevels
Abort	CalcLaplacian	Export Laplacian

Recloser Siting Control Example

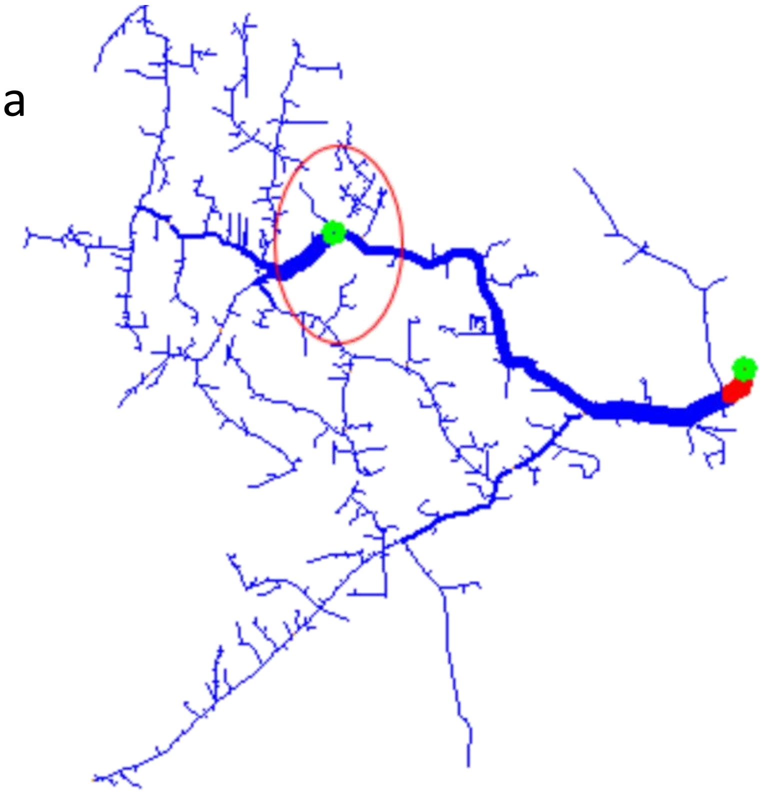


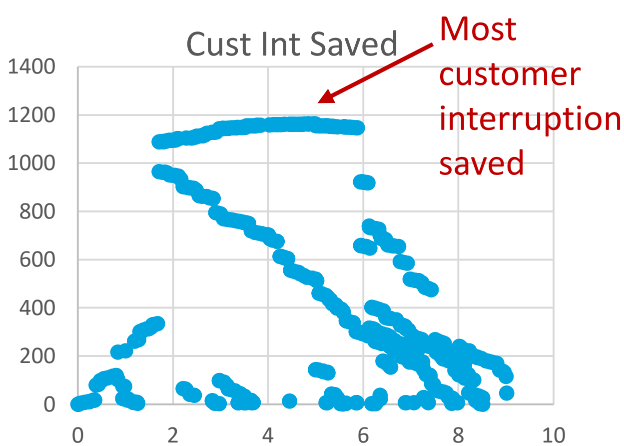


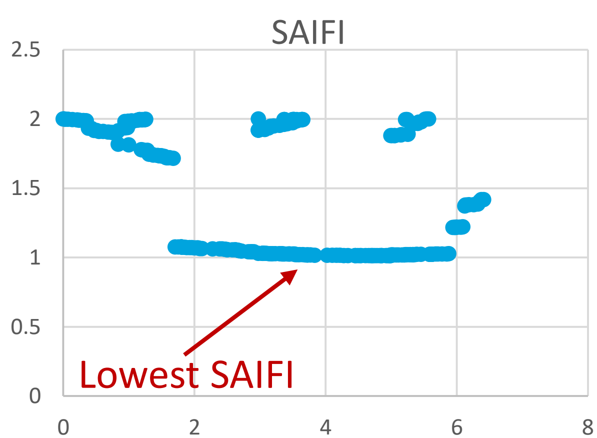
<u>Example</u>: "C:\Program Files\OpenDSS\Examples\Excel\Recloser-Siting-Control.xlsm"

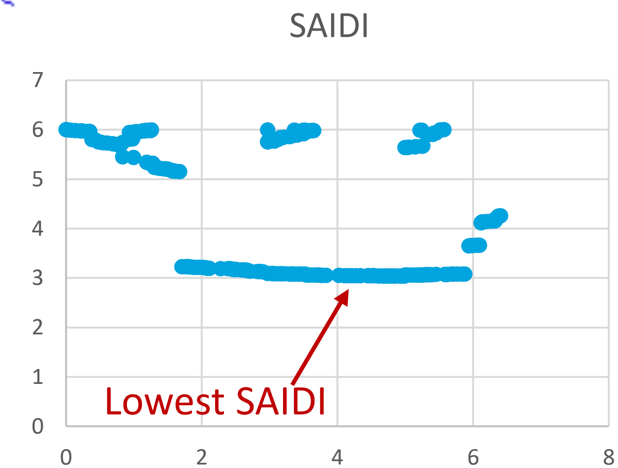
Recloser Siting Control Example

- The <u>objective</u> of the algorithm is to determine a location to reduce the highest number of customer interruption.
- <u>Input</u> data for each element:
  - Line object: faultrate, length, repair
  - Loads: NumCust
  - Location of existing automated switches
- <u>Output</u> of the analysis:
  - Suggested location of new device and resulting SAIFI / SAIDI metrics





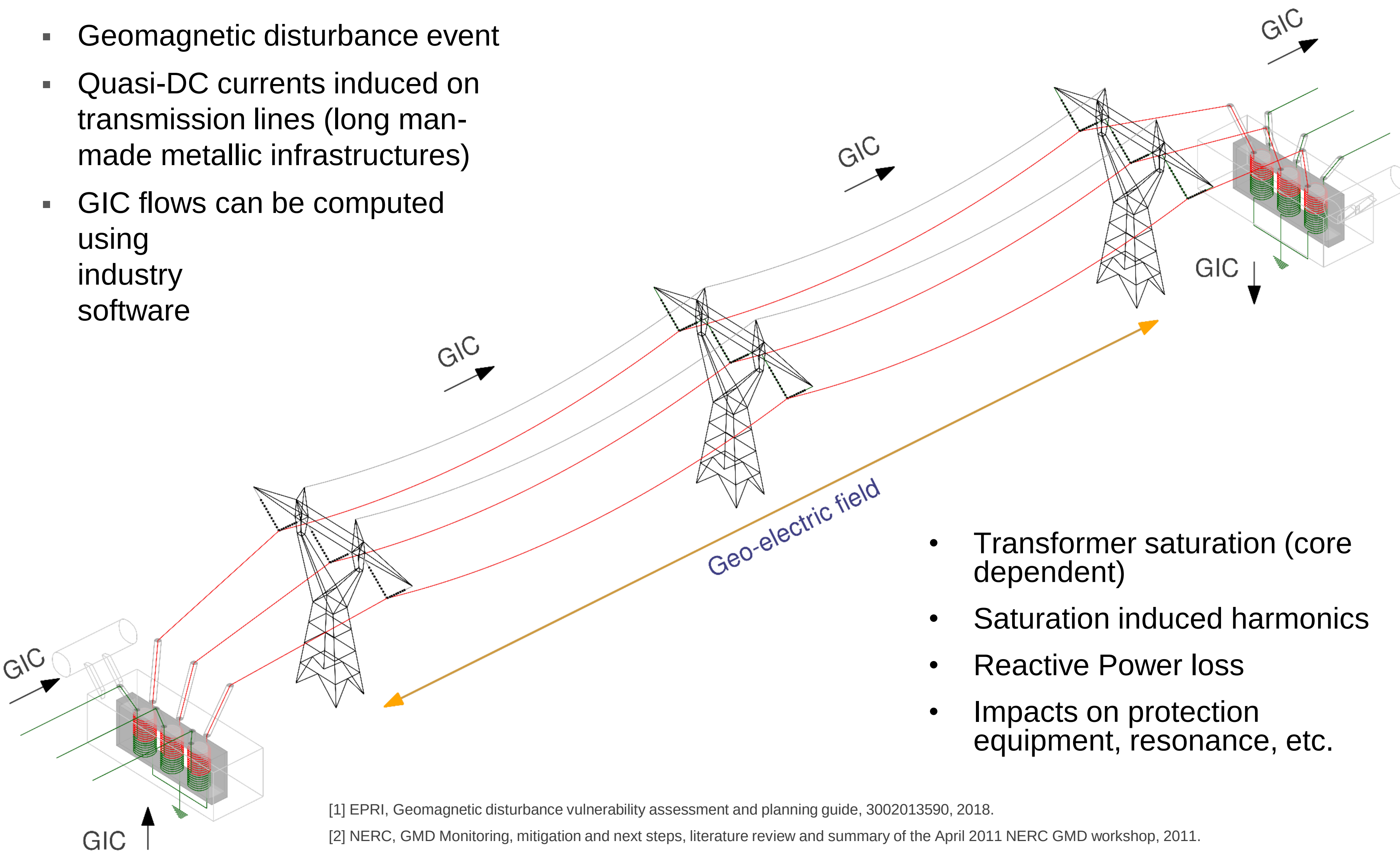




What is GIC?

(Geomagnetically Induced Currents)

- Geomagnetic disturbance event
- Quasi-DC currents induced on transmission lines (long man-made metallic infrastructures)
- GIC flows can be computed using industry software



- Transformer saturation (core dependent)
- Saturation induced harmonics
- Reactive Power loss
- Impacts on protection equipment, resonance, etc.

[1] EPRI, Geomagnetic disturbance vulnerability assessment and planning guide, 3002013590, 2018.

[2] NERC, GMD Monitoring, mitigation and next steps, literature review and summary of the April 2011 NERC GMD workshop, 2011.

[3] IEEE Guide for Establishing Power Transformer Capability while under Geomagnetic Disturbances," in IEEE Std C57.163-2015 , vol., no., pp.1-50, 26 Oct. 2015

