



Accelerating and Scaling Up GETs

ESIG Webinar



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Grid Enhancing Technologies (GETs) are technologies that maximize electricity delivery through transmission lines

Advanced Conductors



Operates at higher temperatures, allowing more power to flow

Dynamic Line Ratings



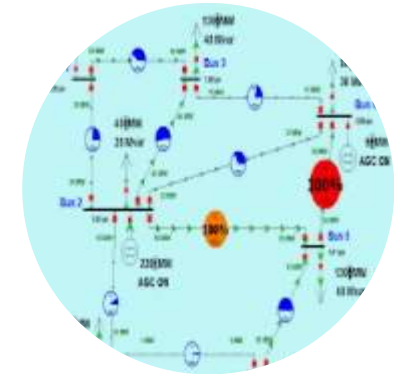
Updates thermal ratings of lines in real time

Power Flow Controllers



Reroutes power to lines with available capacity by adjusting impedance on lines

Topology Optimization



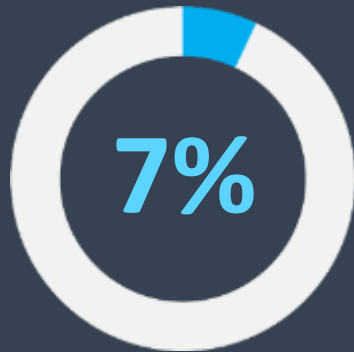
Redirects power to avoid congested or overloaded lines



Global initiative to learn and plan for wide-scale deployment of GETs to increase transmission capacity

Today's Transmission Investments

Transmission



Advanced Technologies

Source: EEI Business Analytics 2022 surveys.

Advanced technologies will have a much greater portion of tomorrow's transmission investments

GETting Mainstream...

Pathways to Commercial Liftoff: Innovative Grid Deployment

APRIL 1, 2024

187 FERC ¶ 61,068
UNITED STATES OF AMERICA
FEDERAL ENERGY REGULATORY COMMISSION

18 CFR Part 35

[Docket No. RM21-17-000; Order No. 1920]

Building for the Future Through Electric
Regional Transmission Planning and Cost Allocation

(Issued May 13, 2024)

AGENCY: Federal Energy Regulatory Commission.

ACTION: Final rule.

The New York Times

The U.S. Urgently Needs a Bigger Grid. Here's a Fast Solution.

A rarely used technique to upgrade old power lines could play a big role in fixing one of the largest obstacles facing clean energy, two reports found.

▶ Listen to this article - 8:04 min [Listen more](#)

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💬 876



Replacing existing power lines with cables made from state-of-the-art materials could roughly double the capacity of the electric grid in many parts of the country. Jim Wilson/The New York Times

Ways to Encourage Greater Broader Deployment

Advanced Conductors	Dynamic Line Ratings	Power Flow Controllers	Topology Optimization
👍	⚠️	⚠️	⚠️
👍	⚠️	⚠️	⚠️
👍	⚠️	⚠️	⚠️
⚠️	⚠️	⚠️	👍
👍	⚠️	⚠️	⚠️

GETs Characteristic Technical Bases

-  Technology Evaluation
-  Planning Models/tools
-  Operations Models/procedures
-  Acquisition & Maintenance
-  Incentives & Markets

Research Activities to Accelerate Deployment

Advanced Conductors



1. Conduct long term thermal-mechanical aging of advanced conductors.
2. Evaluate the effects of high temperature conductors on energized maintenance.
3. Identify and implement inspection technologies.
4. Undertake long term monitoring of advanced conductor installations

Dynamic Line Ratings



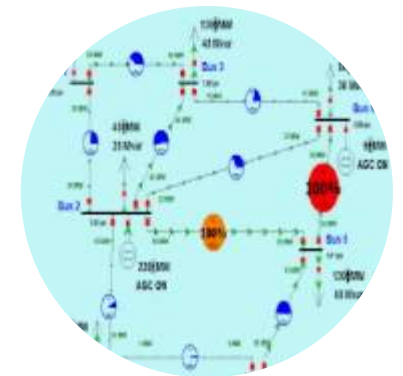
1. Conduct full scale field trials
2. Develop DLR specification and lab evaluations
3. Assess critical span identification and coverage area

