Preparation of Distribution Circuits for Distribution System State Estimation and Advanced Applications

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Outline

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- DSSE Performance Evaluation – Methodology
- DSSE Performance Evaluation – Selected Results
- Summary
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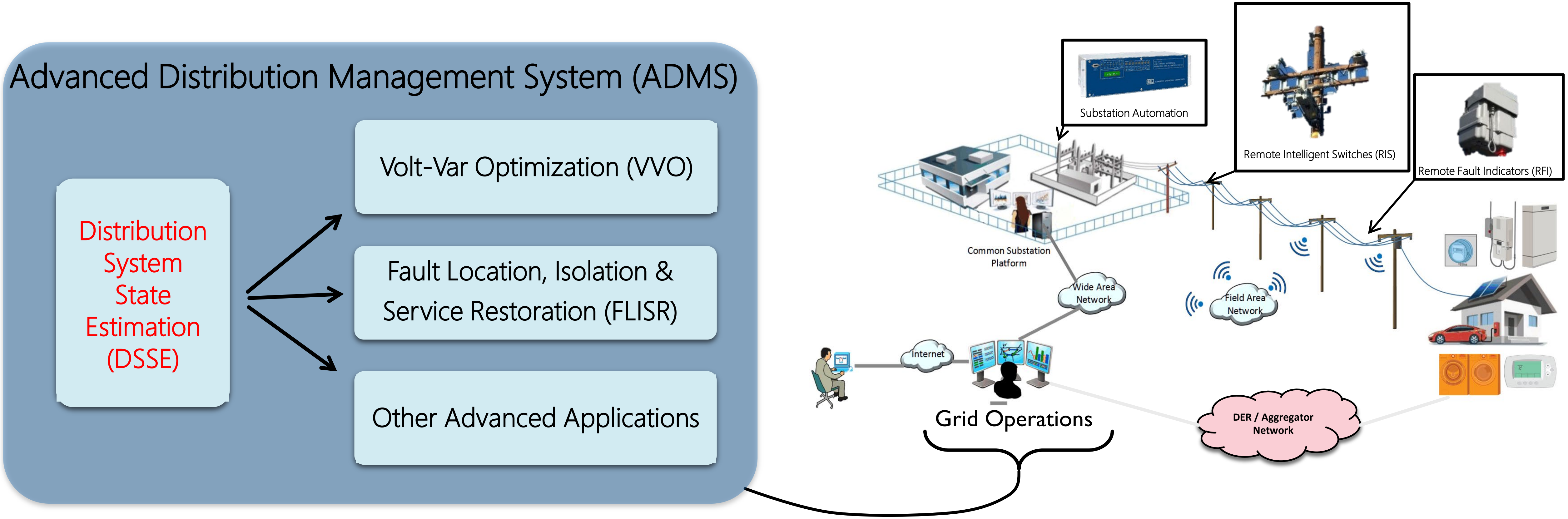
Background and Motivation

Role of Distribution System State Estimation (DSSE) in Grid Modernization

DSSE is a Foundational Application that uses real-time data provided by substation automation (SCADA) and circuit-level devices (e.g., RISs, RFIs, DERs) to estimate voltages and flows on the distribution circuit that inform control decisions of Advanced Applications such as VVO and FLISR.



What's so special about DSSE?

Unlike State Estimation (SE) for Transmission, DSSE is a novel technology that requires thoughtful planning for circuit-level telemetry to achieve optimal and violation-free performance of Advanced Applications.

SE in Transmission Systems

Much Data Available
- System usually observable.
- High data redundancy.
- 'Bad data' detection possible.

High Quality Pseudo Data
- Useful if part of the system is unobservable.
- Often not needed (because of high data redundancy).

Routinely used application that provides robust 'bad data' and 'topological error' detection functionalities.

SE in Distribution Systems

Limited Data Available
- System not observable.
- No data redundancy.
- 'Bad data' detection difficult.

Varying Pseudo Data Quality
- Pseudo data needed to make system observable.
- Important to ensure high quality of pseudo data.

Additional circuit-level sensors and reliable short-term forecasting needed for successful deployment.

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Objectives of the DSSE Performance Evaluation (DPE) Methodology

EnerNex conducted a multi-year project for a California IOU to develop the DSSE Performance Evaluation Methodology that achieves the following planning and operational objectives:

Planning Objective Develop Hardware & Software Requirements to achieve DSSE accuracy needed to run all Advanced Applications optimally and violation-free.				Operational Objective Develop Operational Requirements to maintain adequate DSSE accuracy under all conditions while running Advanced Applications.	
Adding telemetry points to fix data scarcity problem – how many are needed and optimal locations?	How often should the DSSE be executed?	Optimal use of data from line sensors, Large Customer Metering, Short Term Forecasting & Residential AMI?	Are P & Q data needed or is measuring current magnitude enough?	What is the impact of ○ measurement errors? ○ topological errors? ○ DER and disrupting technologies such as Smart Inverters, storage, etc.?	How can the operator tell if DSSE solution can be trusted?

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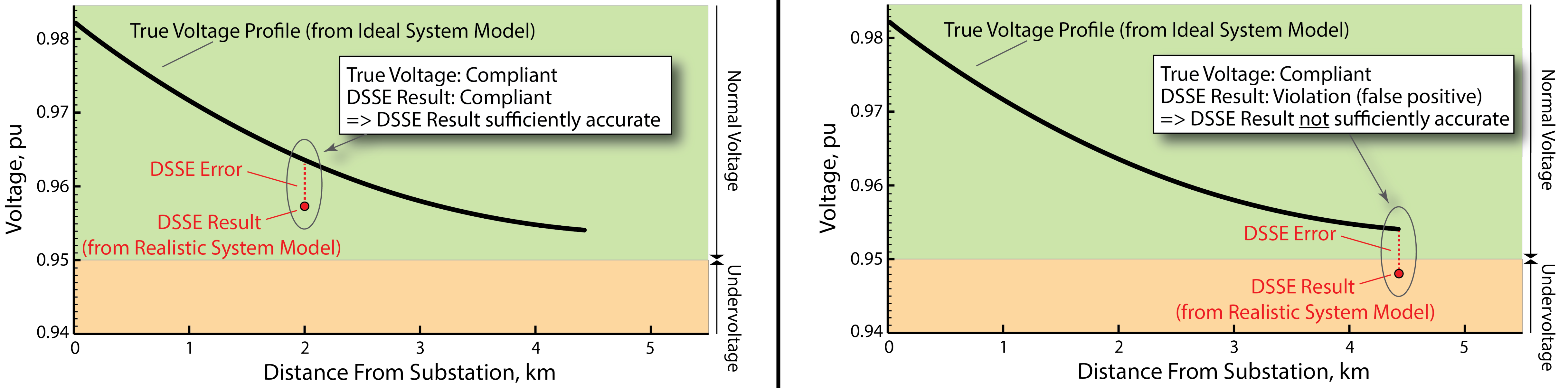
DSSE Performance Evaluation (DPE) – Methodology

DPE Methodology: Concept

Premise: DSSE results are sufficiently accurate if they correctly identify compliances and violations.

