NARUC
National Association of Regulatory Utility Commissioners

NASEO
National Association of State Energy Officials

NARUC-NASEO Initiative: Comprehensive Electricity Planning for Load Growth

Virtual Learning Session: Distribution System Models and Modeling Assumptions

July 1, 2025 3:00 - 4:30 pm ET

Hosts: Danielle Sass Byrnett (NARUC), Kirsten Verclas (NASEO)
Lisa Schwartz (LBNL)
Zoom support: Jessica Diaz (NARUC)

Agenda

- 3:00-3:05 p.m.: Welcome & introductions
- 3:05-4:05 p.m.: Expert presentations and Q&A
    - Enrique Chacon, Electric Power Engineers
- 4:05-4:25 p.m.: Small group discussions
- 4:25-4:30 p.m.: Wrap-up & next session: Modeling

Distribution Planning Modeling Tools and Processes

NARUC / NASEO Comprehensive Electricity Planning

Enrique Chacon, Electric Power Engineers

July 1, 2025

This work was funded by the U.S. Department of Energy, Office of Electricity, under Contract No. DE-AC02-05CH11231.

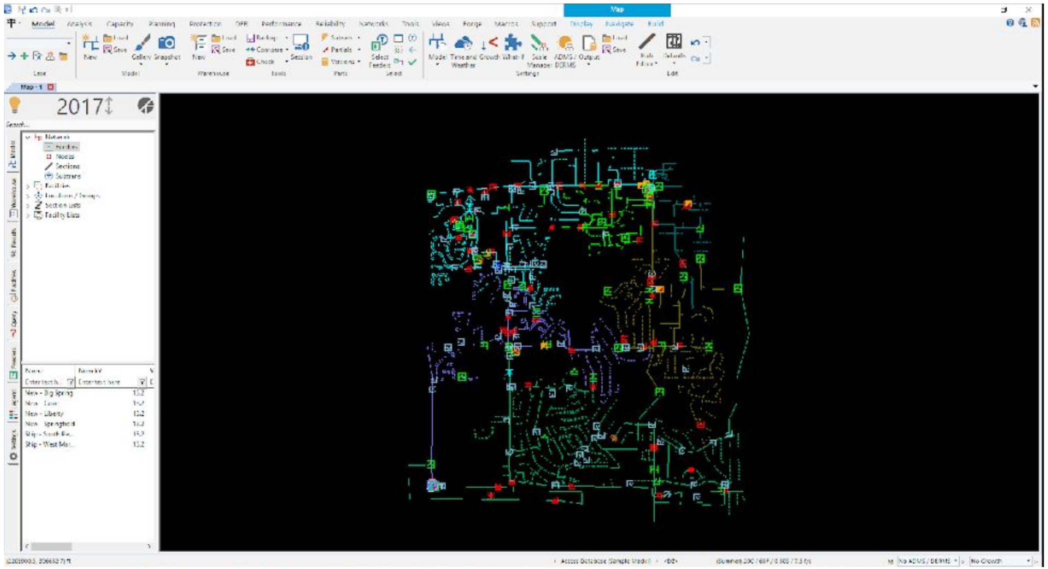
Agenda

- Introduction
- Inputs and Assumptions
- Tools and Methods
- Questions

Introduction

Distribution Modeling Overview

- Distribution Model (Power Flow Model): Digital representation of the distribution network's connectivity and demand
- The modeling process uses known/measured information to determine unknown values or to study the effects of proposed system changes
- Types of modeling
    - Distribution planning
    - Protection & coordination
    - Subtransmission / networks
    - Dynamics (emerging)
- Accuracy of the underlying models significantly impacts study results



Synergi Electric Sample Model and Interface

Distribution Modeling Tools by Purpose

Distribution Planning

SYNERGI™ ELECTRIC

cyme INTERNATIONAL T&D

MILSOFT Utility Solutions

DIGSILENT

DSS

Protection & Coordination

ASPEN

etap Powering Success

PSS®CAPE

Most planning tools also include protection / coordination

Subtransmission / Networks

PSS®E

PSLF

PowerWorld CORPORATION

PSS®SINCAL

Dynamic Models

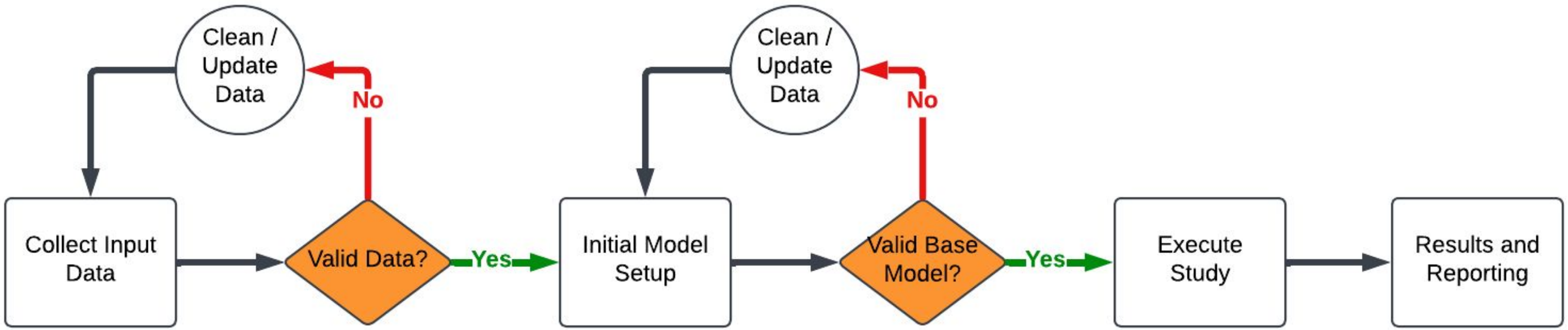
PSCAD

Distribution Planning Modeling Process and Resulting Studies

- Core Concept: Establish the baseline truth/state, and then make hypothetical changes to understand needs/changes

