SMART-DS: Synthetic Models for Advanced, Realistic Testing: Distribution Systems and Scenarios

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Team

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MIT: Claudio Vergara, Pablo Dueñas, Max Luke, Vivian Li

IIT-Comillas: Carlos Mateo Domingo, Fernando Postigo, Fernando de Cuadra, Tomás Gómez

GE grid solutions: Mohan Vinoth, Sree Kadankodu

Data Partners: Pepco, Duke Energy, APS, SCE, City of Loveland, Pedernalas Electric Co-op

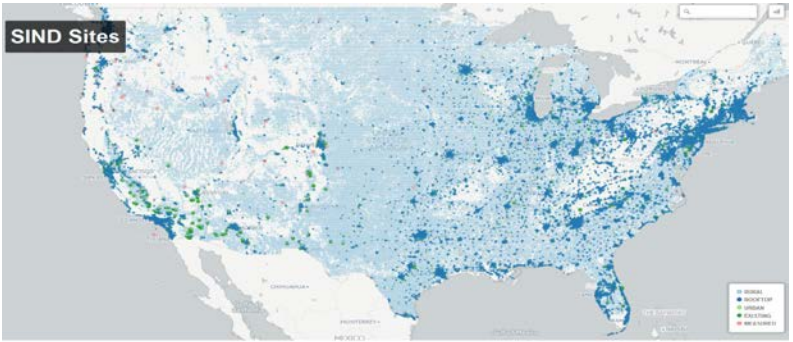
Technical Review Committee (TRC) (additional members): CyME, EDD, Opus One, Solar City, Varentec/GA Tech, VA Tech, EPRI

Smart–DS: Distribution Systems

- Full-scale, high quality synthetic distribution system dataset(s) for testing distribution automation algorithms, distributed control approaches, ADMS capabilities, and other emerging distribution technologies
- Adapt MIT/Comillas-IIT Reference Network Model (RNM) for U.S. (to create RNM-US)
- Detailed statistical summary of the U.S. distribution system characteristics and costs
- Smart-DS Cases:
  - Multiple neighboring substations with attached feeders and switches
  - Milestone: 20+ substations, 400,000 Electrical Nodes
  - Target: 100+ substations, 500+ feeders, 1M+ customers
  - Maybe: T+D connections

Smart–DS: Scenarios

- Advanced, automated scenario generation tools for wind and solar generator data; creating bulk system generator mix realizations; and populating distribution feeder models with scenario data, including DERs
  - Time series data
  - World-class high spatial/ temporal resolution solar and wind resource data with forecasts



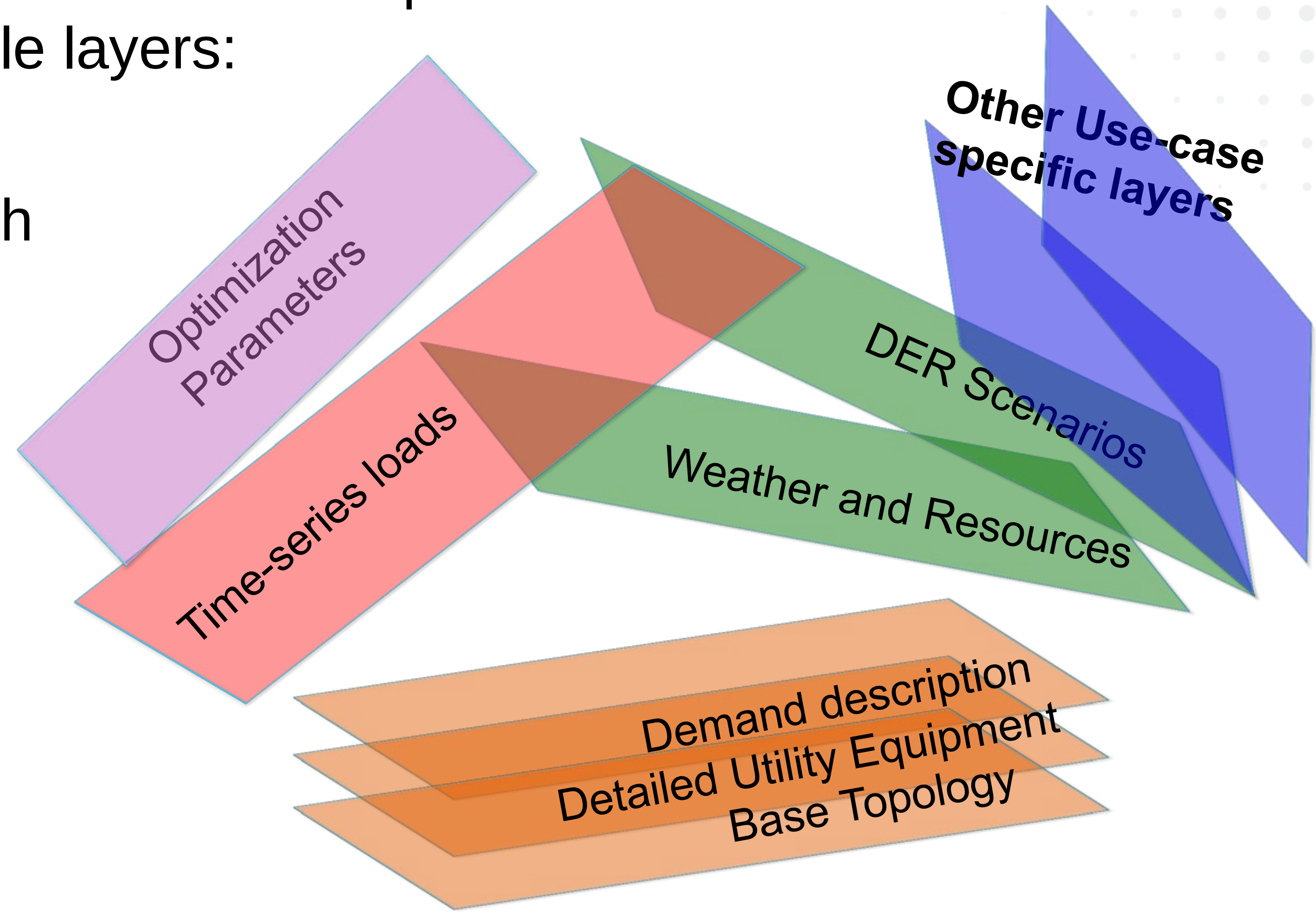
- Distribution scenarios: ZIP load snapshots, DER devices and functionality including solar PV, smart inverters, electric vehicles, batteries and demand response

- Transmission scenarios: API for matching time-synchronized resource data (wind, solar, weather) and generation mix to nodal, geo-coded transmission data

Distribution Models: Layers

Distribution data sets developed as a set of reusable layers:

- Base data
- Mix & Match



ARPA-E
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Target Use Cases

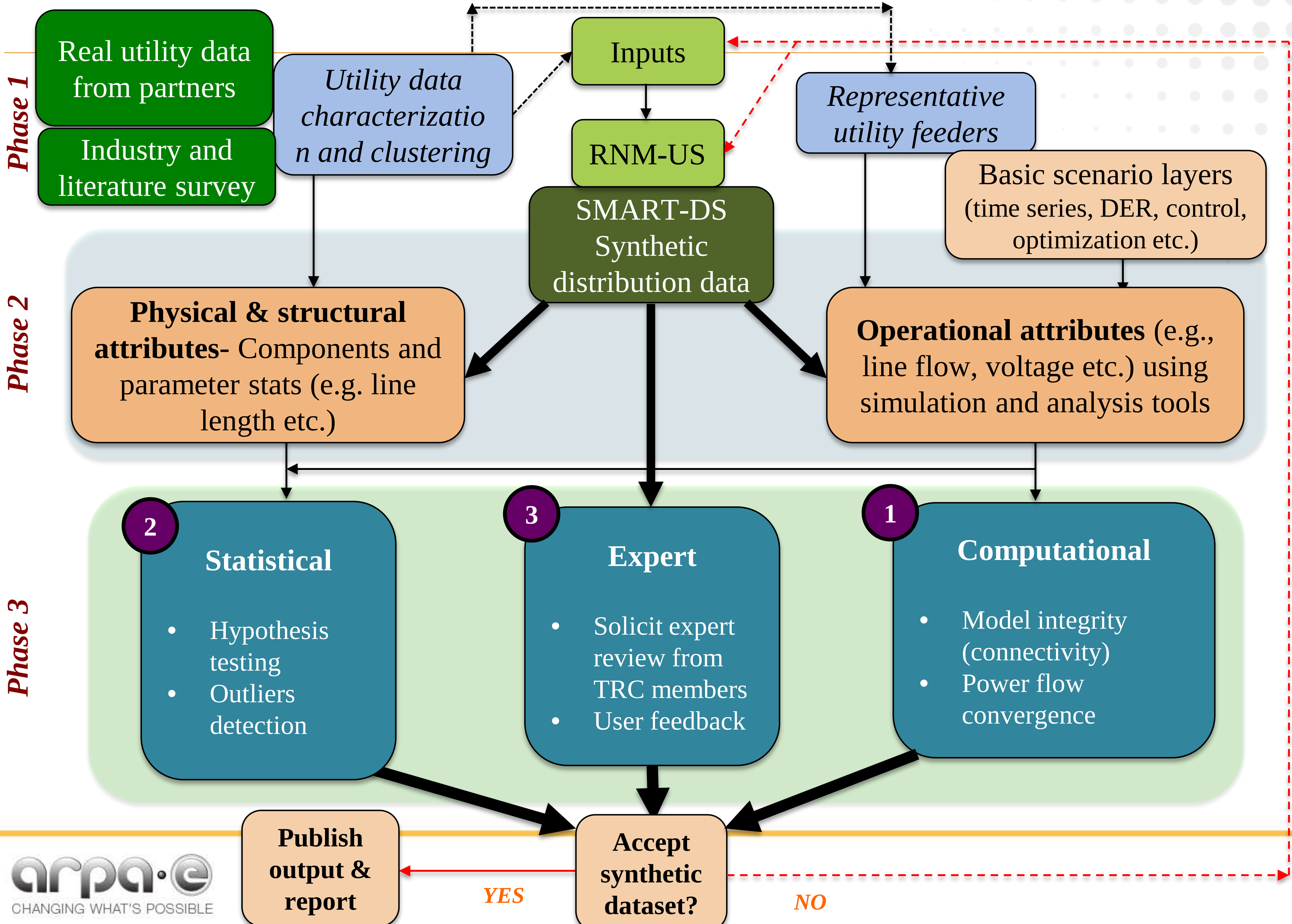
Basic: Power flow, quasi static time series (QSTS) simulations