DSSE correctly reports 'no undervoltage violation' | DSSE incorrectly reports 'no undervoltage violation'

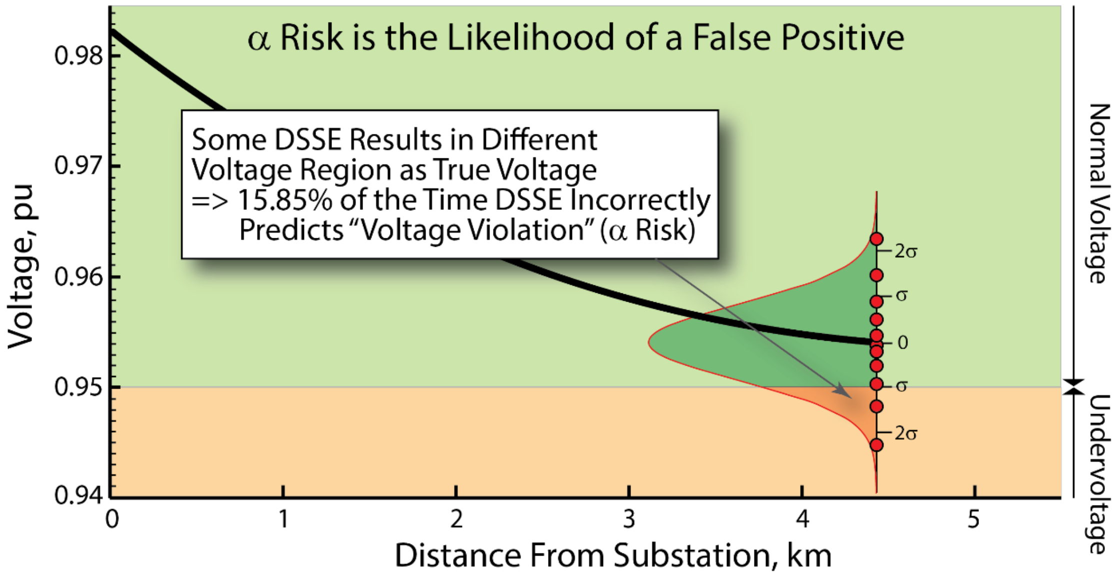


DPE Methodology: Concept

Method: Perform stochastic analysis that accounts for all real-world system conditions resulting in risk values for each sensor deployment scenario.

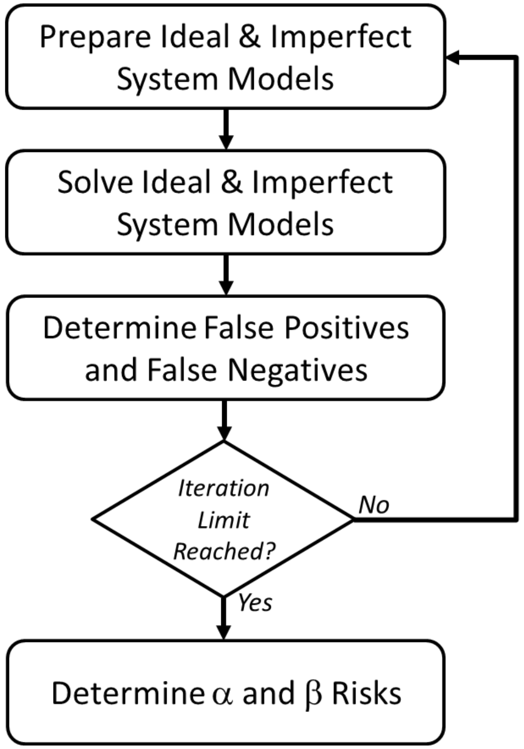
α Risk

Likelihood of DSSE reporting a violation when there is none.



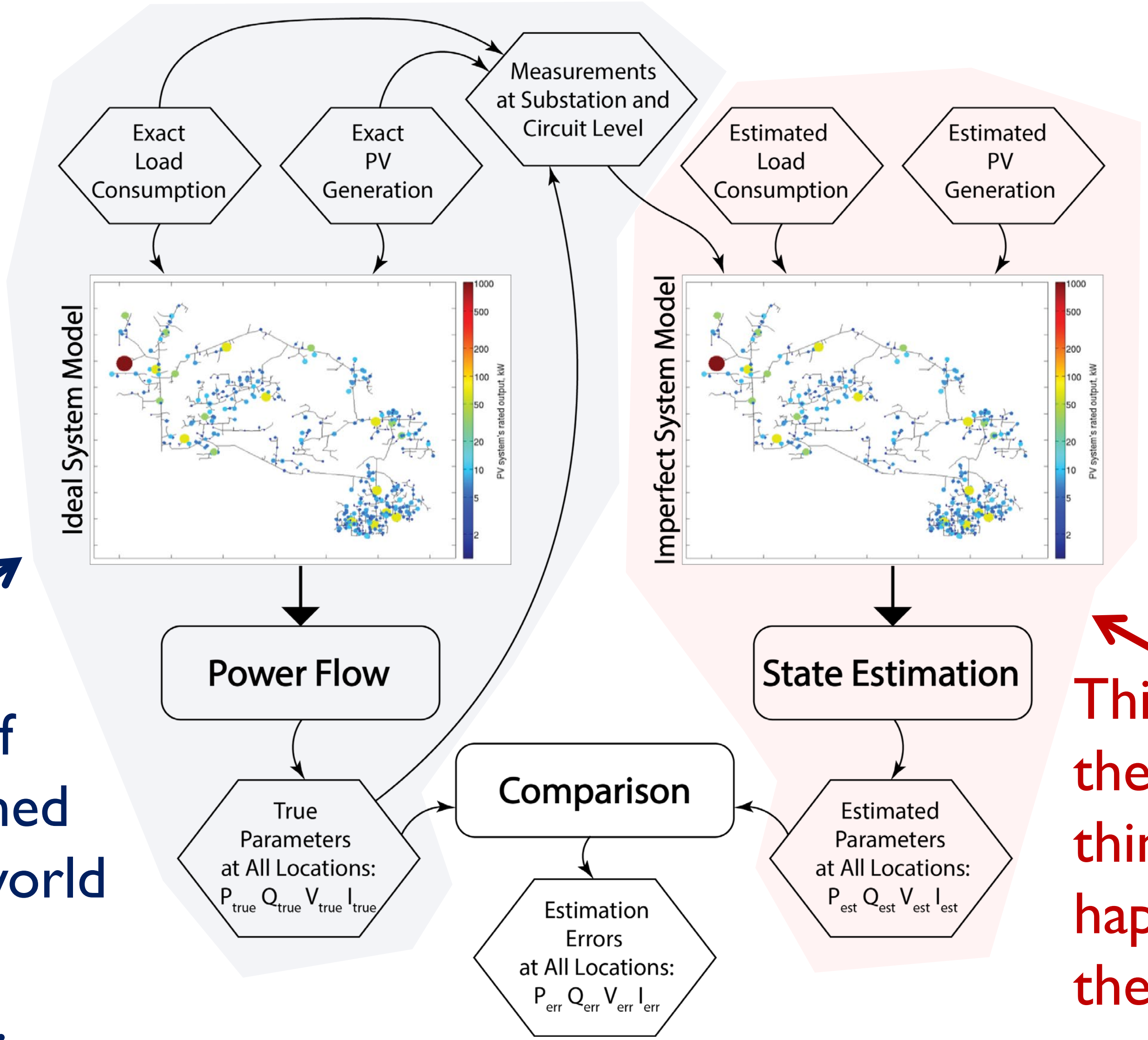
Monte Carlo Analysis

Determines α Risk by quantifying accuracies of DSSE estimates.