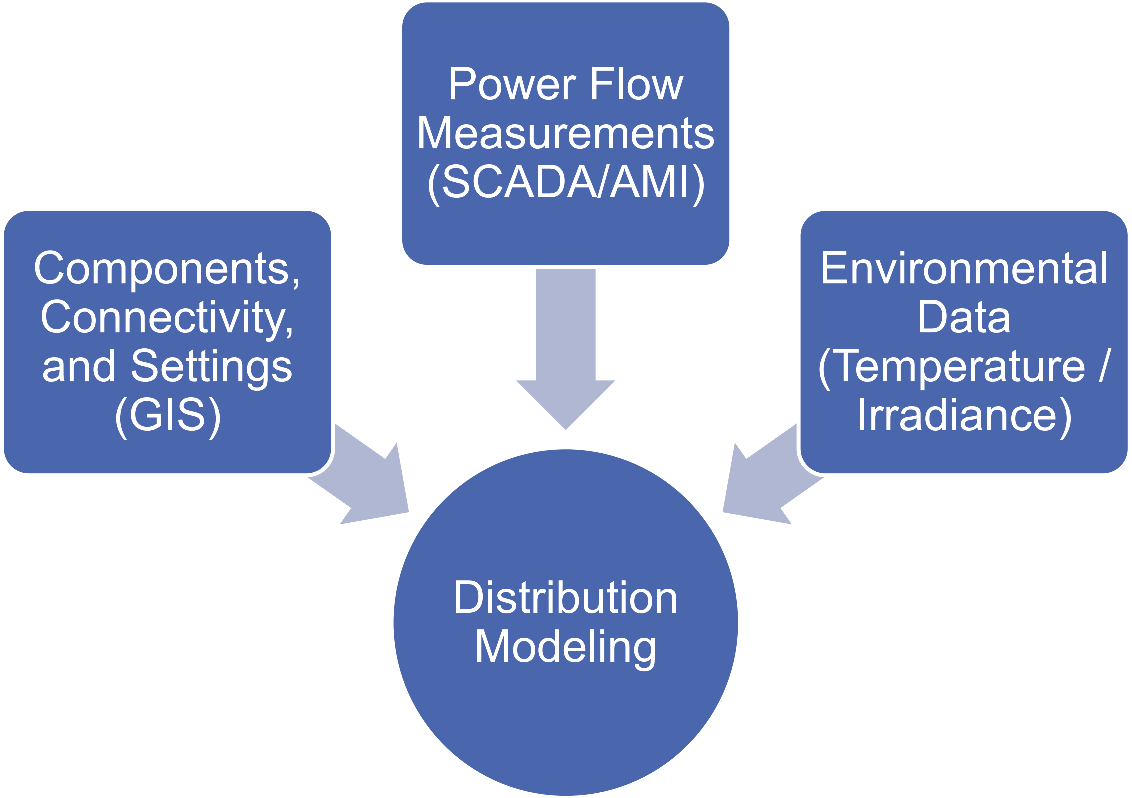
- Types of analyses where models are used
  - Voltage Drop / Power Flow
  - DER Interconnection
  - Contingency Analysis
  - Switching
  - Voltage Optimization

Modeling Process Flow



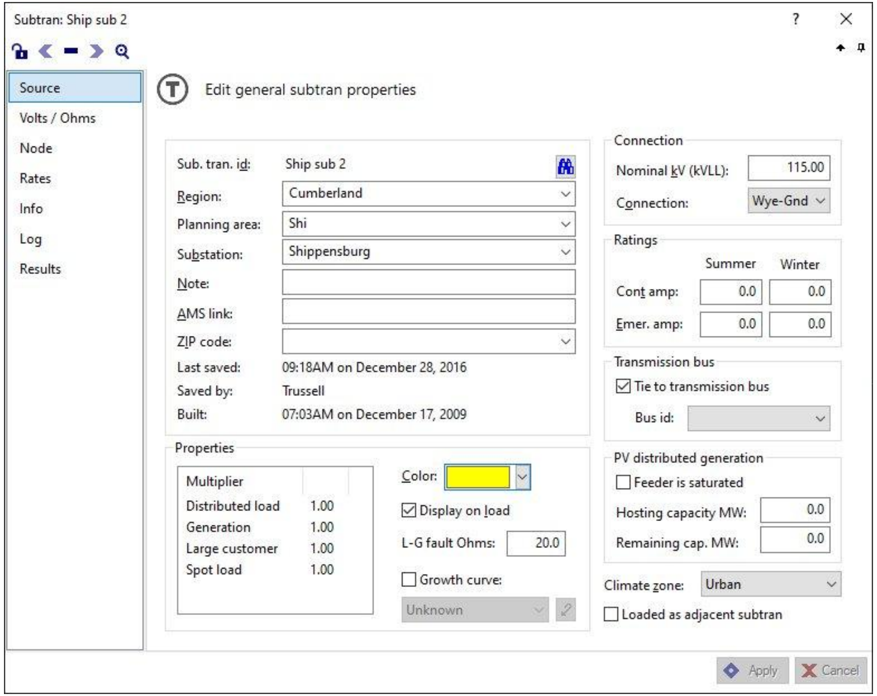
Inputs and Assumptions

Data Inputs for Modeling



Component Information

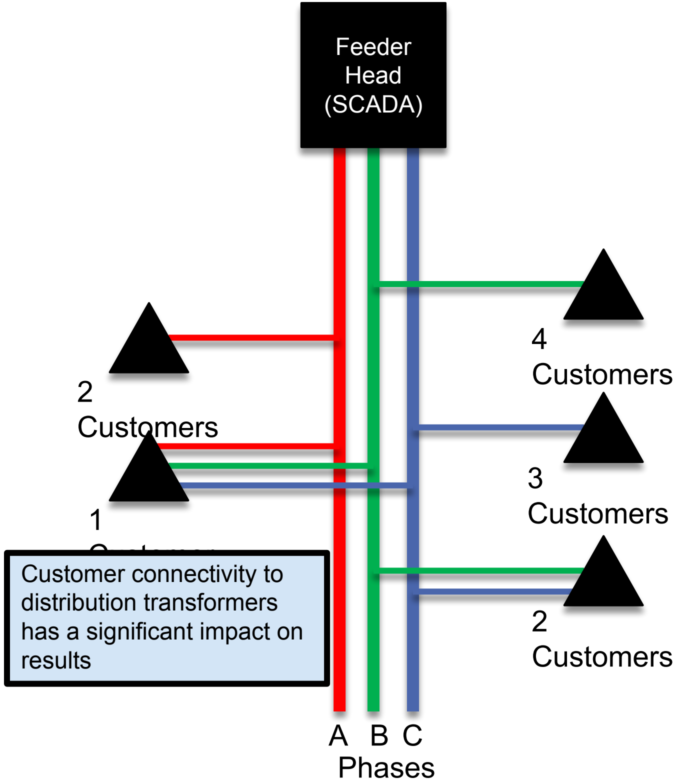
- Includes source(s), lines, devices, and similar components
- A Geographic Information System (**<u>GIS</u>**) can provide specific component **<u>type</u>**, **<u>connectivity</u>**, and **<u>location</u>** data
- Modeling softwares typically use an **<u>equipment database for</u>** component nameplate information such as **<u>ratings and impedances</u>**
- Engineers may model a transmission source and substation or a singular feeder node to represent the source
    - Source modeling can have a significant impact on study results (Thevenin Impedance, Voltage)



Synergi Electric Sample Model Source Settings Interface

Load Data Sources

- A Supervisory Control and Data Acquisition (SCADA) system can provide load and voltage measured at the substation and at line devices
- An Advanced Metering Infrastructure (AMI) system can provide customer metered demand data
- Forecasted load growth data is typically developed and maintained separately
- GIS can provide customer connectivity to the correct distribution transformer and phase
- Accurately modeling large customers with high demand is important because they have a significant impact on study results

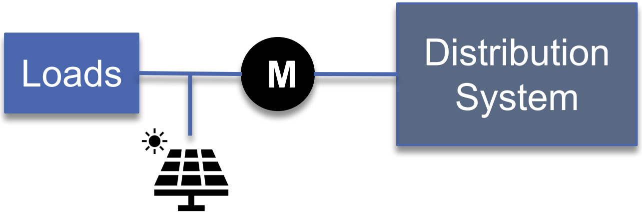


Modeling DERs

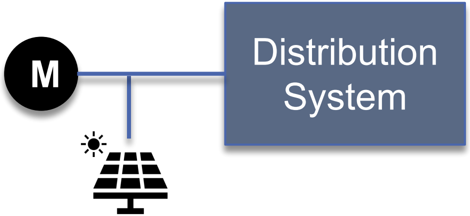
- DER generally modeled as stand-alone components in distribution models
  - Depending on utility conventions, may be modeled on primary (separate from load meter point)