1. Distribution Voltage Impacts of distributed energy resources (DERs)
   - E.g. Solar, EV, Advanced Inverters
   - Optimize control settings (including grid edge devices)
2. Single period Distribution-Optimal Power Flow (D-OPF)
   - Including DLMP or LMP+D calculation
3. Distribution System Reconfiguration
   - Fault Location, Isolation, & Service Restoration (FLISR)
   - Topology changes for enhanced operations
4. (stretch) Volt/VAR optimization
   - Adds dispatchability layer to DER voltage impacts
5. (stretch) Advanced DER Time-series Simulations
   - Storage
   - Deferrable loads, Thermal loads
6. (stretch) Multi-period D-OPF
   - DSO markets, tariffs, transactive energy

Validation- Criteria and parameters

Criteria	Why important?	Parameters to validate?
Realistic physical layout	Increased stakeholder acceptance. Matching of resource, weather, and demographics. Enables future communication layers	Geographic coordinates and arrangements of substation, feeders and equipment
Realistic system size	For testing scalability of advanced algorithms beyond a single feeder	System sub-network counts (e.g., customer class, feeders or MV/LV transformers per substation)
Realistic topology and components	Critical foundation for all use cases to ensure realistic power flow results, component utilizations, control schemes, voltage drops and electrical losses	LV, MV, HV: line length, transformer counts & sizes, parameters
Representative voltage profiles	A key concern for distribution system operations, particularly in time series analysis with volt/VAR control, DERs, and for valuing reactive power for D-ACOPF	Control schemes, voltage profile plots, customer voltage distributions, LTC and regulators, set points
Realistic recon-figuration options	To support both automated reconfiguration algorithms (e.g FLISR) and post-reconfiguration operations simulation	Count of switches, re-closers, breakers, fuses, and set points (delays)
Comprehensive load specification	To support basic power flow and allow for qualitative descriptions to enable rich scenario layers	ZIP parameters, load types, customer fractions
Computational requirements	Typical power flow solution times, challenging scenarios for advanced use cases	Solution times, convergence, violations

Validation Process



Team Roles

- ***National Renewable Energy Laboratory (NREL)***
  - Lead, distribution data characterization from utilities, scenario tools (T&D), and synthetic dataset validation
- ***Comillas-IIT***
  - Core development for synthetic distribution tool (RNM-US)
- ***MIT***
  - Customer loading and GIS data preparation for RNM-US, post-processing tools, and use case simulations (validation)
- ***GE Grid Solutions***
  - Validation of distribution models (*eTerra* tools)

Tech to Market: Datasets Adoption

- Results dissemination
  - GRIDDATA repositories
  - Project Technical Review Committee (TRC) meetings (industry and academia)
  - Conferences (DistribuTECH, PES GM, others)

- Users
  - Early Adopters (Use Case):
    - ARPA-e NODES teams (Distributed Control)
    - DOE ENERGISE teams (DER Volt/VAR and control)
    - DOE SuNLamp project (Distribution State Estimation)
    - Commercial partner (Distribution LMPs)
    - Academic community (Internships, visiting scholars)
  - Late(r) Adopters:
    - Academic community
    - Utilities (new use case demonstrations)
    - Additional commercial partners (tutorials and test cases)

Synthetic Dataset Creation: RNM-US

What is RNM? A Quick Summary

- Tool to create synthetic **large-scale** models, with millions of customers.
- The tool will plan the network installations required (with their technical parameters) and their cost.
  - Design of low, medium voltage and sub-transmission networks.
  - Design urban and rural areas.
- The **objective** of the tool is to find the least cost solution that is able to supply the demand and connect the distributed generation.
- Constraints include: **technical constraints** (current and voltage limits), **geographical constraints** and **reliability targets**.

INPUTS

- **Power** and **GPS location** of every single consumer and distributed generators.
- **Catalogue of equipment** and parameters.

→

RNM-US

Least cost network planning subject to technical geographical and reliability constraints

→

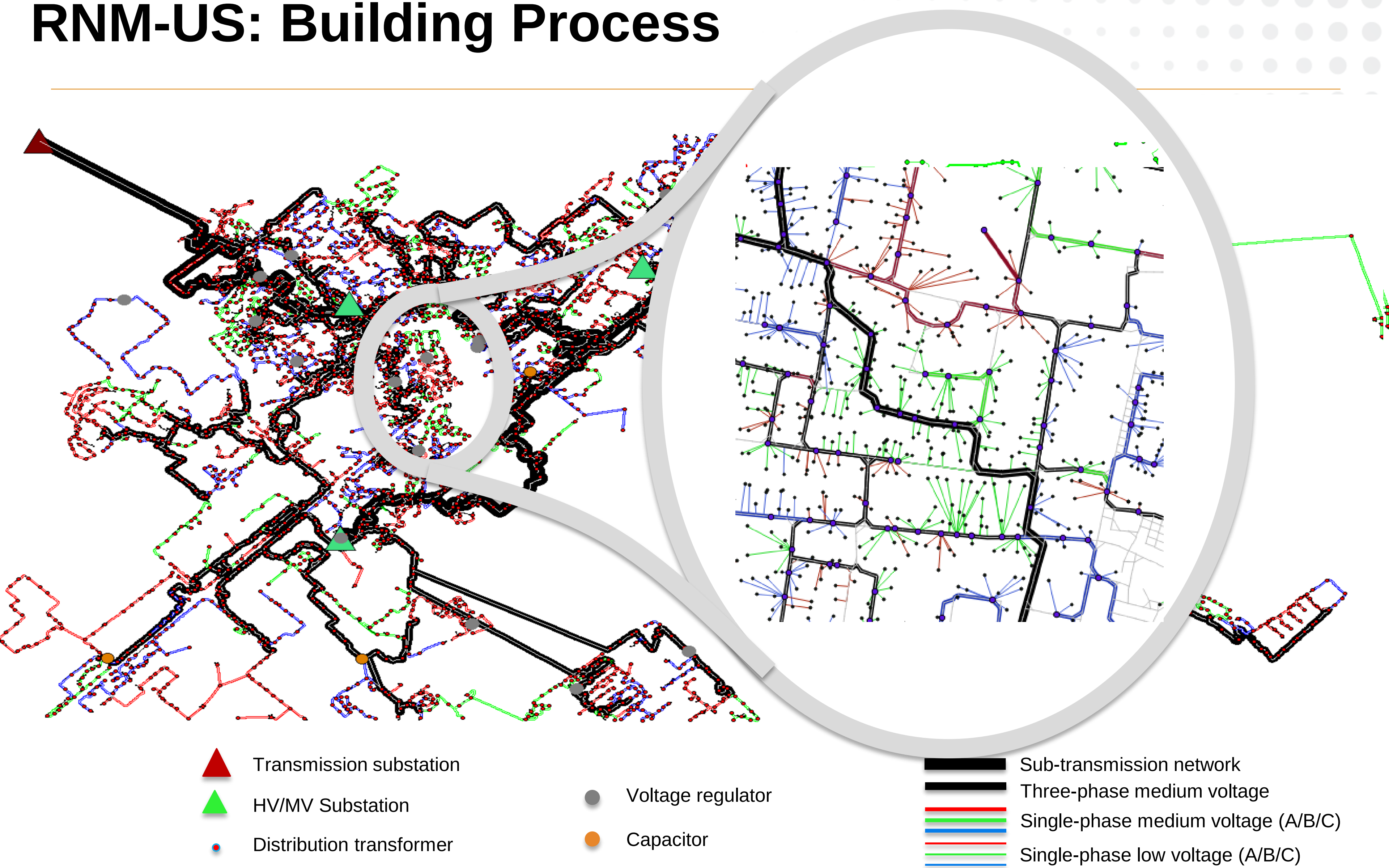
OUTPUTS

- **Topology** and equipment of the output **network**
- **Cost incurred** to build a network.