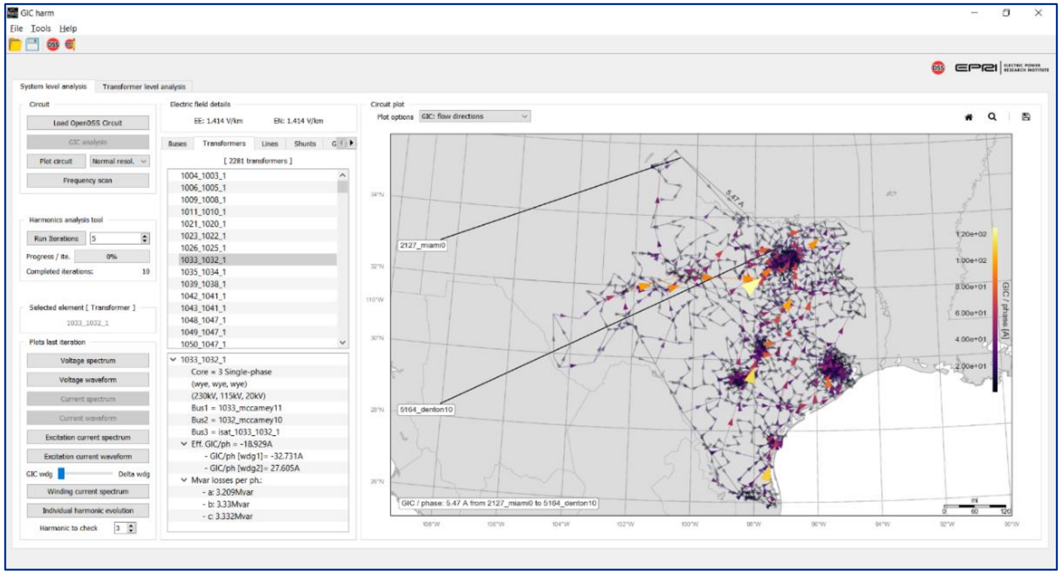
EPRI GICharm v1.0

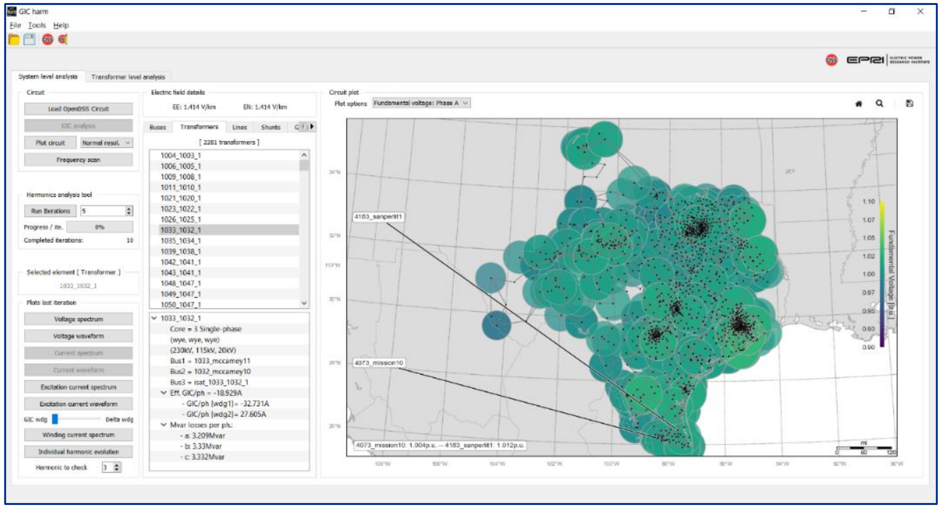
- Software tool to assess the impact of Geomagnetically Induced Currents (GIC) related harmonics
- Beta version available to the public
- Will be released as an Open source software
- Capable of extensive system modeling
- Capable of accurate representation of saturated transformers
- Works with the EPRI OpenDSS simulation software engine
- Accepts system model information from PSS®E vendor software

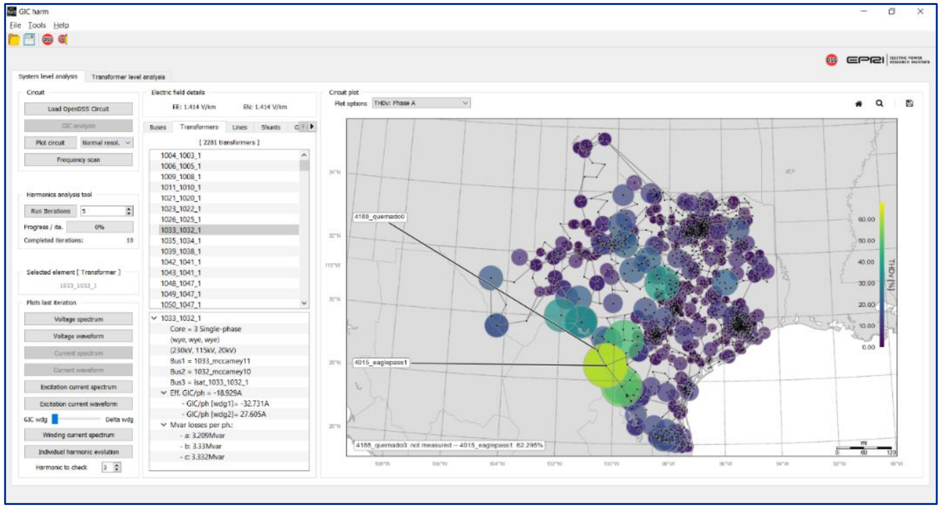
Available on epri.com Product ID# 3002014854

System level Analysis – Explore simulation results

- GUI includes circuit plot capabilities to overlay GIC flows, voltage THD and fundamental voltage data over the circuit footprint







A. B. Birchfield, T. Xu, and T. J. Overbye, "Power flow convergence and reactive power planning in the creation of large synthetic grids," in IEEE Transactions on Power Systems, 2018.

Applying OpenDSS in R&D

Outline

Available tools:

- OpenDSS
- OpenDSS-G
- Excel VBA
- MATLAB toolbox
- Python toolbox

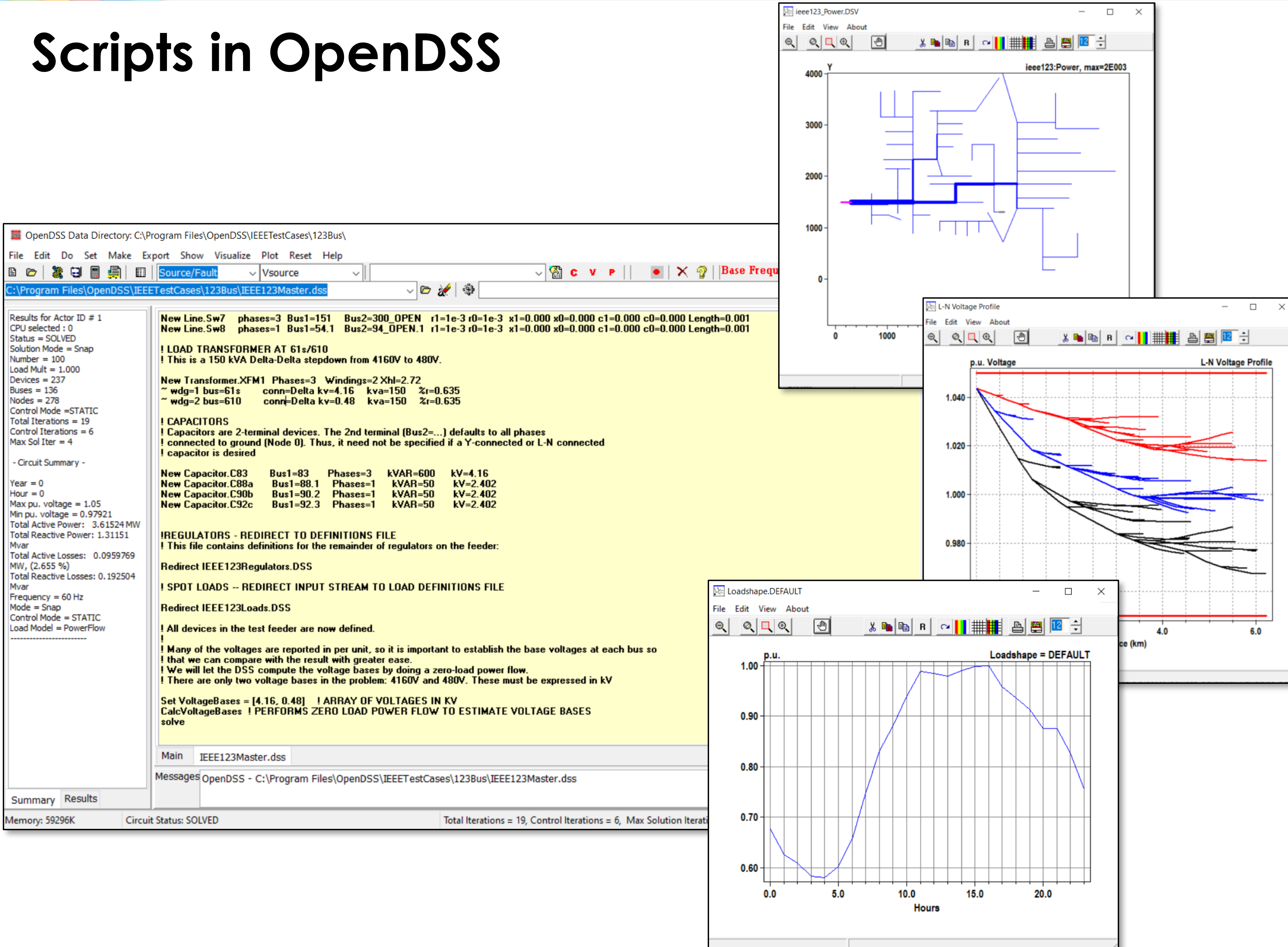
Available feeder models:

- IEEE models
- EPRI models

Available datasets:

- Load / PV profiles
- 3rd party datasets

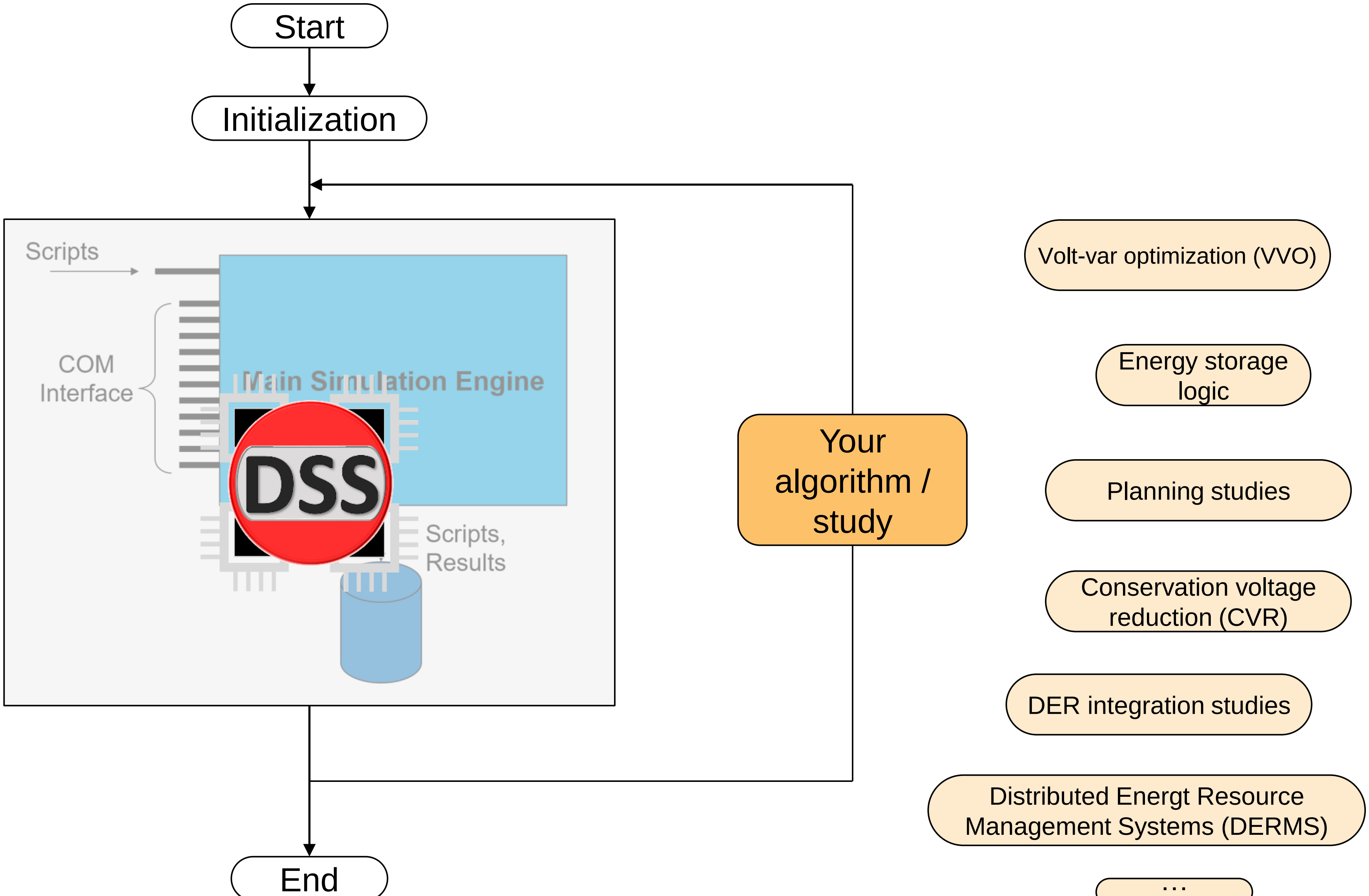
Scripts in OpenDSS



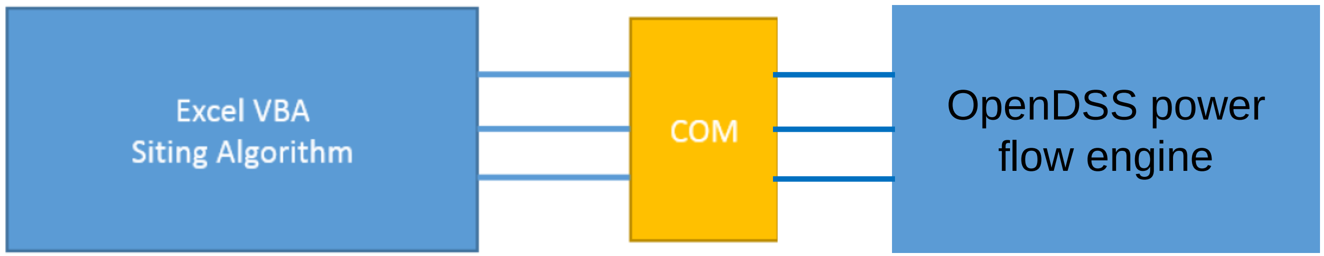
OpenDSS-G

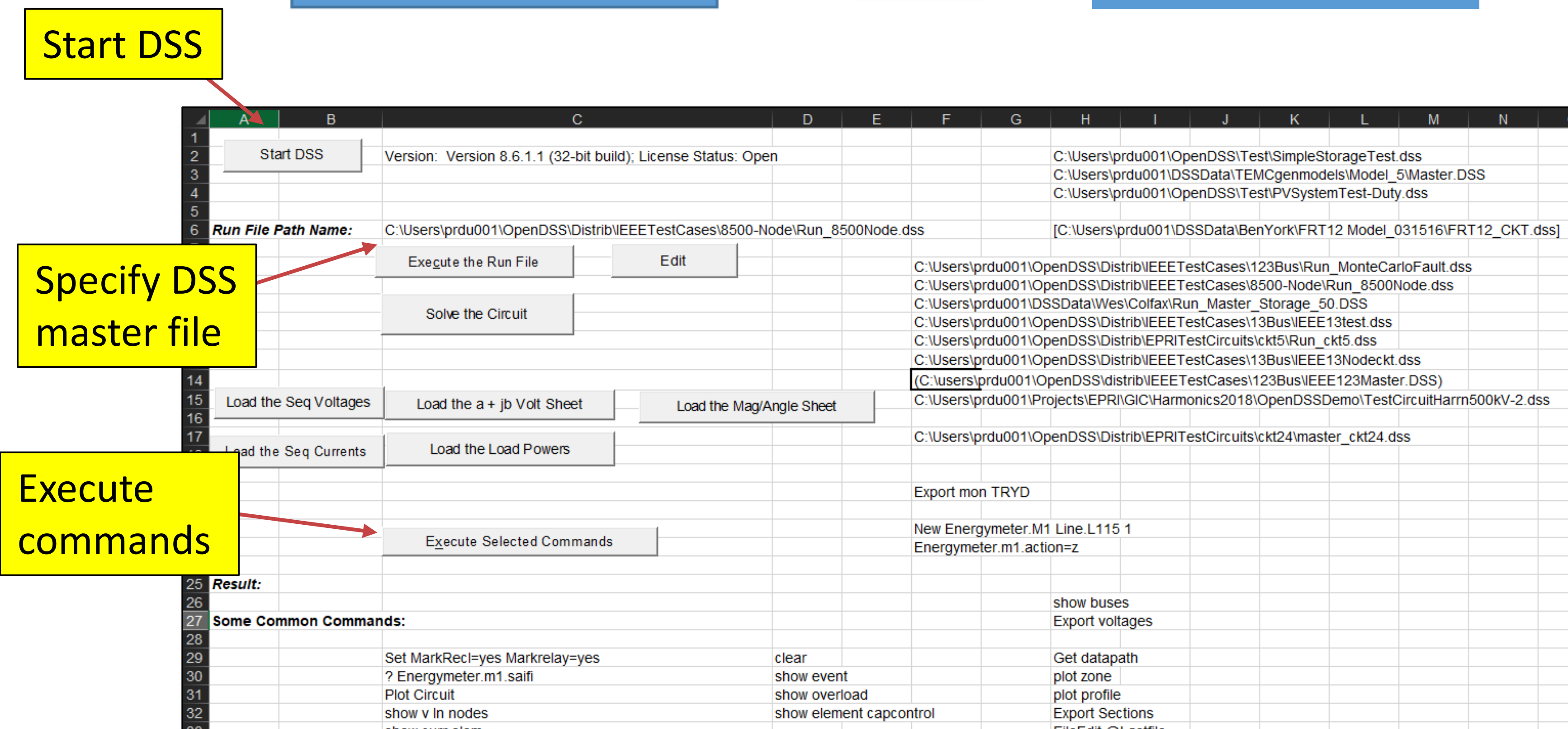
See session #2 from this virtual training

Using OpenDSS for its power flow engine



Excel VBA

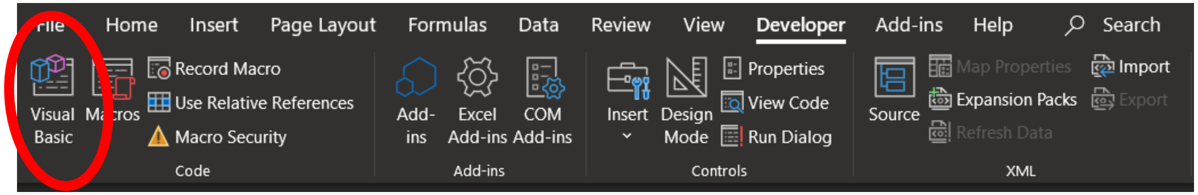




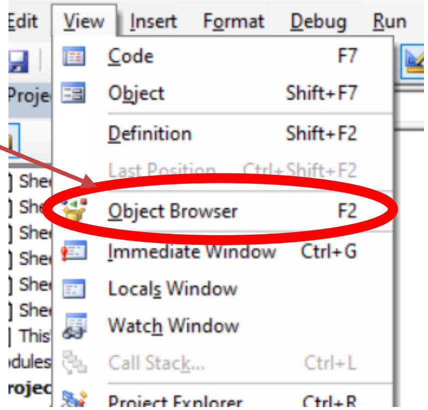
Example: "C:\Program Files\OpenDSS\Examples\Excel\DSSDriver8.xlsm"

Excel VBA – Object Browser

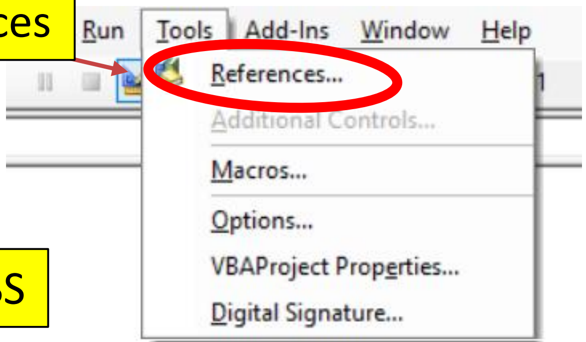
Open VBA



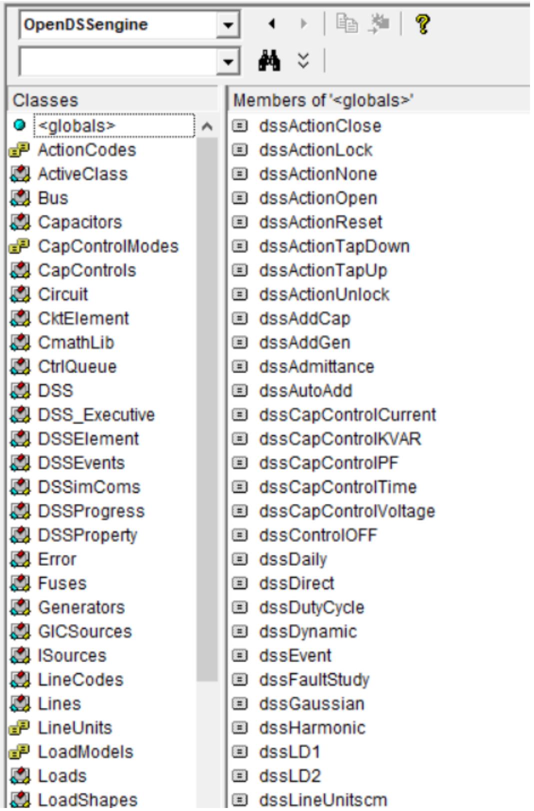
Open Object Browser



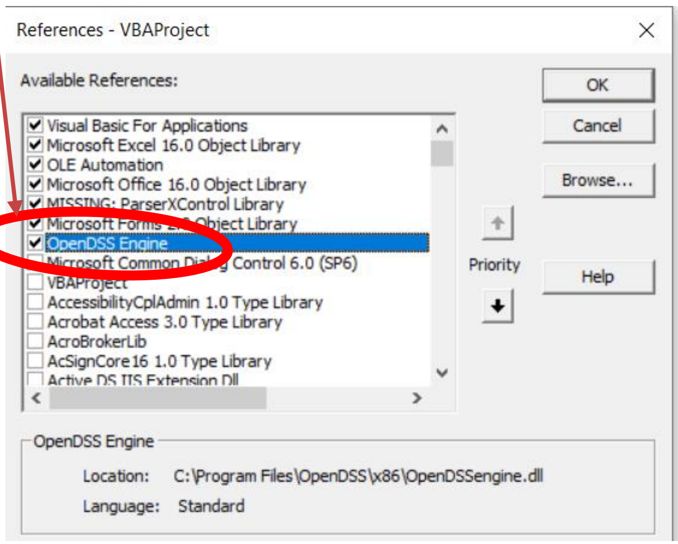
Select References



Object Browser

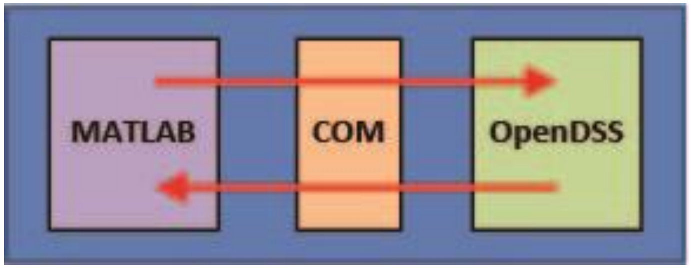


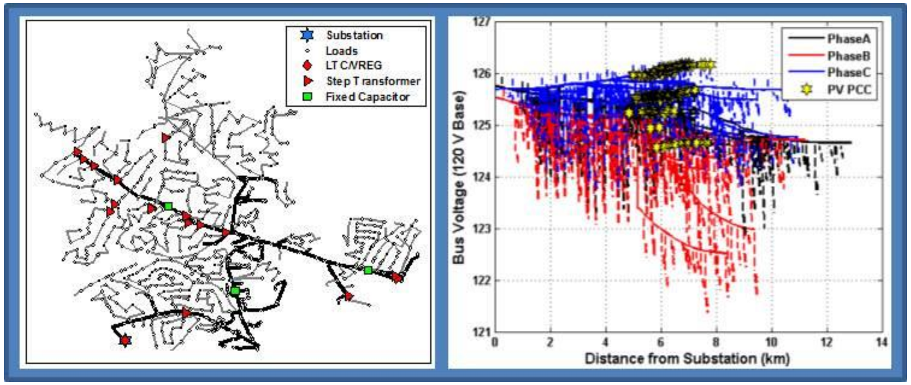
Select OpenDSS

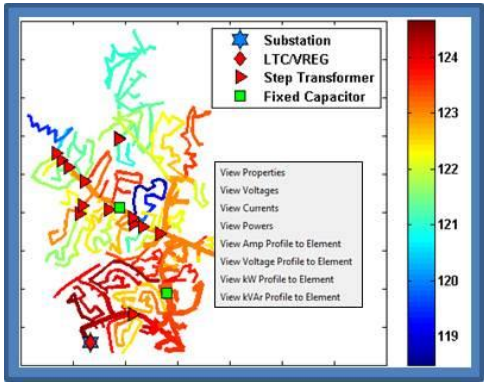


MATLAB integration: GridPV Toolbox

- Set of MATLAB function created by Sandia National Laboratory
- To model and simulate the integration of distributed generation into the electric power system and to determine the impacts on the distribution system for highly variable generation
- Available at: https://pvpmc.sandia.gov/applications/gridpv-toolbox/