- Modeling DERs is complex due to the <u>variable nature</u> of certain distributed generators — for example:
  - Solar generation will only produce when sunlight is available
  - Behavior of energy storage systems may be difficult to predict (depends on use case)

- Engineers must also consider and study DER impact on <u>fault current and protection</u>



[Actual Configuration]



[Common Model Configuration]

- Must be **<u>careful not to double count generation</u>** during model set-up
  - Generation embedded within meter data
  - Explicit DER model may be separate from meter

Model Source Interoperability

Middleware - Software to feed data and information from relevant sources into the model

- Modeling software vendors provide tools or scripts to pull data from multiple sources and translate into a viable model
    - e.g., CYME Gateway
- This can be a highly complex process due to the amount of data that must be transferred from different sources
    - GIS
    - SCADA
    - AMI
    - DER Application Management Solution

Tools and Methods

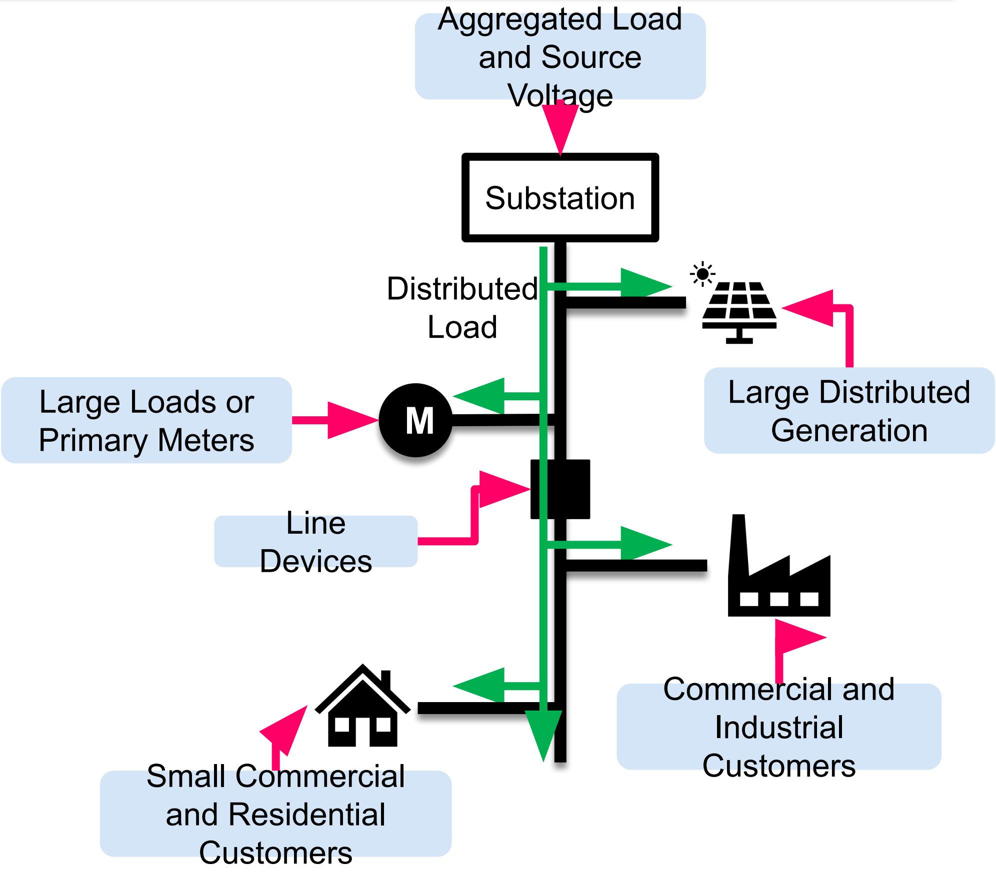
Model Setup

<u>Load Allocation</u>

- The process of distributing the measured load at the feeder head across the meter locations within the model to enable power flow studies
- Multiple methods using varying data sources
  - Connected Capacity
  - Billed kWh
  - Actual Demand (AMI)

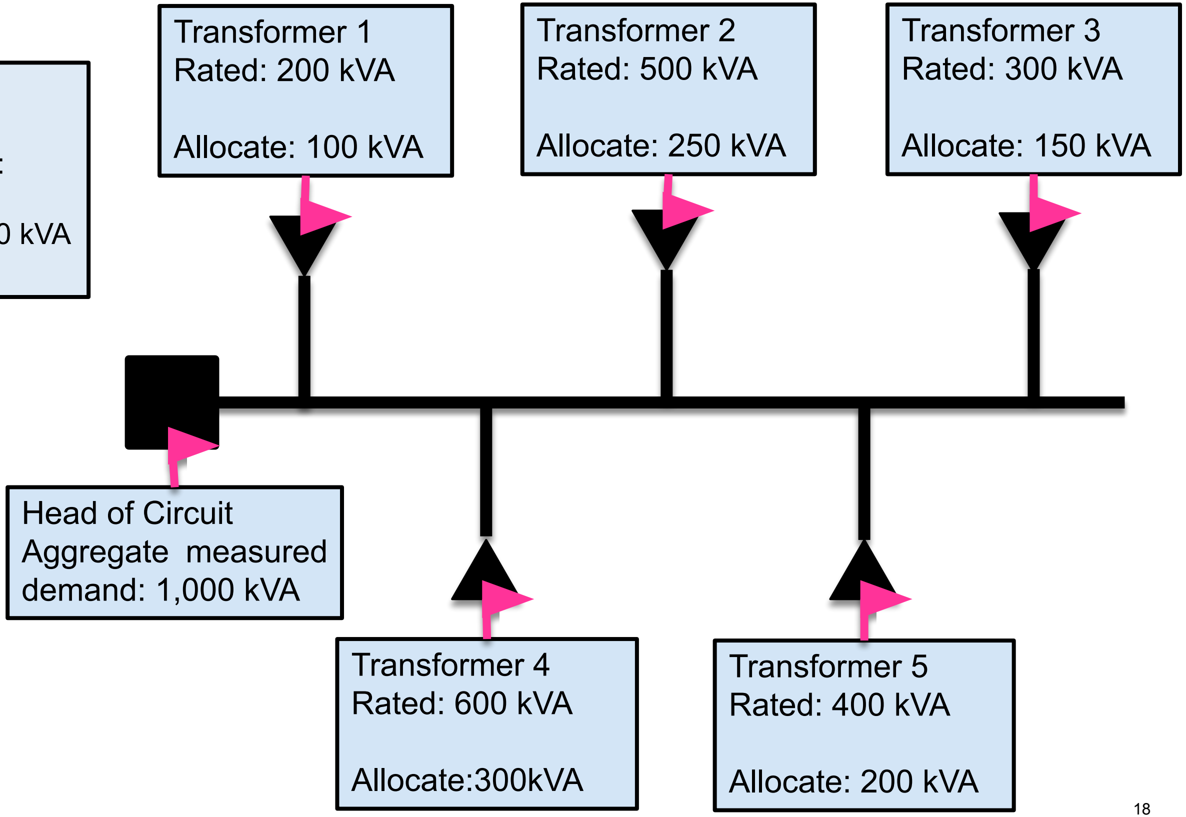
<u>Inputs</u>

- Load data at the substation / feeder head
- Source voltage
- Line distances, configurations, and impedances
- Settings for line devices
- Load data and/or factors for customers
- Types of customers



