Distribution Planning Modeling Tools

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Distribution Systems and Planning Training
for New England Conference of Public Utility Commissioners, Sept. 27-29, 2017

Set-up

- Presentation will be from 10:45 am – noon
- Presenters for this session

Juliet Homer

Emma Stewart

Michael Coddington

- Learning objectives - desired outcomes of this session
- Questions welcome as we go through

Presentation Agenda

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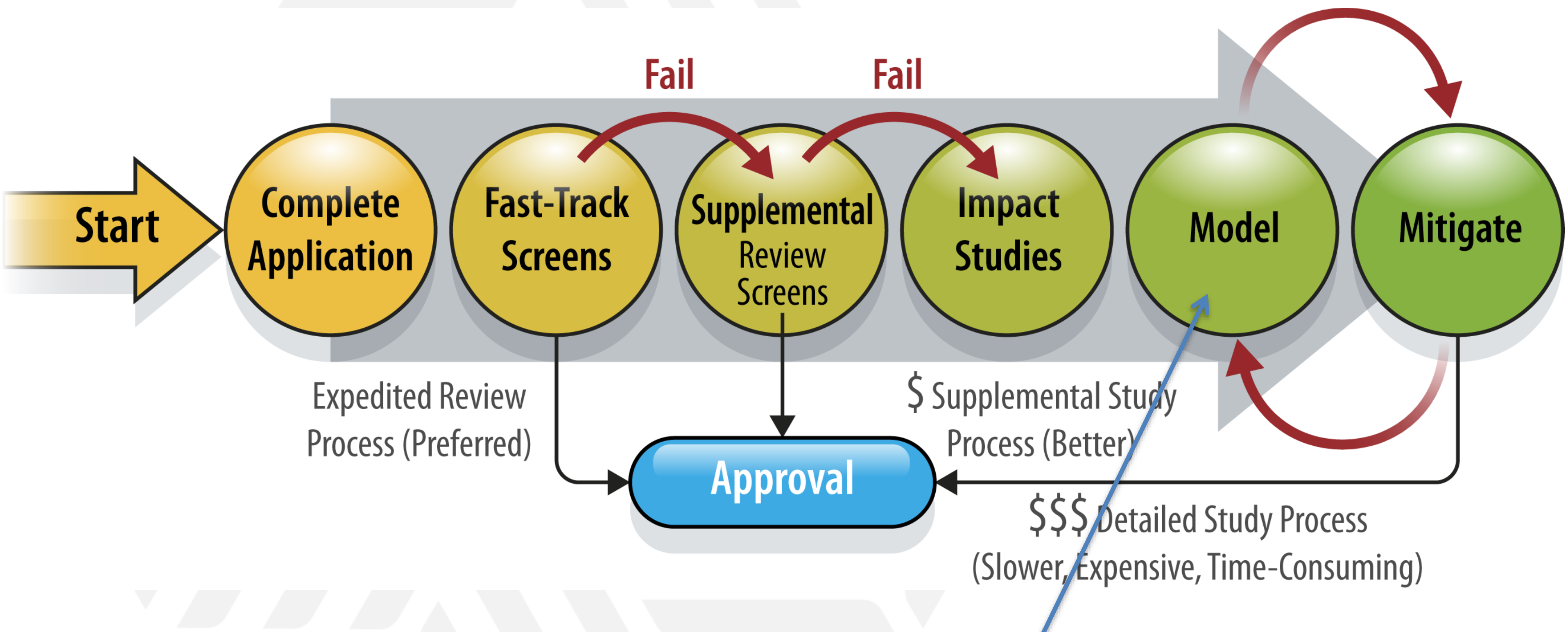
- Set-up
- Review agenda — Juliet
- Modeling with the Interconnection Process — Michael
- Classes of distribution modeling tools
- Inputs, outputs and maturity levels
- Summary of nascent areas — Juliet
- Limitations of current tools
- Modeling challenges with examples — Emma
- Questions PUCs can ask utilities about modeling — Michael
- Questions/discussion — All

Why Modeling is Necessary for *SOME* DER Applications



Large or complex DER applications may go directly to the Impact Study phase, or applications that fail Fast-Track and Supplemental screens may require impact studies.

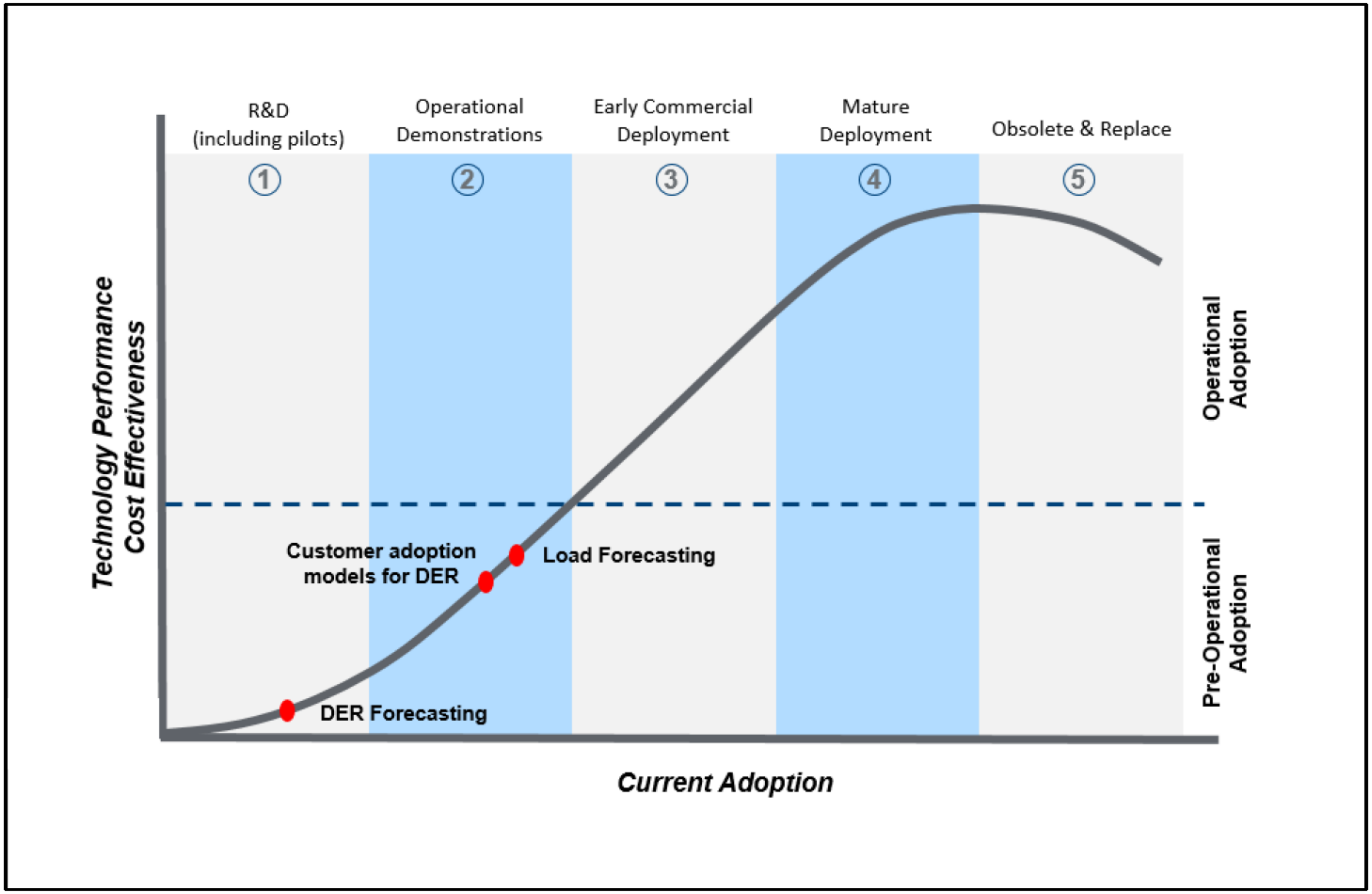
Classes of Distribution Planning Tools

- Forecasting
  - DER forecasting
  - Load forecasting
- Power flow analysis
  - Peak Capacity Power Flow Study
  - Voltage drop study
  - Ampacity study
  - Contingency and restoration study
  - Reliability study
  - Load profile study
  - Stochastic power flow study
  - Volt/var study
  - Real-time performance study
  - Time series power flow analysis
- Power quality analysis
  - Voltage sag and swell study
  - Harmonics study
- Fault analysis
  - Arc flash hazard study
  - Protection coordination study
  - Fault location identification study
- Dynamic analysis
  - Long-term dynamics study
  - Electromechanical dynamics study
  - Electromagnetic transients study
- Advanced optimization

