Grid Enhancing Technologies in Long-Term Transmission Planning

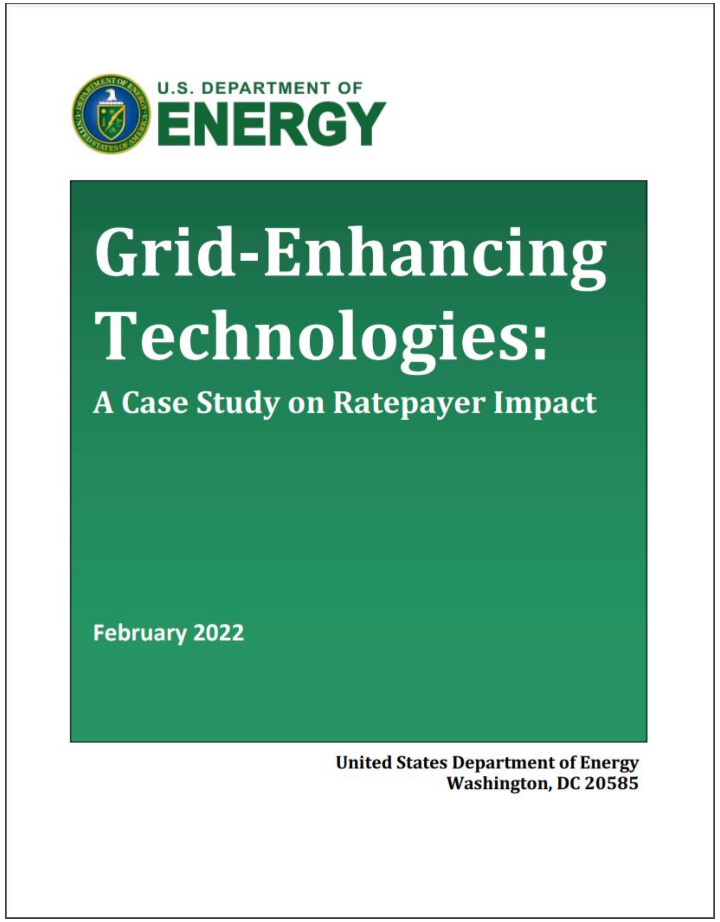
Transmission Planning Approaches for an Uncertain and Volatile Grid

Megan Culler

INL/CON-23-73507

GETs in Long-Term Planning

2022 Report



U.S. DEPARTMENT OF
ENERGY

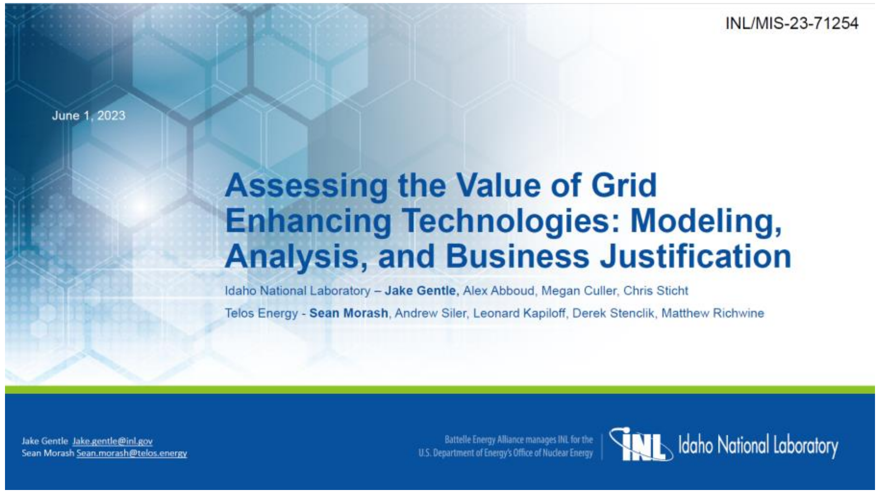
Grid-Enhancing Technologies:

A Case Study on Ratepayer Impact

February 2022

United States Department of Energy
Washington, DC 20585

2023 Presentation-Style Report



INL/MIS-23-71254

June 1, 2023

Assessing the Value of Grid Enhancing Technologies: Modeling, Analysis, and Business Justification

Idaho National Laboratory – **Jake Gentle**, Alex Abboud, Megan Culler, Chris Sticht
Telos Energy - **Sean Morash**, Andrew Siler, Leonard Kapiloff, Derek Stenclik, Matthew Richwine

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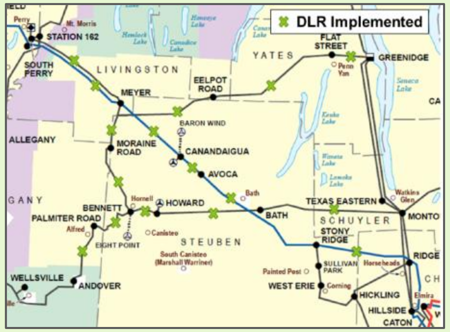
Battelle Energy Alliance manages INL for the
U.S. Department of Energy's Office of Nuclear Energy

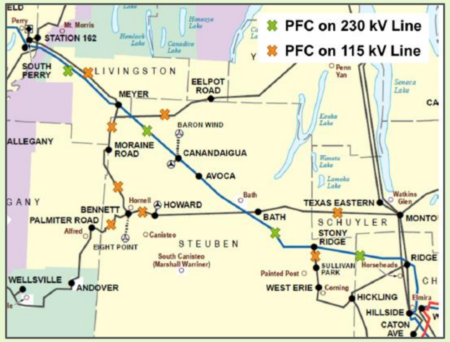
Idaho National Laboratory

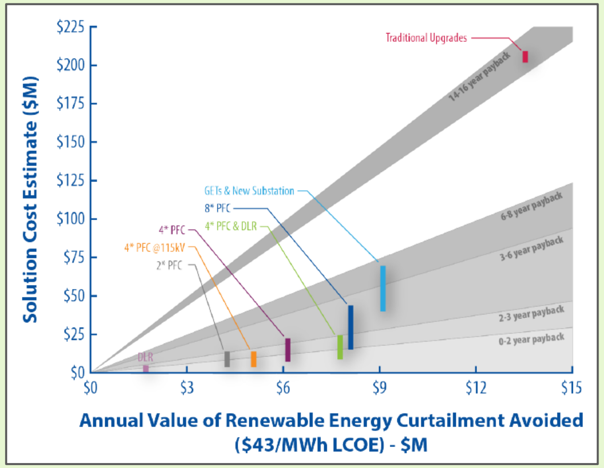
GETs Value in Long-Term Planning

Regardless of approach, payback is quick

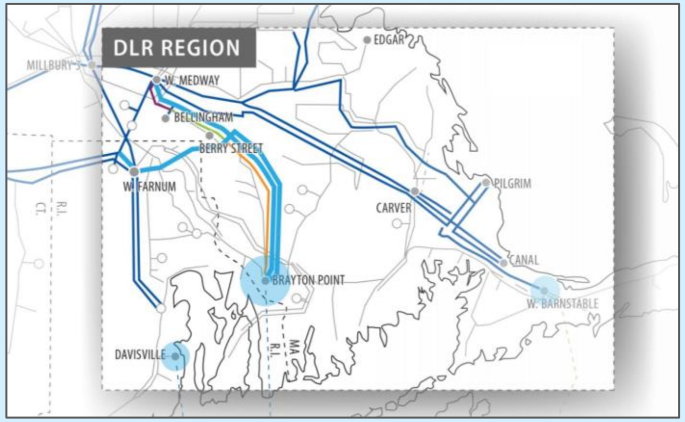
2022 Study on Western New York placed DLR and PFC's **across the system** at varying levels. Results showed 1-3 year payback for GETs.

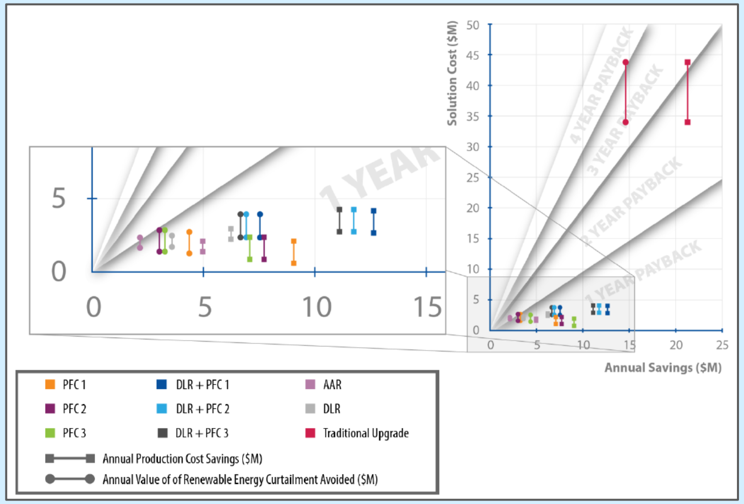






2023 Study on Southern Mass / Rhode Island **strategically placed** DLR and PFC's at targeted locations system. Results showed payback for GETs in terms of months.



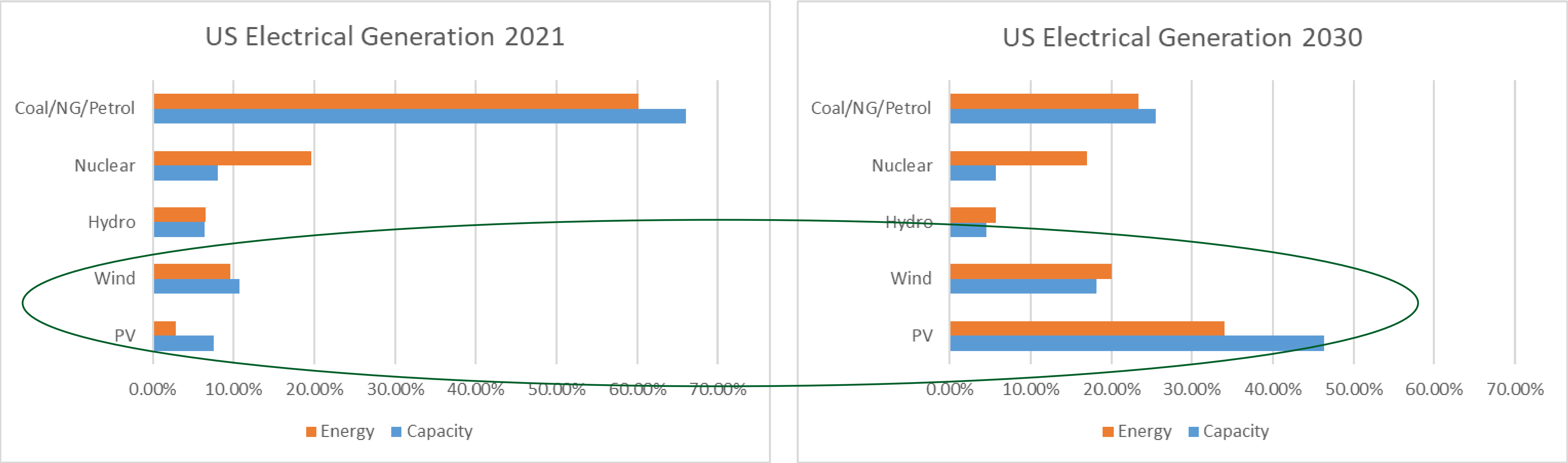


Why do we need GETs in Transmission Planning?