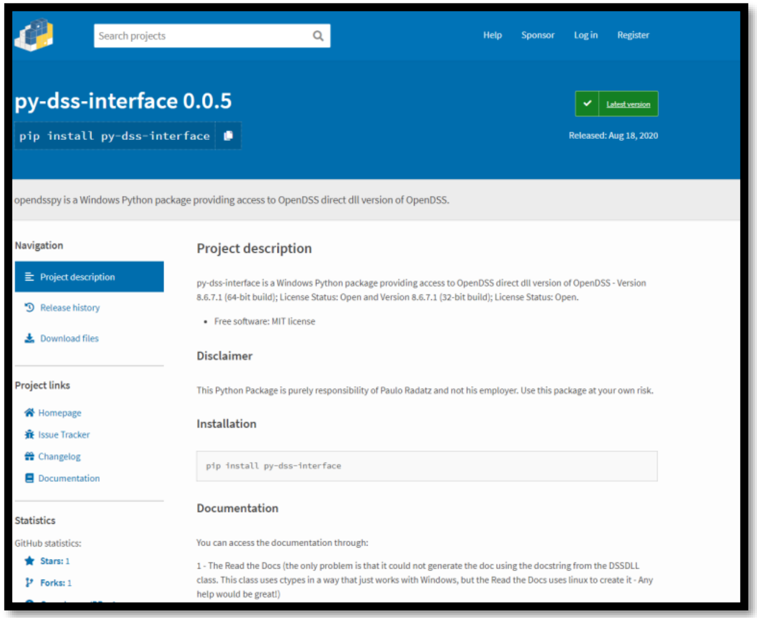




Python integration: py-dss-interface

- Python Package that works on Windows
- Uses the official OpenDSS DirectDLL version
  - Version 8.6.7.1 comes with the Package
  - Users can use their OpenDSS version as well
- Created based on Direct connection Shared Library (DLL) for OpenDSS doc by Davis Montenegro

- Installing from PyPI
  - *pip install py-dss-interface*



Getting Started

User can pass the OpenDSS path as argument: *"C:/Program Files/OpenDSS"*

import package

Create dss Obj

Use text method of dss

Use solution_solve method of dss

Use circuit_allbusvolts method of dss

```
# First import the Package
import py_dss_interface

# Creates an OpenDSS object
dss = py_dss_interface.DSSDLL()

# Select the DSS model
dss_file = r"C:\MeuTCC\Paulo_Example\DSSFiles\MASTER_RedeTeste13Barras.dss"

# Compile
dss.text("compile {}".format(dss_file))

# Solve
dss.solution_solve()

# Show Voltage Report
dss.text("show voltages")

# Get all buses voltages
allbusvolts = dss.circuit_allbusvolts()

print(dss.circuit_allbusvolts())
```

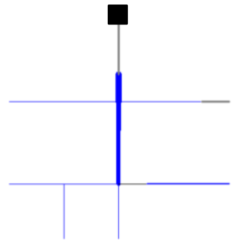
IDE Code Completion is quite useful to select methods of dss

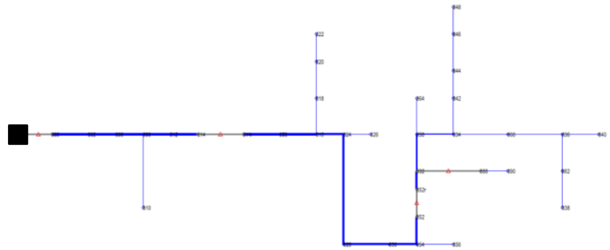
Know more about py-dss-interface

- Resources
  - PyPI (Python Package Index): https://pypi.org/project/py-dss-interface/
  - GitHub: https://github.com/PauloRadatz/py_dss_interface
  - Doc: https://py-dss-interface.readthedocs.io/en/latest/usage.html
  - OpenDSS_Direct_DLL.pdf:https://sourceforge.net/p/electricdss/code/HEAD/tree/trunk/Version8/Distrib/Doc/OpenDSS_Direct_DLL.pdf

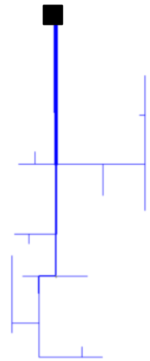
IEEE test feeders

- 13-bus feeder: simple feeder model to test common features

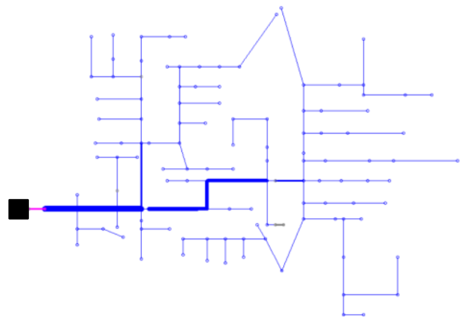




- 34-bus feeder: Actual feeder located in Arizona, which is highly loaded.

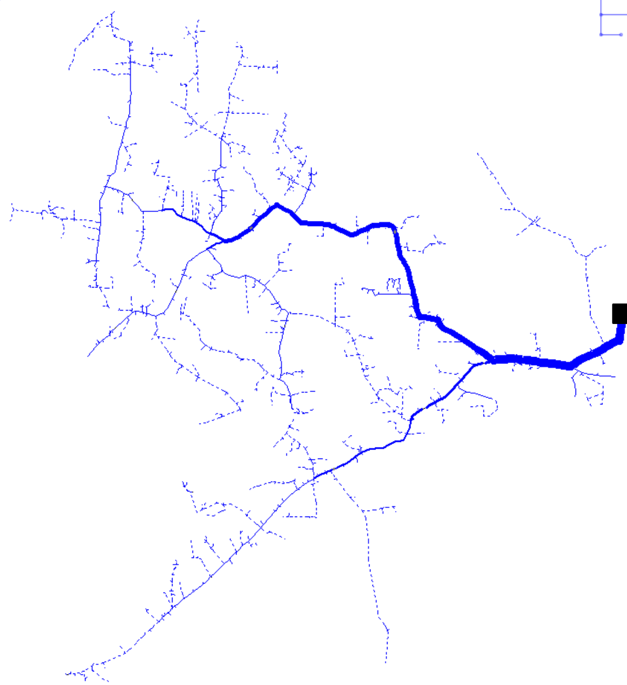


- 37-bus feeder: Actual feeder in California with delta configuration.



- 123-bus feeder: Test feeder with significant voltage drop requiring voltage regulation.

- 8500-node feeder: Large scale feeder intended to test the scalability of an algorithm. Secondaries are modeled.

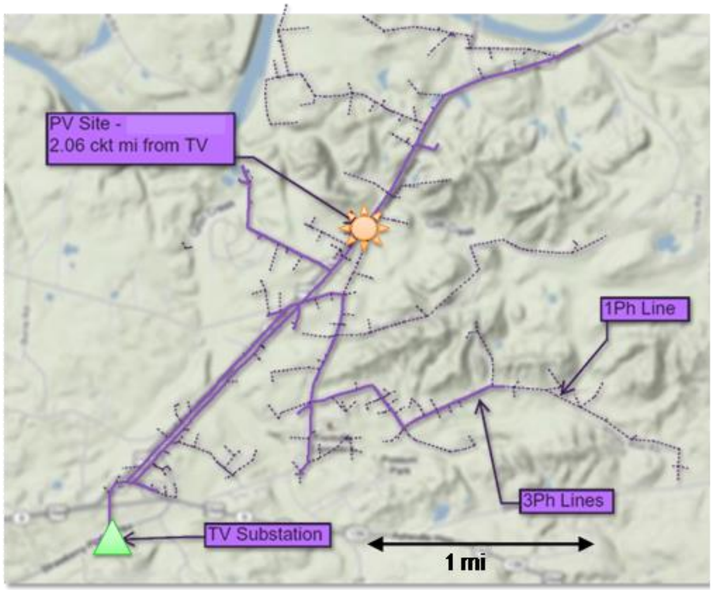


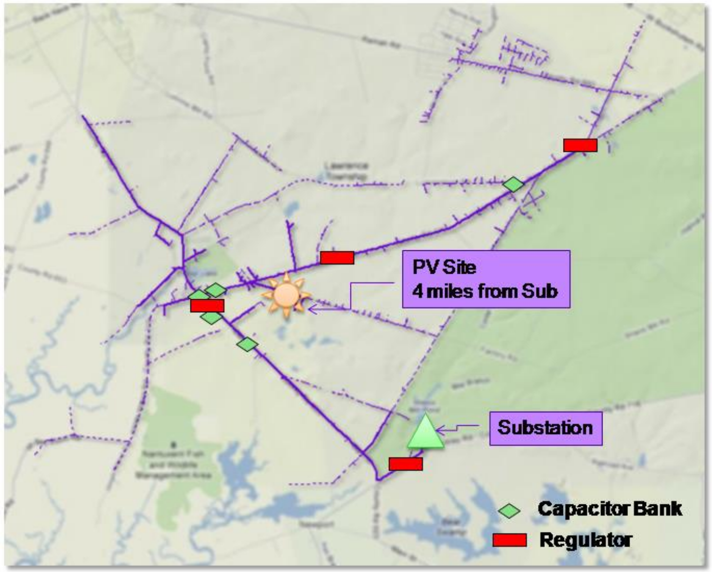
"C:\Program Files\OpenDSS\IEEETestCases"

Available at: https://site.ieee.org/pes-testfeeders/resources/

EPRI test feeders

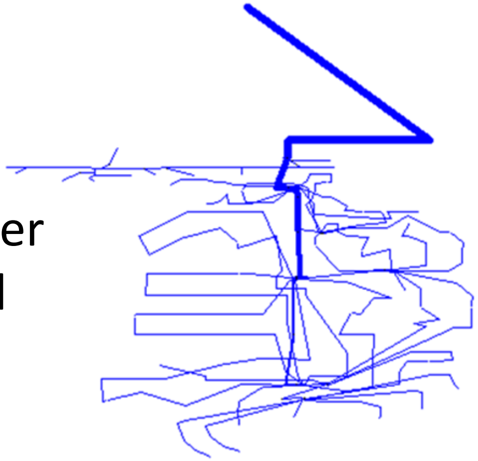
- Feeder J1: Located in northeastern US feeder with 1.7MW of customer-owned PV systems.