Load Allocation Method - Connected Capacity

Example: A simple circuit with 5 transformers and their ratings
- Circuit Aggregate Measured Demand: 1,000 kVA
- Aggregate Connected Capacity: 2,000 kVA
- Allocation Factor: 0.5



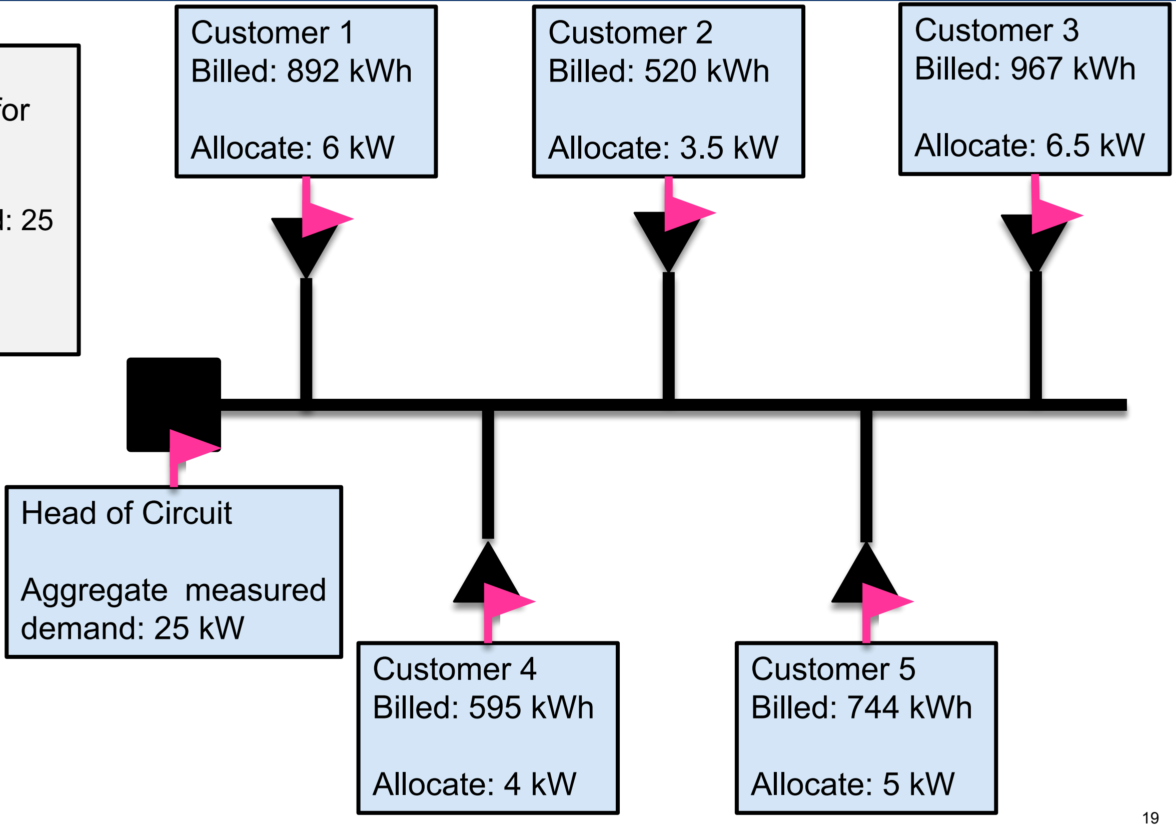
<u>Connected kVA</u>: Relative size of service transformer
<u>Demand</u>: Power delivered during modeled time snapshot

Load Allocation Method – Billed kWh

Example: A small circuit with 5 customers and their billed total kWh for the month

- Circuit Aggregate Measured Demand: 25 kW
- Hours in 31 Days: 744
- Allocation Factor: 0.5

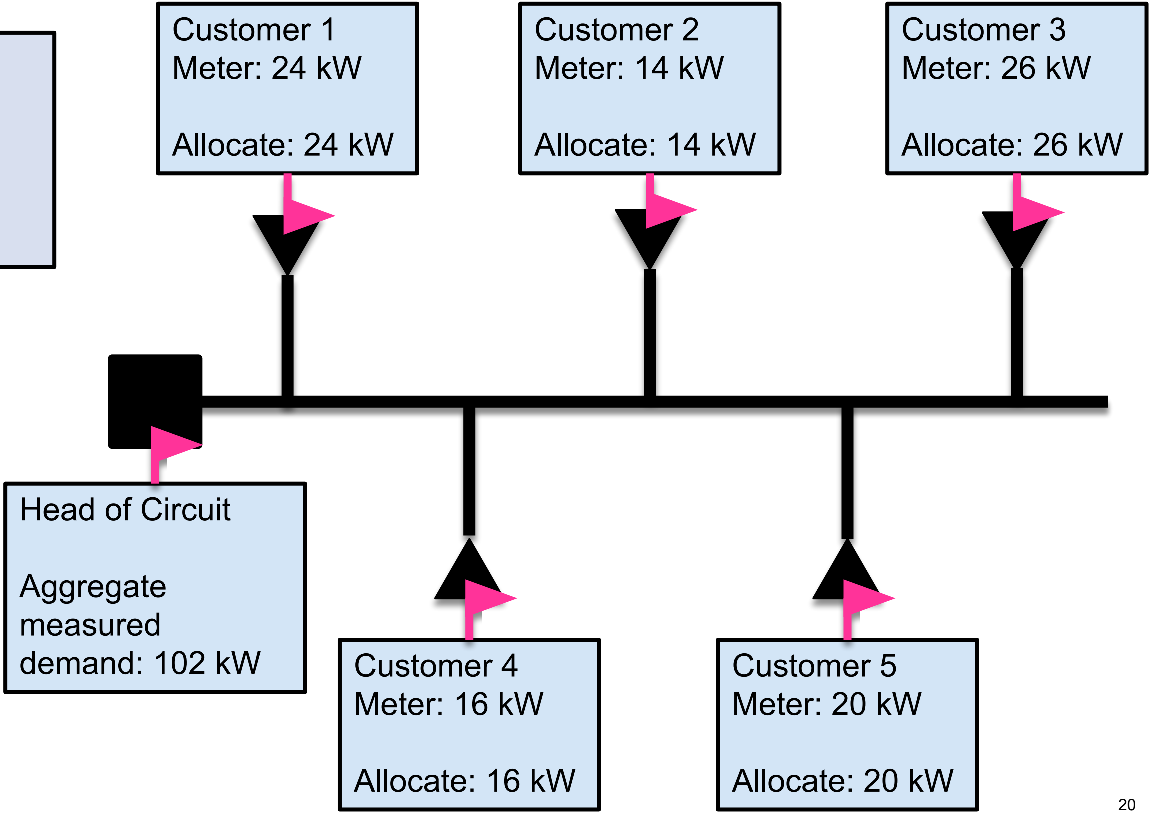
<u>**Billed kWh**</u>**:** Amount of energy used in one billing cycle
<u>**Demand**</u>**:** Power delivered during modeled time snapshot