Power Flow Controllers



1. Develop a planning framework to design APFC-based transmission solutions
2. Develop guidelines for the operation/control of multiple APFCs
3. Characterize performance /reliability
4. Develop planning and EMS models
5. Develop best practices for the operation of APFC in day-ahead and real-time markets
6. Develop specifications, maintenance, inspection practices

Topology Optimization



1. Technology Evaluation
2. Tools for supporting implementations (stability analysis, grid strength, short circuit levels)
3. Understand impacts on markets and existing resources
4. Evolve planning models

GET SET Spring Workshop

Join us as we share learnings from research,
demos, and deployments of GETs

Thursday June 20 – Friday June 21
Georgia Power Corporate HQ, Atlanta, GA

EPRI

NERC
NORTH AMERICAN ELECTRIC
RELIABILITY CORPORATION

NATF
North American Transmission Forum

ESIG
ENERGY SYSTEMS
INTEGRATION GROUP

For More Information or
to register, contact:
GETSET@epri.com

Session Topics



Experiences with Advanced Conductors



Lessons Learned and the Road Ahead for
Dynamic Line Ratings



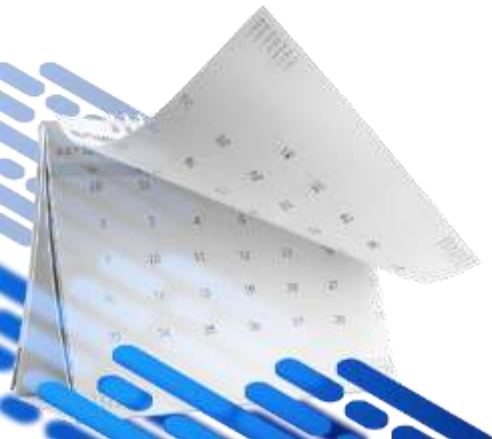
Markets, Incentives, and Regulatory
Considerations to Scale Up



Deployments of Advanced Power Flow
Controllers



Technology Provider Fair





Enhancing the Grid with DLR

Types of Ratings and Their Purpose



Seasonal ratings (summer and winter)

The same every year known years in advance



Ambient adjusted ratings (AAR)