Load forecasting tools

- Inputs to load forecasting tools
  - Weather, geographic, economic, demographic, DER and demand response data
- Forecasting DER growth requires
  - DER type, quantity, location, timing and other attributes
- Factors that that impact DER forecasting:
  - Historical adoption rates
  - Economic return for the customer
  - Available DER incentives
  - Procurement programs
- Output of load forecasting tools:
  - Load profiles across circuits, banks and subsections of the circuit
  - Necessary temporal and spatial granularity to considering impacts
- Inputs for DER forecasting:
  - Market information (e.g., fuel prices, existing electricity tariff)
  - Customer load information (hourly end use loads), and
  - DER technology information (e.g. capital costs, operating and maintenance costs, performance data
  - Other customer decision factors

Maturity levels – Forecasting Tools



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Power Flow Analysis

- Output – A power flow study that calculates voltages, currents, real and reactive power flows, and losses in the distribution feeder.
- Analysis is used to identify potential constraints on the system and scope the need for system upgrades based on violations of planning criteria

Peak Capacity Planning Study

- Examines load growth over a planning horizon
- Determine whether there is a need to upgrade transformers or other grid equipment
- Output – Entire load flow calculation with an evaluation of minimum and maximum values (e.g., voltages or loading levels) and diagrams with info on power requirements and overloaded lines and whether limits have been violated

Voltage Drop Calculations

- Performed as part of integrated power flow study
- Output – Clear indication of voltage limit violation and plan operations of regulators and capacitors

Power Flow Analysis - 2

Ampacity studies

- Input – conductor temperature, ambient temperature, conductor resistance, and thermal resistance and related loss factors
- Output – minimum conductor size and cable configuration required based on design requirements and expected load.

Contingency and Restoration Tool

- Allows for the simulation of multiple “what-if” scenarios in batch Monte-Carlo type analysis.

Reliability study tool

- Assess reliability of distribution networks by computing predicting reliability indices such as SAIFI, SAIDI, and CAIDI.
- Can be used to plan and optimize the placement of new distribution automation devices and compare benefits of different reliability improvements (such as tree trimming, cable replacement, etc.)

Power Flow Analysis - 3

Time series power flow analysis

- Multiple steady-state load flow calculations with user-defined time steps between each power flow - Simulation periods from seconds to years
- Analyzes impacts of variations in solar or wind on power control systems
- Can help verify the sequence and control of automatic switching, voltage control, and protection system operations

Load profile study

- Software module evaluates actual customer consumption curves from interval metering or historical data
- Can use to determine peak and off-peak load days, feeder loading patterns, transformer loading and line losses.

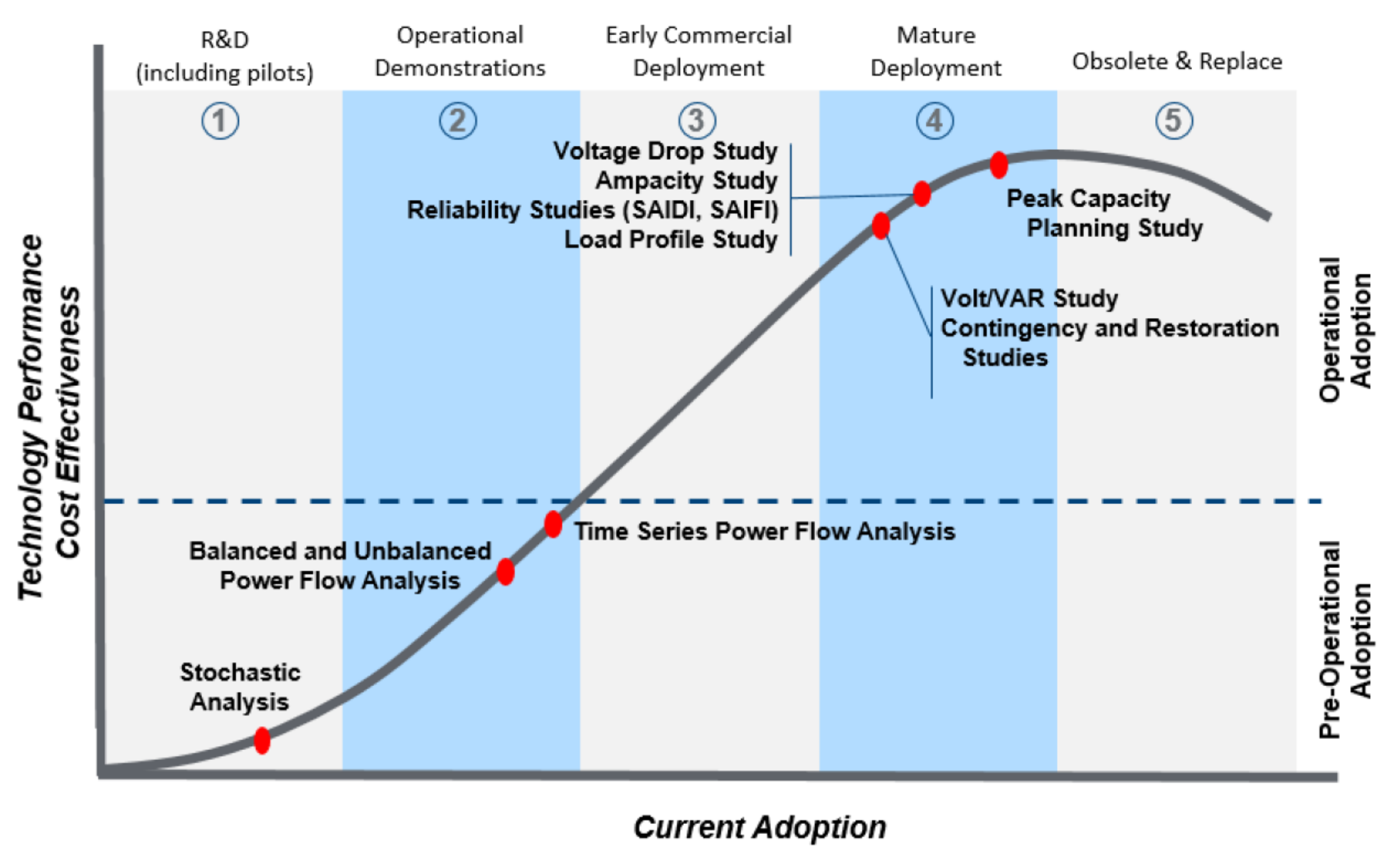
Stochastic analysis tool

- Models the impact of random variations of load, DER changes, and changes to distribution system operation.

Volt-var Study Tool

- Focuses on system design considering voltage and reactive power compensation controls.