DPE Methodology: Implementation

Approach: Perform computer simulations (e.g., in CYME) to determine true states and DSSE estimates.



This is our simulation of what happened In the real world (all possible True States).

This is what the DSSE thinks what happened in the real world.

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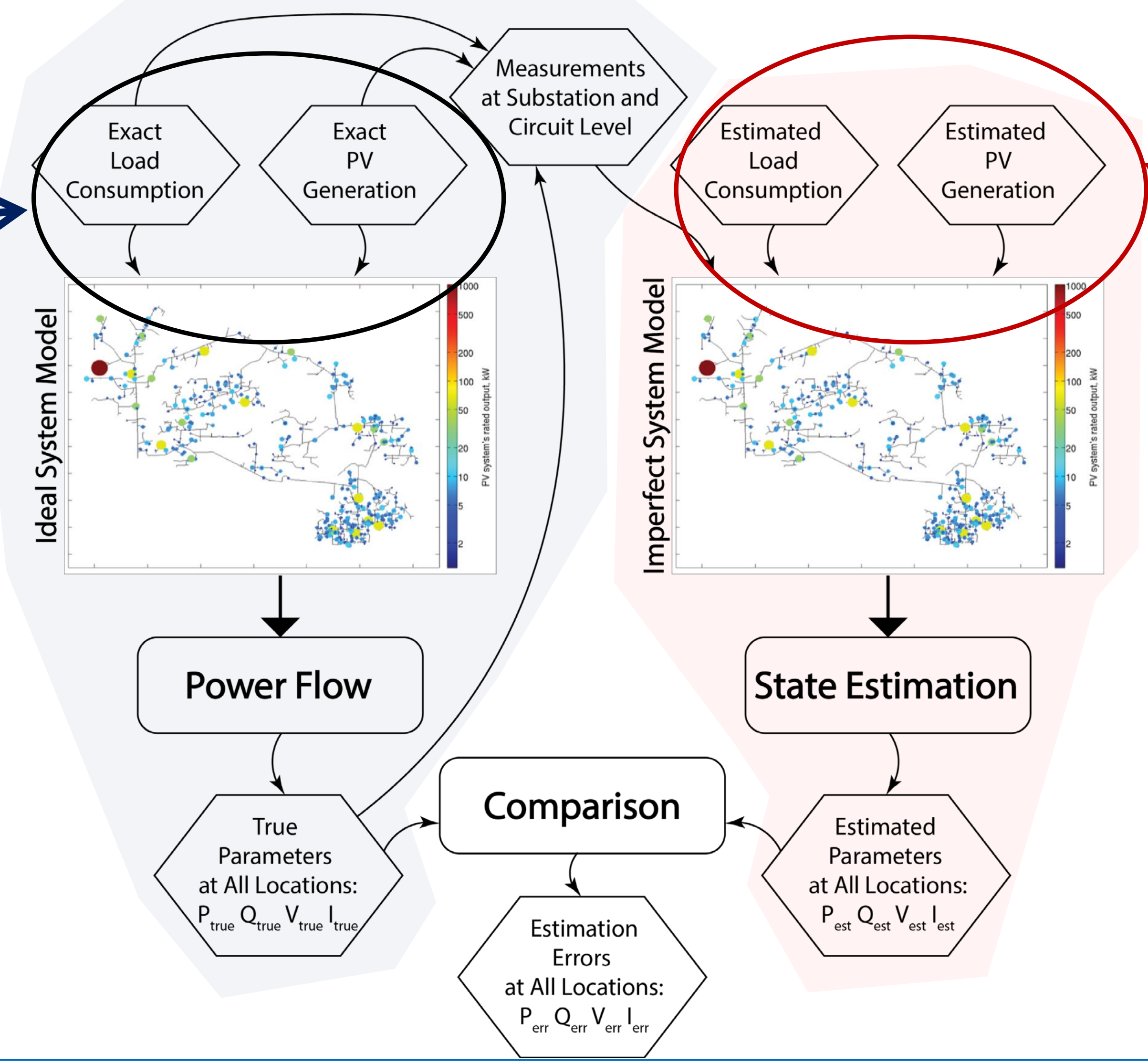
DPE Methodology: Implementation

Required historical data: (1) P & Q measured at Substation, (2) AMI for load consumption, (3) PV generation, and (4) capacitor bank states.

True States: Use historical sets of AMI data from days with similar conditions.



DSSE: Use averages of historical AMI data as pseudo measurements (e.g., AMI Data from previous 14 days).

DSSE Performance Evaluation (DPE) – Selected Results

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Planning Mode Functions

Estimation-Improving Measures	**Quantifies DSSE performance improvements achieved by operational forecasting and adding circuit-level sensors that provide a full measurement set (i.e., P & Q).**
Sensor Type Analysis	Compares the DSSE performance achieved by P & Q line sensors and line sensors that measure 'current magnitude only'.
DSSE Execution Interval Analysis (Work In Progress)	Determines the maximum DSSE execution time interval that is needed to result in violation-free operation during normal operating conditions.
Optimal Sensor Placement Analysis	Identifies locations where placing a line sensor results in maximum DSSE performance improvement.
High PV Penetration	Perform analysis during clear-sky & cloudy-sky conditions when PV-caused voltage variability and DSSE estimation errors are largest.

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Investigated Estimation-Improving Measures

Sensor Deployment Scenarios: Quantify improvements in DSSE accuracy by simulating existing and future sensing devices and operational forecasting.

No Sensors on Circuit (Base Case)	• 0.5 Scheme: Substation Data Only
Automatic Switches w/ Sensors	• 1.5 / 2.5 / 3.5 Scheme: Substation Data + Data from One / Two / Three Circuit Locations • Switch placement driven by provided reliability improvement (for now).
Operational Forecasting	• STFE10: Short-Term Forecast Engine improves operational load forecast from +-30% to +-10% • STFE20: Short-Term Forecast Engine improves operational load forecast from +-30% to +-20%
High Risk (HR) Scheme	• Place sensors near high α risk areas.
Large Load (LL) Scheme	• Place sensors at large loads. This scheme simulates utility's deployment of Real-Time Energy Meters (RTEMs), which monitor loads ≥200 kW capacity.
Combination Scheme	• 1.5+ Scheme: 1.5 Scheme + HR Scheme + LL Scheme