2021 to 2030* Capacity and Energy Production

EIA Energy and Capacity

SETO and WETO Goals



* WETO 2030 Goals and Curve Fitting to SETO 2035 Goals, with Estimated 26 million EV's sold in 2030

Why do we need GETs in Transmission Planning?

EIA Data 2021

Installed Electrical Generation Capacity

- Renewable (24.69%)
  - Solar (7.5%)
  - Wind (10.75%)
  - Hydro (6.44%)
- Nuclear (8.05%)
- Coal, NG, Petro (66.03%)
- Other (1.23%)

Electrical Energy Production

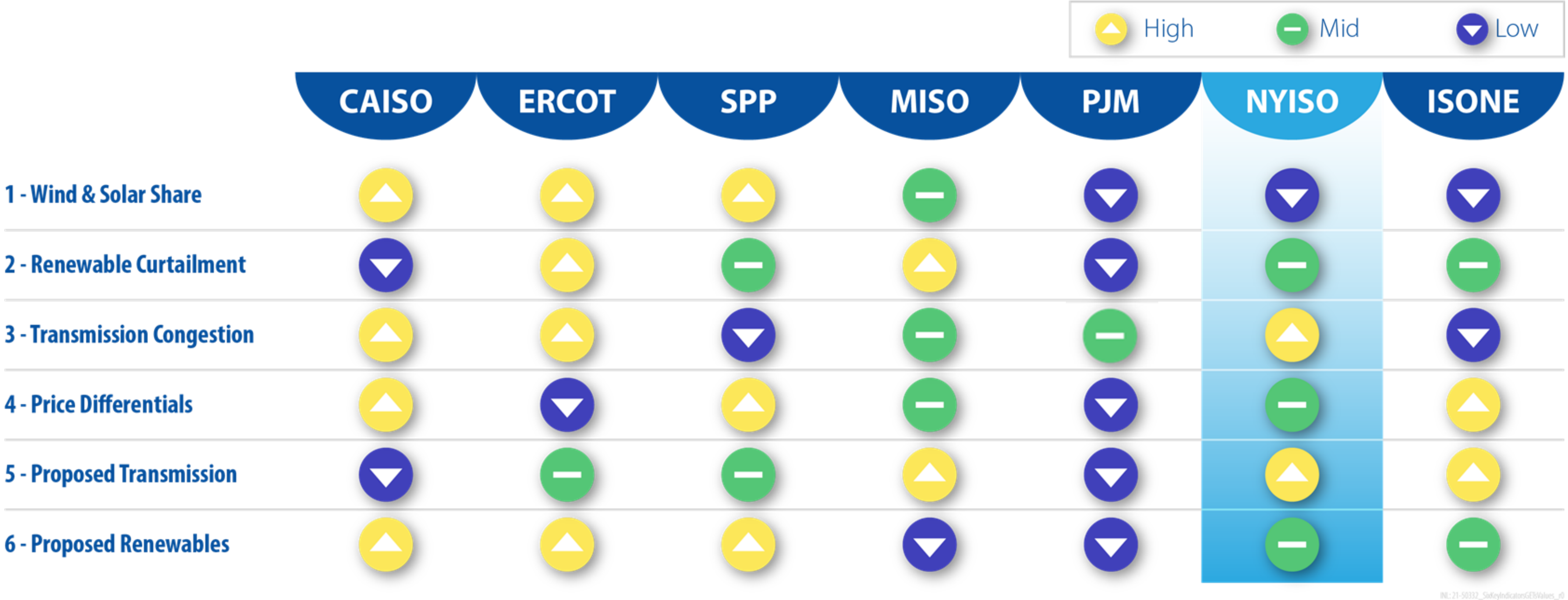
- Renewable (18.96%)
  - Solar (2.87%)
  - Wind (9.55%)
  - Hydro (6.54%)
- Nuclear (19.64%)
- Coal, NG, Petrol (60.17%)
- Other (1.23%)

From Here to There

- Solar 1000 GW installed
- 2035 – 4900 B-kWh (22.5% increase) (6-8% EV's)
- 35% Solar = 1560 B-kWh
- 20% Energy Wind Goal 2030 (920 B-kWh)
- 2030 – 1150 GW PV installed
- Average Plant size 12-20 MW
- 43k to 57k plants installed by 2030 (5.2k today or 8 to 10 times number of plants)
- 3k to 4k wind plants by 2030

Finding GETs Value in Operations

Value apparent in Ops should be reflected in Planning



▲ High ▬ Mid ▼ Low

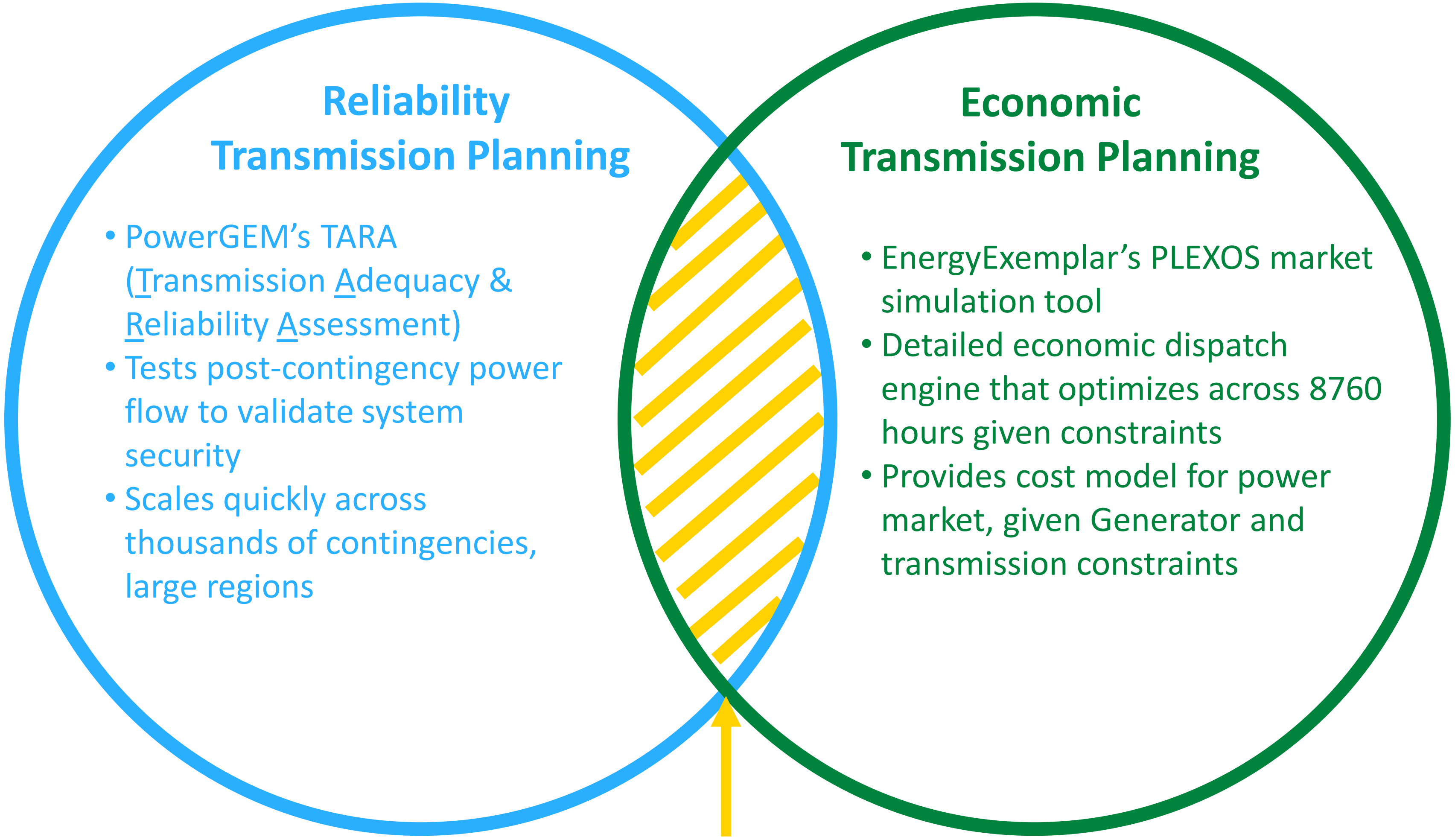
	CAISO	ERCOT	SPP	MISO	PJM	NYISO	ISONE
1 - Wind & Solar Share	▲	▲	▲	▬	▼	▼	▼
2 - Renewable Curtailment	▼	▲	▬	▲	▼	▬	▬
3 - Transmission Congestion	▲	▲	▼	▬	▬	▲	▼
4 - Price Differentials	▲	▼	▲	▬	▼	▬	▲
5 - Proposed Transmission	▼	▬	▬	▲	▼	▲	▲
6 - Proposed Renewables	▲	▲	▲	▼	▼	▬	▬

INL: 21-50332_SixKeyIndicatorsGETsValues_r0

Project quantified normalized indicators across ISOs and RTOs to identify candidate regions for GETs deployment

NYISO selected due to relatively early renewable curtailment, high congestion costs, and proposed renewables and transmission, ***Potential value for GETs***

Improved Transmission Planning with GETs



Reliability Transmission Planning

- PowerGEM's TARA (Transmission Adequacy & Reliability Assessment)
- Tests post-contingency power flow to validate system security
- Scales quickly across thousands of contingencies, large regions

Economic Transmission Planning

- EnergyExemplar's PLEXOS market simulation tool
- Detailed economic dispatch engine that optimizes across 8760 hours given constraints
- Provides cost model for power market, given Generator and transmission constraints

Integrated transmission planning

Integrated reliability & economic transmission planning

- Combined reliability analysis with economic planning will highlight full benefits of GETs and other transmission upgrades
- Reliability analysis in TARA inform PLEXOS contingency modeling and dispatch
- Reliability analysis in TARA paired with PLEXOS congestion costs inform PFC placement

No one tool does it all:

Why we need to link

What is PLEXOS?