Go up and down hourly based on air temperature

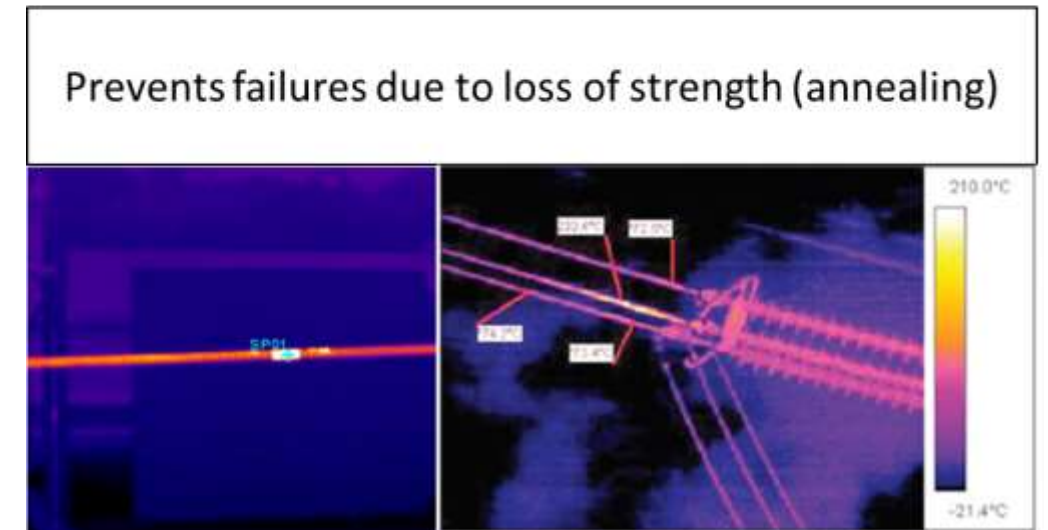
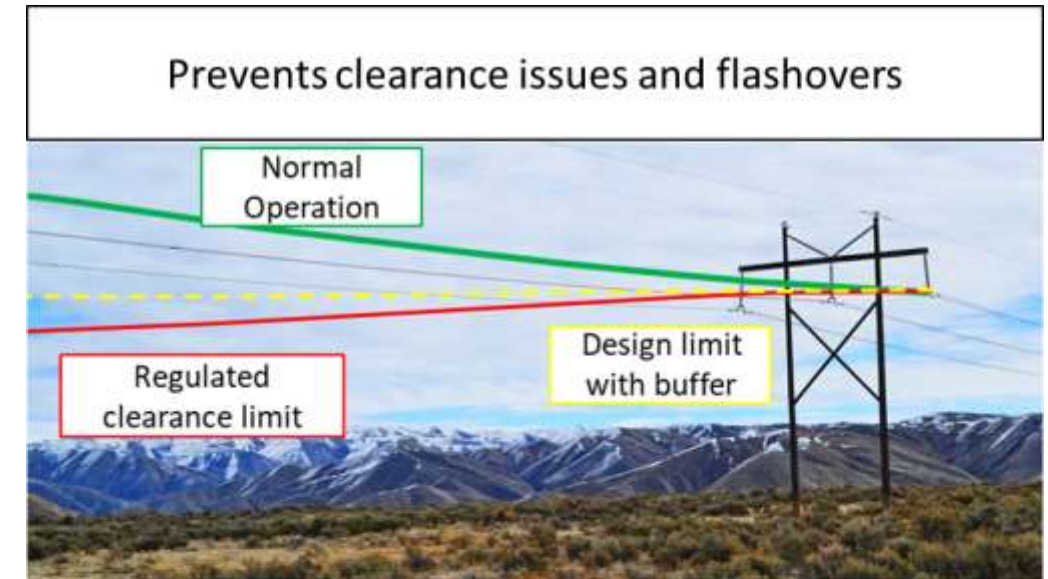
Few models accurately predict (small errors in forecasts can have big effects)



Dynamic line ratings (DLR)

Change every 15-30 minutes based on wind speeds

Very difficult to predict beyond a few hours





Increases transmission capacity on existing circuits without physical changes

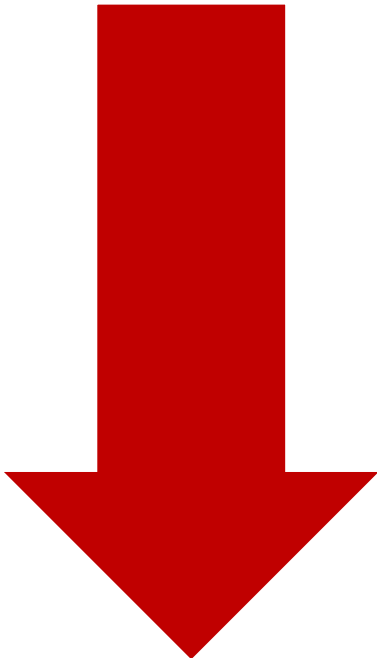
Can increase capacity during favorable weather

There are many technology providers available

Adopting AAR makes later adoption of DLR easier

DLR technologies can provide insight into other system conditions

Capacity gains typically align with peak demand and peak renewable generation



On lines with no clearance buffer, aged conductors, SIL limits, voltage drop limits, limiting substation ratings – to safely apply DLR costly upgrades are needed