RNM US Catalog of Equipment and Inputs

Electrical lines	Code, Type (overhead/underground), R(ohms/km) , X(ohms/km) , C (nF); Current(A) , Overload(p.u.) , Voltage(kV), Failure rate [failures / km year], Investment Cost ($/km), Preventive maintenance cost ($/km), Corrective maintenance cost ($/km), Preventive maintenance time (hours/km), Repair time (hours), Number of phases
Distribution transformers and substations	ID, Type, Voltage level, Installed Power(kVA), Primary Voltage (kV), Secondary Voltage (kV), No load losses(kW), Reactance(p.u. transf), Low-voltage-side short-circuit resistance (ohms), Maximum number of outputs, Investment cost per output ($/output), Failure rate minimum[failures / year], Investment Cost ($), Preventive maintenance cost ($), Corrective maintenance cost ($), Preventive maintenance time (hours), Repair time (hours)
Voltage regulators	Voltage level, Investment Cost ($), Preventive maintenance cost ($), Corrective maintenance cost ($), Failure rate (failures / year), Useful life(years), Short circuit resistance (ohms), Short circuit reactance (ohms), Minimum tap(pu), Maximum tap (p.u.), Step, Number of phases
Capacitors	ID, Voltage (kV), Capacity (kVAr), Investment Cost ($), Preventive maintenance cost ($), Corrective maintenance cost ($), Number of phases,
Switching devices	Type, Investment Cost ($), Preventive maintenance cost ($), Corrective maintenance cost ($)

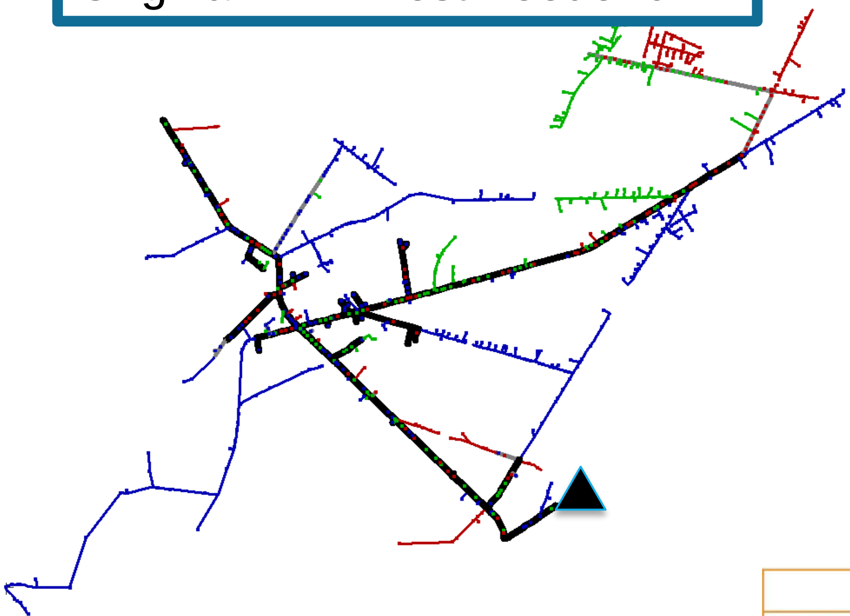
RNM-US: Building Process



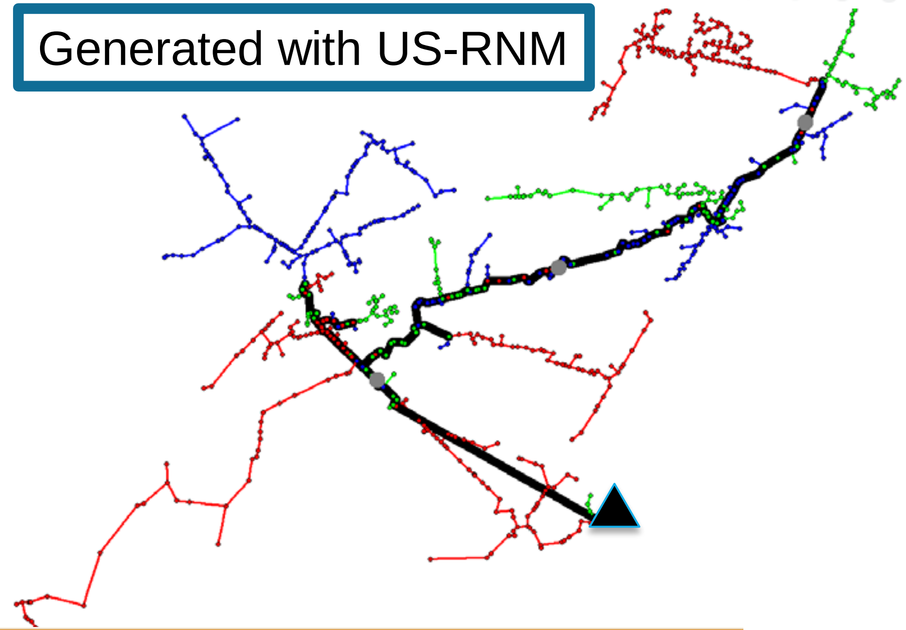
- C. Mateo Domingo, et. al., "A Reference Network Model for Large-Scale Distribution Planning With Automatic Street Map Generation," in *IEEE Transactions on Power Systems*, vol. 26, no. 1, pp. 190-197, Feb. 2011.
- Gómez , T., et. al., (2013), "Reference Network Models: A Computational Tool for Planning and Designing Large-Scale Smart Electricity Distribution Grids," *Book chapter (pp. 247-279) in the book titled, "High Performance Computing in Power and Energy Systems"* by Khaitan, S., and Gupta A., Springer Berlin Heidelberg, 978-3-642-32682-0, 2013