Maturity levels – Power Flow Analysis



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Power Quality Analysis

- ► Defined as maintaining voltage, frequency and waveform to defined standards
- ► Power quality analysis:
  1. Evaluates operating conditions that can cause power quality disturbances
  2. Finds equipment affected by disturbances
  3. Supports identification of strategies to eliminate the causes and mitigate the impacts of disturbances.

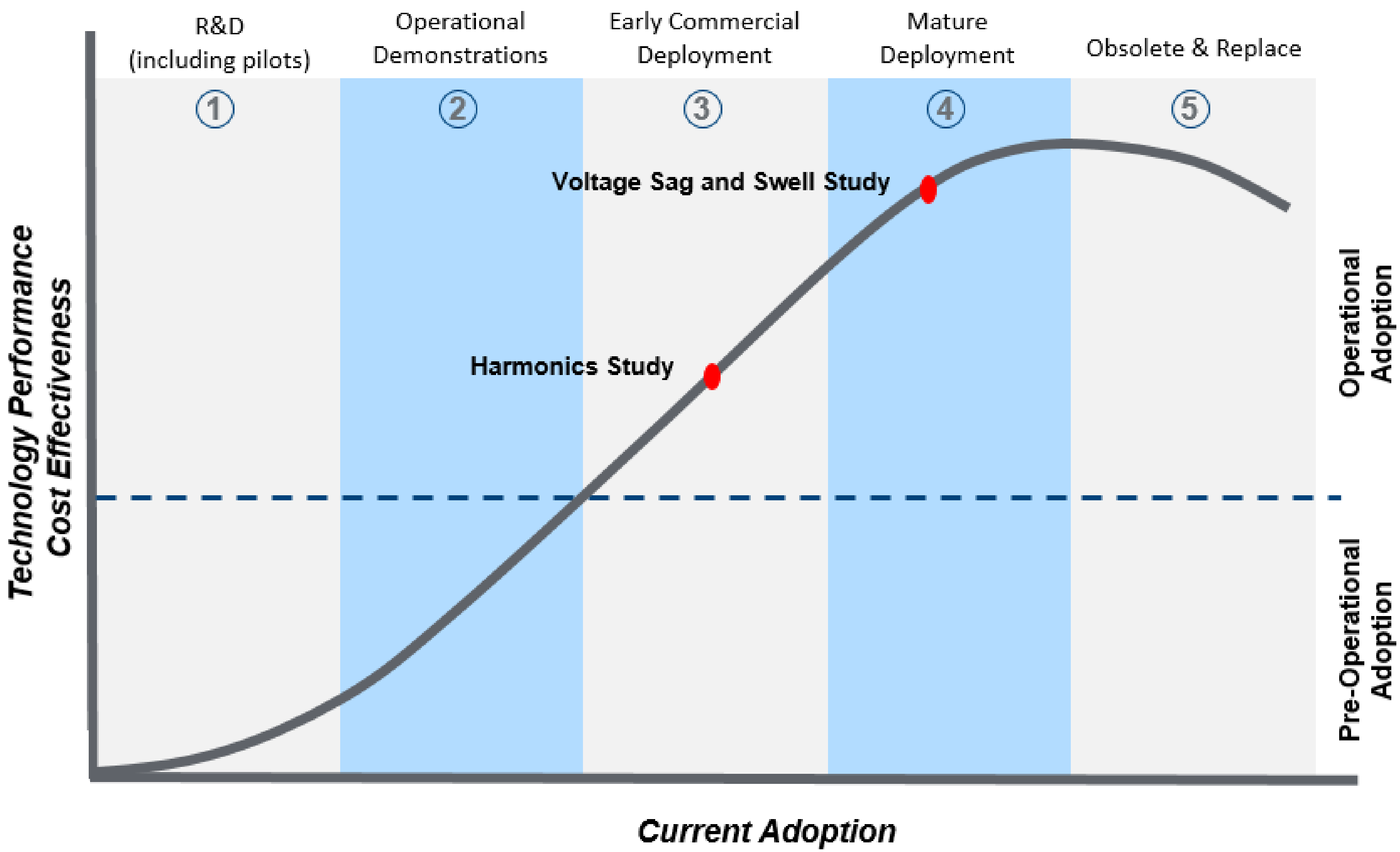
Voltage Sag and Swell Study Tool

- ► Assess voltage stability of a network
- ► Post processing of voltage data is needed for accurate voltage sag and swell studies.

Harmonics Study Tool

- ► Analyzes disruptions to a current or voltage waveform
- ► Users can model non-linear loads and other sources of harmonic currents such as converters and arc furnaces

Maturity levels – Power Quality



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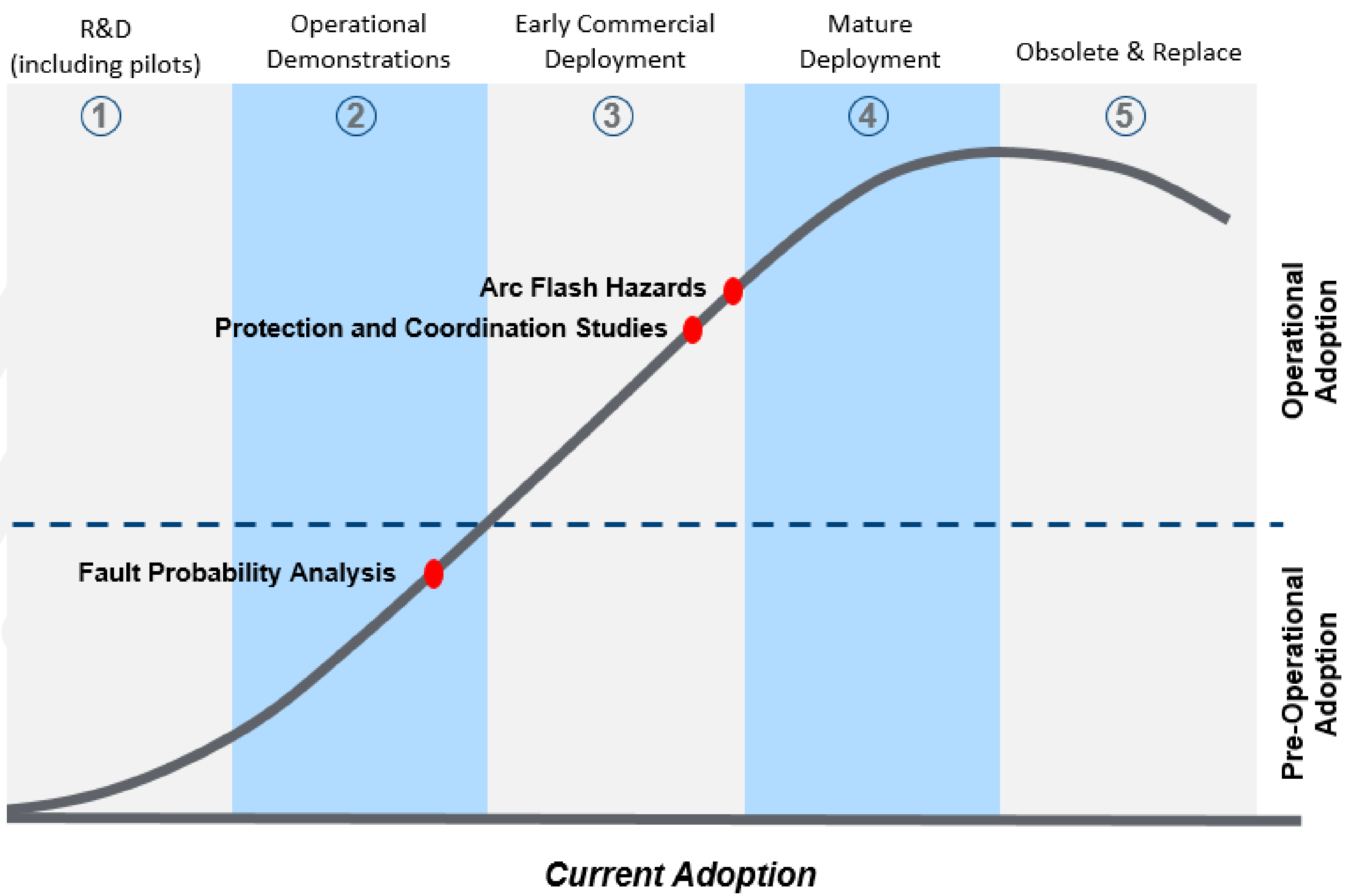
Fault Analysis