Ratings may go down as often as 30-40% of the time

Accuracy, reliability, and cost vary complicating finding best-fit solutions

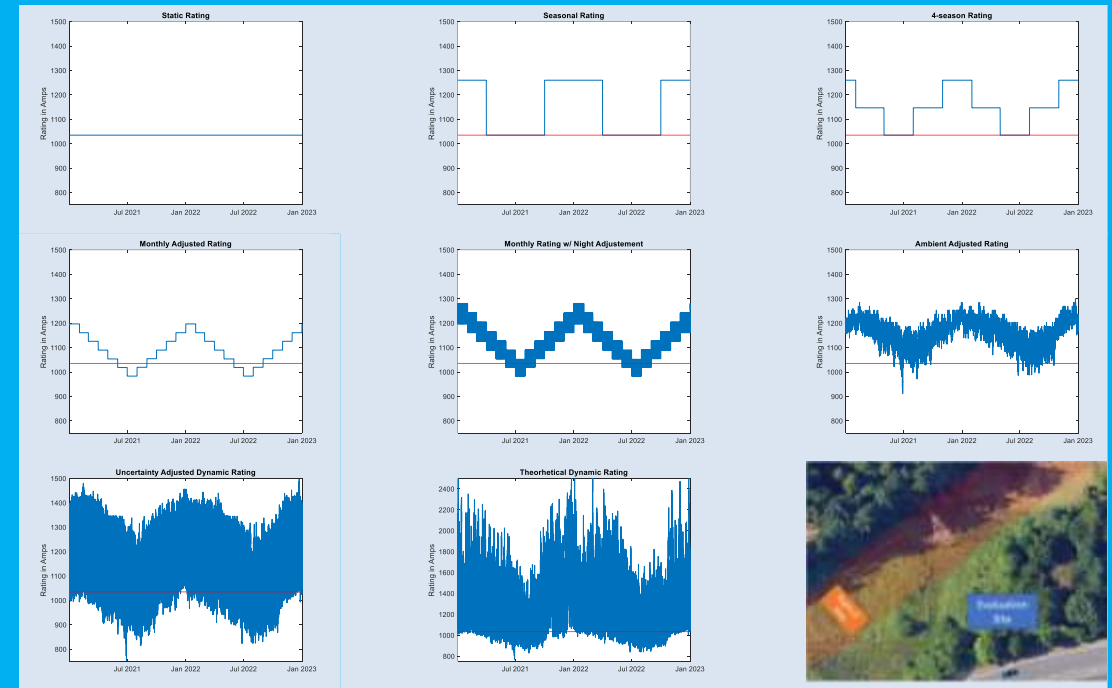
Adopting AAR reduces the ROI of adopting DLR

There are presently no industry standards for specifying or validating DLR systems