- Software Developer: Energy Exemplar
- Used for: Production Cost Modeling
- DC Optimal Power Flow
    - Simplified Network Solution
    - Ignores Voltage Impacts
- Entire year(s) of simulation
- Economic unit commitment & dispatch
- Identifies transmission congestion that should be resolved to reduce costs
- Quantifies system operating costs & benefits

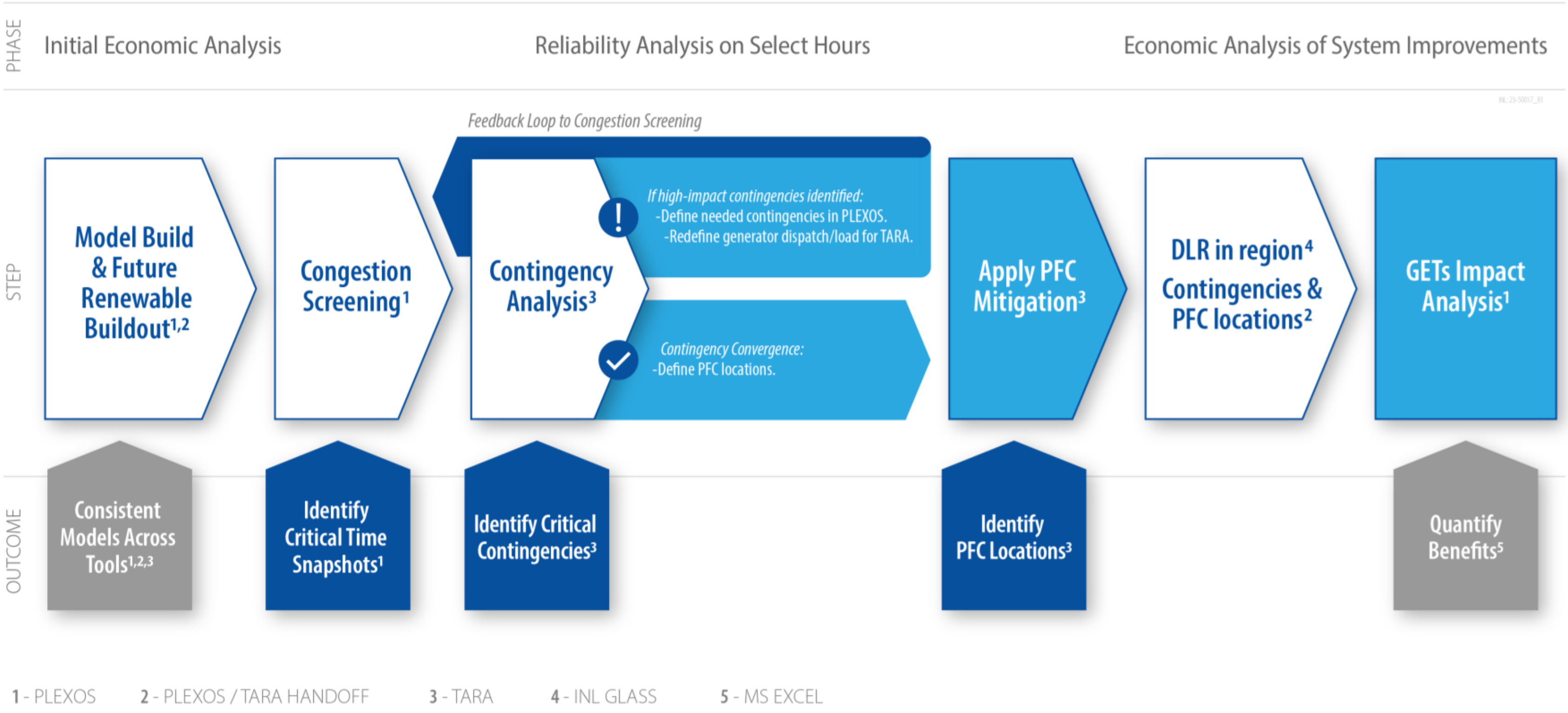
What is TARA?

- Software Developer: PowerGEM
- Used for: Steady State Analysis
- AC Power Flow
    - Complete Network Solution
    - Incorporates Voltage Impacts
- Single period dispatch conditions
- Pre-determined unit commitment & dispatch
- Identifies transmission overloads that need to be resolved for reliability
- Identifies voltage violations

Detailed ACPF is computationally burdensome, can only run selected conditions and does not factor in economic dispatch. Production cost modeling is done hourly and considers chronology and economic dispatch decisions but uses simplified power flow. **Tool linking is necessary, especially for GETs.**

Process Design Pairing Economic and Reliability Analyses

In order to combine these tools, the project team developed a detailed methodology to link the tools before ultimately assessing different GETs scenarios. The process begins with an initial economic analysis, then moves into a reliability analysis on select hours, and ultimately moves back to a (more accurate) security-constrained economic analysis of multiple potential system improvements.



PHASE

Initial Economic Analysis

Reliability Analysis on Select Hours

Economic Analysis of System Improvements

STEP

Model Build & Future Renewable Buildout[1,2]

Congestion Screening[1]

Contingency Analysis[3]

Feedback Loop to Congestion Screening

If high-impact contingencies identified:
-Define needed contingencies in PLEXOS.
-Redefine generator dispatch/load for TARA.

Contingency Convergence:
-Define PFC locations.

Apply PFC Mitigation[3]

DLR in region[4] Contingencies & PFC locations[2]

GETs Impact Analysis[1]

OUTCOME

Consistent Models Across Tools[1,2,3]

Identify Critical Time Snapshots[1]

Identify Critical Contingencies[3]

Identify PFC Locations[3]

Quantify Benefits[5]

1 - PLEXOS

2 - PLEXOS / TARA HANDOFF

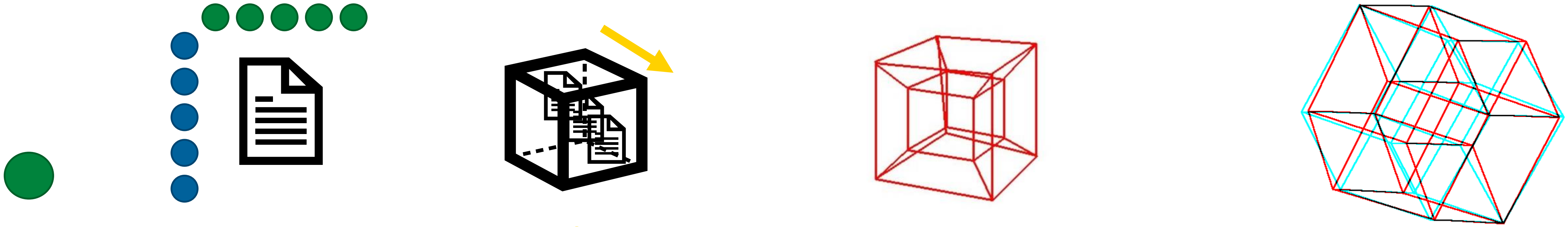
3 - TARA

4 - INL GLASS

5 - MS EXCEL

Finding a Quality PFC Location

Dimensionality Problem: Place PFC's optimally that address the (1) overloaded elements during (2) different contingencies at (3) different hours of the year that (4) have the highest impact on ratepayer costs and (5) consider other GETs.



Elements
associated w/ congestion

Contingencies
Inform Overloading Situations

Snapshots
Different Hours' Dispatch

Economic Dispatch
Refine PFC placement based on economic impact.

GETs Co-Optimization
Adjust PFC placement based on DLR and storage.

Engineering Optimization
PFC placed based on highest impact in addressing N-1 planning criteria at different times of the year

Economic Validation
PFC placement modeled to confirm impact on the security constrained economic dispatch

GETs Planned Together
PFC placement modeled based on unaddressed congestion after DLR implementation

Measuring PFC Impact Using TARA

Engineering Optimization

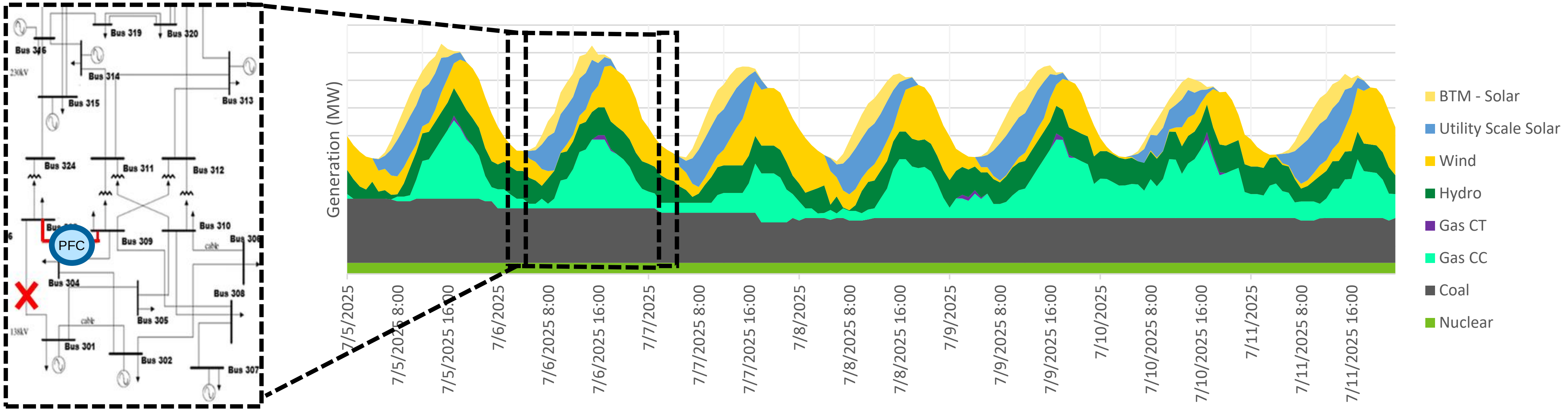
1. PLEXOS passes **several key hours** of gen and load information to TARA
2. TARA runs AC contingency analysis to determine **relevant contingencies** and **monitored elements**
3. In TARA, add PFCs at **potential locations** and measure the impact of a small change in angle for **every combination of hour & contingency**
4. Measure the change in MW flow and change in MW overload **on each monitored element**
   - Radial overloads will have near-zero MW change
5. Combine the MW overload impact across **several key hours**

Applying the PFC Device in PLEXOS

PFC's Siting Method based on Sampling of hours, but PFC's can be flexible across other hours

The PFC device is placed based on a sampling of hours.

PLEXOS is still free to dispatch the PFC as part of the economic optimization throughout the year



1. This has minimal impact on the hour-to-hour dispatch decisions on PLEXOS. Rather, it makes it difficult to assess if and how PLEXOS would use the PFC in post-contingency operations (like is observed in TARA). This could be solved by removing a line from service in PLEXOS and assessing PFC value while operating in that N-1 state for a short period of time.

Complementary Capabilities

Rules of Thumb for picking the right GETs

Device Type	All Export Paths Congested	Some Export Paths Congested	Devices Interactive Effects
DLR	DLR can add additional transmission capacity to congested export paths.	DLR can increase transmission capacity on average if placed on congested export paths.	N/A
PFC	PFC cannot alter power flow to mitigate congestion.	PFC can alter power flow away from congested export paths.	N/A
PFC+ DLR	DLR can add additional transmission capacity to congested export paths.	PFC can alter power flow away from congested export paths.	Adding a PFC can be helpful when DLR (1) Shifts congested hours from the bucket of "All Export Paths Congested" to "Some Export Paths Congested" (2) Does not fully alleviate congestion, particularly in the "Some Export Paths" case.