- A fault is any abnormal flow of current
- Fault analysis evaluates fault current conditions and the ability of the system to quickly isolate faults and power system failures
- Can help design the settings and locations of protective devices, based on calculations of fault current
- Tools that support fault analysis include software modules for:
  - Arc flash hazard analysis
  - Protection coordination study
  - Fault probability analysis

Maturity levels – Fault Analysis



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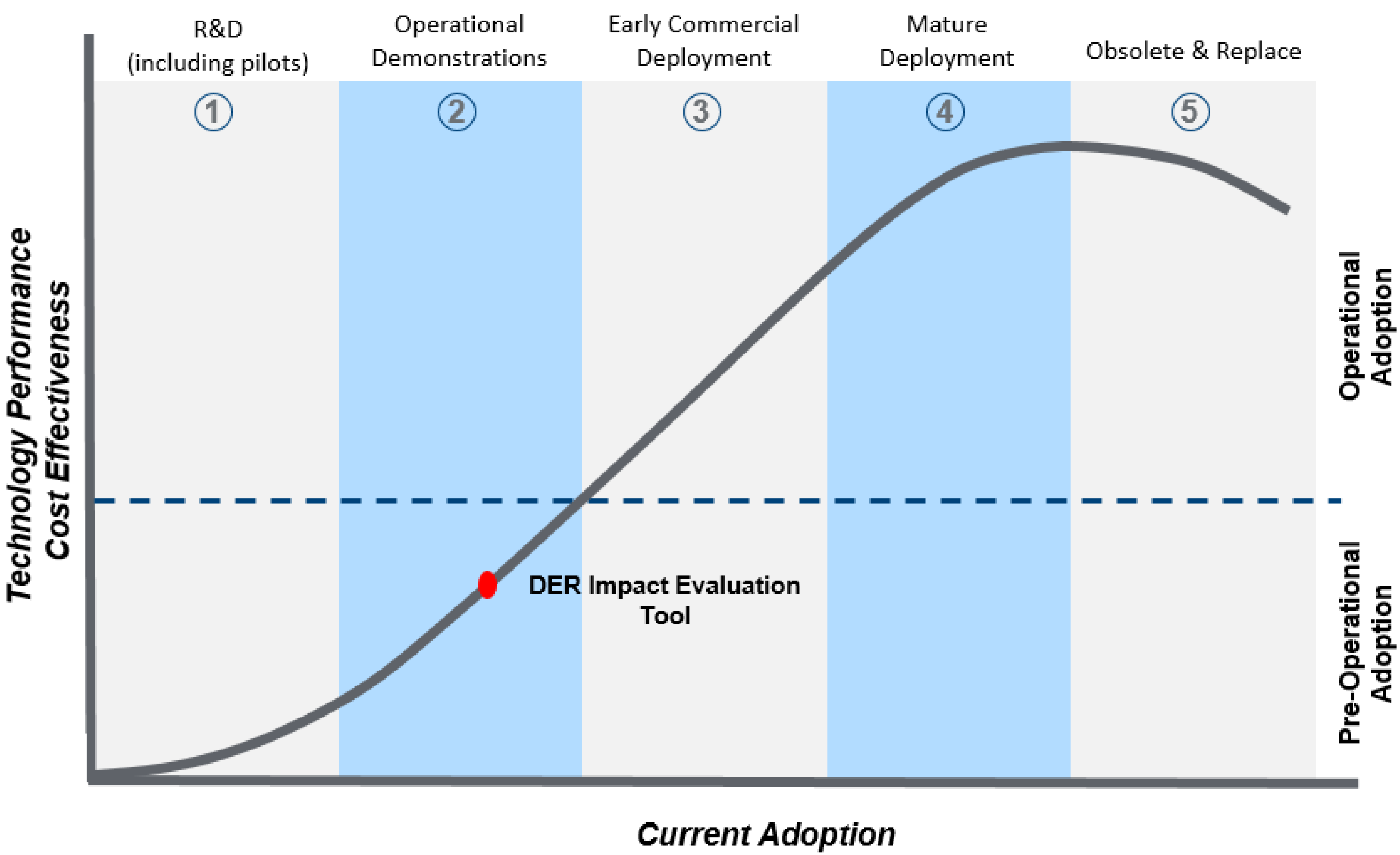
Optimization Tools

- ► Used to identify and select the optimal sizes and locations for interconnection of DER to the distribution grid
- ► Distribution grid software tools that can do this are DER impact evaluation tools.
  - Enables DER interconnection studies and hosting capacity analysis
  - Create various study cases by combining grid loading conditions (e.g. peak and minimum loads) with minimum and maximum DER contributions (0% or 100%)
  - Controlled load flow analyses are then executed on each scenario to assess impacts on the distribution system in terms of voltage, transient voltage variations (flicker), thermal overloads, and reverse power flow to assess protection issues.

Maturity levels – Advanced Optimization



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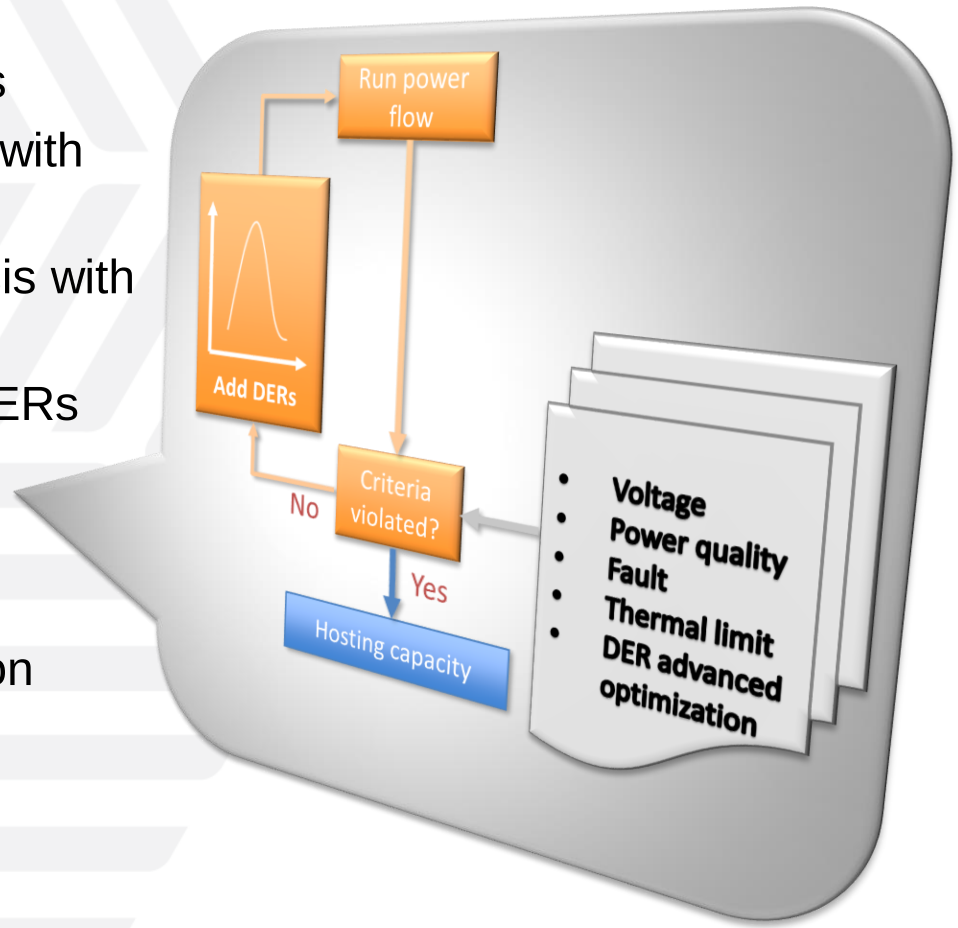
Dynamic Analysis