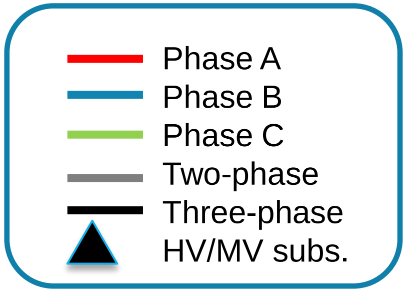
EPRI Test Feeder J1

Original EPRI Test Feeder J



Generated with US-RNM

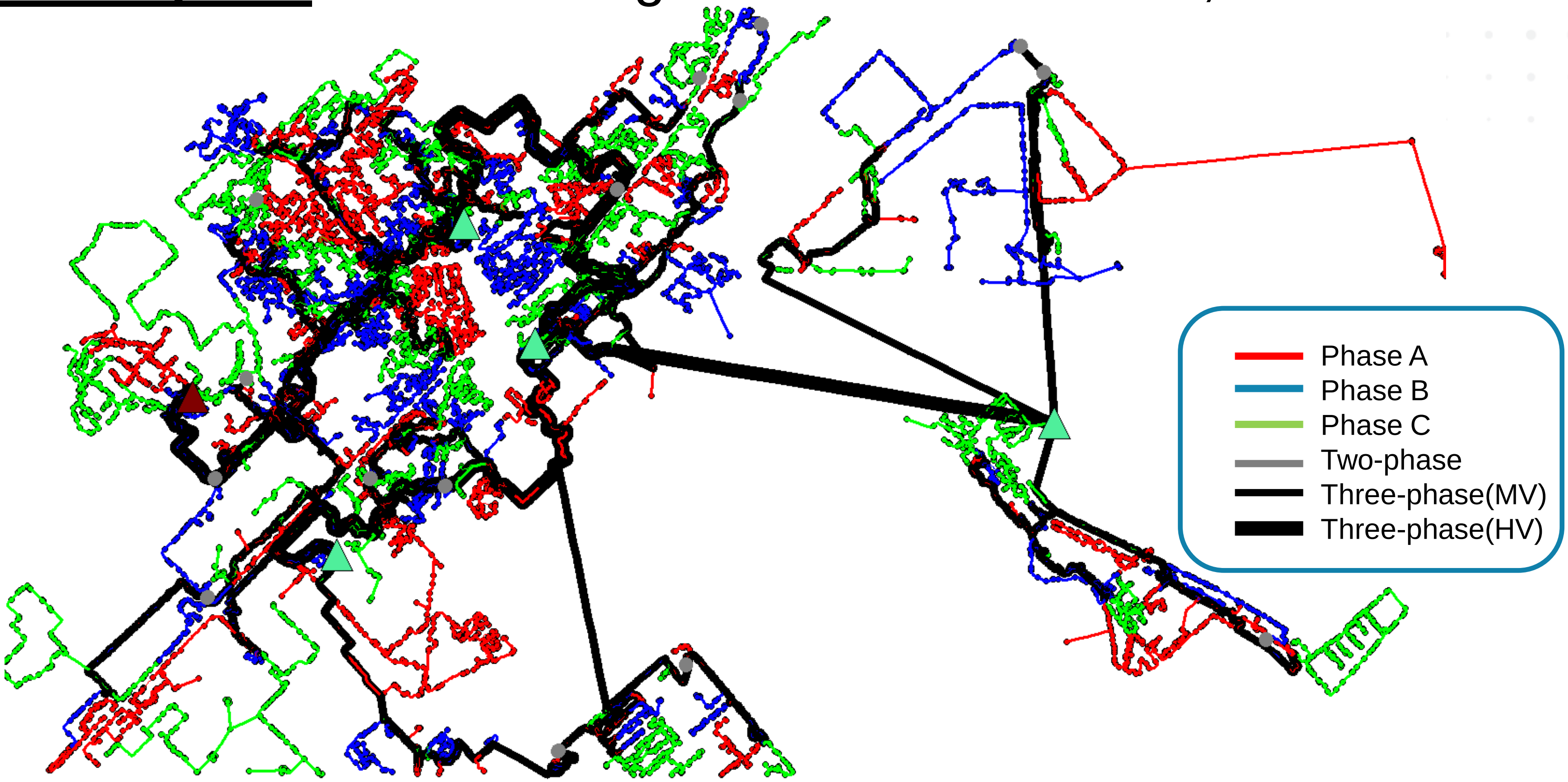




	Units	EPRI	RNM-US
Total network length	km	94.8	86.4
Total medium-voltage length	km	94.7	84.4
Total low-voltage length	km	0.137	1.98
Total 3-phase length	km	25.3	19.4
Total 2-phasic length	km	6.8	0
Total single-phase length	km	62.6	66.9
Number of MV/LV transformers	count	819	726
Mean line utilization	p.u	0.063	0.016
Losses	%	3.91	5.40
Number of branches	count	248	196
Average node degree		1.999	1.999

Demo #1 from RNM-US

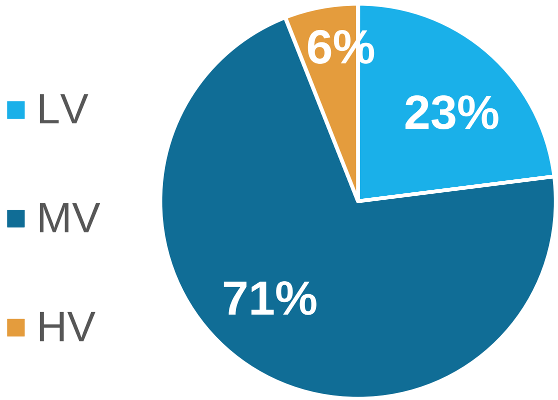
Target: 5+ of feeders, 8000 customers, 4 substations.
Assumption: Random region selected in Texas, USA

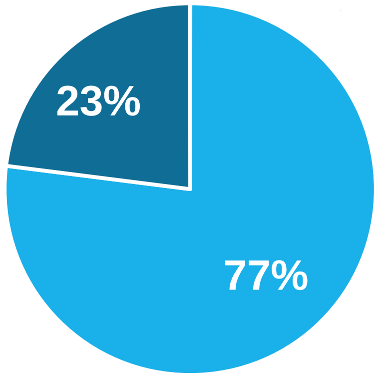


	Customers #	Avg P (KW)	Total S (MVA)	Voltage (kV)
LV	8424	5	43.9	0.4

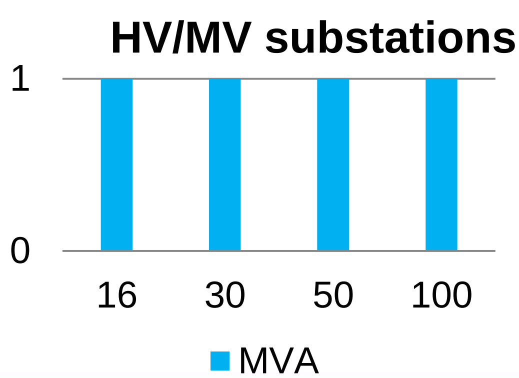
Demo #1 Results: Lines & Transformers

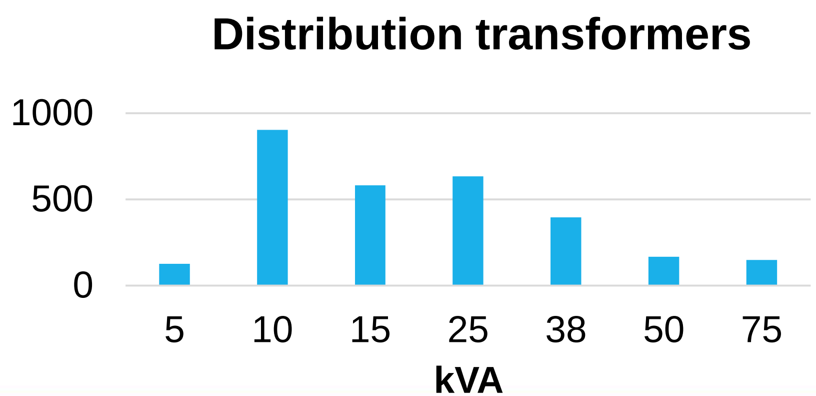
- Length per voltage levels & Underground-Overhead ratio





- Distribution transformers & HV/MV substations





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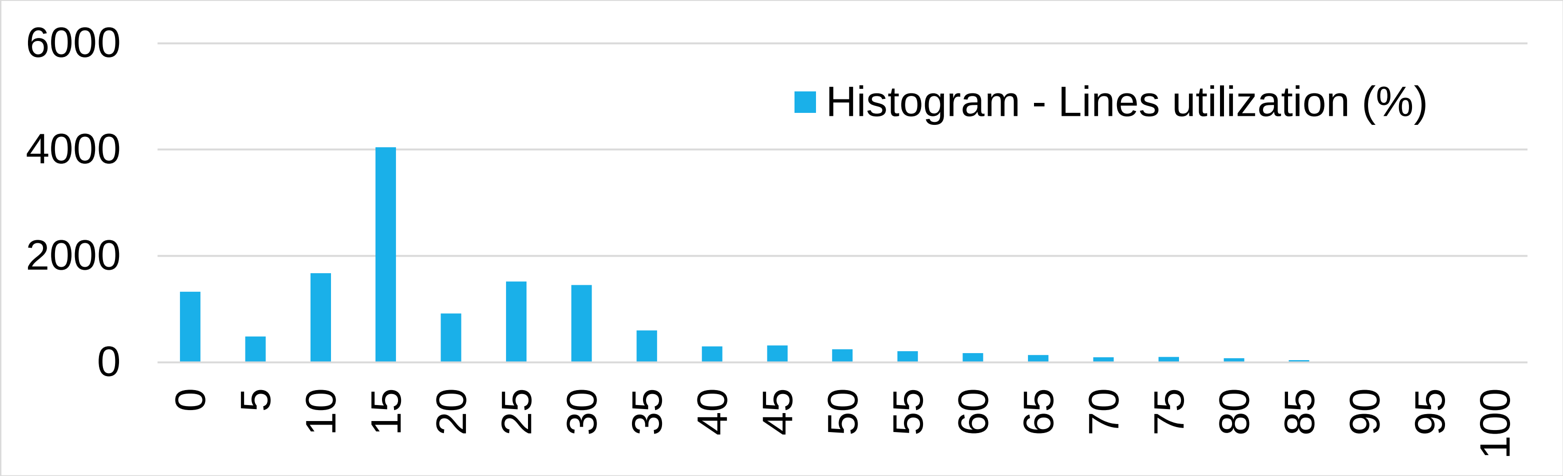
Demo #1 Results: Line utilization & voltages

- Lines load level diagram (Total line losses~ 5.7%)



- Voltages

	HV	MV	LV
Min	0.980	0.942	0.945
Avg	1.010	1.009	1.008
Max	1.033	1.060	1.066

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Demo #1 Results: Physical attributes