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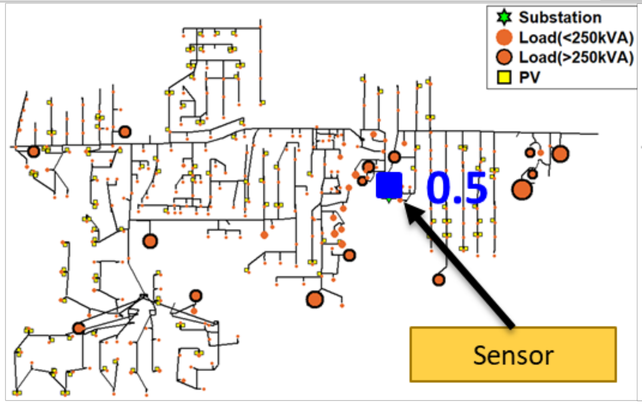
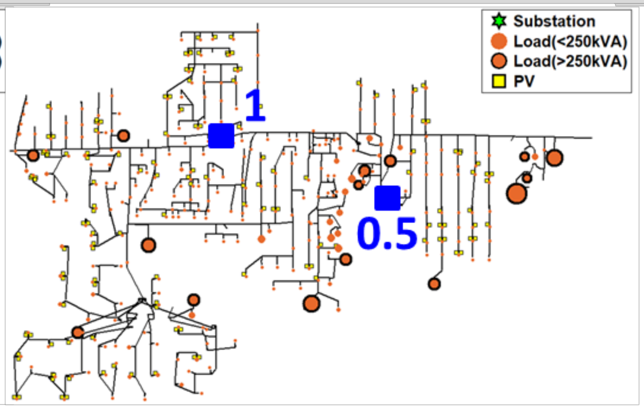
Sensor Deployment Scenarios

Sensor Scheme: 0.5



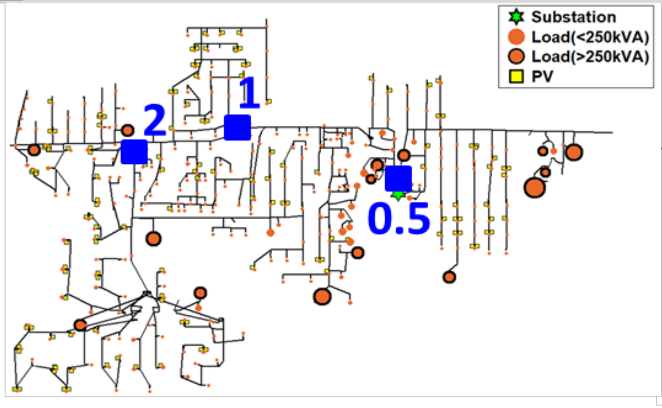
Meter	Connected kVA	% Connected kVA
0.5	21088.5	100

Sensor Scheme: 1.5



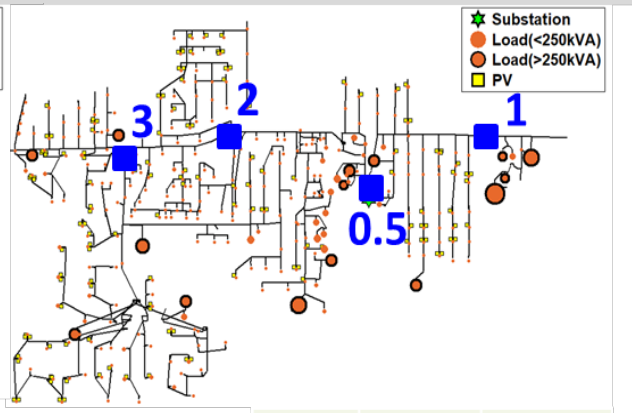
Meter	Connected kVA	% Connected kVA
0.5	11436	54.2
1	9652.5	45.8

Sensor Scheme: 2.5



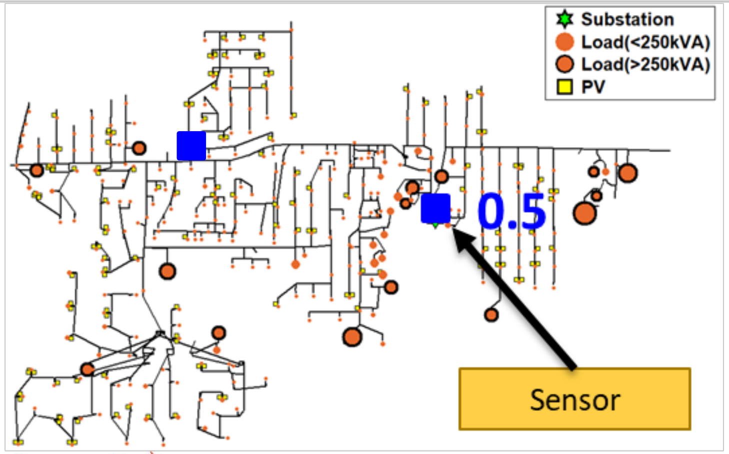
Meter	Connected kVA	% Connected kVA
0.5	11436	54.2
1	3985	18.9
2	5667.5	26.9

Sensor Scheme: 3.5

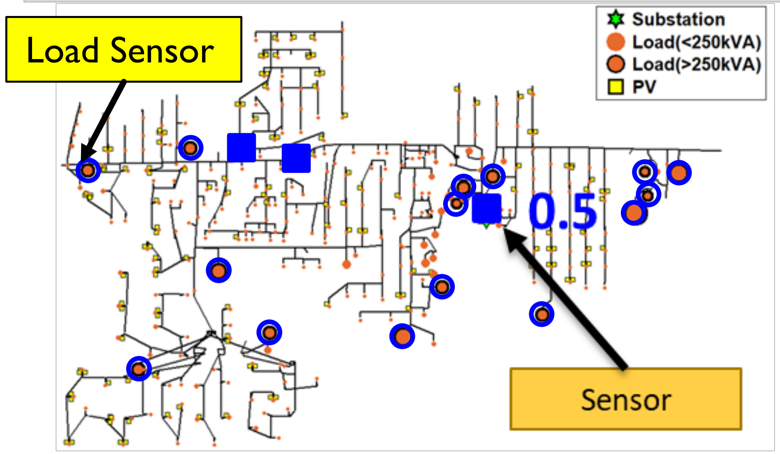


Meter	Connected kVA	% Connected kVA
0.5	8176	38.8
1	3260	15.5
2	3985	18.9
3	5667.5	26.9

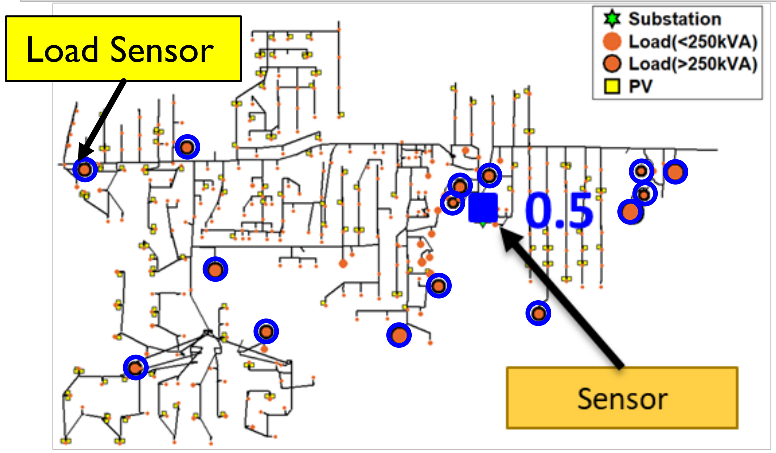
Sensor Scheme: HR



Sensor Scheme: 1.5+



Sensor Scheme: LL



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Alpha Risk Analysis for Undervoltage (VVO)

Results: Sensor deployment scenarios that yield low α risks prepare circuits for the optimal and violation-free execution of Advanced Applications such as VVO and FLISR.