Load Allocation Method – Actual Demand

Example: A small circuit with 5 customers and their metered demand

- Circuit Aggregate Measured Demand: 102 kW



Load Allocation Methods

Connected Capacity Method

- Demand measured at the head of the circuit is distributed across the circuit proportionally to the connected capacity with an applied load factor
  - Service transformer ratings often used as connected capacity values

- Limitations
  - Actual load is not always proportional to the transformer rating
  - Actual loading and customer energy consumption behavior varies across the circuit

Billed kWh Method

Demand measured at the head of the circuit is distributed across the circuit **proportionally to the amount of kWh consumed** at the relevant location

- Monthly customer **billed kWh data** often used due to availability
- Relatively good historical method for determining relative loading

Limitations

- Less effective for time-series analysis (no change in proportions)
- DER reduces accuracy

Actual Load Method

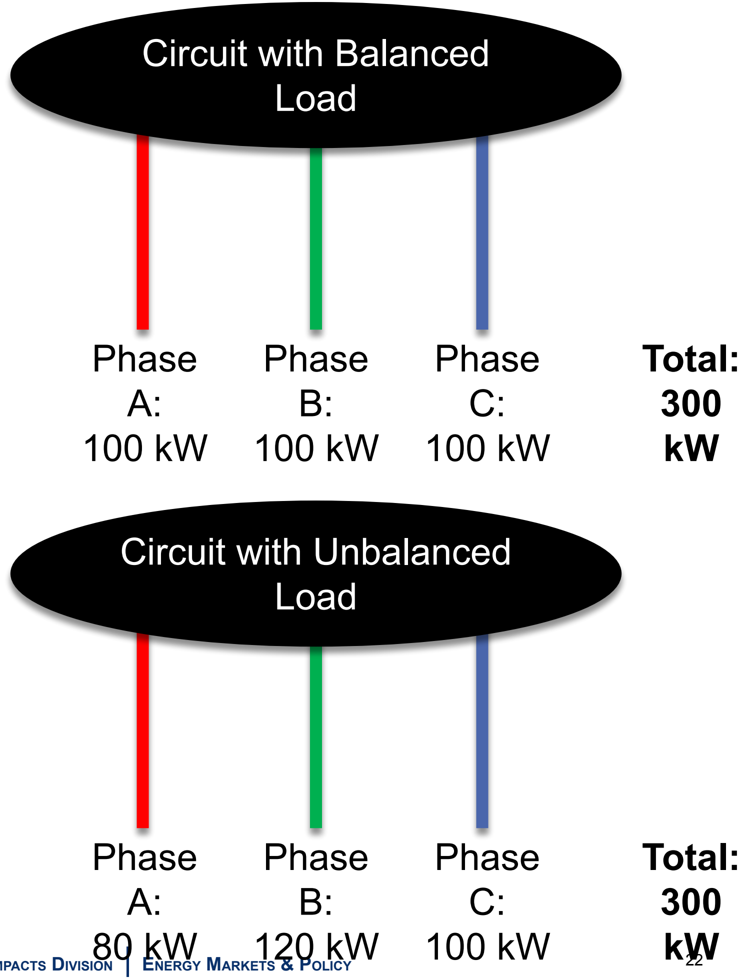
Demand is allocated to each load **proportionally to their metered demand** and adjusted for load factor

Limitations

- Requires **AMI interval data** and the ability to connect the interval database to the modeling software
- Potential to “overfit” – Actual snapshot is not necessarily representative of future conditions

Power Flow Analysis

- Power Flow
  - Power flow (also referred to as load flow) analysis is used to determine the voltages and currents during steady-state operation of an electrical power system
- Protection Analysis
  - Protection studies are based on the response to short-circuit conditions (fault current)
  - Includes protection device coordination and location studies, as well as arc flash studies
- Balanced vs Unbalanced Power Flow
  - Power flow can be performed using a balanced or unbalanced load
  - The distribution system is generally unbalanced, meaning the load across the three phases varies
  - Using a balanced power flow forces the system load to be balanced evenly across the phases
    - Used when GIS connectivity and phase mapping is unreliable
    - Does not properly represent single-phase laterals
    - Results are more conservative than for unbalanced power flow



Time Series Power Flow

Time-Series Analysis (576 / 8760)

- Power flow is run many times covering hourly variations over a year
- **More complex** to setup/analyze due to the volume and accuracy of data
- A **576 analysis** consists of two 24-hour days per month for a year
  - Monthly peak and minimum loading
  - Monthly weekend and weekday
- An **8760 analysis** consists of analyzing every hour of the year

Curtailment (MWh) Weekday Graph

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
12:00 AM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1:00 AM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2:00 AM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3:00 AM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4:00 AM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5:00 AM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6:00 AM	0.00	0.00	0.00	0.00	1.72	2.12	0.00	0.00	0.00	0.00	0.00	0.00
7:00 AM	0.00	0.00	1.19	11.63	11.36	12.38	7.15	5.26	1.60	0.00	0.00	0.00
8:00 AM	0.00	2.55	15.89	15.68	13.67	20.23	11.47	12.10	7.44	2.12	0.00	0.00
9:00 AM	0.68	5.44	23.24	22.61	14.90	19.09	14.37	13.19	7.85	3.36	0.00	0.00
10:00 AM	0.18	3.01	20.54	22.77	16.33	11.52	11.77	9.47	4.79	0.58	0.00	0.00
11:00 AM	0.00	1.63	17.71	20.44	18.19	10.63	9.00	8.92	3.26	0.09	0.00	0.00
12:00 PM	0.00	2.36	15.29	20.17	15.84	12.76	8.25	8.41	3.13	0.32	0.00	0.00
1:00 PM	0.00	4.62	19.13	21.45	13.30	15.50	4.47	8.59	5.60	1.67	0.00	0.00
2:00 PM	0.49	6.23	23.33	22.67	14.51	10.76	6.06	8.52	8.23	2.94	0.15	0.00
3:00 PM	0.00	3.91	20.78	20.31	9.27	11.76	4.38	7.05	5.36	0.49	0.00	0.00
4:00 PM	0.00	0.00	2.92	9.66	4.05	4.67	1.64	1.64	0.08	0.00	0.00	0.00
5:00 PM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6:00 PM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7:00 PM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8:00 PM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9:00 PM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10:00 PM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11:00 PM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Example of 576 Results Showing Hours and Amount of Curtailment of Flexible DER

Training Resources:

- Milsoft Distribution Modeling Training for Windmill: https://vimeopro.com/milsoft/engineering-and-analysis-ea-tutorials/video/461989054

- Utility engineering manuals and distribution planning standards

- Software Vendor trainings (generally only if software is purchased)

Q&A

Assumptions Within Utility Planning and Modeling

NARUC / NASEO Comprehensive Electricity Planning

Enrique Chacon, Electric Power Engineers

July 1, 2025

This work was funded by the U.S. Department of Energy, Office of Electricity, under Contract No. DE-AC02-05CH11231.