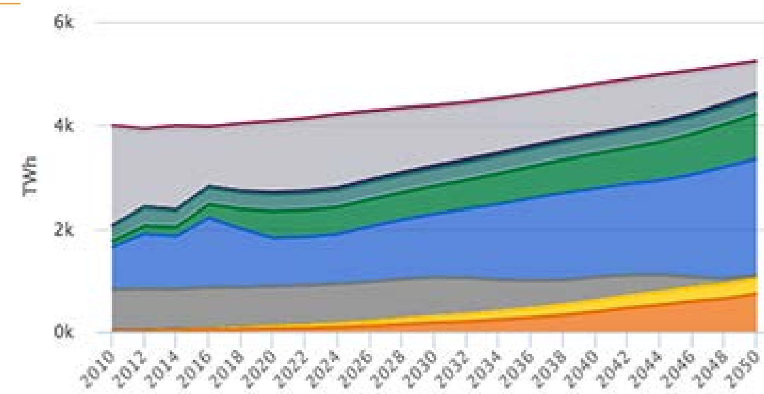
Attributes	Demo#1
1. Metrics associated to substations and feeders	
Typical transformation capacity of HV/MV substations (MVA)	30
Typical transformation capacity of the distribution transformers in urban areas (kVA)	10
Average number of Distribution transformers per feeder in urban areas	77.76
Average length per MV feeder in urban areas (km)	15.93
2. Metrics associated to LV network	
LV consumers per area (1/km2)	43.74
LV circuit length per LV consumer (km)	0.02
LV underground ratio (%)	30%
3. Metrics associated to distribution transformers	
Number of LV consumers per distribution transformer	2.85
Capacity of distribution transformers per consumer (kVA)	8.40
4. Metrics associated to MV network	
Number of MV consumers per area (1/km2)	2.82
MV circuit length per area of distribution (1/km)	3.14
MV underground ratio	22%
5. Metrics associated to HV network	
HV circuit length per HV supply point (km)	12.34
HV circuit length per area (1/km)	0.26

Note: For validation, data from US utilities is needed to compare Demo #1 attributes with typical US network's (of demo #1 type)

Scenarios: Tools for Creating Scenario Layers

Transmission Scenarios Tool

- Leverage **NREL's Standard Scenarios project** to make it easy (and citable) to populate transmission systems with a variety of generation mixes



GENERATOR NODE DESCRIPTIONS

- GIS Locations
- Capacity

+

OPTIONS

- NREL Standard Scenario
- Year

→ **Generator Placement** — Standard Scenarios → **Resource Data Tool** — WIND, NSRDB → **SCENARIO**

- P. Sullivan, W. Cole, N. Blair, E. Lantz, V. Krishnan, T. Mai, D. Mulcahy, and G. Porro, "2015 Standard Scenarios Annual Report: U.S. Electric Sector Scenario Exploration," *NREL Technical Report*, NREL/TP-6A20-64072, July 2015
- http://www.nrel.gov/analysis/data_tech_baseline.html

Distribution Feeder Scenario Tool

CUSTOMER NODE DESCRIPTIONS

- Option for GIS-located

+

OPTIONS

- Climate / location
- Load scenarios (low, med, high)
- Distributed PV penetration
- Distributed storage penetration

→ Load and DER Placement → Resource Data Tool → SCENARIO

Wind Resource	Variables	Temporal Resolution
Weather	Wind speed Wind direction Temperature Pressure	5 min
Power	Wind Power at 100m	5 min
Forecasts	1, 4, 6, 24 hour ahead power	1 hour

Solar Resource	Variables	Temporal Resolution
Irradiance	DNI, GHI	1 min
Weather	Temperature Pressure Wind Speed	30 min
Power	Fixed-tilt 1-axis tracking 2-axis tracking DPV CSP	1 min
Forecasts	1, 4, 6, 24 hour ahead power	1 hour

What's next?

- **Validation (3-pronged process)**
  - Real utility data and survey: US distribution data characterization for RNM inputs and validation (physical and structural attributes for statistical validation)
  - Scenario tools: Resource, DER and time series data for simulations, operational attributes, and computational validation
  - Expert validation: TRC in-person meeting on August 31 2017

- **Products: Synthetic networks, scenario tools, and RNM-US tool**
  - Demonstration 2 (20+ feeders): Sept-Dec 2017
  - Medium scale network (2 substations and 20,000 nodes): Mar 2018
  - Large scale network (20 substations and 400,000 nodes): Apr-Sept 2018

Summary

- Development of publicly accessible full-scale, high quality, validated synthetic distribution system dataset(s) representative of U.S. systems.
- **Core methodologies:** RNM-US tool, embedded with post-processing & scenario tools, 3-pronged validation

Takeaways for ISOs and Transmission modelers?

- RNM-US tool and synthetic datasets: build up realistic, but not real distribution for system of interest.
- Scenario generation & resource data tools: Potential value for long-term investment and short-term operational planning studies
  - Datasets could also help in both D-level market design (DLMP), and possibly in future support D-level OPF

Thank you

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Extra Slides

From RNM (Europe) to RNM-US?

Europe	US
Three phase feeders	Single-phase, two-phase and three-phase feeders
Three phase distribution transformers	Single-phase center tapped transformers
Large Distribution Transformers (~200 cust)	Smaller Distribution Transformers (~8 cust)
Long LV network length (~200 m)	Short LV network length (~30 m)
Underground ratio close to ~90%	Underground ratio close to ~30%
Voltage regulators rarely used	Massive use of voltage regulator
Capacitor banks rarely used	Massive use of capacitor banks

Utility data: US Distribution System Data Collection and Characterization

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Data Needs: RNM Catalog & Validation

- Equipment specifications, costs, & reliability for:
  - HV/MV Substations: rural, urban
  - MV/LV Transformers: Multiple capacities
  - Conductors: rural/urban, HV/MV/LV
  - Voltage Regulators: tap positions, rating
  - Capacitors
  - Protective Devices
  - Maintenance Crews
- Technical/Economic Drivers:
  - Discount Rate
  - Demand growth
  - Simultaneity factor
  - Loss factor
- Planning Parameters:
  - Density: settlement (neighborhood) vs. rural
  - Reserve margins
  - Underground ratios
  - Reliability Zones

Data Sources

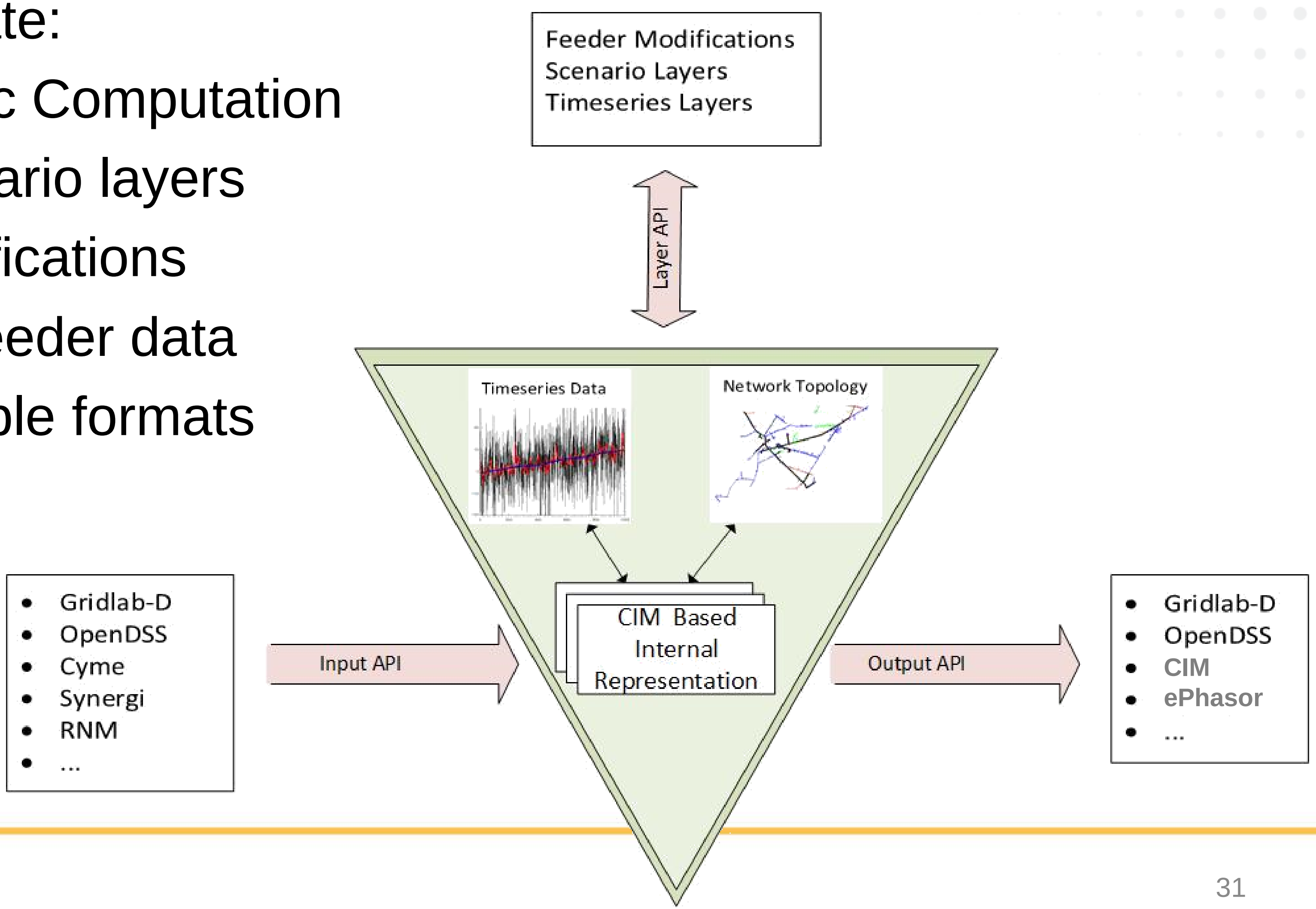
- Open literature:
  - PG&E Unit Cost Guide
  - Eaton Catalog (with quotes)
  - Nexans Catalog (with quotes)
  - RNM-Europe