Low PV Penetration Circuits (C1–C6)

High PV Penetration Circuit (C7)

$\Delta_{min}<10^{-3}$pu		0.5	1.5	2.5	3.5	STFE10	STFE20	HR	LL	PV	1.5+
C1	Δα		9%	11%	11%	14%	9%	14%	7%	N/A	14%
	α	14%	5%	3%	3%	0%	5%	0%	7%		0%
C2	Δα		16%	16%	16%	15%	6%	4%	17%	N/A	18%
	α	18%	2%	2%	2%	3%	12%	14%	1%		0%
C3	Δα		0%	6%	7%	7%	4%	8%	11%	N/A	11%
	α	11%	11%	5%	4%	4%	7%	3%	0%		0%
C4	Δα		16%	N/A	N/A	11%	3%	9%	44%	N/A	44%
	α	44%	28%			33%	41%	35%	0%		0%
C5	Δα		7%	29%	N/A	17%	3%	12%	35%	N/A	37%
	α	37%	30%	8%		20%	34%	25%	2%		0%
C6	Δα		9%	9%	9%	20%	15%	22%	5%	N/A	24%
	α	24%	15%	15%	15%	4%	9%	2%	19%		0%
C7	Δα		2%	2%	N/A	10%	7%	4%	13%	0%	28%
	α	47%	45%	45%		37%	40%	43%	34%	47%	19%

α risk = 0%	0% < α risk ≤ 3%	3% < α risk ≤ 10%	α > 10%

DSSE Performance evaluated for 7 circuits (C1-C7) with different sensor configurations.

Some observations:

- Combination Scheme needed to reduce α risk to near zero for all circuits.
- Large Load (LL) and High Risk (HR) Sensor Scheme can be very effective for reducing α risks.
- DSSE performs poorly (i.e., largest risks) on high PV penetration circuit.
- Risks vary considerably between circuits.
  => Circuit-by-circuit analysis needed.

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Summary

Summary

- A de facto requirement for running Advanced Applications such as VVO and FLISR optimally and violation-free is a well-performing Distribution System State Estimator (DSSE).
- How many sensors are needed, where to deploy them, and what data do they need to provide to the DSSE in order to achieve adequate performance are questions that have a considerable impact on the effectiveness of these applications and significant economic consequences for utilities.
- EnerNex has developed the DSSE Performance Evaluation (DPE) method, which is a stochastic method that informs telemetry and operational forecasting requirements by quantifying the DSSE performance in supporting Advanced Applications.
- Circuit-by-circuit analysis is needed to assess the improvements in DSSE accuracy brought by telemetry and operational forecasting.

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Thank you!

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References

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5. J. Schoene, B. Russel, and M. Humayun, “Implementation of DSSE into utility grid operation,” in IEEE PES General Meeting, Atlanta, USA, Aug. 2019.
6. M. Humayun, J. Schoene, B. Poudel, B. Russel, G. Sun, J. Bui, A. Salazar, N. Badayos, M. Lak, C. Clarke, and M. Zhong, “Quantifying distribution system state estimation accuracies achieved by adding telemetry and operational forecasting,” in IEEE SoutheastCon, Huntsville, Alabama, USA, Apr. 2019.
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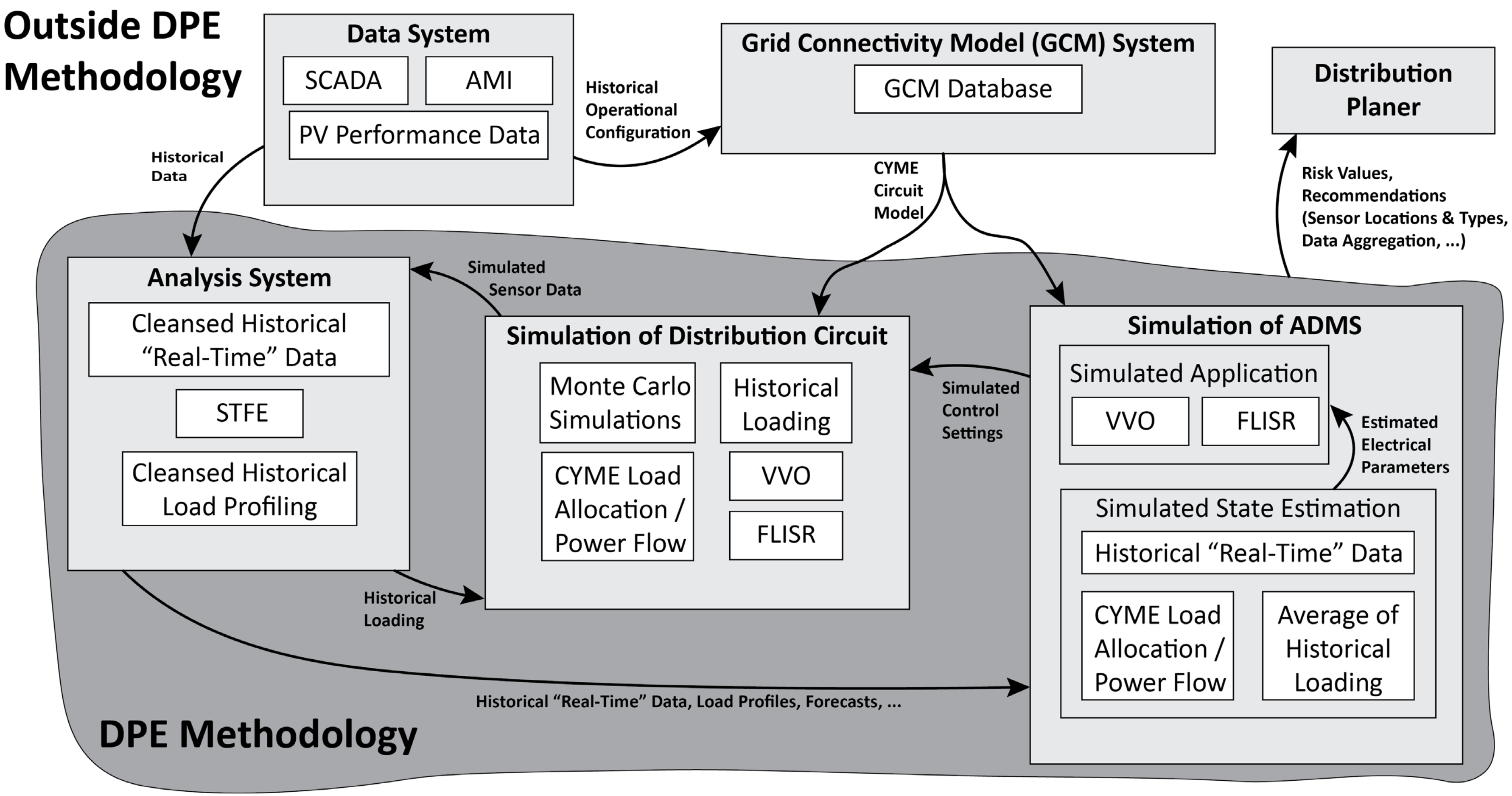
Data Consumed by DPE Methodology

Data Flow: Uses historical field data and Grid Connectivity Model to evaluate DSSE performance .