- A time-dependent response to some trigger or stimulus is simulated
- Analysis measures the oscillatory response, or how long it takes to return to a stable operating state after a system disturbance
- Primarily important in microgrids, planned-island systems, or “weak” grids.
- Not such an issue in large, high inertia systems
- Three variations:
  - Long-term dynamics
  - Electromechanical dynamics
  - Electromagnetic dynamics
- Dynamic analysis capabilities are offered in less than 50% of the tools studied for the GMLC project on distribution system analysis tools based on literature review

Distribution System Analysis with DERs

- Distributed Energy Resources (DER) analyses categories:
  - DERs and net load projections
  - Basic distribution engineering with DERs
  - Time-series power flow analysis with DERs
  - Advanced optimization with DERs
  - Hosting capacity and interconnection
  - Dynamic studies with DERs
  - Co-simulation with transmission systems



Hosting capacity and interconnection

- Integration of DERs may result in overcurrent, overvoltage, and miscoordination between protective devices
- Hosting-capacity studies determine the amount of DERs that can be accommodated without affecting feeder power quality or reliability
  - Four aspects: Voltage, power quality, protection and thermal limits
- Most existing modeling tools can do basic distribution engineering studies and time-series simulations with DERs

Hosting Capacity Analysis Capability	Percentage of DSA Tools
Time-Series Voltage Analysis	90%
Power Quality Harmonic Analysis	90%
Fault Analysis	100%
Thermal Limits Analysis	30%
DER Advanced Optimization Study	70%

Key Findings from GMLC Distribution Analysis Tools Report

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- Although most tools offer time-series power flow analysis, it is not widely used by utilities due to its nascence, relative complexity, and the lack of time-varying data available
- Dynamic studies will become increasingly important with higher levels of DERs to investigate whether control systems can maintain voltage and frequency when subjected to disturbances
- Some utilities are requiring DER inverters to absorb reactive power or curtail power output in response to high voltage, but the use of these smart inverter functions in installations is not predominant in the industry
- While traditional load forecasting is a mature field, DER forecasting –as a precursor to forecasting net-load profiles – is a relatively immature field of study.
- DSA tools are general capable of conducting four types of analyses for hosting capacity studies, but often require the addition of external scripts to automate the considerable amount of analysis undertaken in such studies.

Nascent areas and gaps

1. Projecting growth of types and locations of DERs
2. Developing and validating an accurate distribution system model
3. Interactions between the distribution and transmission systems
4. Advanced optimization studies for DERs with storage systems
5. Automation of hosting capacity / interconnection analysis, including workflow management aspects
6. Multiple DER anti-islanding studies
7. Simulating microgrids with custom controls
8. Inverter modeling for volt/var control
9. Support for holistic planning for sensing and measurement devices: Types, number, and location

Model Validation Case Study

A key use of distribution level measured data & modeling tools

Emma M Stewart

Outline

- What is model validation and why is it important?
- Terminology
- Transmission validation task force – outcomes that are relevant and not relevant to distribution
- How inaccurate can it be before we have a problem?

Definitions of “Model Validation, Verification & Calibration”

- Model Validation
  - Process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model
- Model Verification
  - Determining that a model implementation accurately represents the developers conceptual description of the model and the solution to the model
  - Find errors in the model by comparing numerical solutions to analytical or highly accurate benchmark solutions
- Model calibration:
  - Input of values to set a baseline for analysis
- Software V & V very different to model – predictive accurate model is the end output to model verification, not solution code
- Goal: System model that can reasonably represent incidents and power systems phenomena to within a degree of confidence for operations and planning

Problems with transmission model validation: NERC Case Study

- High value issues and incidents highlight need for validation and verification in transmission
- Industry should make periodic model validation and benchmarking an integral part of offline study model maintenance
- Industry should validate operation (offline) planning models by comparing them with models developed from real time data
  - Requires data standardization, and exchange formats
- Time synchronization of measurement devices needs to be improved such as EMS, SCADA etc
- Three areas of interest
  - Transmission system line and substation components
  - Generating units
  - Load
- Criteria for passing is not absolute perfection: Passing to a level of sound engineering judgment is recommended

What is of interest (to transmission)

- Steady state validation
  - Accurate impedances and ratings
  - Real and reactive power capability of generators
  - Load, constant impedance, current etc
- Dynamic validation
  - Time constants of devices from ms to s
  - Controls, governors
  - Dynamic load components
  - Power electronic devices

Translation to distribution model problems in validation, calibration and verification

- Need for a proactive approach to distribution model validation
  - Transmission was in response to incidents, build a distribution system model validation process from lessons learned in transmission
- Challenges:
  - Unbalanced non-symmetrical systems, harder to solve
  - transmission assumption (R/X ratio not true)
  - More components
  - Dispersed load, many dynamic types
  - Less measured data, time synchronization, more time series changes
- Operations models in early stages of implementation
  - Create a process to validate planning and operations models concurrently

Partner Utility: Public Utility in Southern CA

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- Publicly Owned Electric and Water Utility
- Population - 311,896
- Service Area - 82 square miles
  - Substations – 14
  - Transmission Lines – 91 Circuit Miles
  - Distribution Lines – 1,323 Circuit Miles
  - Electric Meters – 107,500
- Record peak demand of 612 MW on 9/14/2014
- 2014 – Total of 13 MW installed PV
- 2015 – Anticipating >10 MW of new PV
- Limited visibility into distribution system and a number of known validation issues, including lack of knowledge of minimum load conditions, and imprecise knowledge of impedances and topology

Risks of un-validated distribution system models

- Unnecessary capital expenditure, barrier to increasing renewable penetrations
- Real world example
  - "during the system impact study we found the 1 MW PV site would cause flicker at a number of large customers, mitigation solutions presented cost $1M +"
  - Result of study 1
    - 1) second study (extra cost)
    - 2) large expenditure or
    - 3) no-go decision
- What happened
  - 2nd consultant re-did the study and investigated the data sources fully (distribution model, source impedance representing the transmission, modeling technique used), found these were mostly unvalidated, no data, or very best guess estimates
  - Less costly solution proposed to mitigate risk and increase comfort level of utility, making use of full dynamic range of inverter capability
  - Measurement devices were installed to ensure the flicker issue would be "seen"
  - The site was approved and interconnected with the less expensive solution…no flicker issues were reported
- Lessons learned
  - Validate & calibrate models
  - Use the correct tools for the issue