- Utility data partners: EDD, Pepco, Duke Energy, APS, SCE, City of Loveland, Pedernalas Electric Co-op

- Utility survey: Load types, feeder data (design, voltage classes, transformer configurations, maintenance crew, etc.), substation and sub-transmission designs

Distribution Transformation TOol (DiTTo)

- Read any feeder data
- Manipulate:
  - Metric Computation
  - Scenario layers
  - Modifications
- Output feeder data
  - Multiple formats



Cost Table Data

- Catalog data with associated sources

#Urban-Overhead											
#Name	Type of line	Resistance(	Reactance(	Current(A)	Overload(p	Voltage(kV)	Failure rate r	Failure rate r	Failure rate r	Investment	Preventiv
1P_OH_Voluta	TRPLX #6	0.661	0.033	95	1.1	0.24	0.1	0.1	0.1	340	10
1P_OH_Periwinkle	TRPLX #4	0.416	0.031	125	1.1	0.24	0.1	0.1	0.1	360	10
1P_OH_Conch	TRPLX #2	0.261	0.03	165	1.1	0.24	0.1	0.1	0.1	450	10
1P_OH_Neritina	TRPLX 1/0	0.164	0.03	220	1.1	0.24	0.1	0.1	0.1	710	10
1P_OH_Runcina	TRPLX 2/0	0.13	0.029	265	1.1	0.24	0.1	0.1	0.1	910	10
1P_OH_Zuzara	TRPLX 4/0	0.082	0.027	350	1.1	0.24	0.1	0.1	0.1	1370	10
1P_OH_Swanate	ACSR #4	0.407	0.113	140	1.1	12.47	0.1	0.1	0.1	110	1000
3P_OH_Swanate	ACSR #4	0.407	0.113	140	1.1	12.47	0.1	0.1	0.1	110	1000
1P_OH_Sparrow	ACSR #2	0.259	0.11	185	1.1	12.47	0.1	0.1	0.1	140	1000
3P_OH_Sparrow	ACSR #3	0.259	0.11	185	1.1	12.47	0.1	0.1	0.1	140	1000
3P_OH_Raven	ACSR 1/0	0.163	0.104	240	1.1	12.47	0.1	0.1	0.1	210	1000
1P_OH_Raven	ACSR 1/0	0.163	0.104	240	1.1	12.47	0.1	0.1	0.1	210	1000
3P_OH_Pigeon	ACSR 3/0	0.103	0.0992	315	1.1	12.47	0.1	0.1	0.1	320	1000
1P_OH_Pigeon	ACSR 3/0	0.103	0.0992	315	1.1	12.47	0.1	0.1	0.1	320	1000
1P_OH_Penguin	ACSR 4/0	0.0822	0.0964	365	1.1	12.47	0.1	0.1	0.1	400	1000
3P_OH_Penguin	ACSR 4/0	0.0822	0.0964	365	1.1	12.47	0.1	0.1	0.1	400	1000
#Urban-Underground											
#Name	Type of line	Resistance(	Reactance(	Current(A)	Overload(p	Voltage(kV)	Failure rate r	Failure rate r	Failure rate r	Investment	Preventiv
1P_UG_Vassar	TRPLX #4	0.508	0.0333	117	1.1	0.24	0.1	0.1	0.1	440	10
1P_UG_Stephens	TRPLX #2	0.319	0.0299	154	1.1	0.24	0.1	0.1	0.1	530	10
1P_UG_Brenau	TRPLX 1/0	0.201	0.0281	193	1.1	0.24	0.1	0.1	0.1	820	10
1P_UG_Converse	TRPLX 2/0	0.159	0.028	221	1.1	0.24	0.1	0.1	0.1	980	10
1P_UG_Sweetbriar	TRPLX 4/0	0.101	0.0265	290	1.1	0.24	0.1	0.1	0.1	1280	10

Cost Table Data

- Catalog data with associated sources

#Urban-Overhead						
#Name						
1P_OH_Voluta	http://www.nexans.us/eservice/US-en_US/nav	http://www.nexans.us/eservice/US-en_US/navig	http://ww	http://ww	From RNM	Triplex is 2
1P_OH_Periwinkle	http://www.nexans.us/eservice/US-en_US/nav	http://www.nexans.us/eservice/US-en_US/navig	http://ww	http://ww	From RNM	Triplex is 2
1P_OH_Conch	http://www.nexans.us/eservice/US-en_US/nav	http://www.nexans.us/eservice/US-en_US/navig	http://ww	http://ww	From RNM	Triplex is 2
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3P_OH_Swanate	http://www.nexans.us/eservice/US-en_US/nav	http://www.nexans.us/eservice/US-en_US/naviga	http://ww	http://ww	From RNM	Heuristic:
1P_OH_Sparrow	http://www.nexans.us/eservice/US-en_US/nav	http://www.nexans.us/eservice/US-en_US/naviga	http://ww	http://ww	From RNM	Heuristic:
3P_OH_Sparrow	http://www.nexans.us/eservice/US-en_US/nav	http://www.nexans.us/eservice/US-en_US/naviga	http://ww	http://ww	From RNM	Heuristic:
3P_OH_Raven	http://www.nexans.us/eservice/US-en_US/nav	http://www.nexans.us/eservice/US-en_US/naviga	http://ww	http://ww	From RNM	Heuristic:
1P_OH_Raven	http://www.nexans.us/eservice/US-en_US/nav	http://www.nexans.us/eservice/US-en_US/naviga	http://ww	http://ww	From RNM	Heuristic:
3P_OH_Pigeon	http://www.nexans.us/eservice/US-en_US/nav	http://www.nexans.us/eservice/US-en_US/naviga	http://ww	http://ww	From RNM	Heuristic:
1P_OH_Pigeon	http://www.nexans.us/eservice/US-en_US/nav	http://www.nexans.us/eservice/US-en_US/naviga	http://ww	http://ww	From RNM	Heuristic:
1P_OH_Penguin	http://www.nexans.us/eservice/US-en_US/nav	http://www.nexans.us/eservice/US-en_US/naviga	http://ww	http://ww	From RNM	Heuristic:
3P_OH_Penguin	http://www.nexans.us/eservice/US-en_US/nav	http://www.nexans.us/eservice/US-en_US/naviga	http://ww	http://ww	From RNM	Heuristic:
#Urban-Underground						
#Name	Type of line	Resistance(ohms)	Reactanc	Current(	Overloac	Voltage(kV
1P_UG_Vassar	http://www.nexans.us/eservice/US-en_US/nav	http://www.nexans.us/eservice/US-en_US/fileLib	http://ww	http://ww	From RNM	Triplex is 2
1P_UG_Stephens	http://www.nexans.us/eservice/US-en_US/nav	http://www.nexans.us/eservice/US-en_US/fileLib	http://ww	http://ww	From RNM	Triplex is 2
1P_UG_Brenau	http://www.nexans.us/eservice/US-en_US/nav	http://www.nexans.us/eservice/US-en_US/fileLib	http://ww	http://ww	From RNM	Triplex is 2
1P_UG_Converse	http://www.nexans.us/eservice/US-en_US/nav	http://www.nexans.us/eservice/US-en_US/fileLib	http://ww	http://ww	From RNM	Triplex is 2
1P_UG_Sweetbriar	http://www.nexans.us/eservice/US-en_US/nav	http://www.nexans.us/eservice/US-en_US/fileLib	http://ww	http://ww	From RNM	Triplex is 2
1P_UG_2-1 (named from size and number of strandings)	http://www.nexans.us/eservice/US-en_US/nav	http://www.nexans.us/eservice/US-en_US/naviga	http://ww	Electric Di	From RNM	Assume 12
3P_UG_2-1 (named from size and number of strandings)	http://www.nexans.us/eservice/US-en_US/nav	http://www.nexans.us/eservice/US-en_US/naviga	http://ww	Electric Di	From RNM	Assume 12
3P_UG_2/0-19 (named from size and number of strandings)	http://www.nexans.us/eservice/US-en_US/nav	http://www.nexans.us/eservice/US-en_US/naviga	http://ww	Electric Di	From RNM	Assume 12