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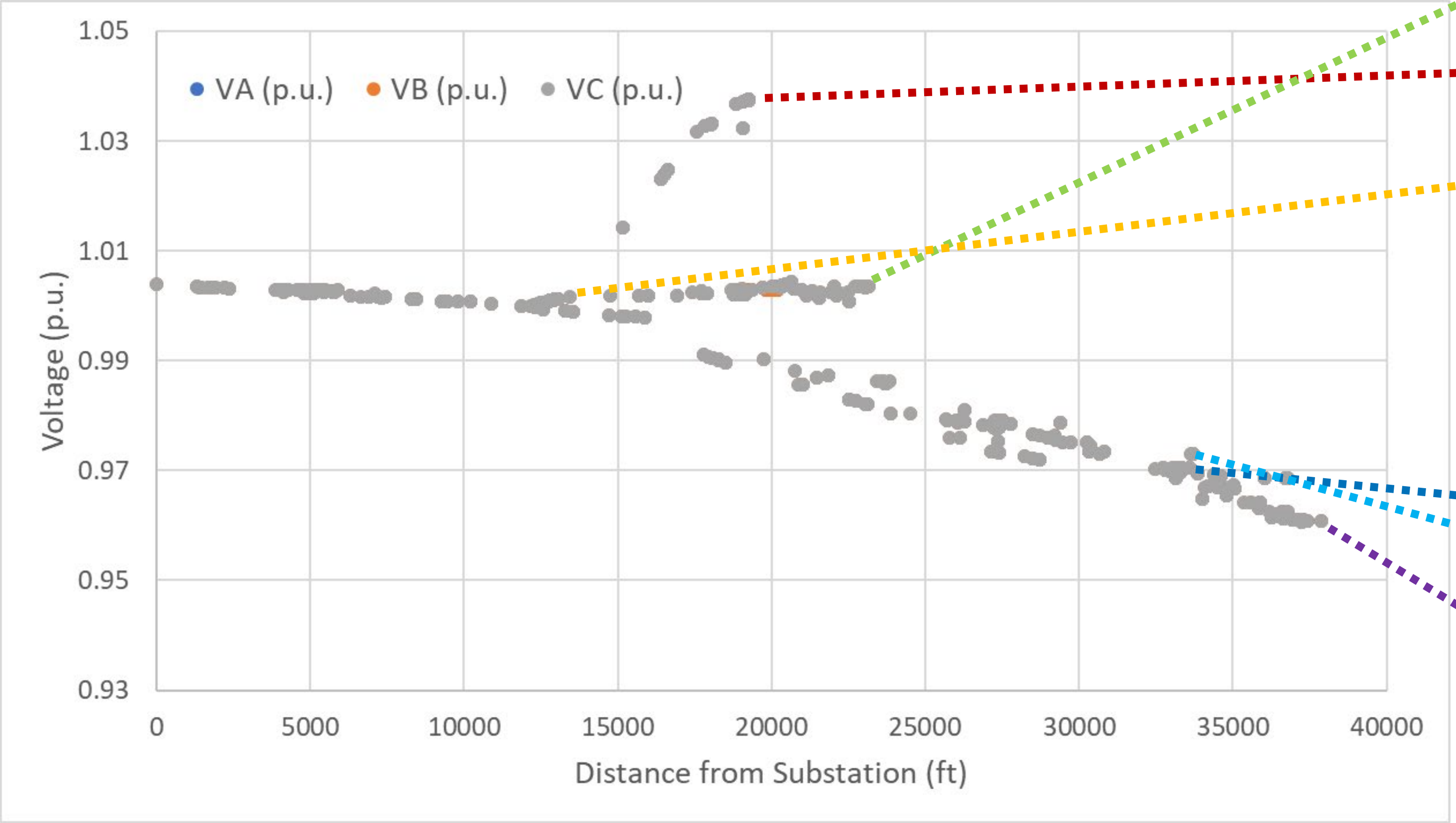
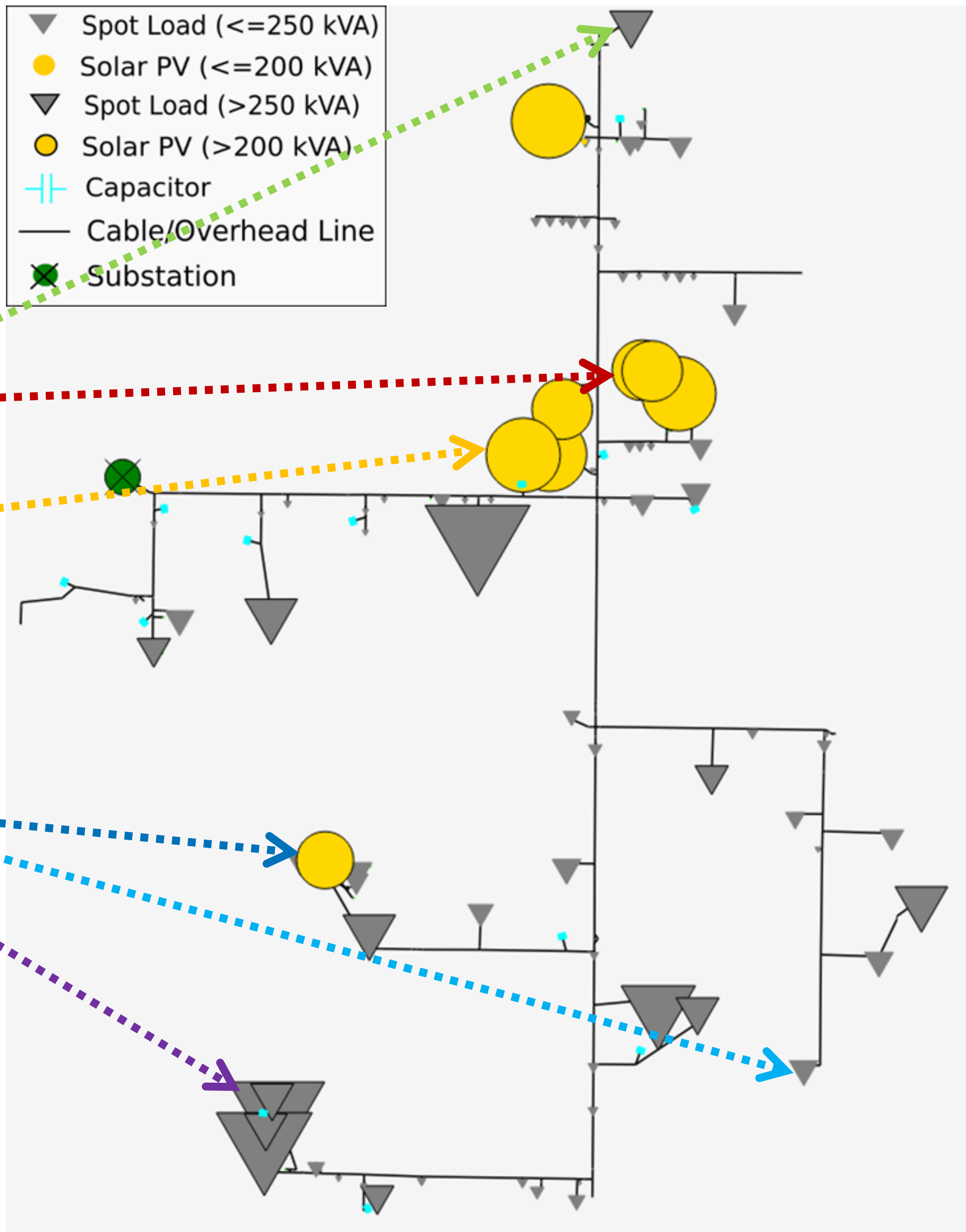
Voltage Profile During a Clear-Sky Day (High PV Generation)