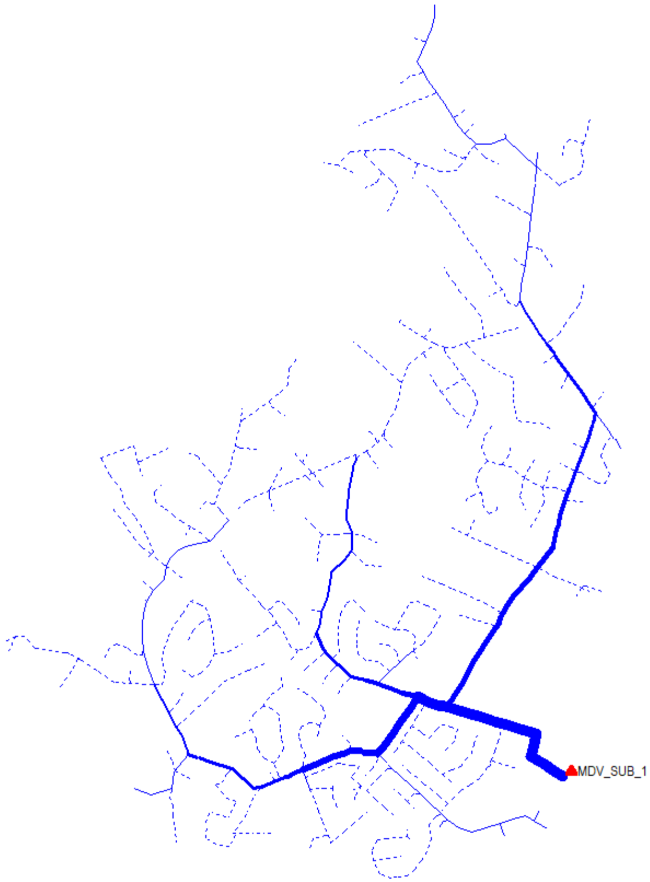
- Feeder K1: Located in southeastern US with a 1.0MW customer-owned PV system.

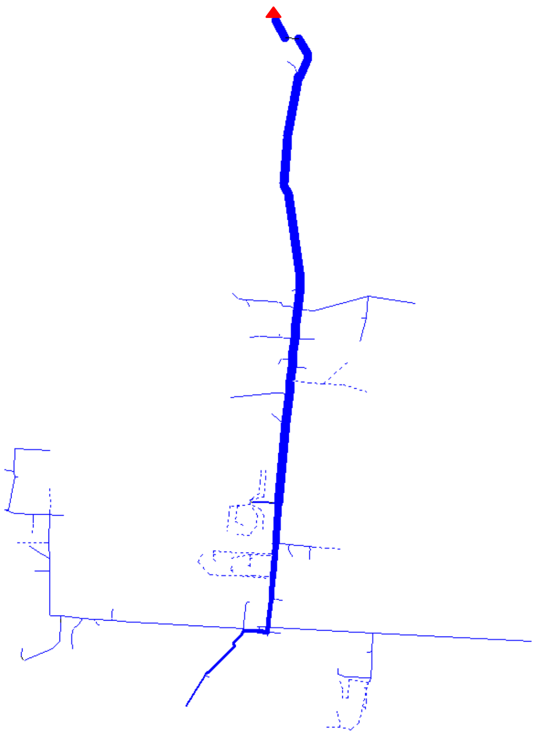
- Feeder M1: Short and compact feeder with 1500 residential customers and radio-controlled capacitor banks.

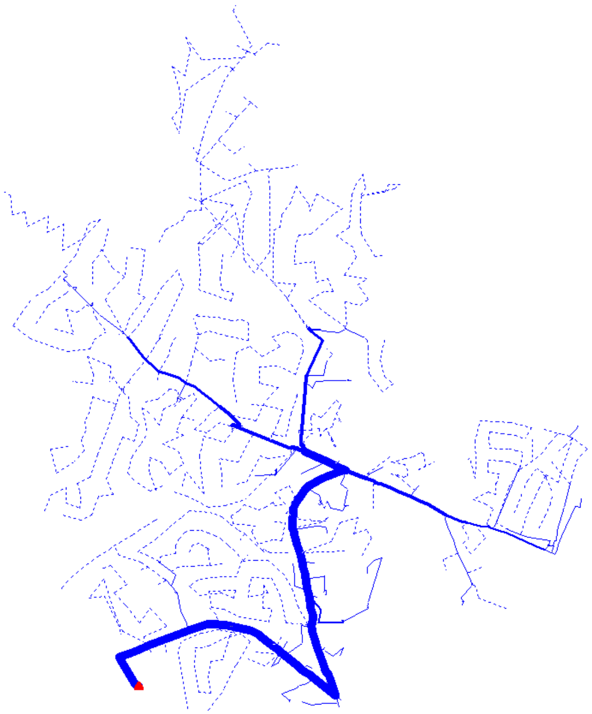


Available at: https://dpv.epri.com/index.html

EPRI test feeders (cont'd)







EPRI Ckt5

Primary voltage: 12.5kV

# of feeders: 1

EPRI Ckt7

Primary voltage: 12.5kV

# of feeders: 14

EPRI Ckt24

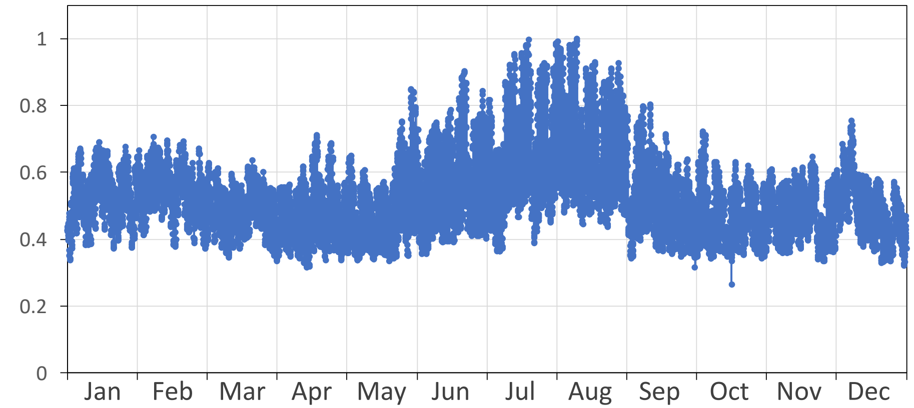
Primary voltage: 34.5kV

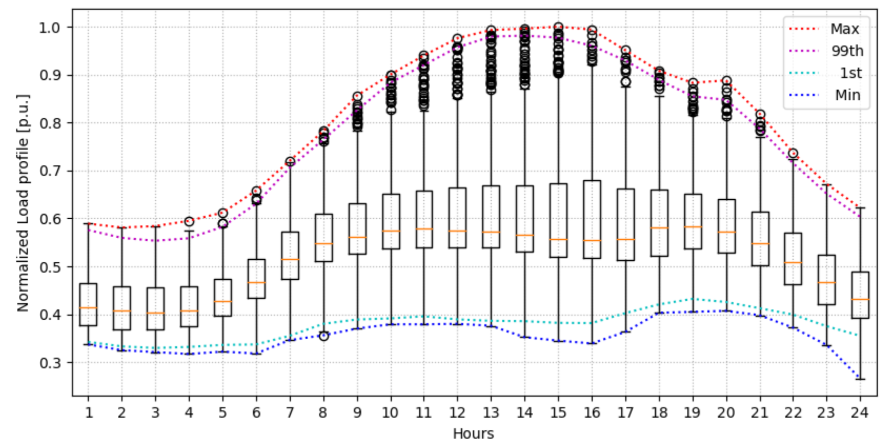
# of feeders: 2

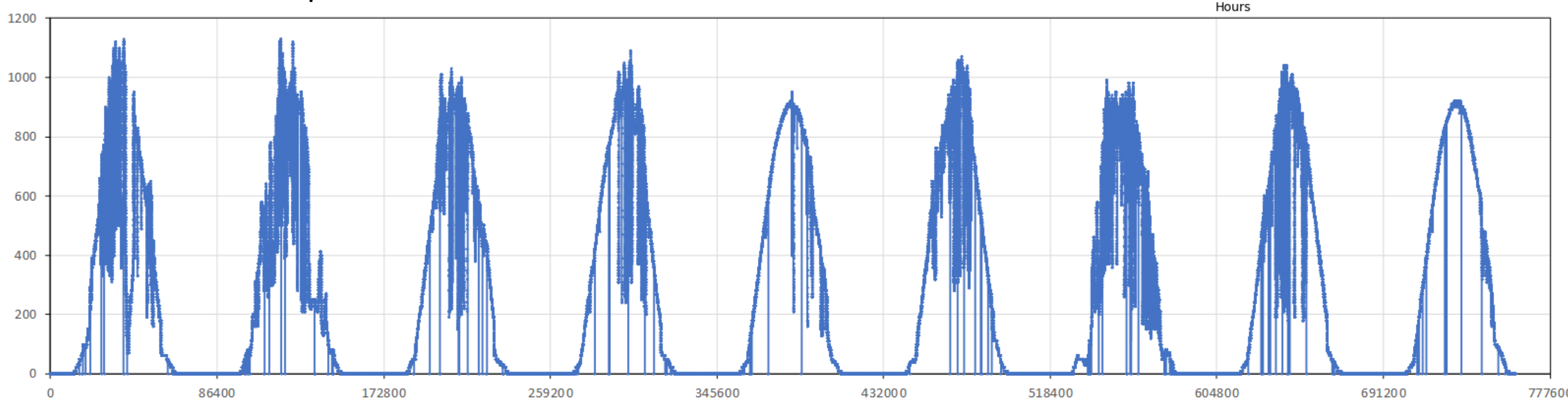
Available at: "C:\Program Files\OpenDSS\EPRITestCircuits"

Datasets

- <u>Load profiles</u>: (available with feeder model)
  - IEEE 123 bus: ‘paperloadshape.txt’
  - EPRI ckt5: ‘loadshape_ckt5.dss’
    - Residential load profile
    - Small & Medium commercial load profiles
- <u>PV profiles</u>:
  - EPRI models: (available at: dpv.epri.com/)
    - Resolutions: 1 sec, 1-, 15-, 60-min
  - NREL dataset: (available at: pvwatts.nrel.gov/)
    - Location-specific TMY data at 1hr resolution