arpa·e CHANGING WHAT'S POSSIBLE

Survey Contents: Catalog

	A	B	C	D	E	F	G	H	I	J
1	HV/MV Substations									
2	Catalog Field	Description	Units	Format	Priority	Source	CYME/Synergi Field	Comments/Questions	Substation1	Substation2
3										
4	Name	Commercial name or	N/A	String	3	Suvey			SUB_1	SUB_2
5	Capacity (kVA)	Installed Capacity	kVA	Float	1	Survey			30	40
6	Urban/Suburban	Whether the substat	N/A	String	2	Survey			Suburban	Suburban
7	Firm Capacity (kVA)	Amount of capacity a	kVA	Float	4	(Manipulations)			30	40
8	Loss 0 (kW)	No-load losses	kW	Float	1	Survey			24.75	33
9	Short Circuit Resistance Low Side (Ohm	It is used to calculate	Ohms	Float	1	Survey (short-circuit losses)			0.7125	0.95
10	Number of Maximum outputfeeders	Number of feeders c	N/A	Int	1	Survey			15	15
11	Investment Cost per ouptut feeder	Cost associated with	$/feeder	Float	4	Survey			8625000	11500000
12	Failure Rate minimum	Minimum Frequency	Fails/Year	Float	5	(Manipulations)			0.005	0.005
13	Failure Rate average	Average Frequency w	Fails/Year	Float	4	Survey			0.005	0.005
14	Failure Rate maximum	Maximum Frequency	Fails/Year	Float	5	(Manipulations)			0.005	0.005
15	Labor for installation	e.g 1 electrician, 2 cc	N/A	String	4	Survey				
16	Install Time	e.g. 500 hours	Hours	Int	4	Survey				
17	Material Cost	Cost of installed equi	$	Float	4	Survey				
18	Cost of supporting install equipment	e.g. truck, crane etc.	$/install	Float	4	Survey				
19	Investment Cost	Combined total inves	$	Float	3	Survey			8625000	11500000
20	Preventive Maintenance Cost	Cost associated to pr	$	Float	4	Typical ratio based on survey Investment cost			154017.8571	205357.1429
21	Corrective Maintenance Cost	Cost associated to cc	$	Float	4	Typical ratio based on survey Investment cost			123214.2857	164285.7143
22	Ratio GIS	Indicates the influen	pu	Float	4	(rapid)			0.1	0.1
23	Repair Time (Minimum)	Minimum Time assoc	Hours	Float	5	(Manipulations)			14	14
24	Repair Time (Medium)	Average Time associ	Hours	Float	4	Survey			30	30
25	Repair Time (Maximum)	Maximum Time asso	Hours	Float	5	(Manipulations)			44	44
26	Prev Maint Time	Time required to cari	Hours	Float	4	(rapid)			230	230
27	Number of phases	Number of phases w	N/A	Int	1	Survey				
28	Primary rated voltage	(Self described)	kV	Float	1	Survey			69	69
29	Secondary rated voltage	(Self described)	kV	Float	1	Survey			12.47	12.47
30	Short circuit reactance	(Self described)	Ohms	Float	2	Survey				
31										

Configuration Parameters | Distribution Transformers | **Substations** | Lines | Protection | Capacitors | Regulators | Trenches and Poles | Visibilty | Metering | SCADA

CHANGING WHAT'S POSSIBLE

Survey Contents: Feeders

	A	B	C	D	E	F	G
1	Feeder Data						
2	Question	Format	Priority	Comments/Questions	Feeder Type 1	Feeder Type 2	...
3							
4	Voltage levels	String	2				
5	Typical number of voltage levels concatenated in distribution, for example 1 low voltage level (LV), :	String	2				
6	Are there several HV voltages connected each other? Or each of them connected to transmission su	String	2				
7	Are there several MV voltages connected each other? Or each of them connected to HV?	String	2				
8	Typical voltage levels (kV) and ranges (LV, MV and HV)	String	2				
9	Is there any criterion for determining the limit between three-phase and single phase feeders? For e	String	2				
10							
11	Voltage regulators and capacitors						
12	Where are voltage regulators typically installed? Only in medium voltage?	String	2				
13	Where are capacitors typically installed? In what voltage levels? Are there also capacitors in the low	String	2				
14	What is the main objective when installing capacitors? Improving voltages or reducing losses?	String	2				
15	Is there a criterion to choose between voltage regulators and capacitors?	String	2				
16	Average number of voltage regulators per feeder	String	2				
17	Average number of capacitors per feeder	String	2				
18							
19	Consumers						
20	Typical peak power demand of HV consumers (MW)	float	2				
21	Typical peak power demand of MV consumers (kW)	float	2				
22	Typical peak power demand of LV consumers (kW)	float	2				
23							
24	Transformation capacities						
25	Typical transformation capacity of transmission substations in urban areas (MVA)	float	2				
26	Typical transformation capacity of transmission substations in rural areas (MVA)	float	2				
27	Typical transformation capacity of HV/MV Substations in urban areas (MVA)	float	2				
28	Typical transformation capacity of HV/MV Substations in rural areas (MVA)	float	2				
29	Typical transformation capacity of the distribution transformers in urban areas (kVA)	float	2				
30	Typical transformation capacity of the distribution transformers in rural areas (kVA)	float	2				
31							

Survey Contents: Substations

	A	B	C	D	E	F	G	H
1	Substation Data							
2	Substation Field	Description	Units	Format	Priority	Source	Comment	Entry1
3								
4	High Voltages used for distribution substation	Voltage classes entering the distributio	kV	float	1			
5	Low Voltages used for distribution substation	Voltage classes leaving the distribution	kV	float	1			
6	HV Topology (Image)	Schematic diagram showing the configu	N/A	jpeg/png etc.	3			
7	MV Topology (Image)	Schematic diagram showing the configu	N/A	jpeg/png etc.	1			
8	Type of substation configuration	Written description of the configuratio	N/A	String	1			
9	Feeders per transformer bank	Number of feeders connected to each t	N/A	int (list)	2			
10	Number of transformer banks	Number of transformer banks in the sul	N/A	int	2			
11	Number of tie-breakers	Number of tie-breakers in the substatic	N/A	int	2			
12	Total number of feeders	Total number of feeders that the substa	N/A	int	1			
13	Number of breakers per transformer bank	Number of breakers in each transforme	N/A	int (list)	2			
14	Number of Capacitor Banks	Total number of capacitor banks on the	N/A	int	2			
15	Capacitor Bank kVAR	kVAR rating of the capacitor banks in us	kVAR	float (list)	2			
16	Capacitor configuration	Written description of the placement o	N/A	String	3			
17	Number of LTCs	Number of LTCs in the distribution subs	N/A	int	2			
18	LTC configuration	Written description of the placement o	N/A	String	3			
19	Number of transformers	Total number of transformers in the dis	N/A	int	1			
20	Transformer Configuration	Written description of any additional in	N/A	String	4			
21	HV/MV transformer MVA	MVA ratings of the distribution substati	N/A	float (list)	2			
22	HV/MV transformer short-circuit resistance	Resistance values for the distribution su	p.u.	float (list)	2			
23	HV/MV transformer short-circuit reactance	Reactance values for the distribution su	p.u.	float (list)	2			
24	HV/MV transformer no-load losses	Reactance values for the distribution su	kW	float (list)	2			
25	Switchgear Ratings	Amperage rating of the distribution sub	Amps	float	2			
26	Reclosing Breakers (Y/N)	Whether or not reclosing breakers are u	N/A	boolean	4			
27	Feeder LV Exit OH/UG/BOTH	Whether the distribution feeders exit th	N/A	String	1			
28	Feeder HV Exit OH/UG/BOTH	Whether the transmission lines exit the	N/A	String	2			
29	Type of switchgear	A description of the type of switchgear	N/A	String	1			
30	Switch configuration	A written description of the placement	N/A	String	3			
31	Amapcity per feeder	Ampacity ratings for each feeder of the	Amps	float (list)	1			