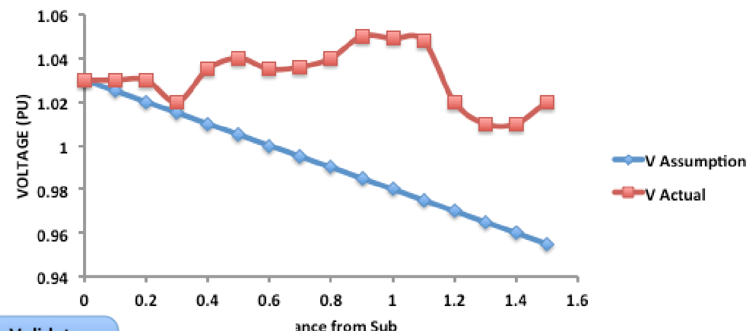
Operational vs. planning models

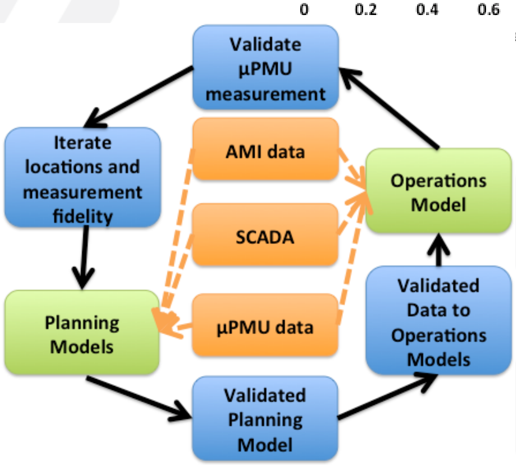
- Generally separate models and software packages
- Distribution planning and operations models often both extracted from GIS
- Planning need a validated model baseline to forward plan to system for years to come – need to start from a relatively accurate point
- Operations need a validated model to respond to outage and day to day conditions
- Need a better process for them coming together
  - Planning on a shorter time frame
  - Operations on a longer time frame with more automation and control

Distribution has more non-symmetrical variables

Feature	Transmission Electrical Characteristics	Distribution Electrical Characteristics
Overhead Conductors	Impedance, kVA rating	Spacing, Phasing, Height, Conductor
Underground Conductors	Unlikely, Impedance, kVA rating	Spacing, Phasing, Conductor/Cable Type, Thickness
Conductor Data	Geometric Mean Radius (GMR), Diameter, Resistance, Ampacity, Failure Rate	Geometric Mean Radius (GMR), Diameter, Resistance, Ampacity, Failure Rate
Voltage Regulators	Impedance, kVA rating, voltage rating, losses	Potential Transformer Ratios, Current Transformer Ratios, Compensator Settings, R and X
Transformers	Capacity (KVAR), Control	KVA rating, voltage rating, Impedanace (R, X or %), Iron Core Losses
Capacitors	Impedance, kVA rating	Capacity, Phasing, Control type
Switches		Type, Capacity
Protection		Settings

Model Validation with Improved Data

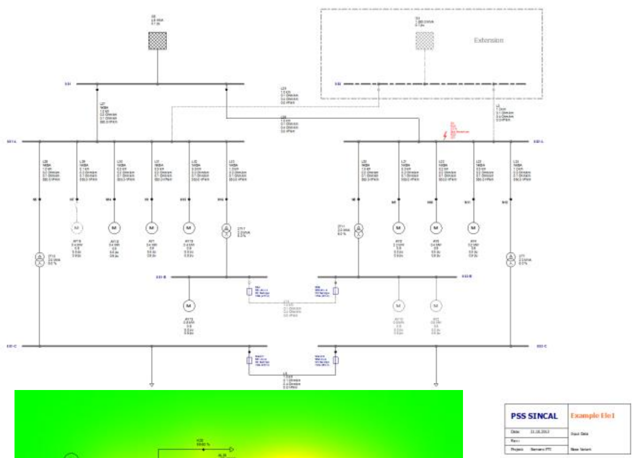


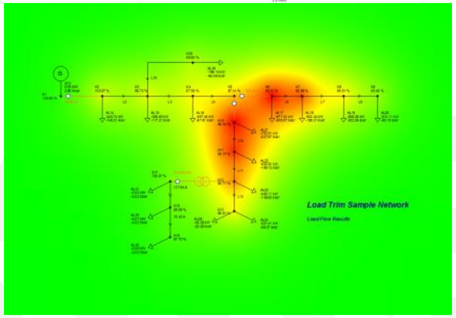


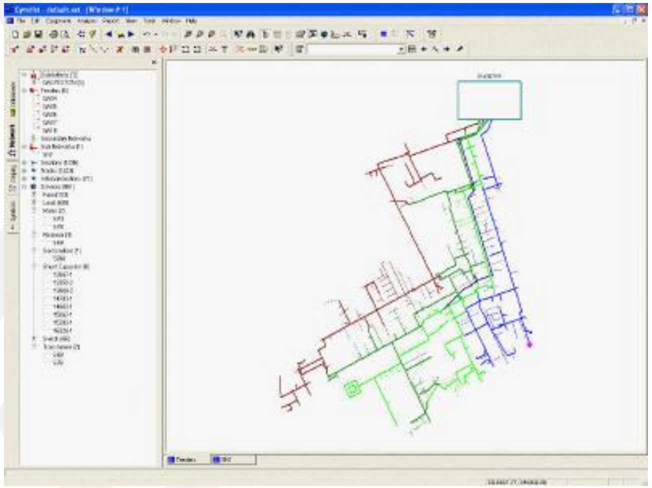
- We often model and assume distribution lines flow (top graph) and voltage is represented by the blue line
- In reality it looks like the red line
- Distribution model may have been constructed assuming traditional flow (all one direction)
- Current and future needs more fidelity at line and phase level

Visualization, GUI's and Results Presentation

► Features: Topology or Schematic/One-line?



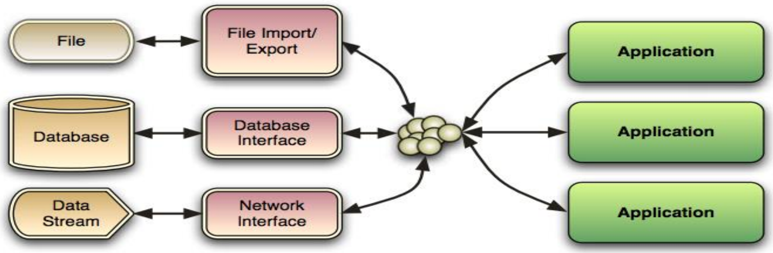




- **Presentation of results graphically or tabular?**

Data Standardization

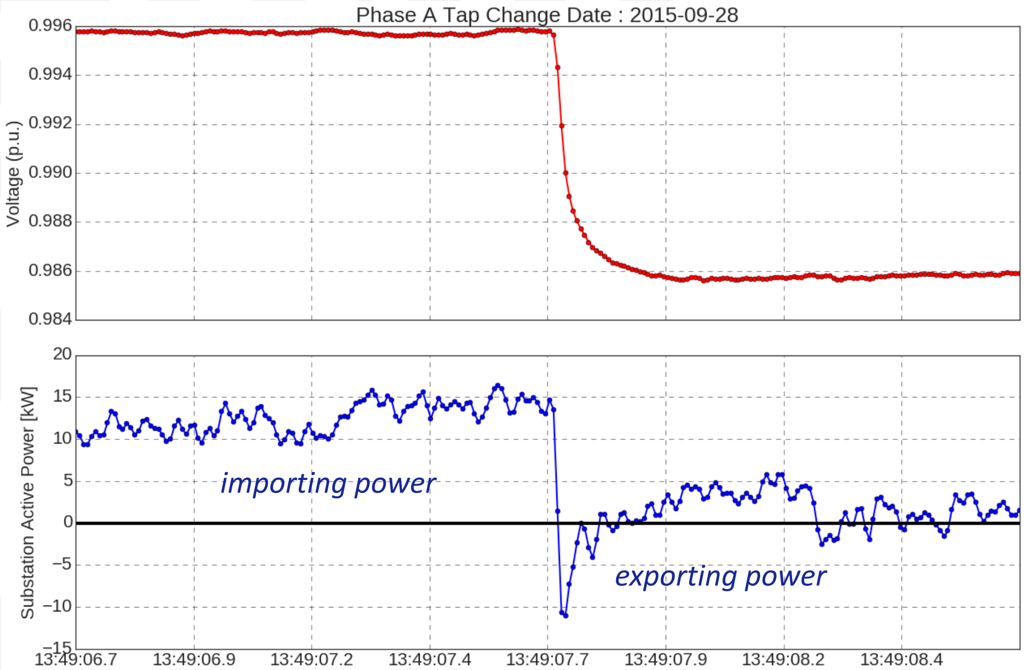
- CIM: Common Information Model
  - Defines the structure of data in a logical model
- Originally for the exchange of data between EMS and GIS
  - Enabling the integration of network models at both transmission and distribution levels
  - Expanded to include distribution extensions
- Does not include all data required for increasingly complex analyses on distribution systems, but can be extended for use cases and further development