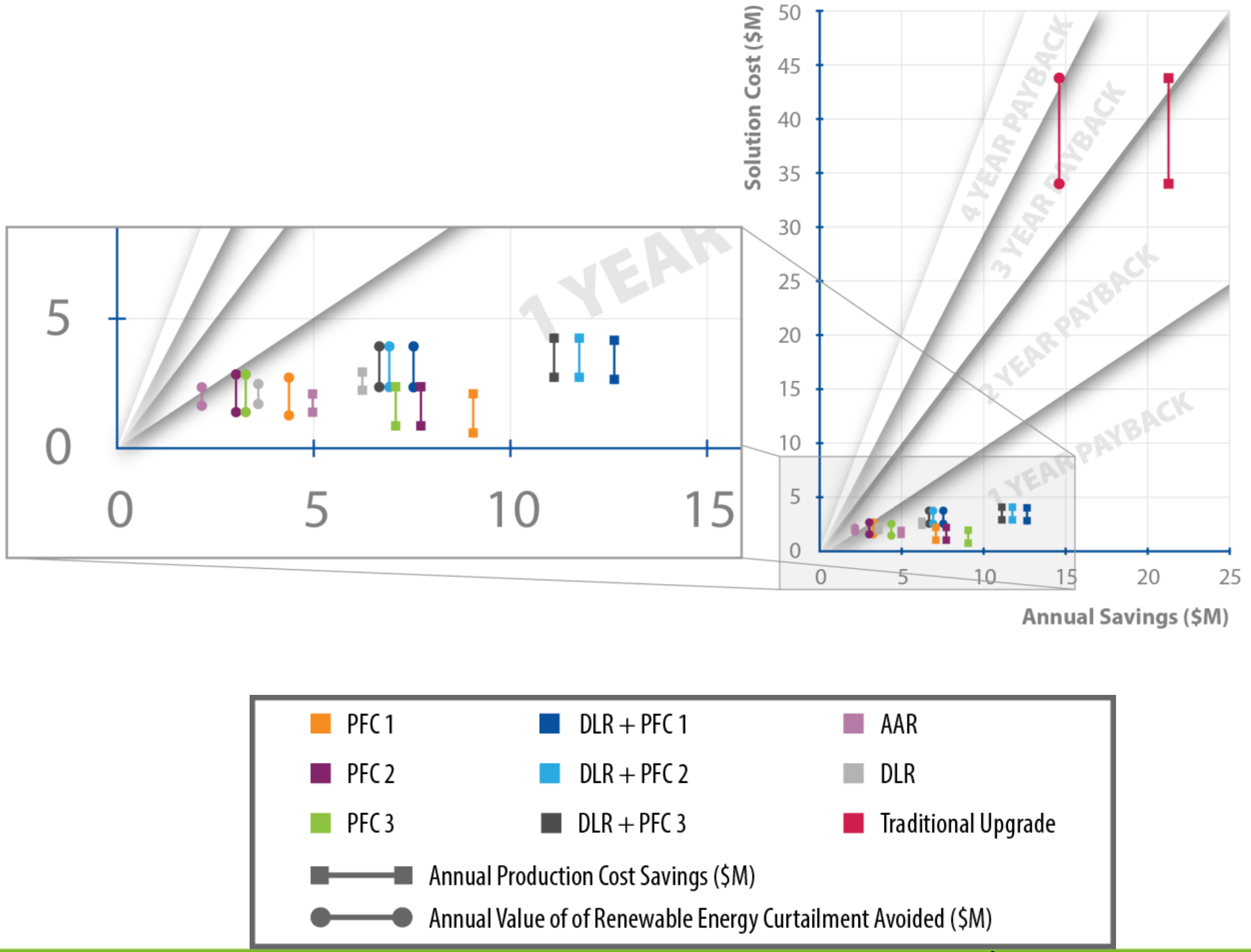
Summary of 2023 Efforts

Key Technical Insights from this project:

1. Individual GETs devices can make an impact on the overall system performance. Even in future planning cases (like 2030)
2. The value of GETs is highly system and congestion dependent.
3. PFC and DLR together can be better than each individually.

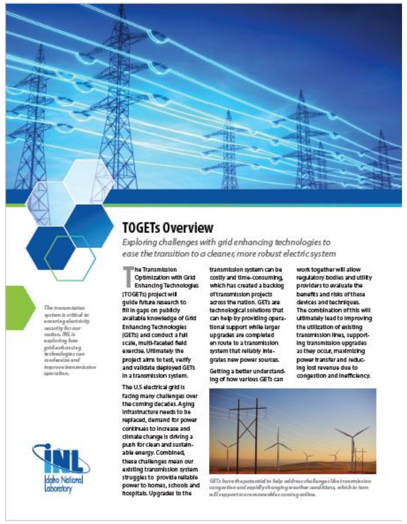
This analysis is distinct in the following ways:

1. Individual GETs devices were placed in a targeted fashion to assess economic impact.
2. The Economic Dispatch (SCED) model was validated and improved with the use of a reliability screening tool that solves A/C power flow across multiple hours.
3. Offshore wind integration and GETs is a novel overlap analysis.



Want to learn more?

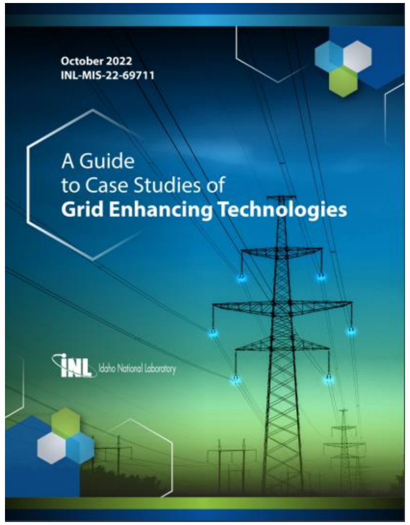
Resources from INL Transmission Optimization for Grid Enhancing Technologies (TOGETs) Project



TOGETs Overview

Exploring challenges with grid enhancing technologies to ease the transition to a cleaner, more robust electric system

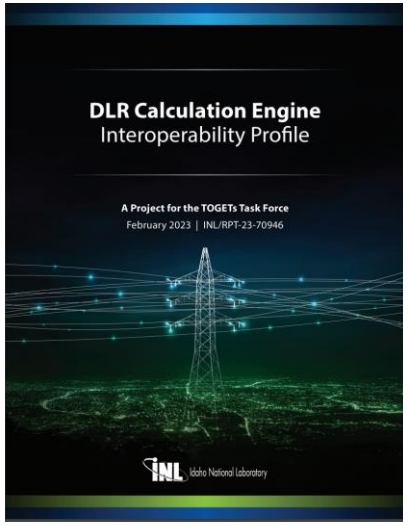
INL Idaho National Laboratory



October 2022
INL-MIS-22-69711

A Guide
to Case Studies of
Grid Enhancing Technologies

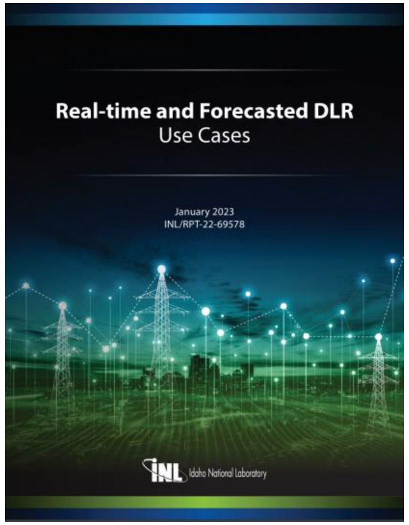
INL Idaho National Laboratory



DLR Calculation Engine
Interoperability Profile

A Project for the TOGETs Task Force
February 2023 | INL/RPT-23-70946

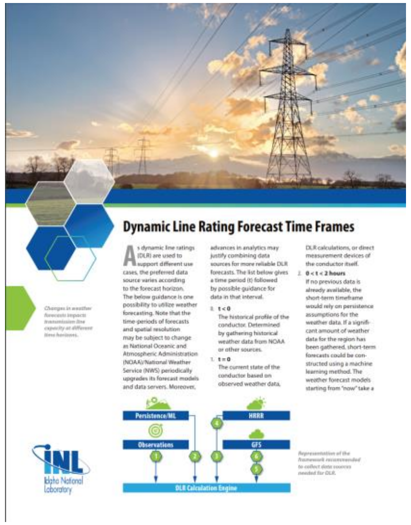
INL Idaho National Laboratory



Real-time and Forecasted DLR
Use Cases

January 2023
INL/RPT-22-69578

INL Idaho National Laboratory

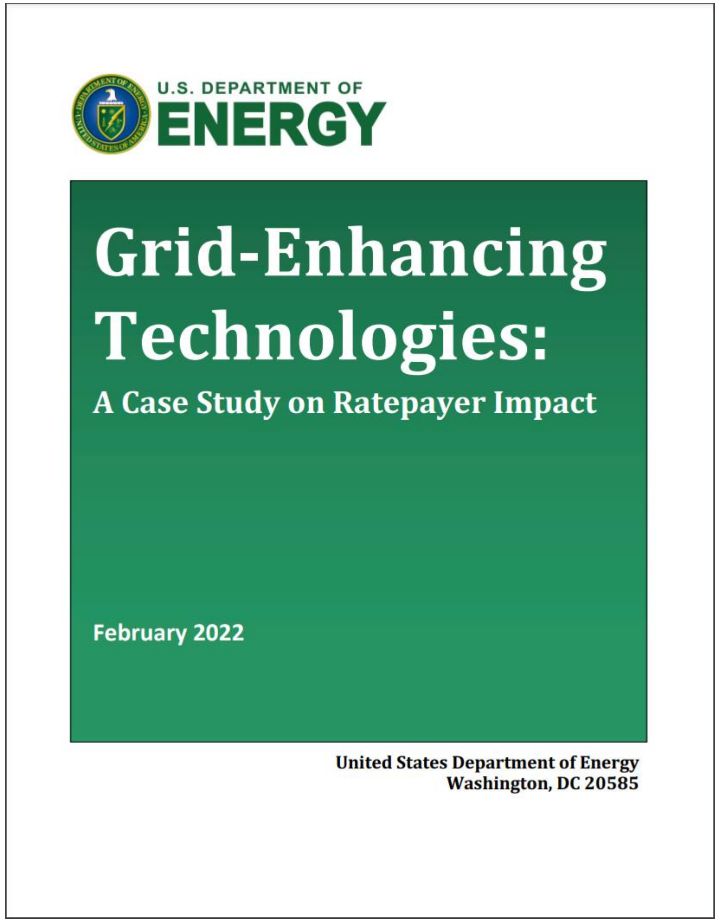


Dynamic Line Rating Forecast Time Frames

INL Idaho National Laboratory

inl.gov/national-security/grid-enhancing-technologies

2022 Report to Congress: Study on Ratepayer Impact



U.S. DEPARTMENT OF
ENERGY

Grid-Enhancing Technologies:

A Case Study on Ratepayer Impact

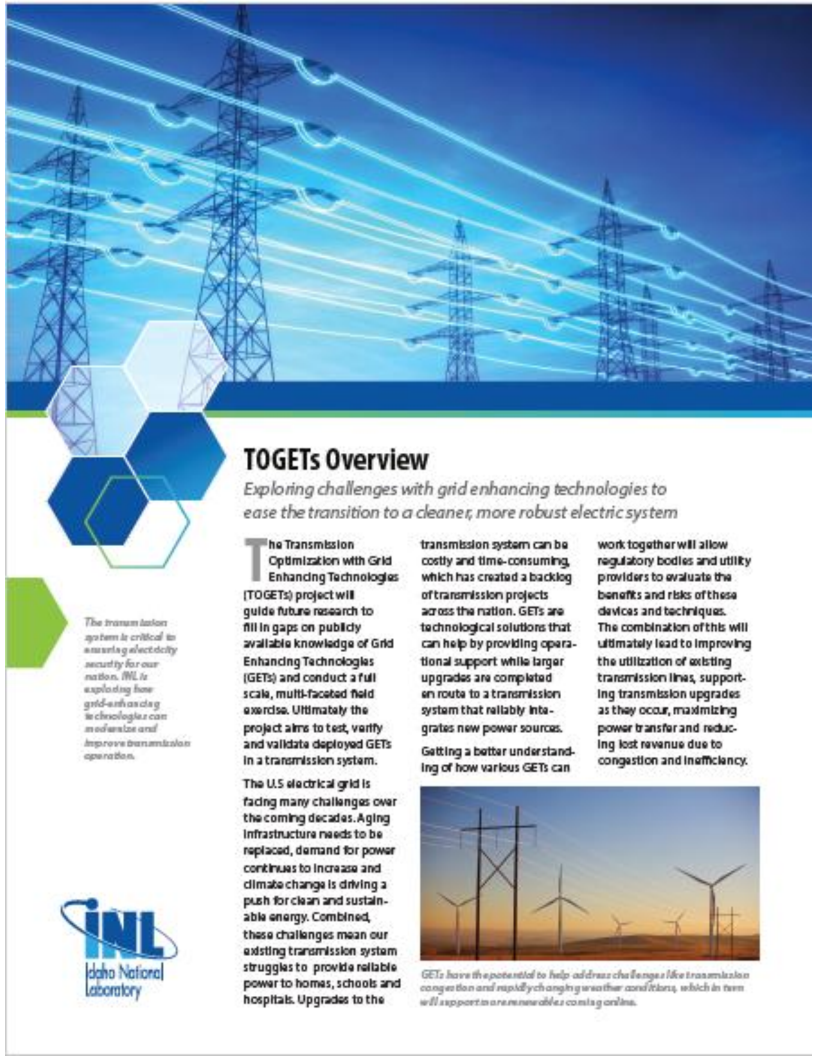
February 2022

United States Department of Energy
Washington, DC 20585

Backup

Website and Publications

TOGETs Info Sheet



TOGETs Overview

Exploring challenges with grid enhancing technologies to ease the transition to a cleaner, more robust electric system

The transmission system is critical to ensuring electricity security for our nation. INL is exploring how grid-enhancing technologies can modernize and improve transmission operation.

The Transmission Optimization with Grid Enhancing Technologies (TOGETs) project will guide future research to fill in gaps on publicly available knowledge of Grid Enhancing Technologies (GETs) and conduct a full scale, multi-faceted field exercise. Ultimately the project aims to test, verify and validate deployed GETs in a transmission system.

The U.S electrical grid is facing many challenges over the coming decades. Aging infrastructure needs to be replaced, demand for power continues to increase and climate change is driving a push for clean and sustainable energy. Combined, these challenges mean our existing transmission system struggles to provide reliable power to homes, schools and hospitals. Upgrades to the transmission system can be costly and time-consuming, which has created a backlog of transmission projects across the nation. GETs are technological solutions that can help by providing operational support while larger upgrades are completed en route to a transmission system that reliably integrates new power sources.

Getting a better understanding of how various GETs can work together will allow regulatory bodies and utility providers to evaluate the benefits and risks of these devices and techniques. The combination of this will ultimately lead to improving the utilization of existing transmission lines, supporting transmission upgrades as they occur, maximizing power transfer and reducing lost revenue due to congestion and inefficiency.

GETs have the potential to help address challenges like transmission congestion and rapidly changing weather conditions, which in turn will support more renewables coming online.

Idaho National Laboratory

Key Topics and Questions Addressed by TOGETs

Modeling
- What protection studies are needed?
- How do we integrate device models into system models?

Procurement
- What are common lead times?
- How much per span do devices cost?

Installation
- Can we safely do hot-installs?
- Where should devices be installed for maximum impact?
- How many devices are needed?

EMS Integration
- Does it require external connections?
- What data security measures are needed?

Data Collection
- How is data collected?
- How often should data be collected?
- How often should models and calculations be updated?

Data Integration
- How can data be leveraged from GETs to inform operation decisions?

TWO PARTS, ONE GOAL

The first part of the project consists of compiling information on cost, data, and outcomes from previous studies. These are vital to understanding the use of GETs devices and allow all entities to leverage lessons learned from earlier efforts to streamline future investments. The study of existing resources will collect these lessons learned into a centralized repository and identify gaps in the publicly available literature. This will allow the TOGETs team to focus on filing these gaps.

GETs	Grid Enhancing Technologies: devices or techniques that enhance existing grid hardware to prolong useful life or increase capacity.
DLR	Dynamic Line Rating: Using weather conditions such as wind speed, direction and ambient air temperature to determine the true temperature of a conductor and consequently the maximum power that can safely flow on a transmission line at a given time. This is often greater than the static rating normally assigned to a transmission line.
PFC	Power Flow Controller: A device which can actively push and pull power by changing the reactance in the lines. This is useful for redistributing power flow in a mesh network to relieve congestion.
Other GETs	Other GETs exist other than those being studied in this project such as Topology Optimization, which uses geological space and placement to improve infrastructure systems and Dynamic Transformer Ratings, which is comparable to DLR, but for transformers instead of transmission lines.

The second part of the TOGETs program is a full-scale demonstration of GETs using INL's full-scale Power Grid Test Bed. Specifically, it will use Dynamic Line Rating (DLR) and Power Flow Controllers (PFCs) to clarify and answer unaddressed concerns such as integration challenges, cyber security and data management. The data collected will be made publicly available to make implementation and operation of GETs more transparent to future users.

FOR MORE INFORMATION

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www.inl.gov

A U.S. Department of Energy National Laboratory

Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy.

Case Study and Pilot Review

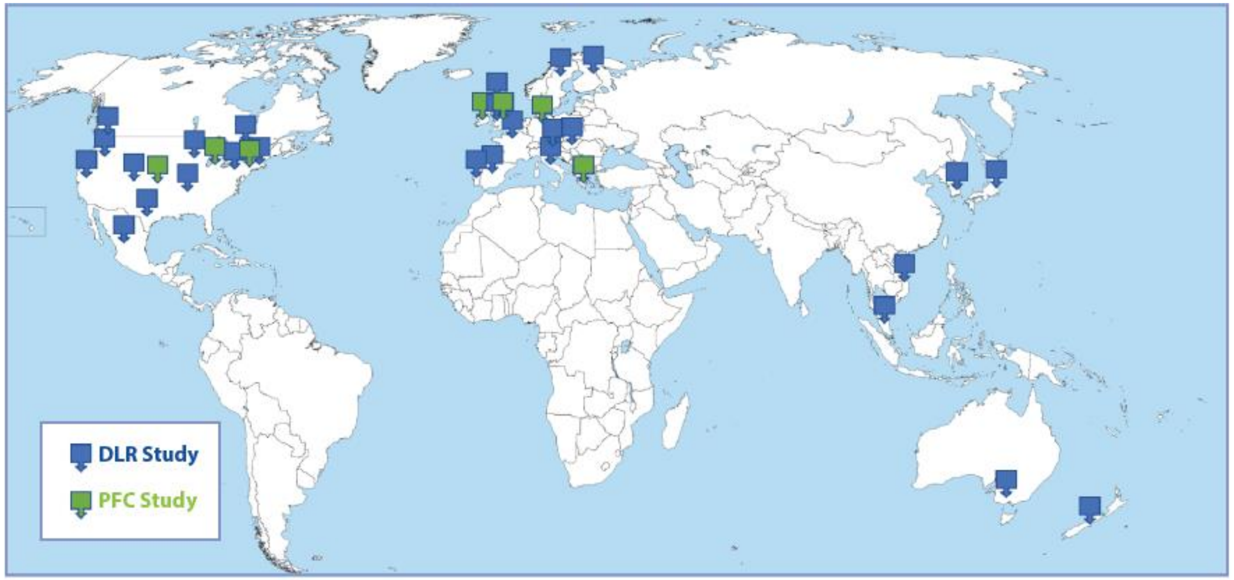
55 reports reviewed
~30 with informative cost discussions on single pages
Key takeaways:

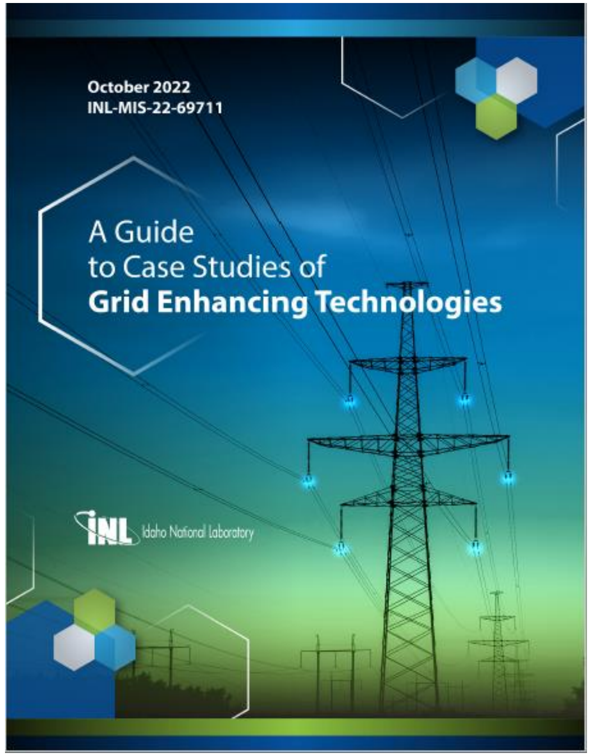
- Detailed technical information available for simulated/research studies
- Lack of detailed technical information for real hardware studies/pilots
- Real hardware studies/pilots often announced, but results hard to find
  - Lots of press saying what “will happen”
  - Not a lot of after action reporting on what “did happen”
- Common motivation: support more renewables integration and unlock the transmission queue
- Information on total system costs is inconsistent
  - Adjusted for inflation/currency across studies
  - Passive Cost Estimates within TOGETs scope
- Several European utilities have successfully moved from pilots to operational systems that could be used as guides for US

A Guide to Case Studies of GETs

Flipbook Excerpts

- 28 cases discussed in detail
- Highlights GETs validation efforts
- Key similarities and differences extracted





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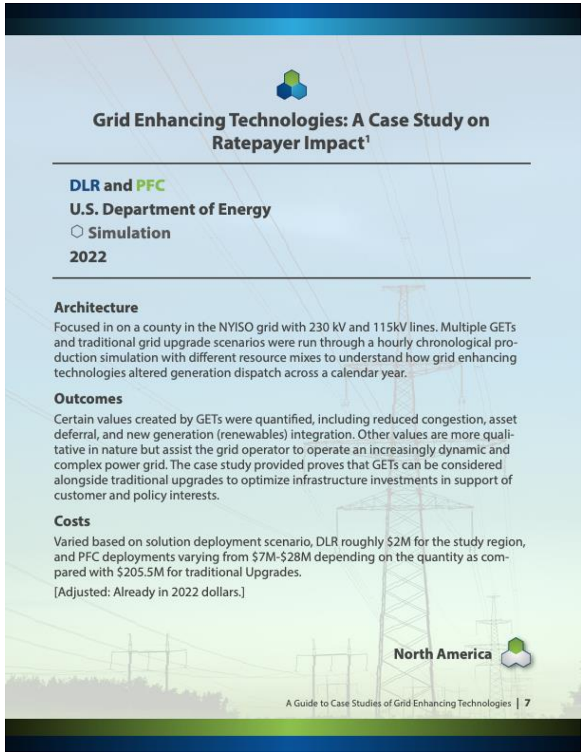


Grid Enhancing Technologies: A Case Study on Ratepayer Impact[1]

DLR and PFC
U.S. Department of Energy
⬡ Simulation
2022

Architecture

Focused in on a county in the NYISO grid with 230 kV and 115kV lines. Multiple GETs and traditional grid upgrade scenarios were run through a hourly chronological production simulation with different resource mixes to understand how grid enhancing technologies altered generation dispatch across a calendar year.