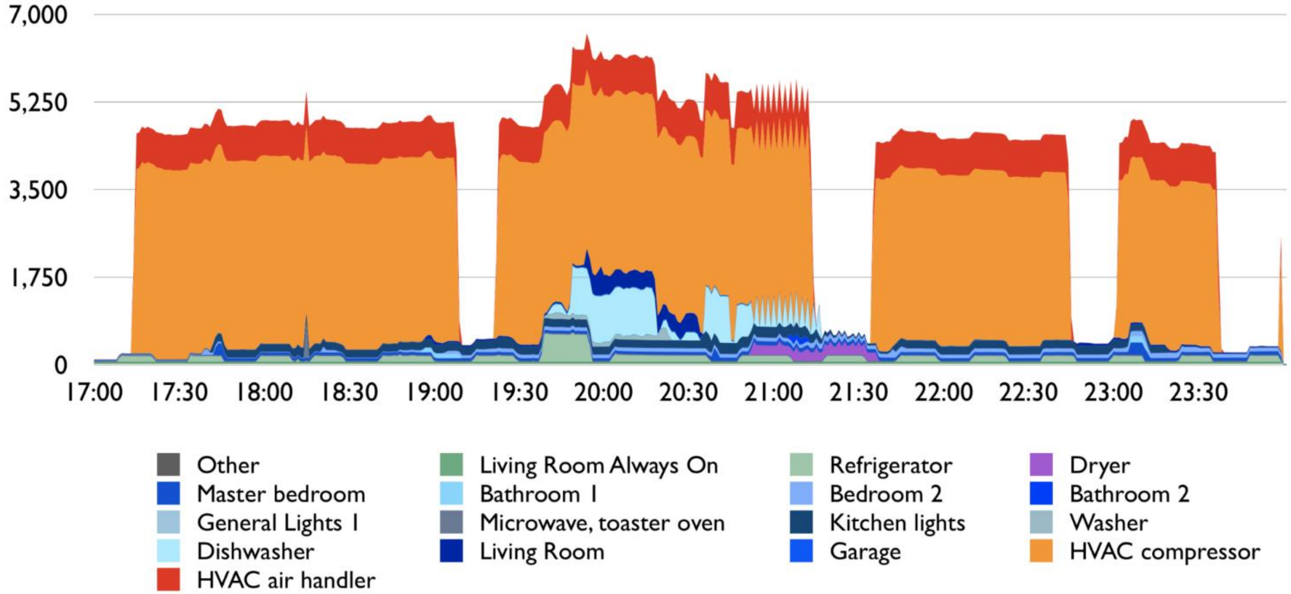






3rd party datasets: Pecan Street

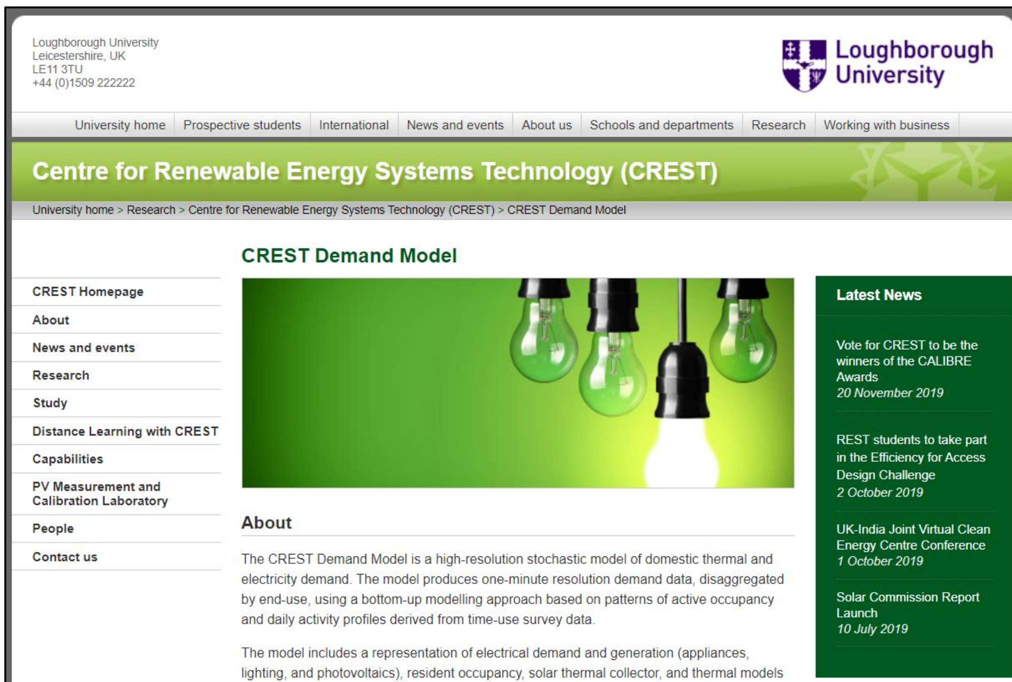
- Available at: https://www.pecanstreet.org/dataport/about/
- Dataport provides access to a variety of residential energy and water data including:
  - Whole-home and circuit-level energy use,
  - Appliance use,
  - Solar generation,
  - EV charging behavior,
  - HVAC use, etc.



https://www.pecanstreet.org/wp-content/uploads/2019/01/1-minute.png

3rd party datasets: Centre for Renewable Energy Systems Technology (CREST)

- Available at: https://www.lboro.ac.uk/research/crest/demand-model/
- High-resolution stochastic model of domestic thermal and electricity demand.
- Produces one-minute resolution demand data, disaggregated by end-use.
- Using a bottom-up modelling approach based on patterns of active occupancy and daily activity profiles



How is OpenDSS used ?

<u>DER integration studies</u>:

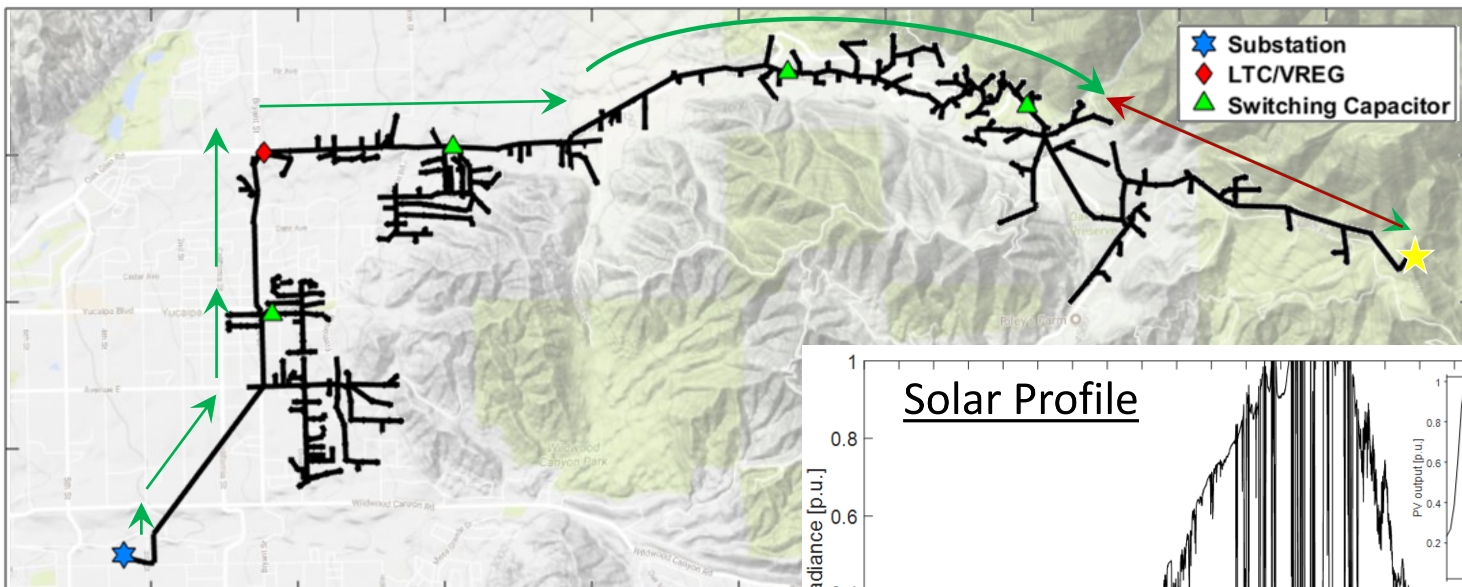
- Large-scale **PV systems** (centralized),
- Residential rooftop **PV systems** (distributed),
- **Wind** turbines,
- **Electric vehicles,**
- Customer-owned **storage,**
- Large-scale energy **storage**, etc.

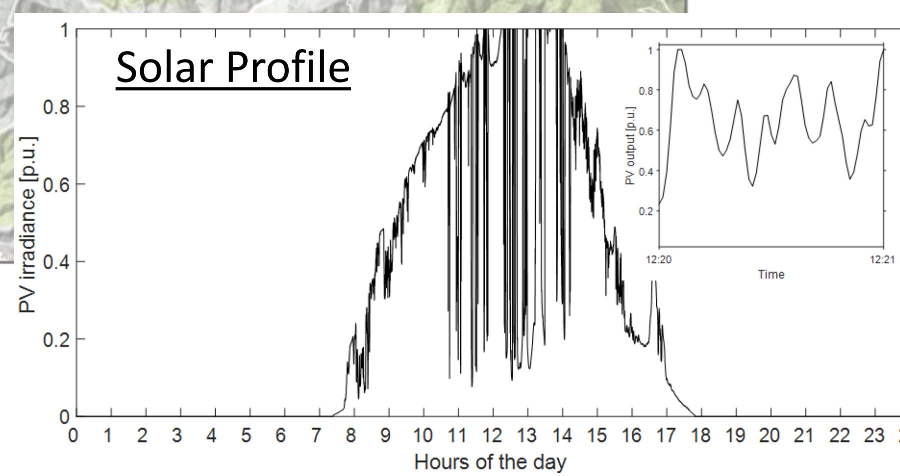
- **<u>Planning studies</u>**:
  - Time-varying feeder behaviors,
  - Load modeling: (load allocations, load growth, AMI data, etc.),
  - System reliability study, etc.
- **<u>Advanced System Controls</u>**:
  - Distributed Energy Resource Management Systems (DERMS),
  - Volt-var optimization (VVO),
  - Conservation Voltage Reduction (CVR),
  - Fault Location, Isolation, and Service Restoration (FLISR), etc.

Detailed interconnection studies

PV systems can cause negative impacts on a distribution system feeder:

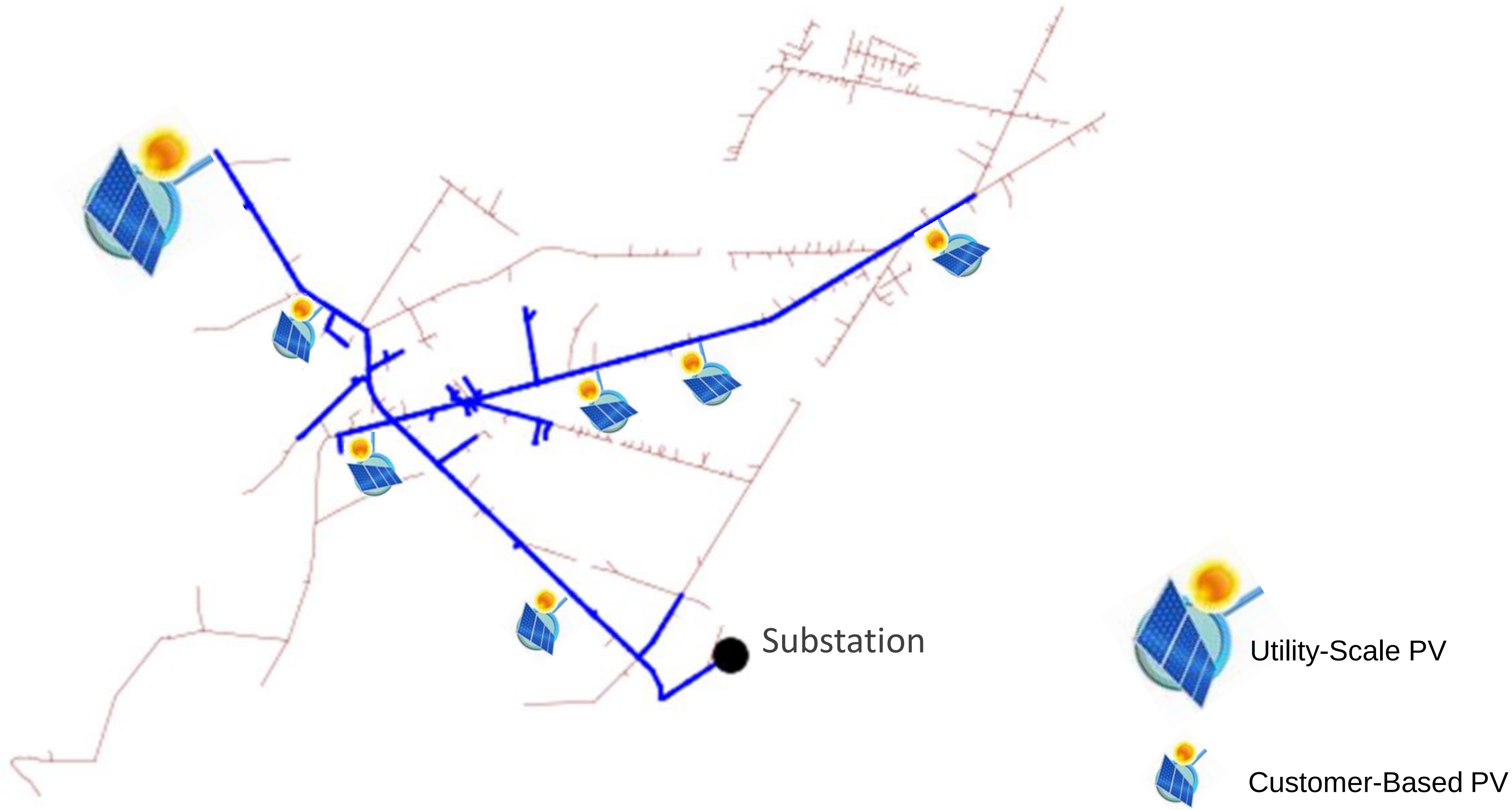
- Over/under-voltage conditions,
- Reverse power flow,
- Thermal limit violations,
- Rapid power flow fluctuation,
- Excessive voltage controller actions,
- Etc.