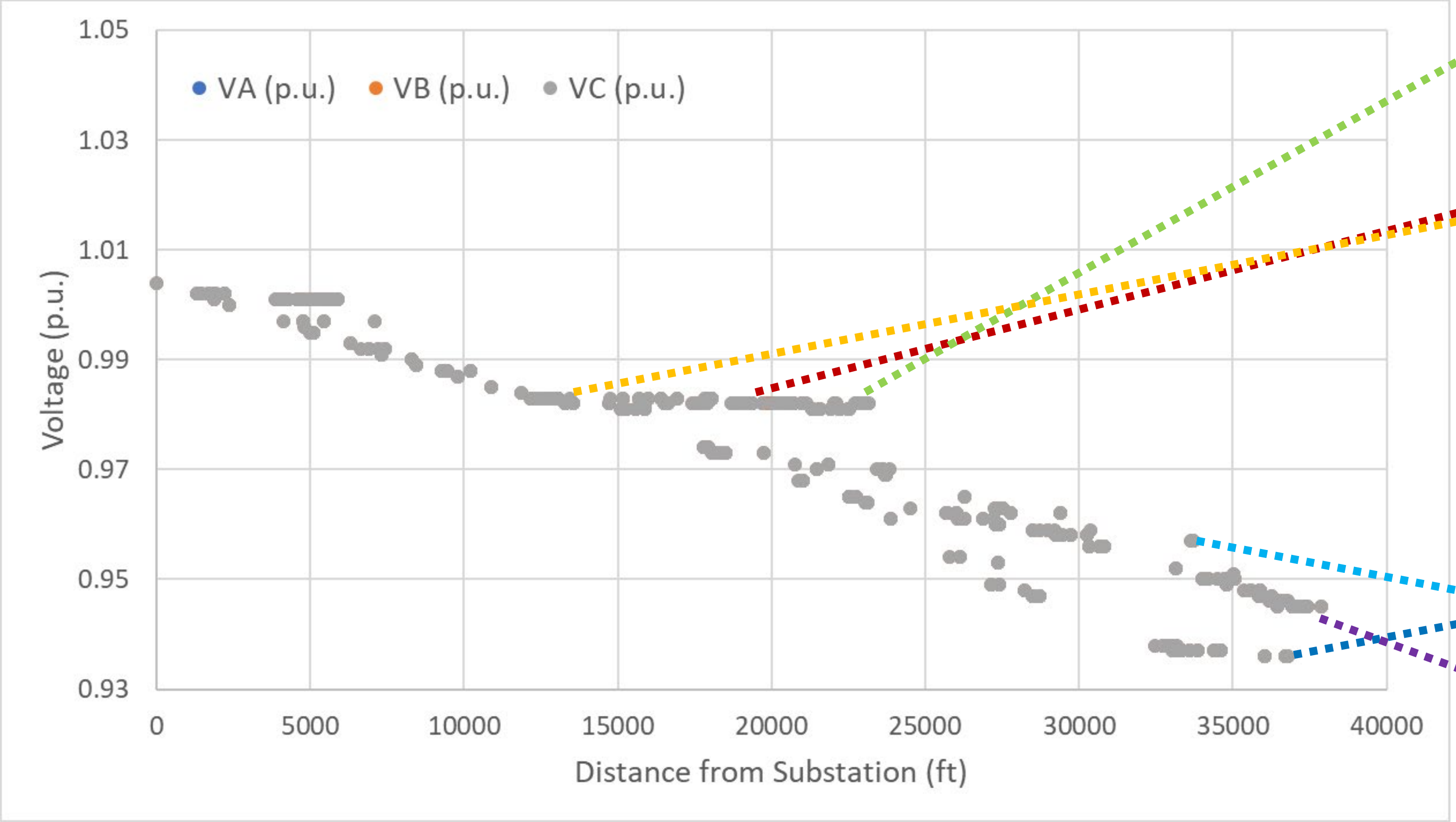
- High PV generation creates non-traditional voltage profile.
- Situational awareness needed to avoid overvoltage and undervoltage violations (both are a concern).