Overview

Distribution planning and modeling rely on and incorporate assumptions and results from other processes, including:

- Equipment Ratings – Assumed equipment thermal capacity ratings and their impacts on capacity planning

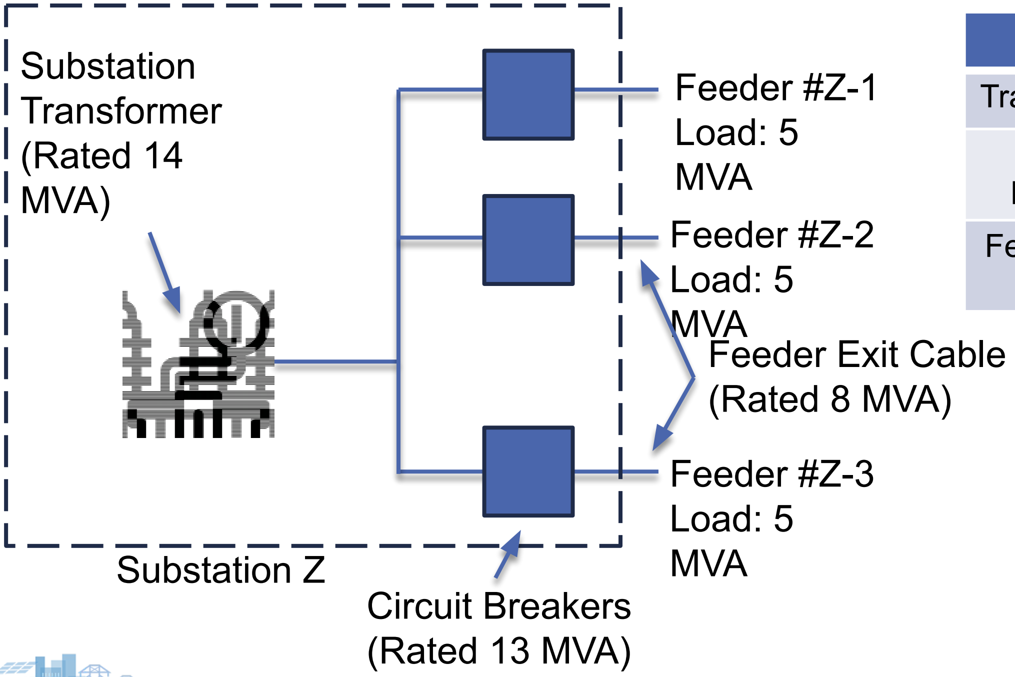
- Solar PV Performance & Capacity Impact – Estimating PV output profiles and their dependability as distribution capacity resource

- Distribution Load/DER Forecasting Allocation – Modeling techniques for translating adoption forecasts into specific locational circuit/substation impacts

Distribution Equipment Ratings

What is Distribution Capacity?

Distribution Capacity: The amount of **load** that can be supported before **equipment** exceeds its **rated value**



Asset	Rating	Load	Overload?
Transformer	14 MVA	15 MVA	Yes
Feeder Breaker	13 MVA	5 MVA	No
Feeder Exit Cable	8 MVA	5 MVA	No

How are Equipment Ratings Determined?

- Moving energy through equipment creates **heat**, which builds up, raising equipment temperature

- Equipment ratings are generally based on the **allowable maximum operating temperature** before significant degradation of performance or risk of equipment failure
  - Ex: 65°C Rating on Transformer Insulation
  - Ex: ANSI C57.91 Standard for Oil-Immersed Transformer and Regulator Ratings Calculations

- Equipment ratings (in units of MVA or Amps) are calculated based on factors that influence temperature rise and temperature withstand capabilities, such as:
  - Ambient Temperature Assumptions
  - Equipment Heat Dissipation Dynamics – Fans, Wind, Oil Circulation, Multiple Cables, etc.
  - Conductor Sag Limitations (for Overhead Wires)

- Rating Calculations vary by equipment type and are often stated by the manufacturer

Types of Equipment Ratings

- Many different ratings may be used for the same equipment by varying the calculation assumptions for different types of expected conditions

- Because heat builds over time, equipment ratings for limited durations can allow for higher ratings
  - Normal Rating: Loading level which can be sustained indefinitely without equipment damage
  - Emergency Rating: Loading level which can be sustained temporarily for specific durations during outage restoration or other contingency scenarios (ex: 2-Hr, 4-Hr, 8-Hr, 12-Hr, 24-Hr, 48-Hr)
  - Utilization and duration of emergency ratings vary significantly by utility

- Seasonal changes in ambient temperatures allow for corresponding seasonal ratings
  - Summer Rating: Rating developed using highest expected summer ambient temperature
  - Winter Rating: Rating developed using expected winter ambient temperature
  - Utilities with summer-peaking systems may not utilize winter ratings due to lack of historic need

Impact of Increasing Peak Temperatures on Equipment Ratings

- Extreme heat events are increasingly severe, with peak **temperatures** expected to continue **increasing** (See Right)

- Ambient temperature assumptions during summer peak may need to be adjusted, which will **reduce rated capacity**