Hosting capacity

The results from a Hosting Capacity analysis estimates the amount of DER that can be accommodated without adversely impacting power quality or reliability under current configurations and without requiring infrastructure upgrades.



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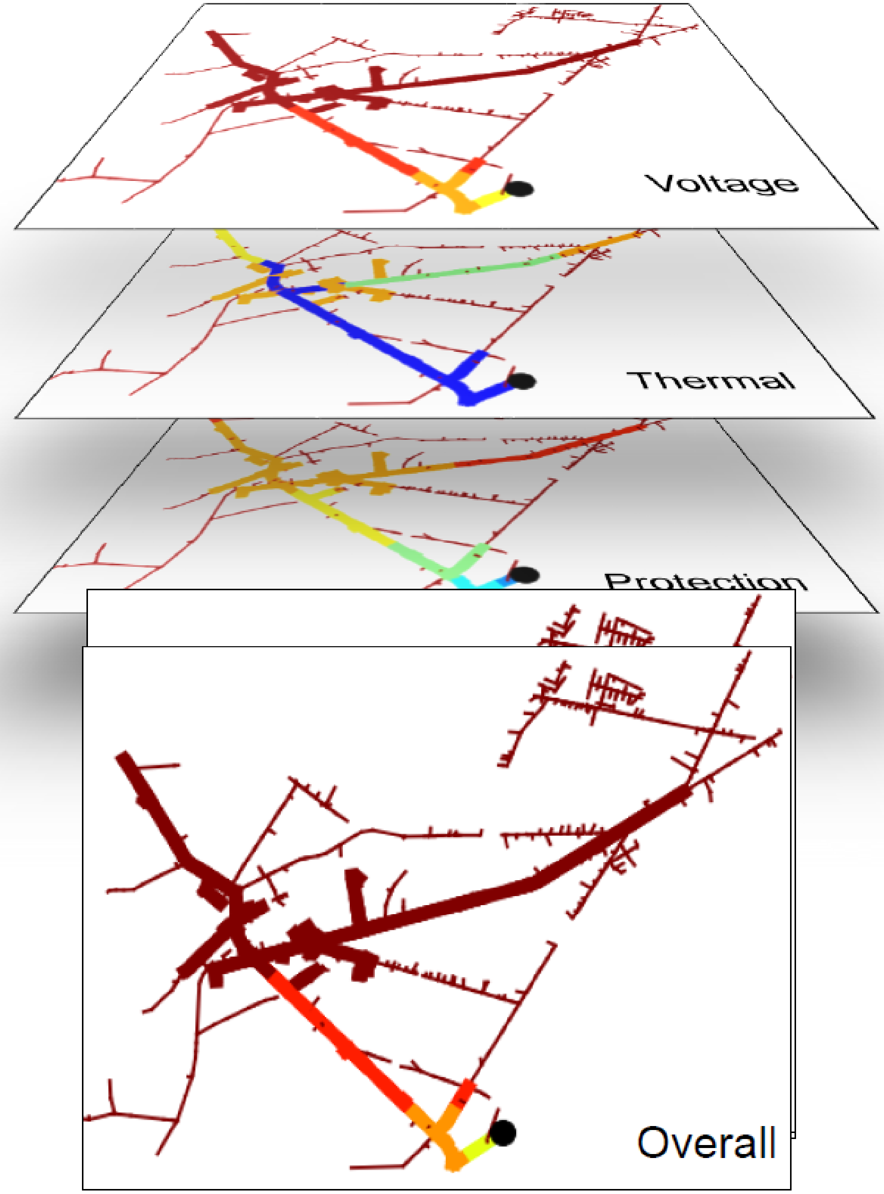
Hosting Capacity is Issue Dependent

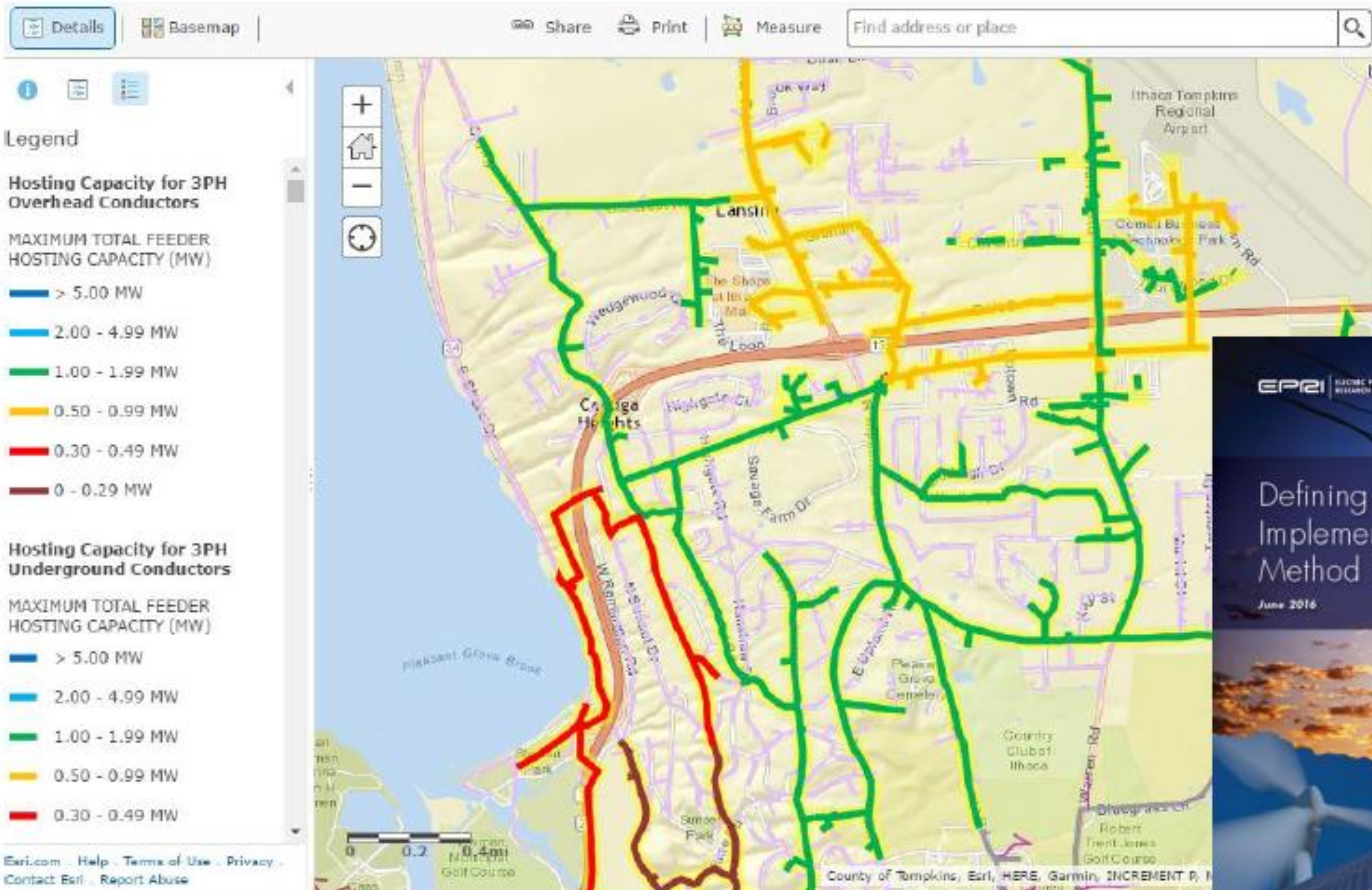
Impacts Considered

- Voltage
  - Primary overvoltage
  - Primary undervoltage
  - Primary voltage change
  - LTC/Regulator tapping
- Thermal
  - Generating power
  - Demanding power
- Protection
  - Element fault current
  - Breaker relay reduction of reach
  - Sympathetic breaker relay tripping
  - Reverse power flow
  - Unintentional islanding



DRIVE Hosting Capacity Maps Inform DER Developers

https://www3.dps.ny.gov/W/PSCWeb.nsf/All/6143542BD0775DEC85257FF10056479C?OpenDocument



Hosting Capacity Maps courtesy of NYSEG/RGE

DRIVE

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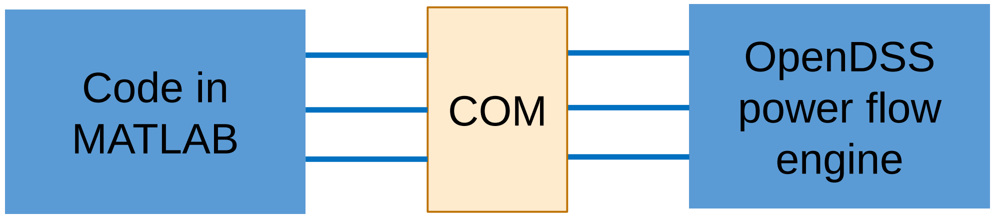
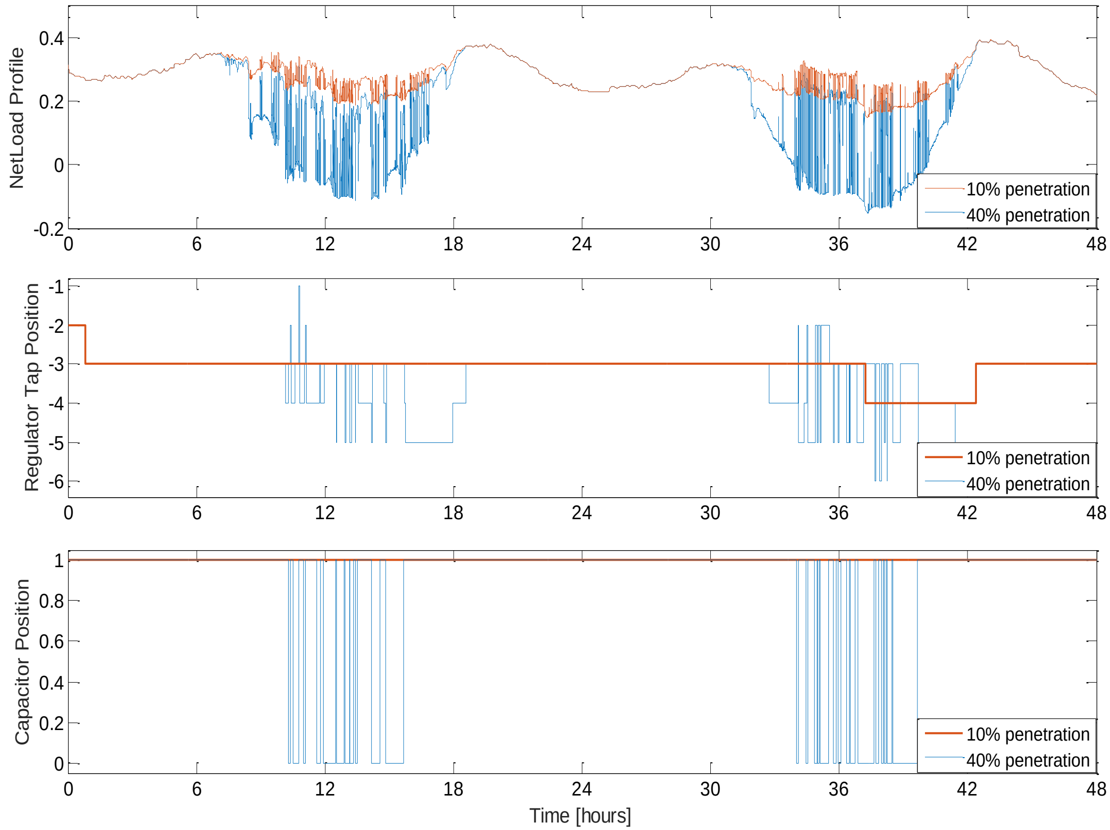
Impact of DER on Voltage Regulating Equipment