Outcomes

Certain values created by GETs were quantified, including reduced congestion, asset deferral, and new generation (renewables) integration. Other values are more qualitative in nature but assist the grid operator to operate an increasingly dynamic and complex power grid. The case study provided proves that GETs can be considered alongside traditional upgrades to optimize infrastructure investments in support of customer and policy interests.

Costs

Varied based on solution deployment scenario, DLR roughly $2M for the study region, and PFC deployments varying from $7M-$28M depending on the quantity as compared with $205.5M for traditional Upgrades.

[Adjusted: Already in 2022 dollars.]

North America

A Guide to Case Studies of Grid Enhancing Technologies | 7

DLR Use Cases

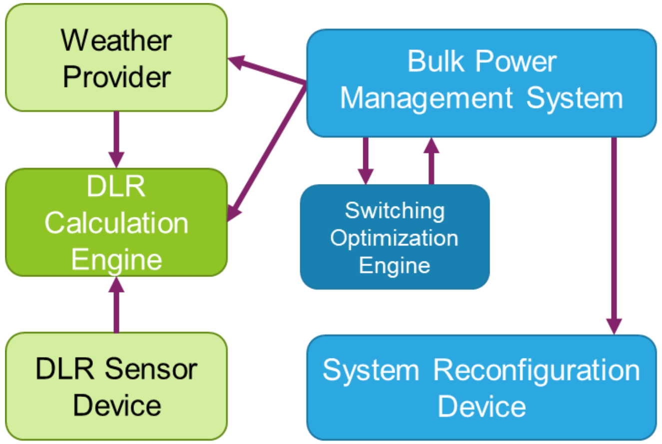
What are we doing with GETs?

Why?

- Industry lacked a reference on operationalization of DLRs
- Need to provide common definitions and terms across vendors

What?

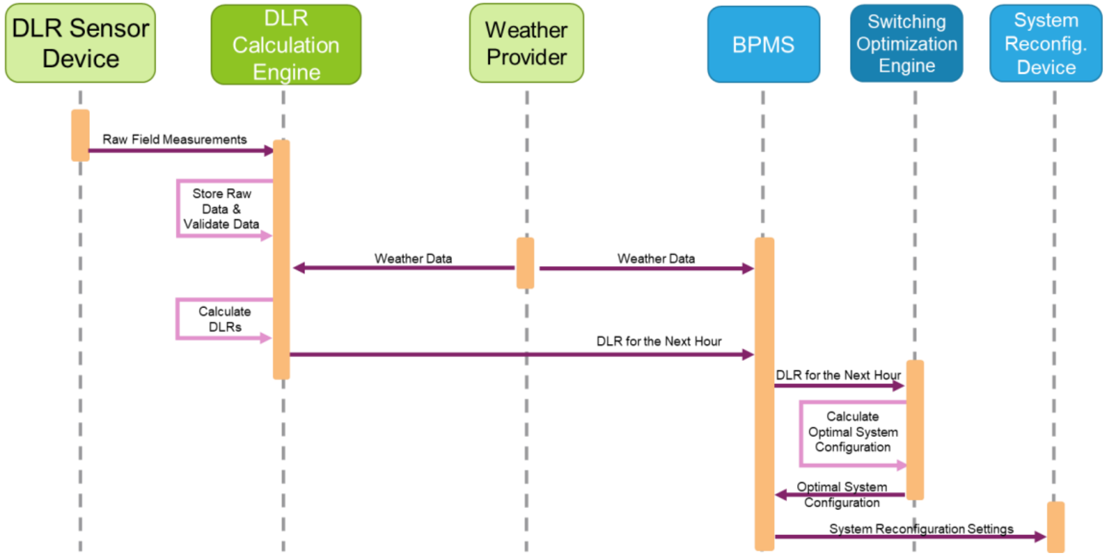
- 18-page document outlining two use cases
  - Real-Time DLR Informs System Reconfiguration
  - Forecasted Dynamic Line Ratings Used in Generation Fleet Unit Commitment
- Defines common actors with technology agnostic functional descriptions
- Provides diagrams, step by step analysis, highlights data requirements, and information exchanges
  - Reference functional requirements for DLR to be published



Use Case 1:

Real Time DLRs Inform System Reconfiguration

Precondition: Communication tested and secure, field device data validation period complete



GETs Architecture Considerations

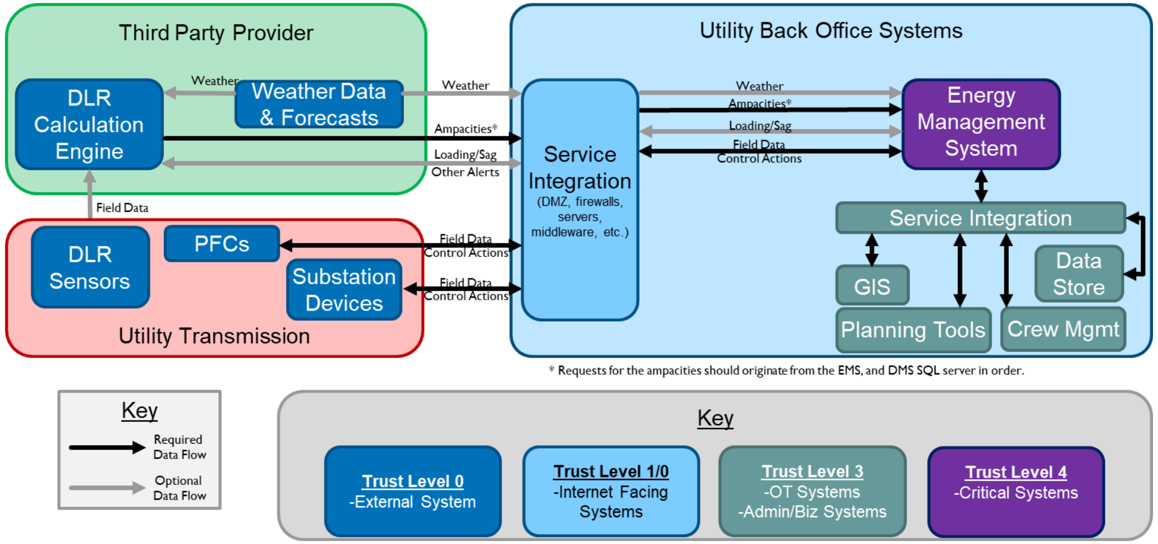
How do we do that within existing systems?

Why?

- Utility systems are complex and require cybersecurity considerations
- Operational projects need to be aware of potential challenges

What?

- Graphically rich document outlining optionality inherent in GETs implementations
- Builds upon NIST Smart Grid Framework

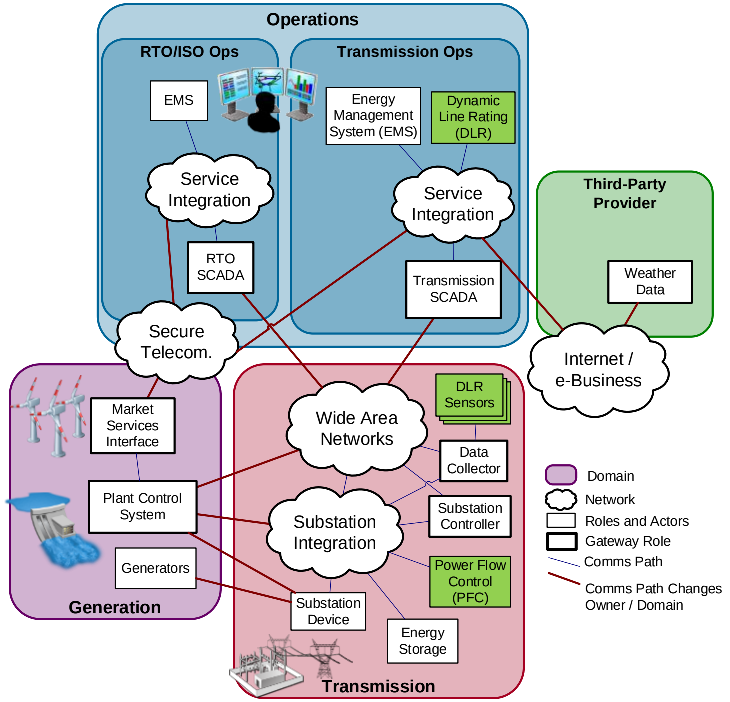


Third Party Provider
DLR Calculation Engine
Weather
Weather Data & Forecasts
Weather
Ampacities*
Loading/Sag
Other Alerts
Field Data
Utility Transmission
DLR Sensors
PFCs
Substation Devices
Field Data
Control Actions
Field Data
Control Actions
Utility Back Office Systems
Service Integration
(DMZ, firewalls, servers, middleware, etc.)
Weather
Ampacities*
Loading/Sag
Field Data
Control Actions
Energy Management System
Service Integration
GIS
Data Store
Planning Tools
Crew Mgmt

* Requests for the ampacities should originate from the EMS, and DMS SQL server in order.