- Ex: Duke Energy T&D Climate Resilience and Adaptation Report

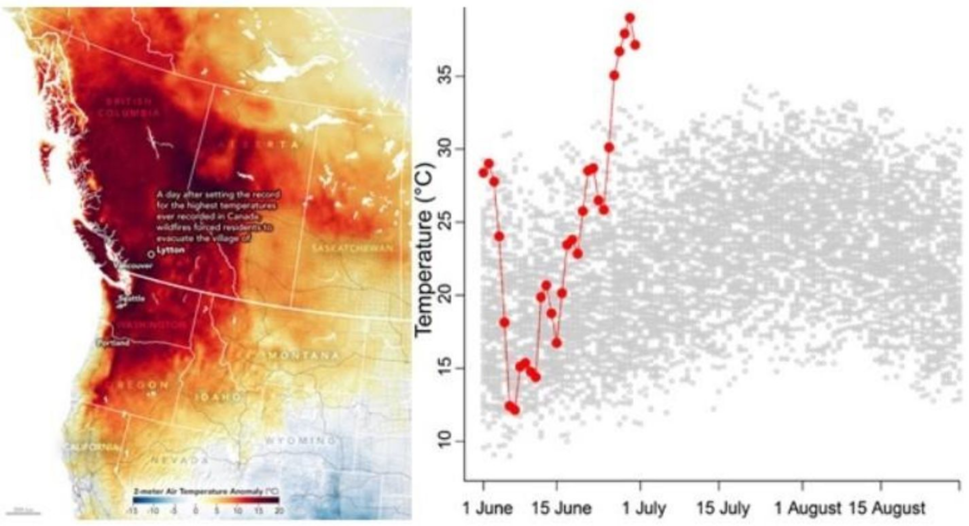


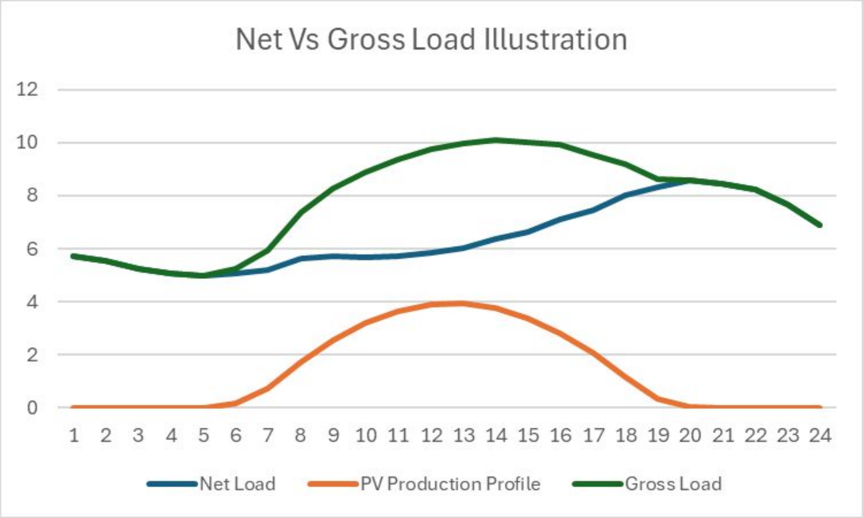
Figure1: (left) Temperature anomalies during the 2021 Pacific Northwest heatwave (NASA 2021) and (right) area-average temperatures in 2021 (red) compared to the period 1950-2020 (grey dots) in ERA5 reanalysis (plot by Erich Fischer).

Solar PV Performance and Distribution Capacity Impact

DER Impacts on Capacity Planning - Terminology

Key Terminology:

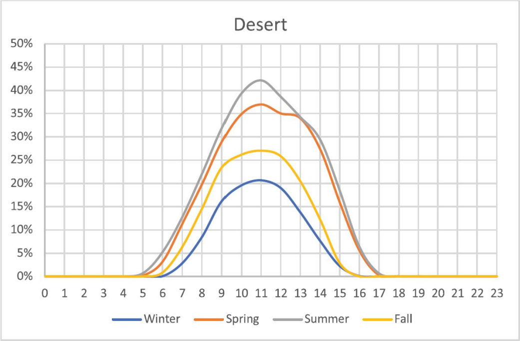
- Net Load:
  - Amount of load **measured** at a given point (e.g., feeder breaker)
- Hidden Load or Masked Load:
  - Amount of local **DER production** offsetting local loads that would otherwise flow through substation/feeder equipment
- Gross Load or Native Load:
  - **Total** amount of load operating, with estimated "hidden" or "masked" load **added back**
  - Gross = Net Load Profile + DER Profile



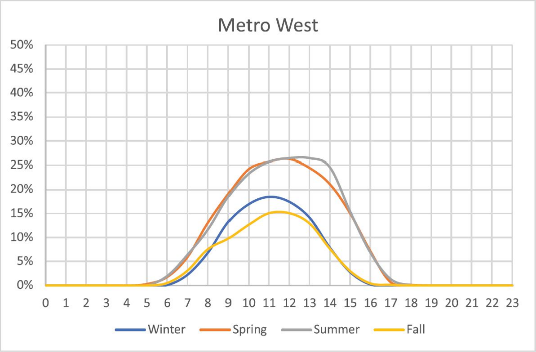
DER Capacity Planning Practices

- Typical Practice #1: Plan to Gross Load
  - In effect, assume no DER production at peak and no DER capacity contribution
- Typical Practice #2: Plan to Net Load
  - In effect, assume the current level of DER production will occur at peak in future years
  - Embedded DER capacity contribution
- Emerging Practice: PV Dependability
  - Estimate the degree of “reliable” PV production
  - Results in a non-zero capacity contribution if peak load occurs during daylight hours
  - Result: Planned Net Load or Planned Peak Load
  - Planned Peak = Gross Load - Dependable PV

Desert Region Seasonal Profiles



Metro West Region Seasonal Profiles



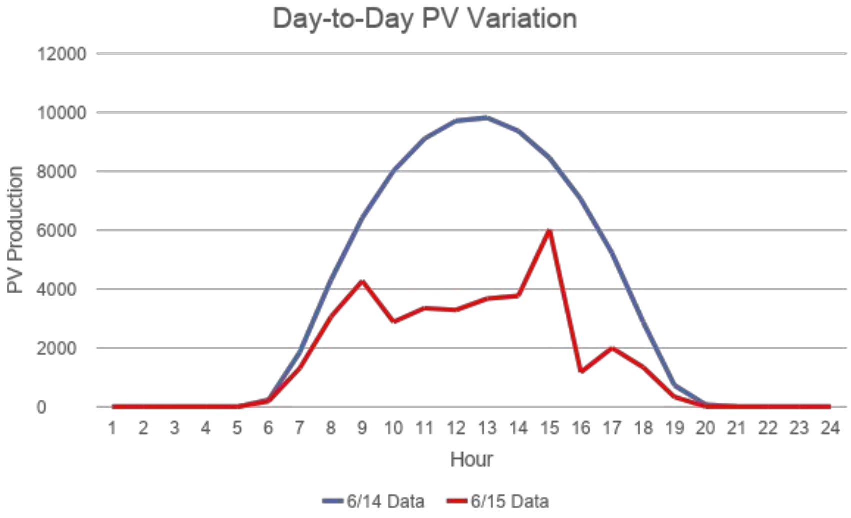
SCE Dependable PV Workpaper (Pg. 84-90): https://docs.cpuc.ca.gov/PublishedDocs/SupDoc/A2305010/7166/528468078.pdf

Input Data Sources, Assumptions, and Challenges

- Measured SCADA data or actual historical data is preferred where available

- Synthetic data sources such as NREL's PVWatts use "typical meteorological year" data, which are not synchronized with actual local variations in temperature/weather
  - Day-to-day variations may mis-align with actual production on peak days

- Granular estimates of PV performance from historical weather can be challenging (volume, locational specificity)

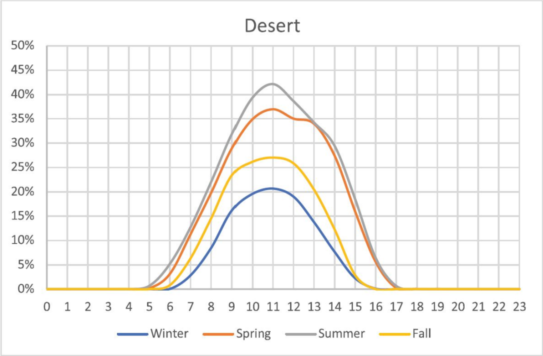


PV Watts Data Variability Illustration - Summer

SCE PV Dependability Methodology

- Uses actual measured behind-the-meter PV data to develop profiles
- Different Profiles by Geographic Region
- Hourly profiles by season – Summer, Winter, Spring, Fall
- Uses 10th percentile for PV performance in 15-minute increments

Desert Region Seasonal Profiles



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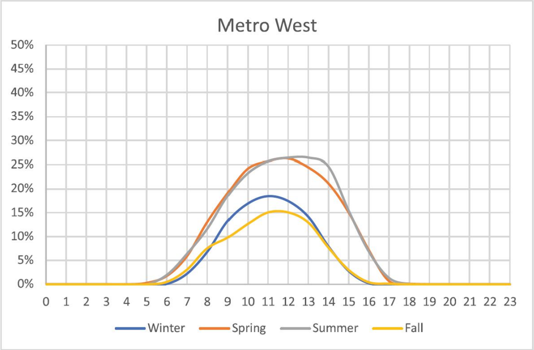