Substations

Validation: Attributes and Statistical Tests

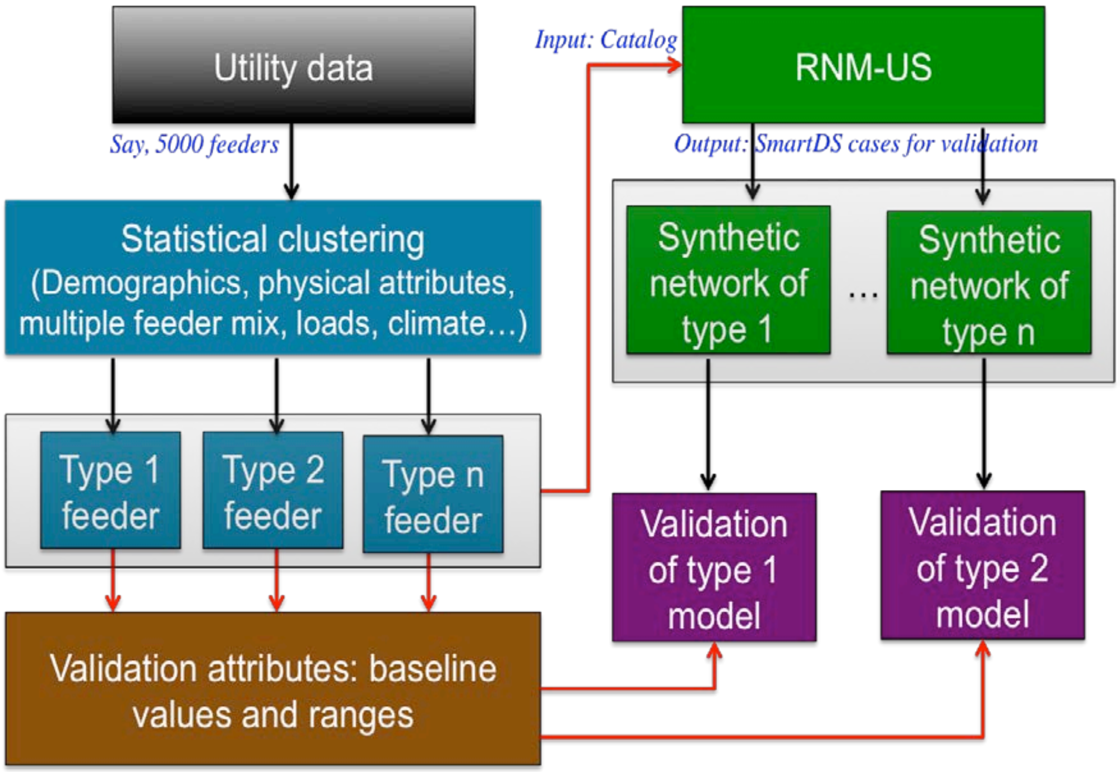
Attributes

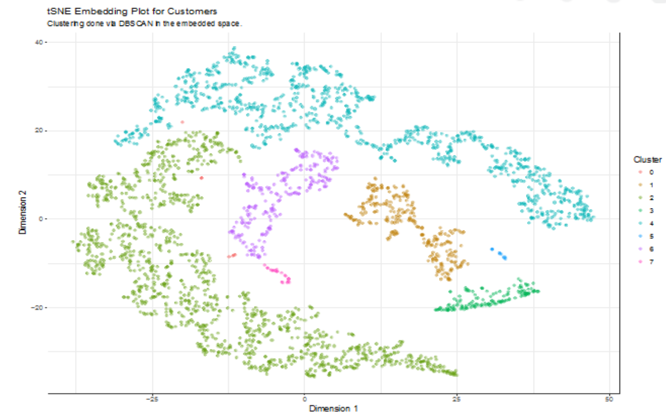
Attribute 1: Synthetic → Compare metrics ← Attribute 2: Real utility

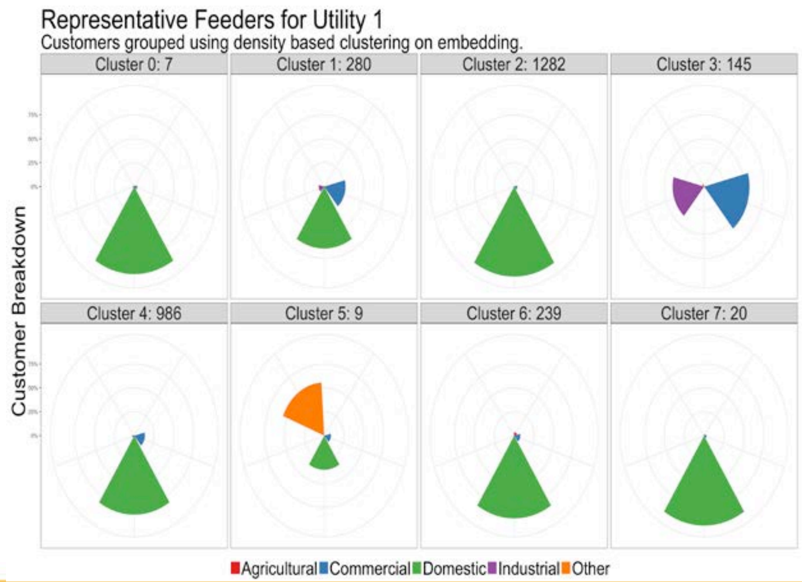
Bare minimum
FLISR & Reconfiguration
Impacts of DERs
Quasi-static time-series simulation?
Volt-Var Optimization?
D-OPF? (single & multi-period?)

Attribute	Categories (metric extraction in terms of count, average, ratios)
PHYSICAL METRICS (component inventory, characteristics and ratings)	
Substation	Source impedance, transformer size and specifications, number of feeders
Node types	Counts: MV, LV nodes, Load, urban, residential, commercial
Load data	Single phase, three phase, MW, MVAR, ZIP, Y vs. delta connected, **diversity factor**
Line data	Count, capacity, length (voltage classes, 3-ph, 2-ph, 1-ph), UG vs. OH, parameters, pole geometry
Transformers	MV/LV count, capacity per customer, rating & parameters
Customers	Count (residential, commercial,… rate classes), **phase allocations**
Voltage regulators	Rating, voltage limits, tap position, number of shunt (capacitors) & series compensators, control delays, grid edge devices (CVR and control settings)
Other components	Circuit breakers, fuses, switches, reclosers
DER data	Count, ratio of PV to load size, advanced inverters (const PF, volt-var), storage, thermal loads
OPERATIONAL METRICS (based on simulations and stability assessments)	
Power flow convergence	Time, iterations, largest mismatch
Voltages	MV, LV voltages, voltage angles
Line flows	Branch utilization, losses, **imbalance currents (degree of imbalance)**
Power factor	Load types, seasonal variations
Reliability indicators	SAIDI, SAIFI, **LTC operations, switched shunt operations, curtailments**
STRUTURAL METRICS (reflective of topological features)	
Average node degree	Average number of branches connected to a node
Mean line length	Between pairs of nodes *i* & *j*, minimum number of lines needed to traverse from node *i* to *j*
Clustering co-efficients	Tendency for nodes to cluster together (enmeshment), spatial frequencies (e.g., customers per mile, voltage regulator per MW-mile, PV per mile)
MARKET RELATED METRICS? (Tariff, NEM, FIT, energy transactions, control (OpenFMB, Volttron?))	

Feeder Clustering for Enhanced Statistical Validation



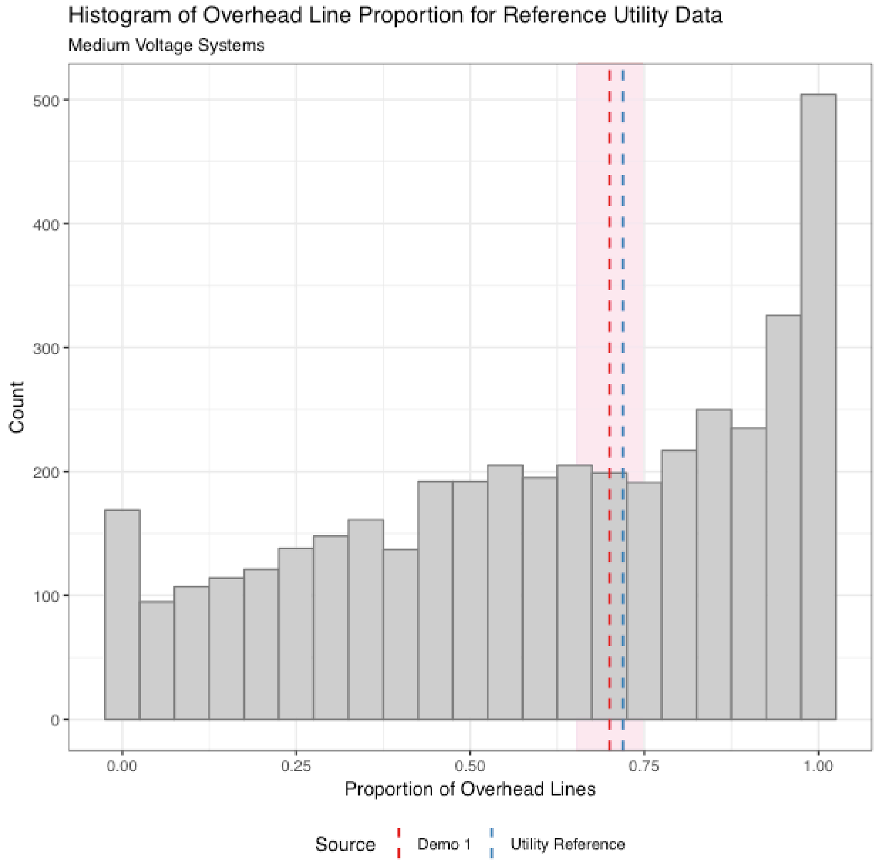




Statistical Hypothesis Test

Demo #1 attribute (overhead line proportion)

Demo 1 Proportion Overhead (p_{Demo})	Reference Proportion Overhead ($p_{Utility}$)	Hypothesis Test	95% CI for $p_{Utility} - p_{Demo}$	Decision
0.7	0.719	$H_0: p_{Utility} = p_{Demo}$ vs. $H_A: p_{Utility} \neq p_{Demo}$	[-0.029, 0.066]	Fail to reject null hypothesis (p-value of 0.4456)



CHANGING WHAT'S POSSIBLE