Key
Required Data Flow
Optional Data Flow

Key
Trust Level 0
-External System
Trust Level 1/0
-Internet Facing Systems
Trust Level 3
-OT Systems
-Admin/Biz Systems
Trust Level 4
-Critical Systems



Operations
RTO/ISO Ops
EMS
Service Integration
RTO SCADA
Transmission Ops
Energy Management System (EMS)
Dynamic Line Rating (DLR)
Service Integration
Transmission SCADA
Third-Party Provider
Weather Data
Internet / e-Business
Secure Telecom.
Market Services Interface
Plant Control System
Generators
Generation
Wide Area Networks
DLR Sensors
Data Collector
Substation Integration
Substation Controller
Power Flow Control (PFC)
Substation Device
Energy Storage
Transmission
Domain
Network
Roles and Actors
Gateway Role
Comms Path
Comms Path Changes Owner / Domain

DLR Calculation Engine Interoperability Profile

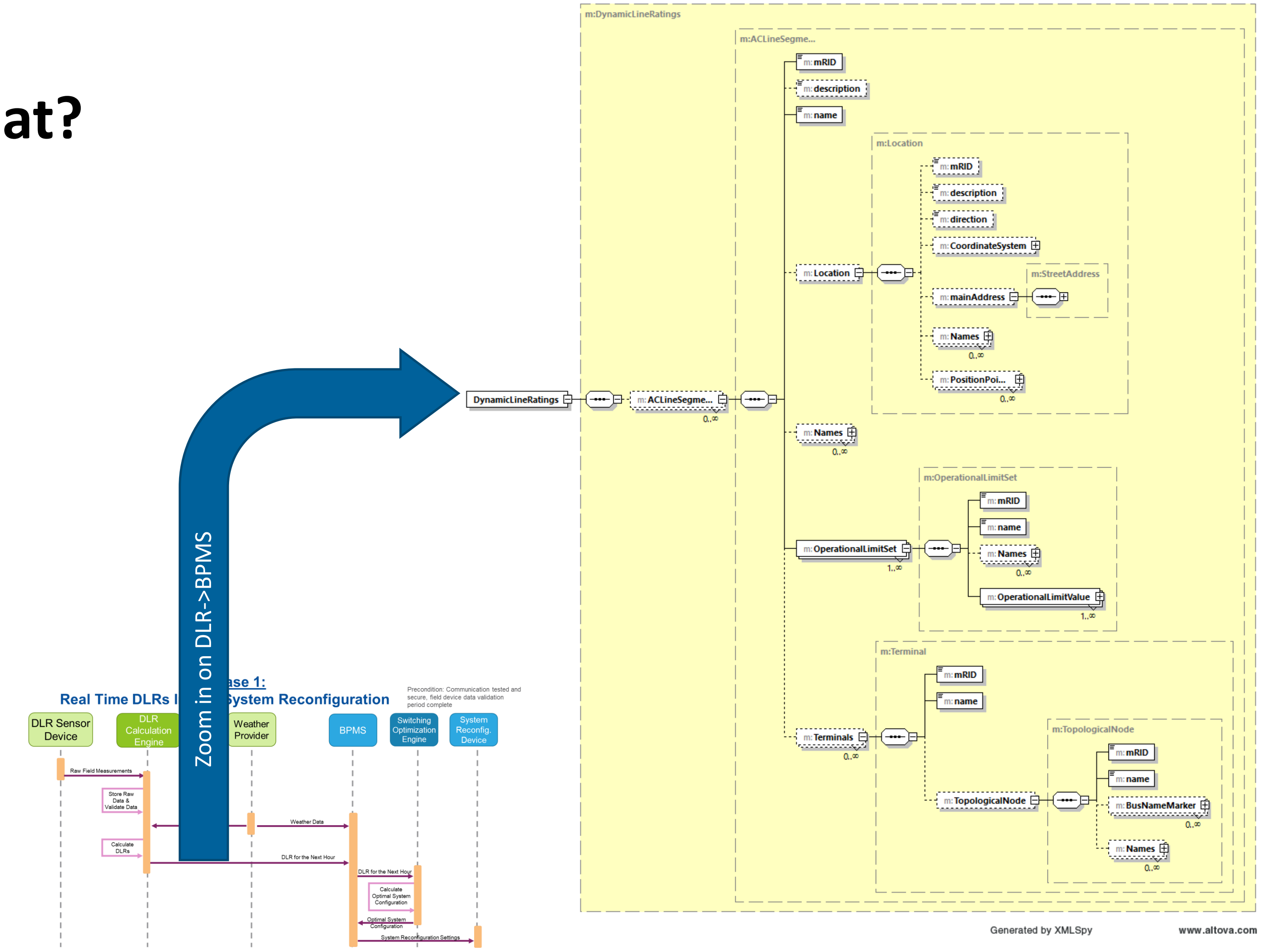
No really, how do we do that?

Why?

- Interoperability concerns exist among DLR vendors, utility personnel, EMS vendors
- Need to minimize customization for each DLR installation

What?

- 10-page “friendly” introduction and software specification for a DLR specific information Interoperability Profile
- Publish the XSD on the Common Information Model (CIM) user’s group website for visibility among practitioners
- Leverages existing utility standards (IEC TC 57 family of standards)
- Allows for application-specific configuration (e.g. Normal vs. Emergency Ratings)



GETs Modeling

INL/CON-23-73507

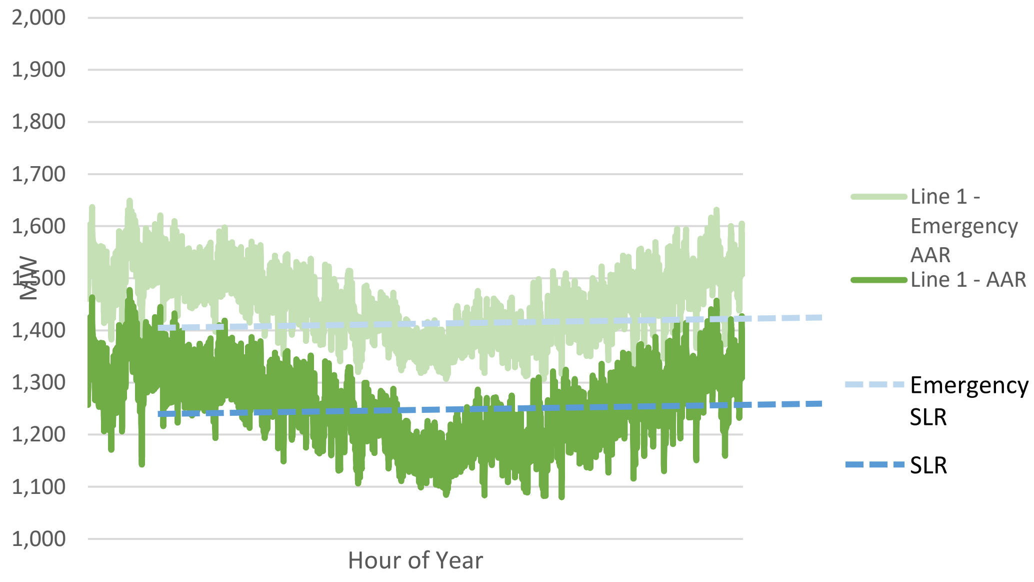
DLR and AAR Calculations and Data

For both DLR and AAR, this project used a conductor temperature of 100 for normal operations and 115 for emergency (N-1) situations.

- These were calculated using INL's GLASS tool to capture any nonlinearities with respect to conductor heating relative to ambient conditions. Note that these non-linearities primarily arrive at high temperatures with high-temperature conductors.
- The emergency line ratings are used in the formulation of the economic dispatch to ensure security of the system while in N-1 conditions. This helps to ensure a fair comparison between advanced line rating techniques and static line ratings.

INL expects to publish a more complete report on the implications for DLR and AAR calculations on this case study. The table below outlines the hours in the study year when various line ratings exceed other line ratings.

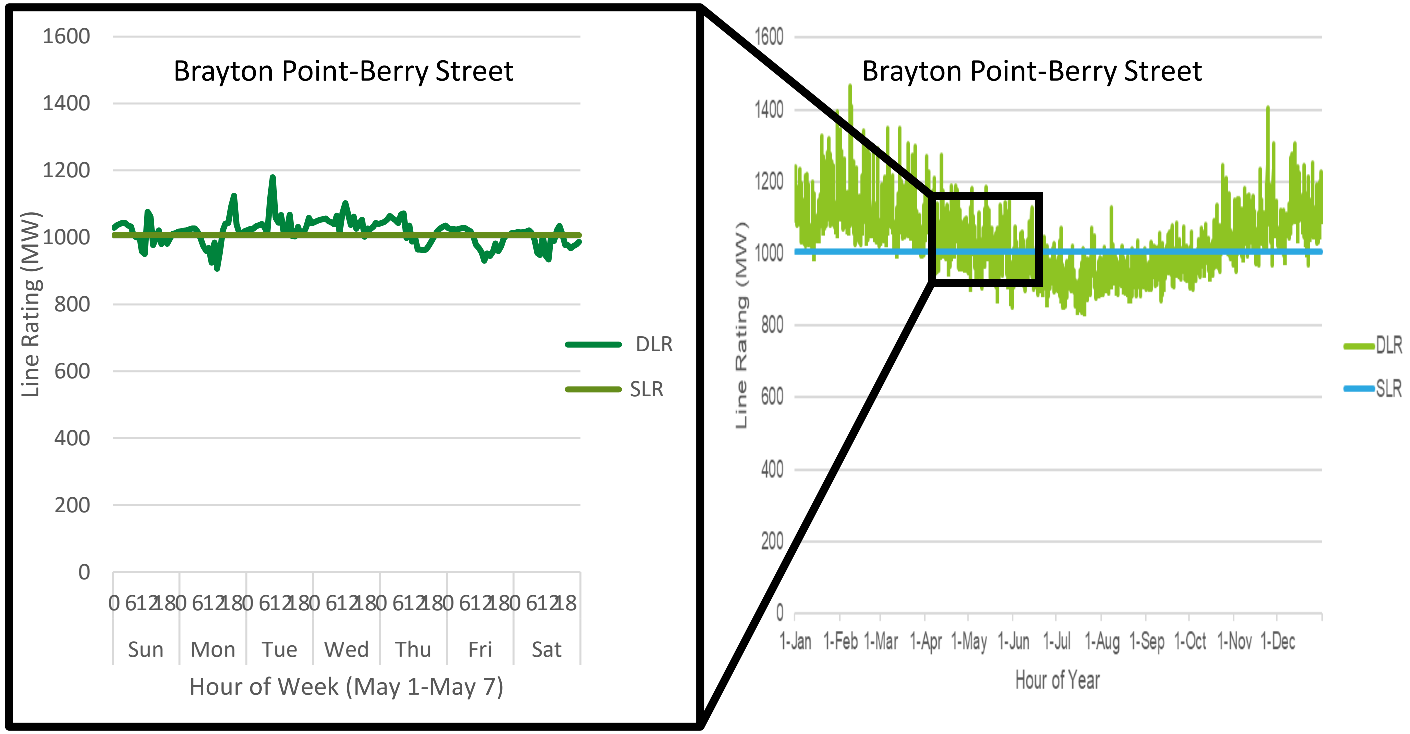
- DLR is greater than the static line rating 57 percent of the time for Brayton Point to Berry Street. Note that this is much lower than INL has observed in other case studies largely due to challenges in 2013 weather data measurement granularity (wind speed detection).
- Note further that DLR is greater than AAR just 37 percent of the time in this case study, meaning that an AAR-only technique potentially exposes higher risk temperatures by using a too-high base wind assumption.