Gains may not be there when needed, and vary rapidly over time

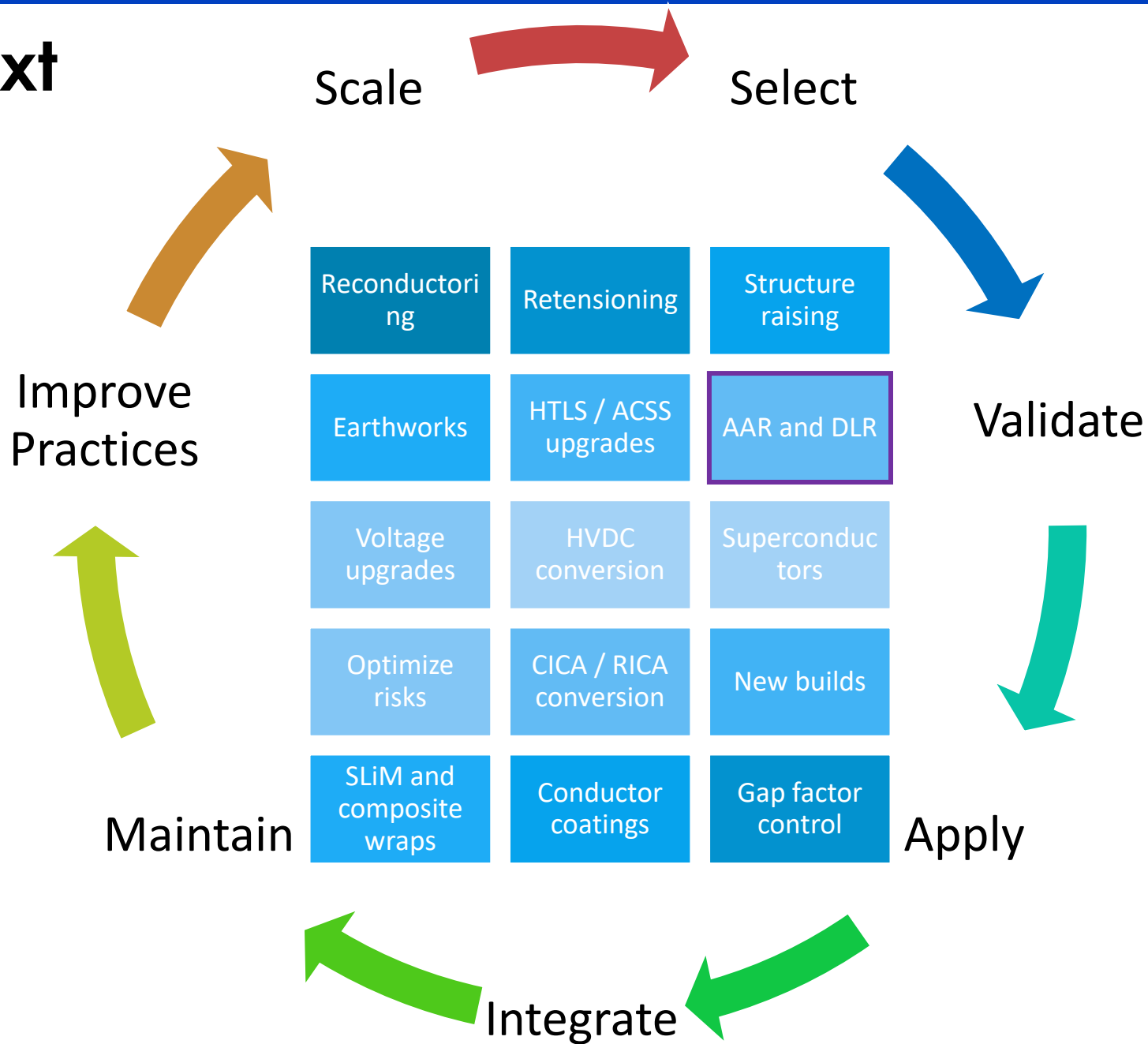
How DLR Differs From Other Ratings

Simplified Examples of Rating Types



Keeping DLR in Context

- DLR can be a very useful “tool in the toolbox”
- To leverage DLR capabilities, we need to understand the full life cycle performance and costs
- We also need to know how DLR compares to traditional upgrades and emerging technologies so we can “Right size” solutions
- In some cases, DLR can be applied in tandem with other upgrades to get improved capacity / ROI