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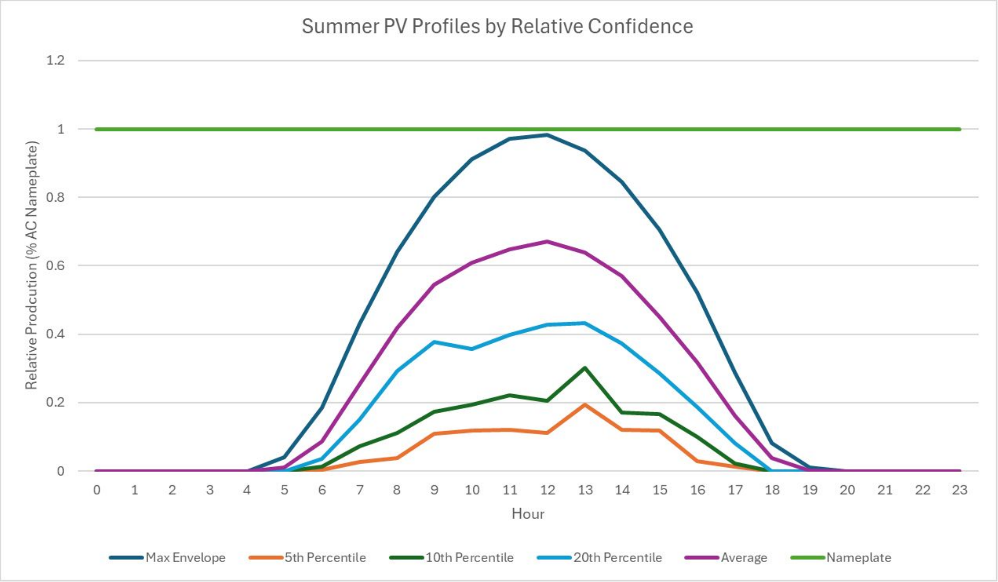
Dependable PV Profile Development - Percentiles

- Aggregate hourly PV profiles for the season by "hour"
  - Ex: Group all the "Hour 12" Values for all days from 6/1 to 9/31 for Summer Peak Calculations

- Calculate "percentiles" of performance (per unit) for each hour for varying degrees of dependability
  - 10th Percentile (Used by SCE Methodology)

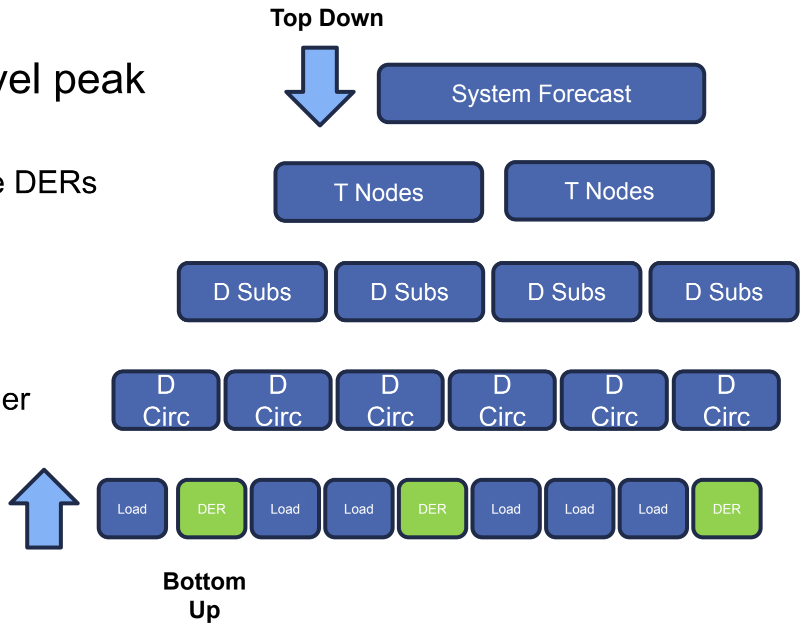
- Use by scaling per unit performance for individual feeders/substations based on total nameplate PV



Distribution Load and DER Forecasting Allocation

Translating Top-Down Forecasts to Feeder/Substation Impacts

- Transmission: Typically uses a top-down system-level peak load allocated to transmission nodes
  - The top-down ISO or corporate forecast might or might not include DERs
  - Coincident forecast with various assumptions (weather, EV, etc..)
- Distribution: Typically uses local load forecasts
  - The bottom-up forecast typically includes new known local customer business load growth and might or might not include DERs
  - Peak Forecasts are Non-Coincident with weather assumptions



DER Disaggregation Techniques

Source – Forecasting Load on Distribution Systems with DERs

Proportional Allocation

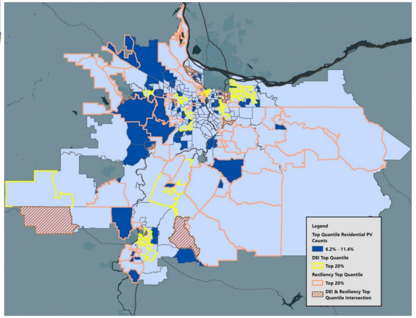
- Allocates system-level DER forecast to individual circuits using specific local distribution data
  - Proportional to Load
  - Proportional to # of Customers
  - Proportional to Existing DER
- Another approach is to use adoption patterns of one technology (e.g., PV) to drive adoption for another (e.g., energy storage)

Propensity Models

- Propensity models use customer characteristics to compute a propensity score. Based on the score, a fraction is computed as the ratio of the score for that area divided by the sum of scores across all areas.
- For example, the propensity model can be estimated using ZIP code data where the models relate historical adoption to customer characteristics in each ZIP code.
- Statistics- based (Regression and ML)

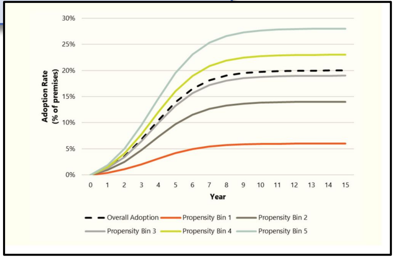
Adoption Model

- This uses a bottom-up adoption approach based on adoption patterns and estimated adoption model parameters.
- These models are S Curve-based. They forecast technology adoption based on characteristics of early adaptors, market factors, and adoption rates, applied to the remaining potential.

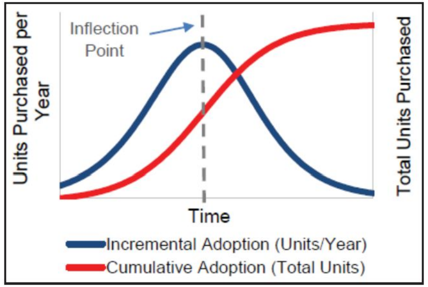


Solar PV Locational Adoption PGE

Source PGE Load and DER forecast



PGE Propensity Scoring Results



Generalized S-Curve Model

Source SCE DFWG Progress Report

Q&A

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Breakout Rooms

- Two breakout room options
  - Modeling Tools
  - Assumptions in IDSP Modeling

- Once breakout rooms open, please click ‘join’ next to the option you would like, and you will be taken to your breakout room

Next Session

Transmission planning models & assumptions

August 5, 2025 3:00 - 4:30 pm ET