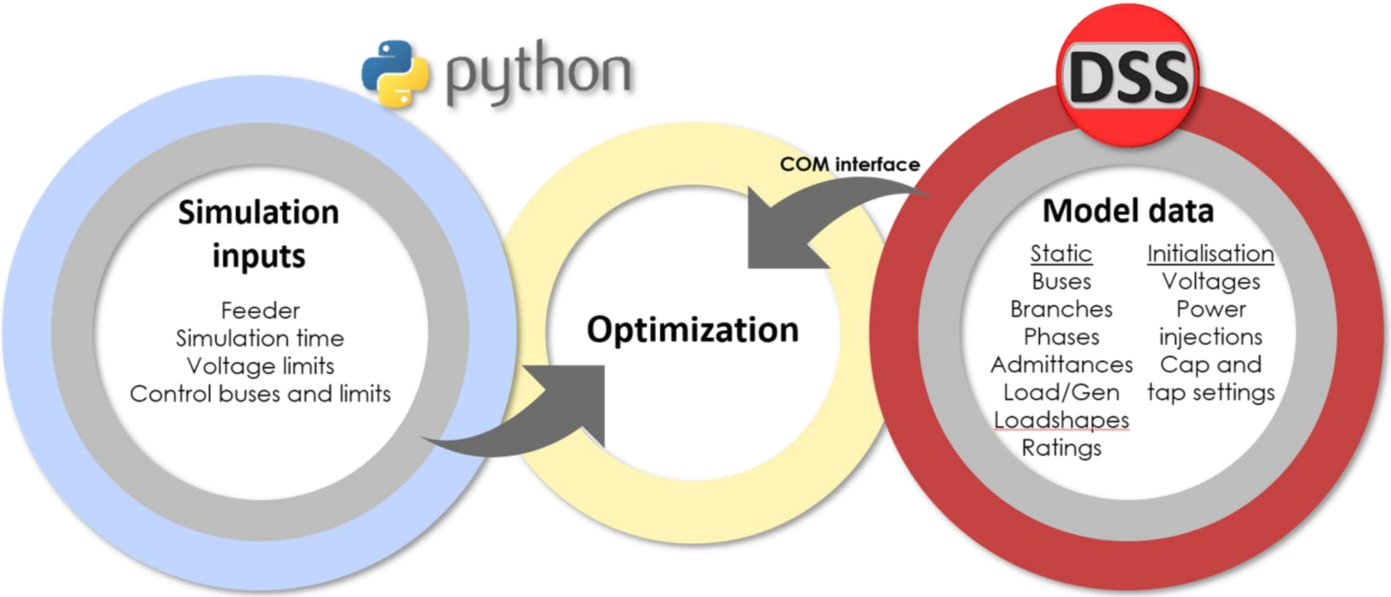




REFERENCE: J. Deboever, 'Fast Interconnection Analysis Of PV Systems Using Vector Quantization'. Georgia Institute of Technology, 2018.

Distribution OPF

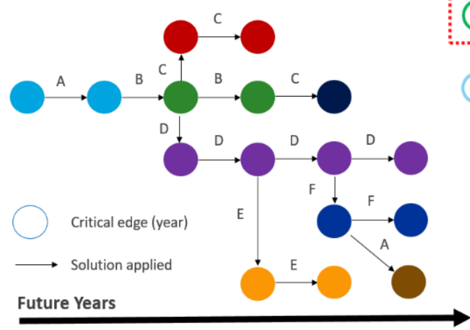
- Three-phase unbalanced optimal power flow
- Python based
- Input data from OpenDSS through COM interface
- Optimization modelled with Pyomo
  - Ipopt solver for problems without integer/binary variables
  - Bonmin solver for problems with integer/binary variables
- Major distribution components modelled
  - Loads, generators, lines, transformers, regulators, capacitors, PV
- Time series simulations (looping optimization)

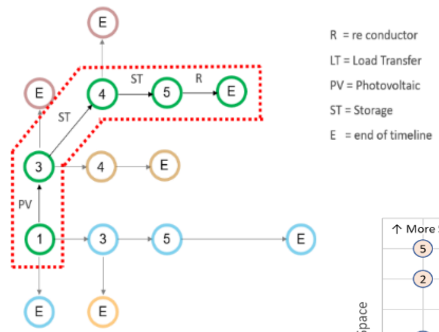


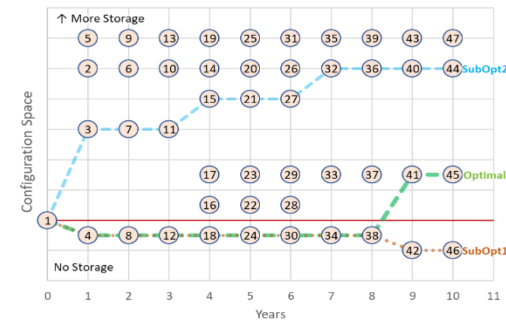
Automated Distribution Assessment Platform and Tools

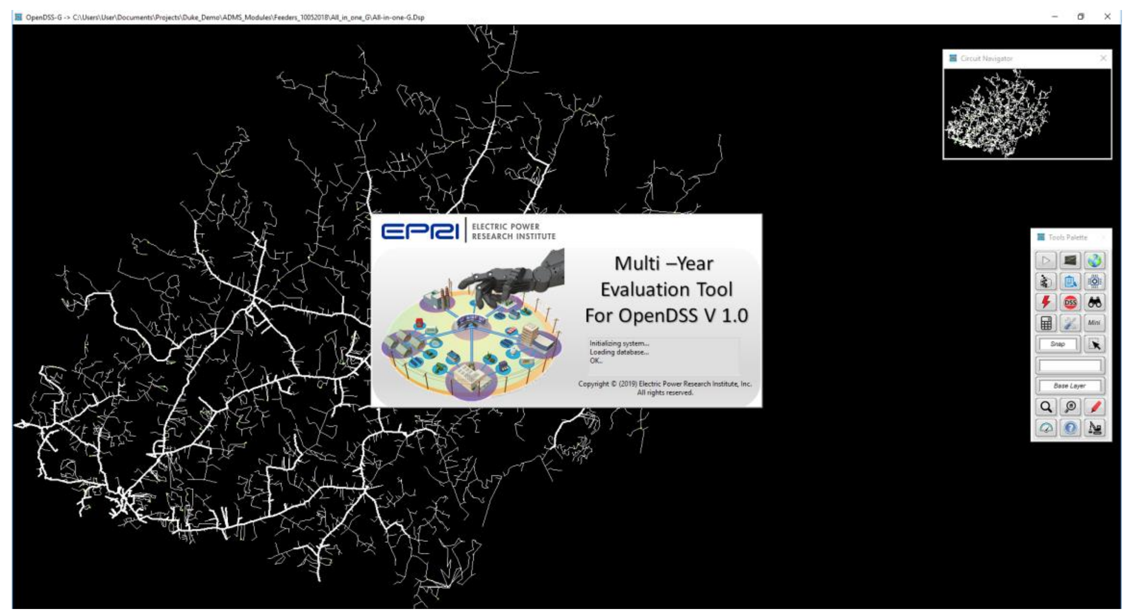
ADAPT

Enable distribution planners to effectively account for the dynamics introduced by NWA, more effectively evaluate NWA versus traditional solutions, as well as identify optimal deployment strategies.

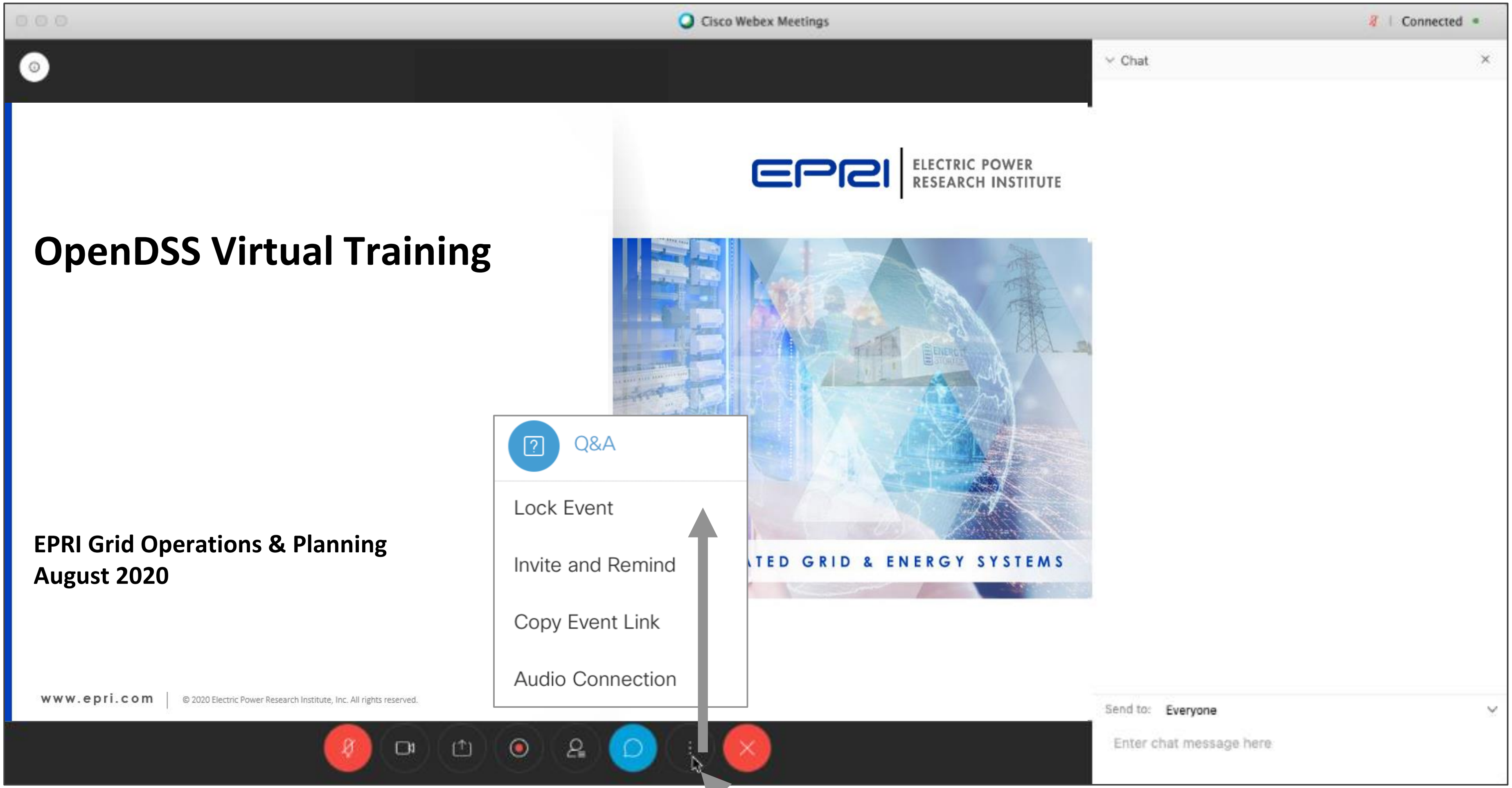








Questions and Answers



Polling, Q&A

OpenDSS Virtual Training 2020

Date	Time (NY time)	Session Topic
August 24	11:30 am – 12:00 pm	Distribution System Basics
	12:00 pm – 12:30 pm	Intro to OpenDSS
	12:30 pm – 1:00 pm	OpenDSS Basics and Scripting
August 25	11:30 am – 12:00 pm	Intro to OpenDSS-G
	12:00 pm – 12:30 pm	APIs, COM interface, etc.
August 26	11:30 am – 12:30 pm	PVSystem, InvControl, Storage, Storagecontroller
August 27	11:30 am – 12:30 pm	Advanced Topics
	12:30 pm – 1:00 pm	Applying OpenDSS in R&D

Recordings and presentation slides will be made available for free at www.epri.com/OpenDSS

Together…Shaping the Future of Electricity