Use cases: Feeder and load model validation Reverse power flow detection

Example: ascertain impacts of voltage regulation with hi-pen DG

- 1.2% step down in voltage
- significant drop in kW due to highly voltage dependent load
- high-penetration solar PV feeder goes from net kW import to backfeed



Ciaran Roberts and Emma Stewart, Lawrence Berkeley National Lab

Distribution Modeling Tools & GIS Systems

Questions and Considerations for PUC Staff and Utilities

Michael Coddington

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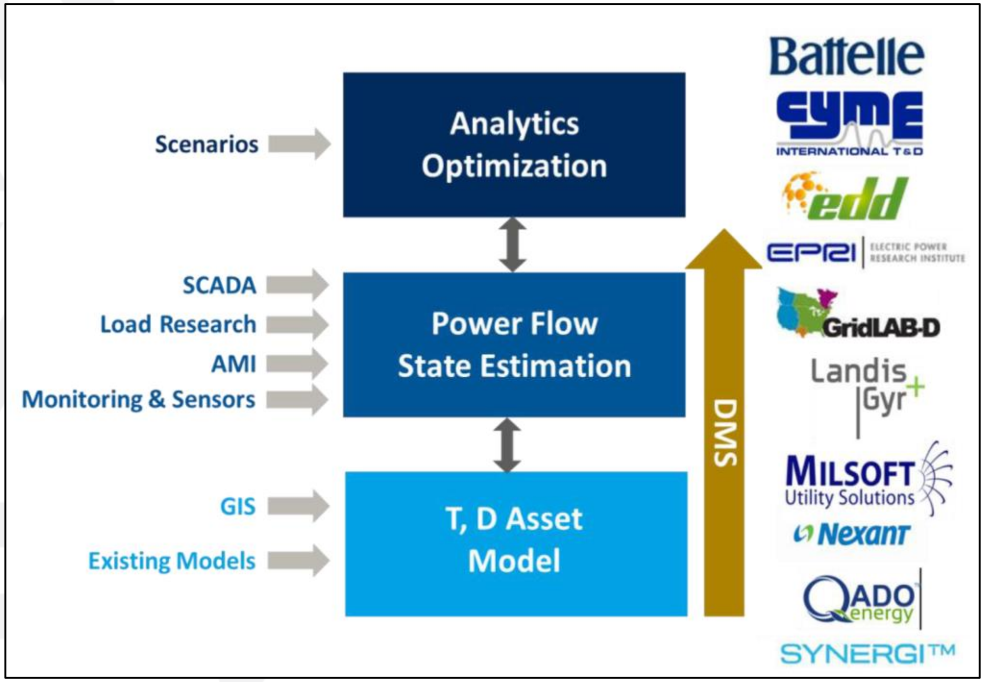
Distribution Modeling Tools - Observations

Larger utilities typically use the following (with exceptions):

- CYMDIST (power flow)
- Synergi (power flow)
- ASPEN (protection)
- DEW (power flow)
- Others….

Small-Medium utilities typically use

- Milsoft Windmil (power flow)
- Milsoft Light Table (protection)
- Others….
- Consultants



Modeling software can be a very large investment, as is trained staff, thus utilities are typically hesitant to change platforms!

Larger utilities have teams of model experts, while smaller utilities rely on institutional knowledge or third parties

Other Notes on Distribution Modeling Systems

- Most utilities have a Geospatial Information System (GIS) in place, where they track their distribution lines, transformers, customers, substations, and sometimes the DER (like PV) systems.
- GIS departments only update GIS systems to track any system changes
- Modeling platform users “Extract” the GIS data and then run the model

- Thus, it is critical to have a high-quality GIS system which is accurate

GE Smallworld

esri

Basic Questions for PUC Staff Related to Utility Distribution Mapping & Modeling

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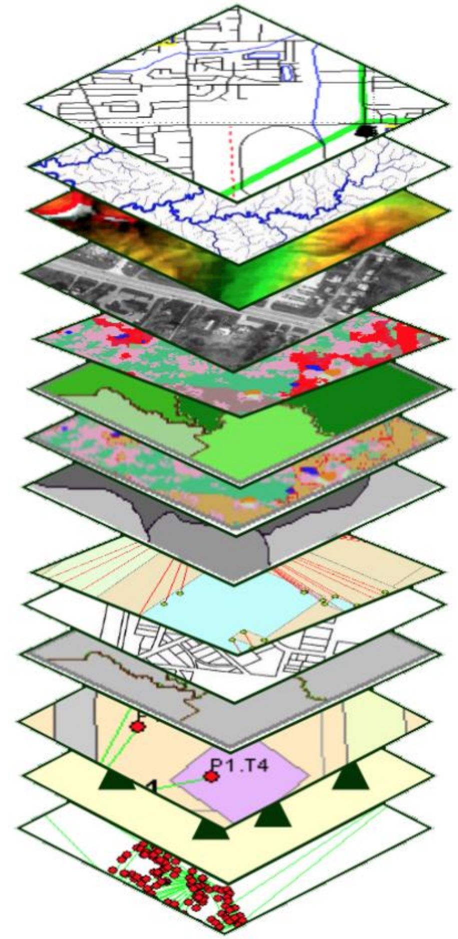
- What GIS platform has the utility invested in?
- How many staff are dedicated to updating or cleaning GIS models?
- How accurate is their system?
- What updates are planned?
  - Adding secondary wires?
  - Adding load points (customers)
  - Adding DERs?
- What is the lag time between construction/changes and GIS updates in the system?
- Are phases identified correctly?
- *Is the GIS system obsolete? What is the cost of replacement?*