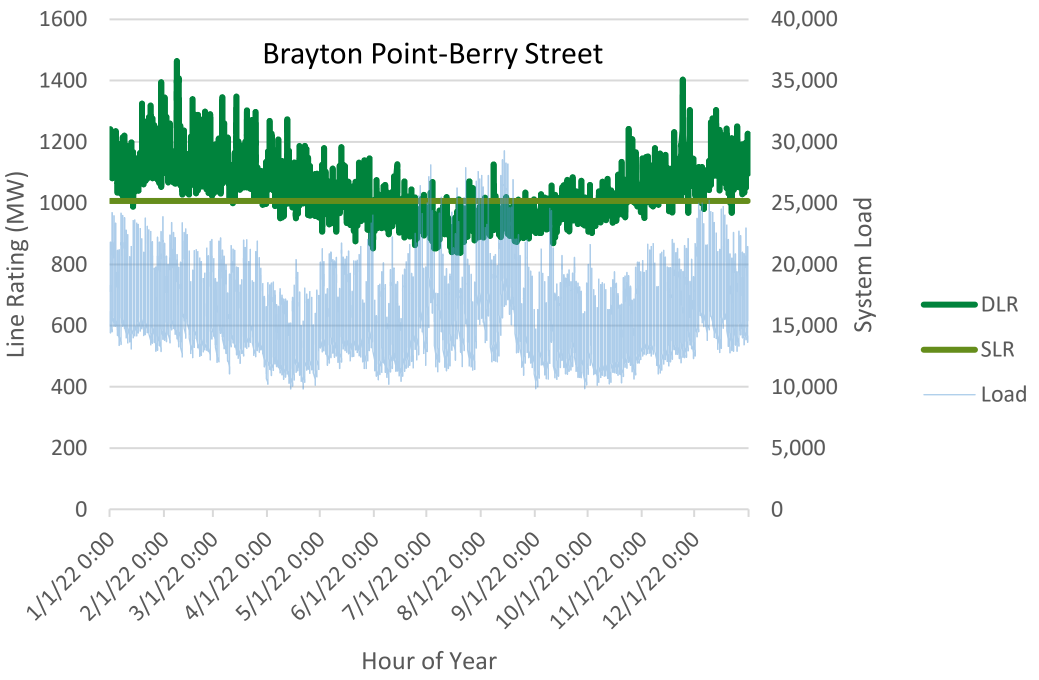


Line	Units	DLR>SLR	eDLR>eSLR	AAR>SLR	eAAR>eSLR	DLR>AAR	eAAR>DLR
Brayton Point-Berry St	Hours in Year	4977	4945	6177	6554	3209	8563
Brayton Point-Berry St	% of Hours	57%	56%	71%	75%	37%	98%
Brayton Point-West Farnum	Hours in Year	5556	7273	4284	6445	6119	8509
Brayton Point-West Farnum	% of Hours	63%	83%	49%	74%	70%	97%

Understanding the DLR’s

The DLRs were developed for this project using Idaho National Laboratory’s (INL’s) GLASS tool. Consistent with the resource mix, the 2013 weather year was used to create the DLR’s*. There is a clear seasonality to the DLR’s as the summer heat leads to warmer ambient air conditions and thus lower overall line ratings. There is a particular concern with respect to the impact on economics as the lower line ratings on these lines correspond with system peak load. As we will see in the coming slides, the benefits of DLR across the year outweigh specific hours where the system may be less economically (but more safely) operated.





*Note that the DLR’s calculated in this study are significantly worse than are expected in modern DLR calculations because of the cutout speed associated with the anemometer at the local weather station in the weather year selected. INL anticipates a forthcoming publication on the importance of assessing multiple historical weather years in calculating DLR potential.

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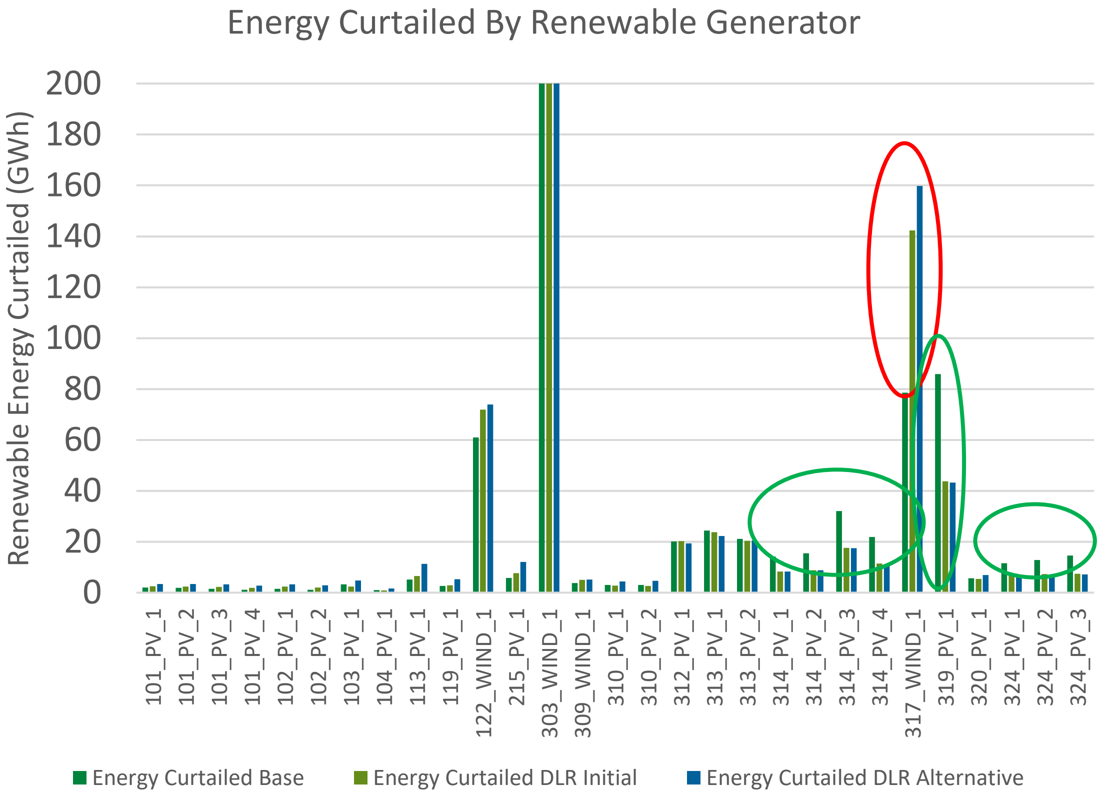
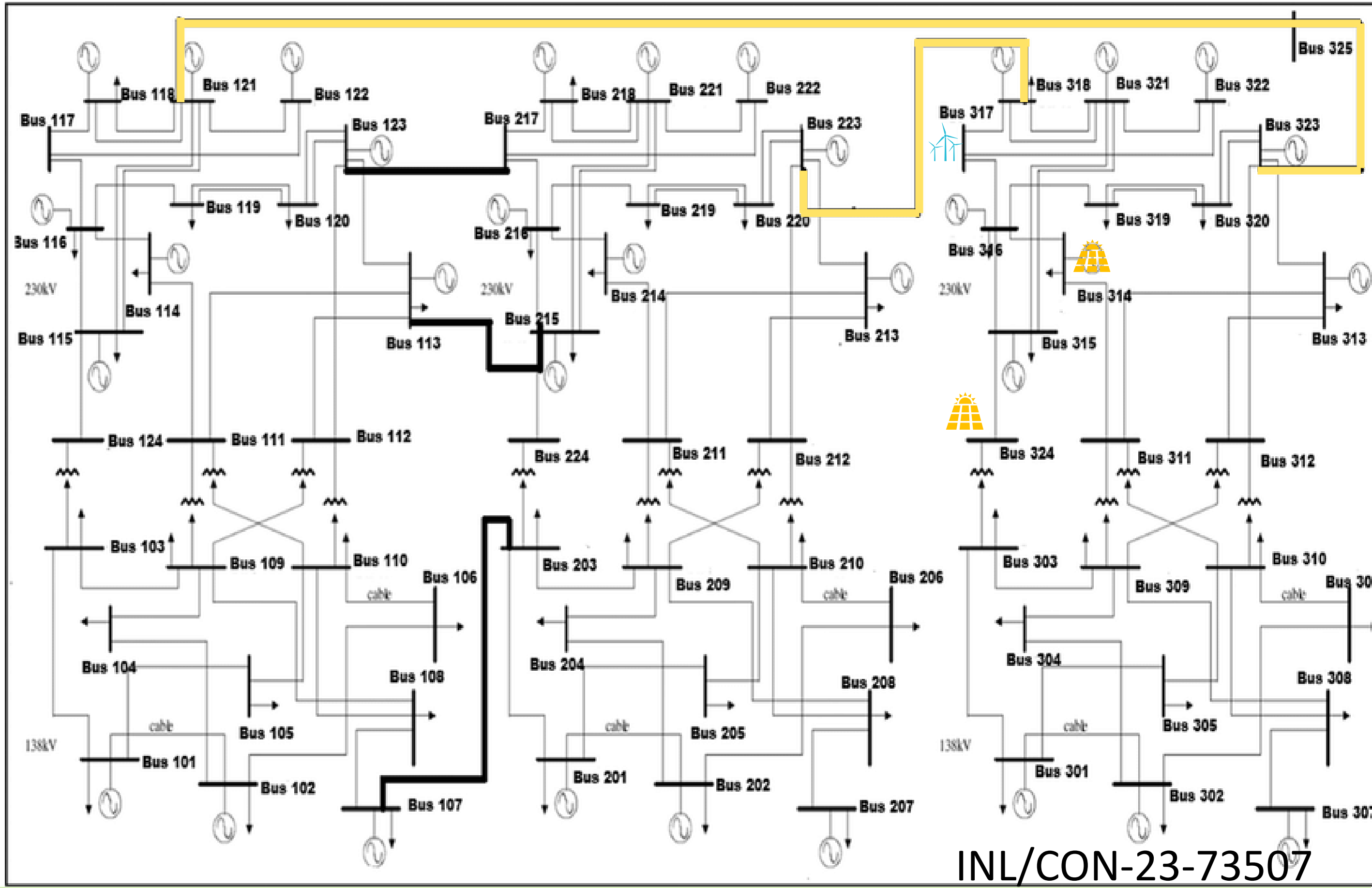
RTS-GMLC with DLR

- The lines selected for DLR represent inter-regional lines
  - Ill-suited lines for DLR impact on Unit Commitment Decisions
  - The challenges within this region are not fully alleviated by DLR





Picking PFC Location (in TARA)

PFC Locations were chosen according to a PFC siting optimization script using TARA. Additional information is available in the Modeling Methodology report.

The three PFC locations identified in the map and table were identified by TARA as the most suitable to mitigate congestion in the Brayton Point area.

PFC Location	Ranking
● Berry St - Brayton Point	1
● Medway - Bellingham	2
● Berry St - Bellingham	3

This analysis modeled a single PFC device capable of shifting the angle on a 345kV system by 1.5° at each of the locations independently.1