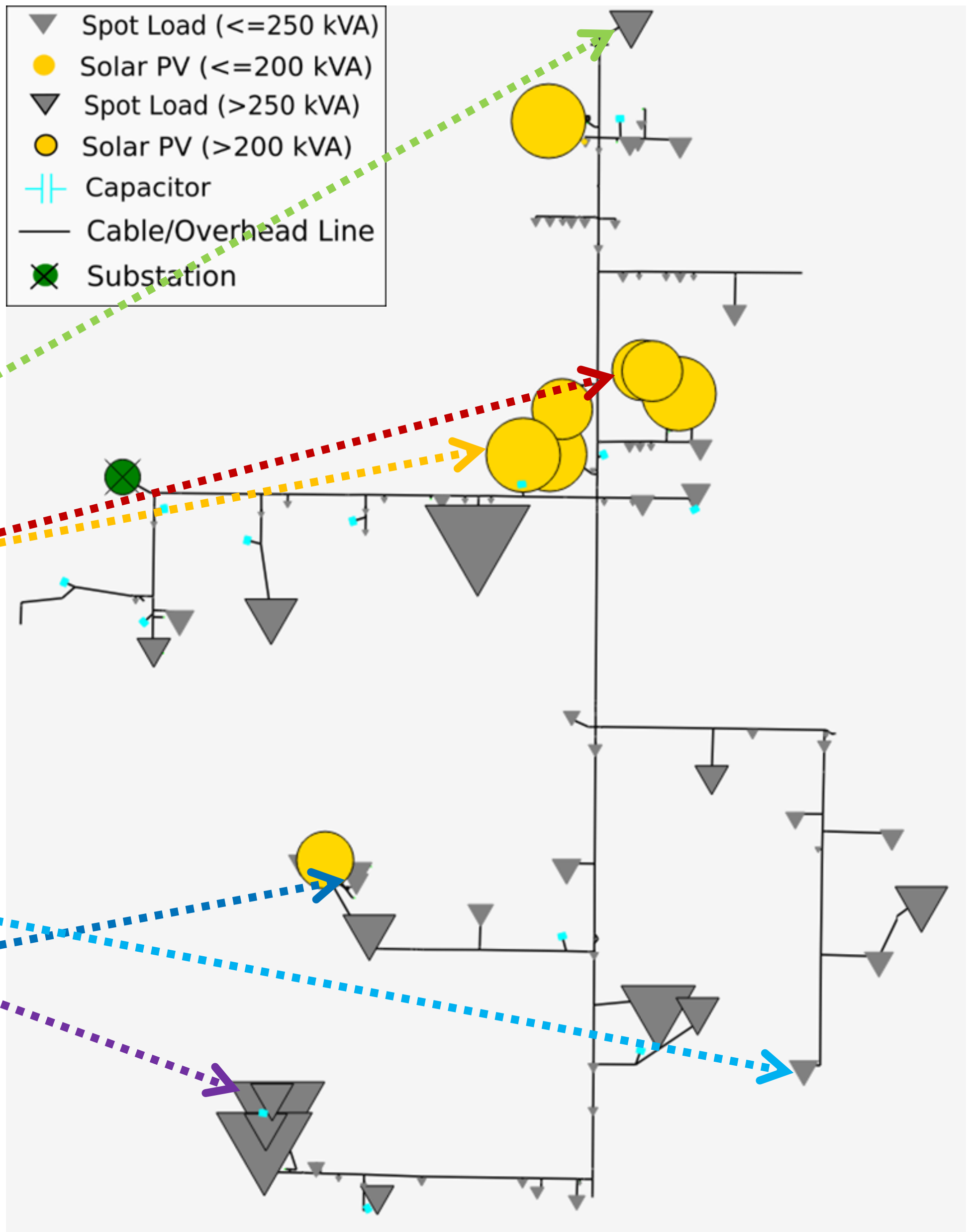




Voltage Profile During a Cloudy Day (Low PV Generation)

- Cloudy-day voltage profile very different from clear-day profile (the circuit now has undervoltage violations).
- Situational awareness needed to account for PV-cause voltage variability.





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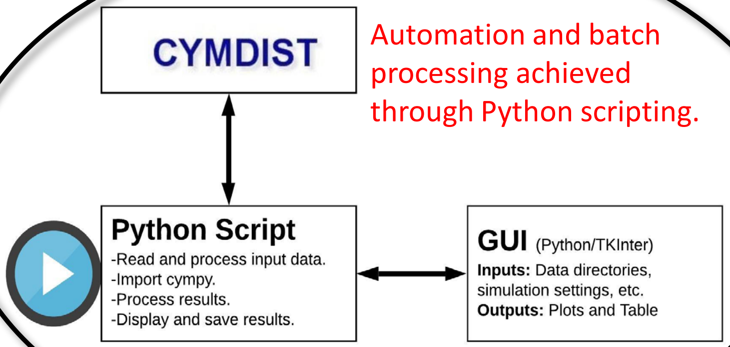
DSSE Performance Evaluation (DPE) Tool

Developed a tool that automates analysis so that it can be applied by utility engineers on many circuits.

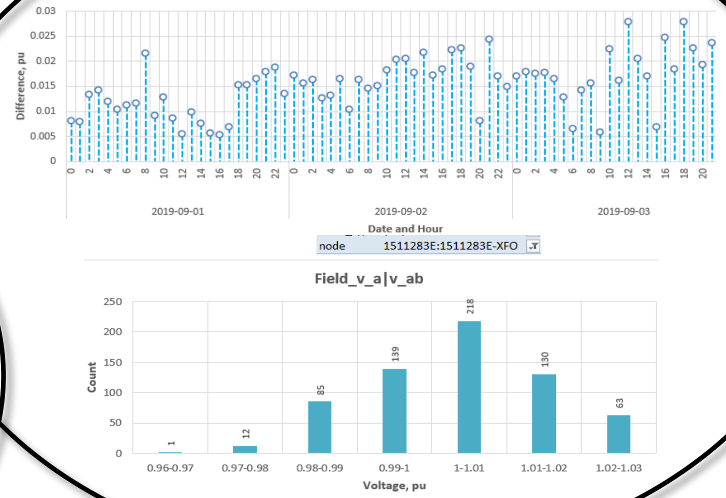


Automation and batch processing achieved through Python scripting.

Variety of analysis and data processing functions.

- Optimal Sensor Placement
- Sensor Placement for CVR
- Bellwether Meter Placement
- Consistency Checks
- Data Cleansing

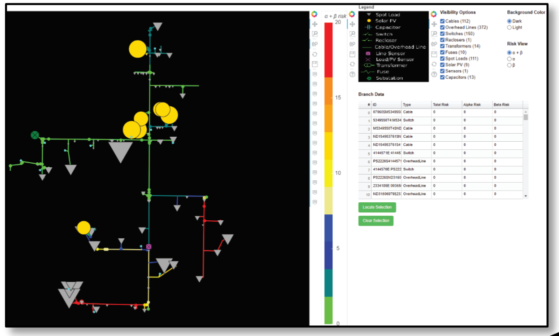
Model validation using AMI and sensor data.



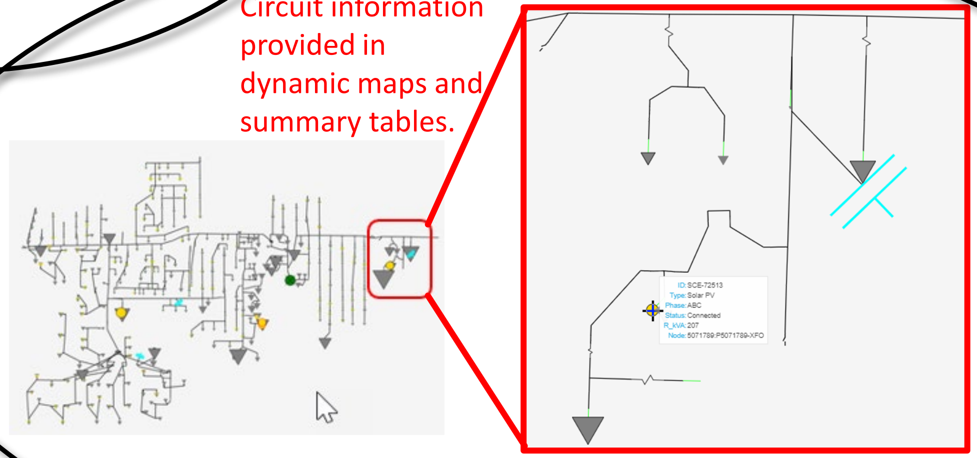
Risk analysis and other results visualized in heat maps and exportable to tables.

Summary Export Table

Scheme Name	(α+β) Risk, %	Δ(α+β) absolute, %	Δ(α+β) relative, %	Rank
0.5	14.856			4
Present	9.995	4.861	32.719	3
b11	6.256	8.601	57.892	2
b11b4	4.914	9.942	66.923	1



Circuit information provided in dynamic maps and summary tables.



Connected Capacity	Number (1P)	Number (2/3P)	kVA % (1P)	kVA % (2/3P)	Percentage (Large Load)
21.0 MVA	222	88	37.265	62.735	4.839

Show information: Substation Loads PVs Lines Capacitors

C:/DPE_Tool/COBALT_12KV.sxst

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