Source: EPRI GIS Interest Group

Basic Questions for PUC Staff Related to Utility Distribution Mapping & Modeling

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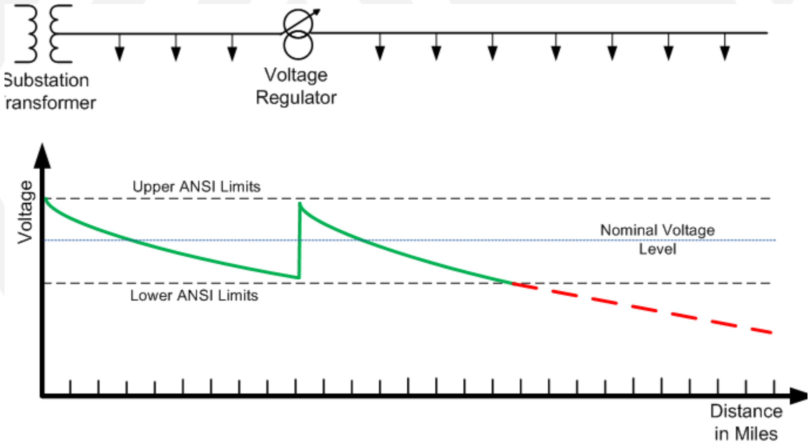
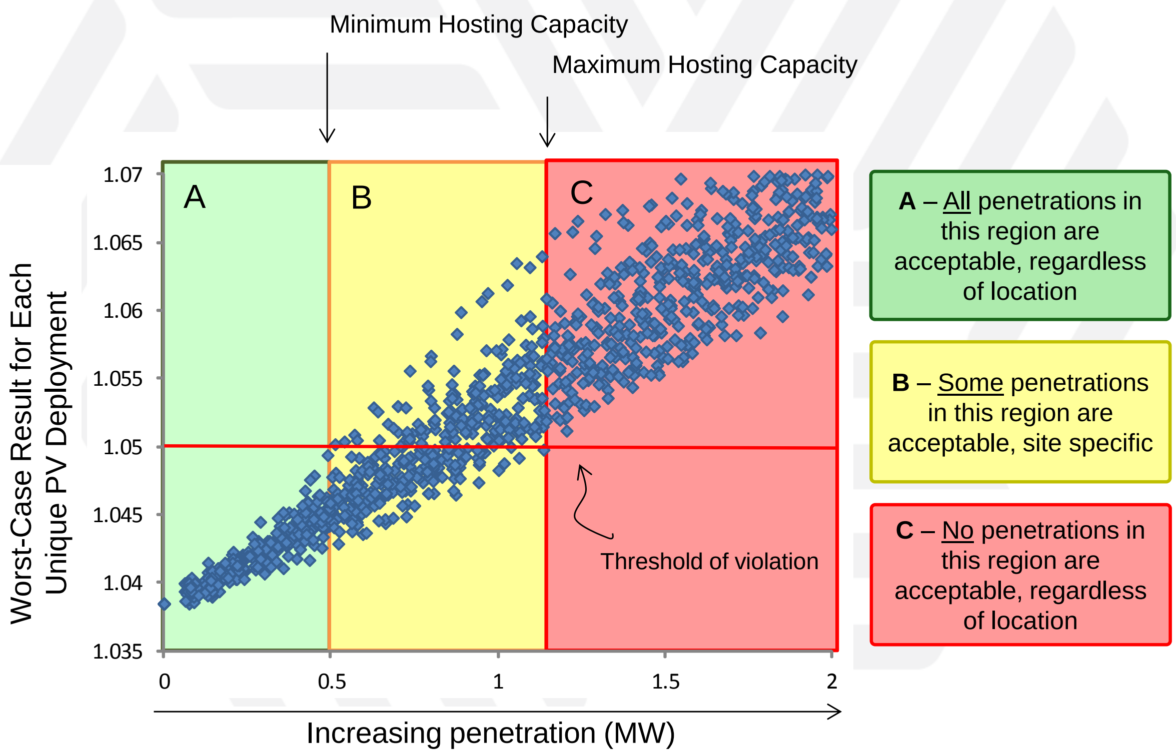
- What power flow modeling platform does the utility use?
- How many staff use this platform?
- What modeling platform is used for protection coordination? (i.e. fuses, circuit breakers)
- How often does the power flow model extract data from GIS?
- Are DERs modeled in power flow?
- Are DERs tracked for combined analysis?
- Is the utility prepared to model advanced inverters?



Other Distribution Modeling Questions

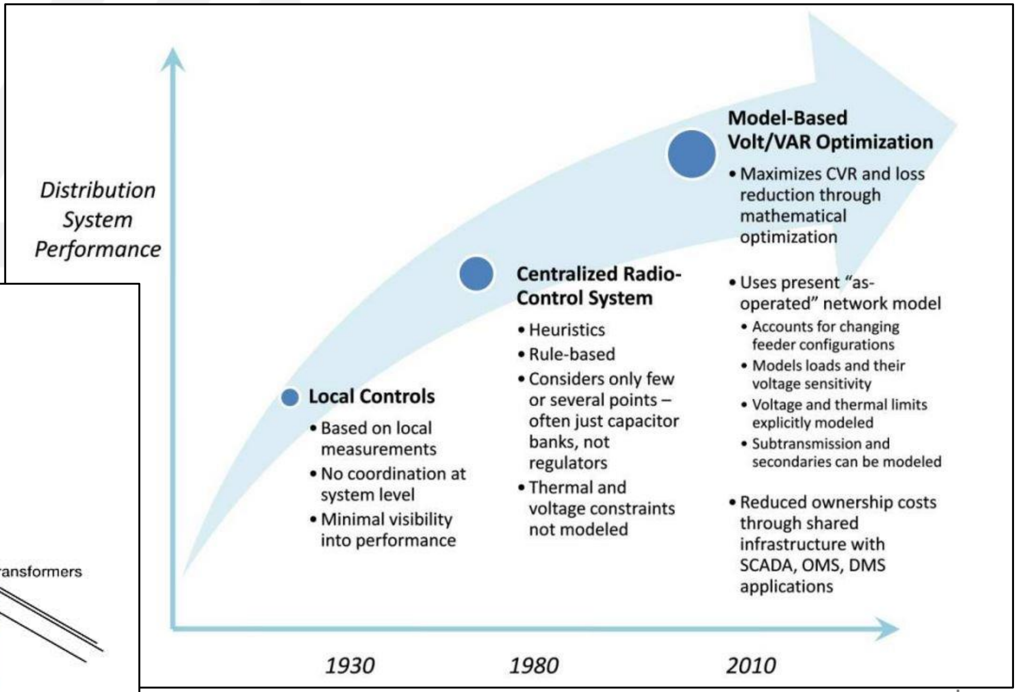
- Does the utility use any type of "Hosting Capacity" metrics on distribution circuits?
- Are there defined limits of DER hosting capacity based on location, load, voltage or just policy?

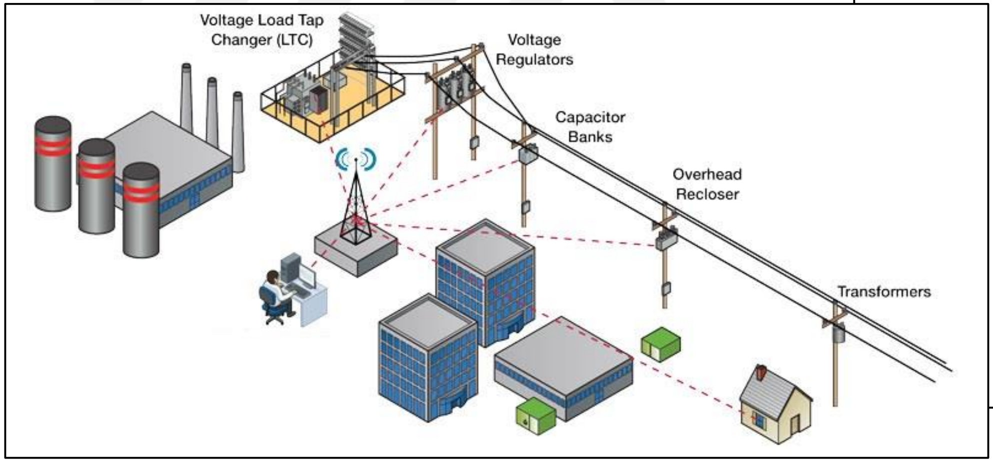


Source: EPRI

Other Distribution Modeling Questions

- ► Does the utility pursue a Volt-VAr Optimization (VVO) strategy?
  - If so, how do they use power flow models to assist them?
  - Does a VVO strategy impact the operation of other devices such as capacitors, voltage regulators, or substation load tap changers (LTCs)? If so, do the models allow that to be simulated?





Source: NEMA "The Value of Volt/VAr Technologies"

Thank You

Resources

- ► DSPX Volume II - Modern Distribution Grid – Volume II Advanced Technology Maturity Assessment
- ► Summary of Electric Distribution Planning Analysis with a Focus on DERs. Tang et al. 2017 GMLC Report
- ► Note: Other platforms of interest include CymDist, Synergi, Milsoft Windmil, OpenDSS (R&D), GridLab-D, DEW, ASPEN (protection)