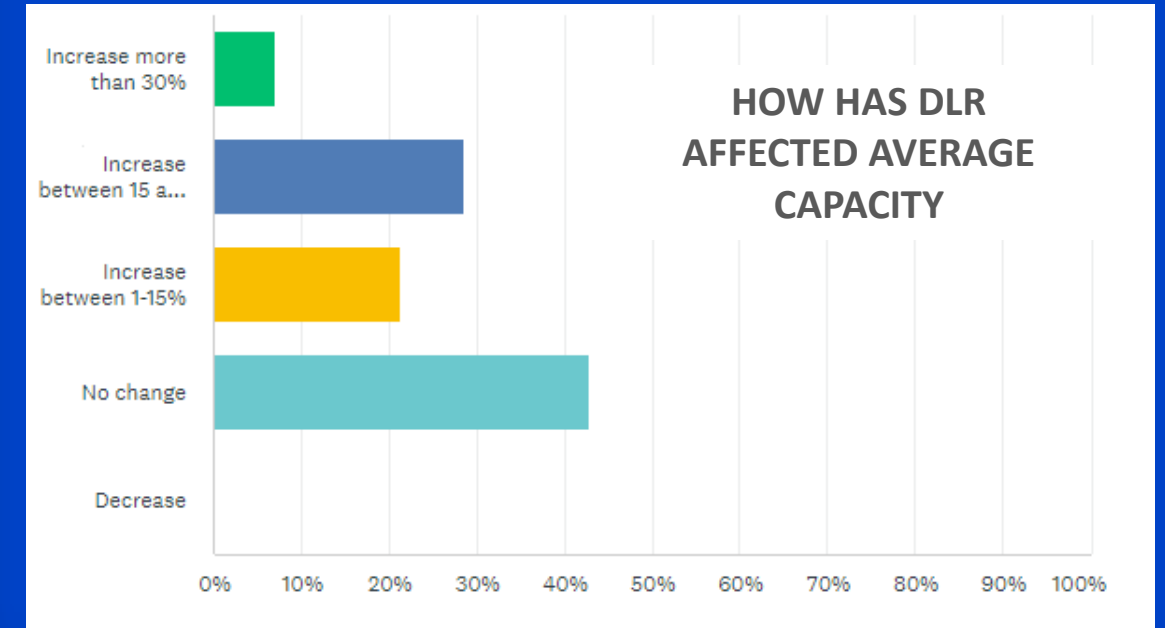
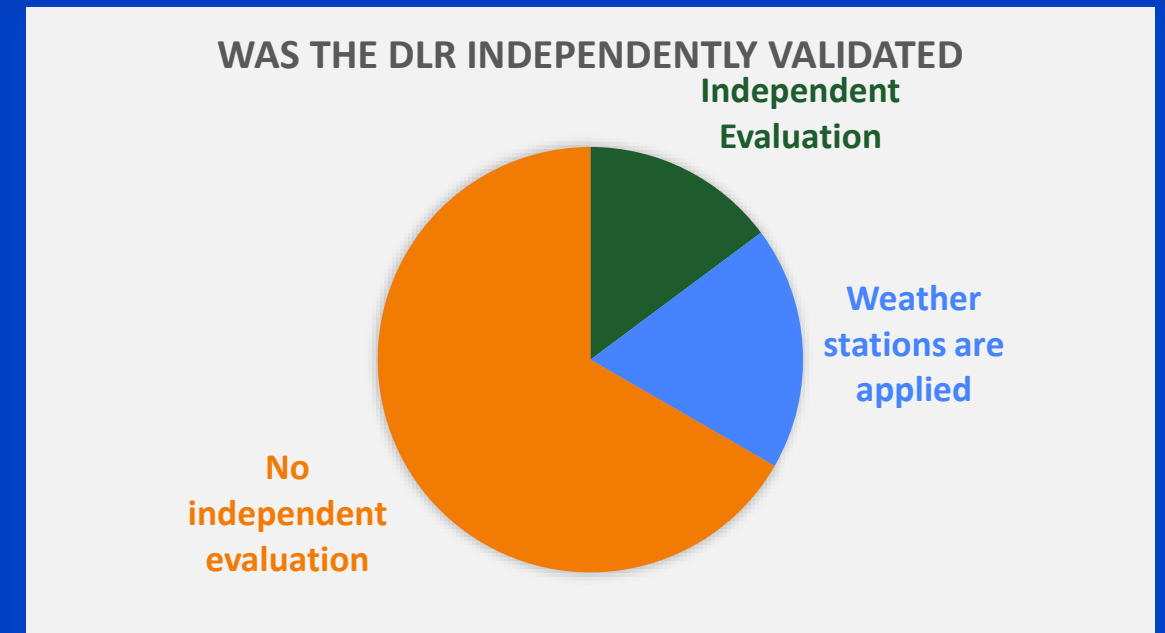
The Range of DLR Technologies Available

Ampacimon	Awesense	Bandweaver	Cat-1	Commercial Weather Models (>10)	DeAngeli OPGW	DeAngeli Smart	DOL	EGM – MSU
EMO (Micca)	Enline	GE Digi-DLR	GridGuard DLR	Grid Pulse	Grid Raven	Gridwell	Infravision	LakiPower
Line IQ	Lindsey	Line Ranger	LineVision	Luna - LIOS	Neara	NEC SpectralWave	Neuron	PitchAero-DLR
PMU method	Power Donut	Praetorian	Prisma Photonics	Prysmian OPGWatch	Public Weather Models (>13)	Public Weather Networks (>80)	Ritherm	Sagometer
SentriSense	Smartwires SUMO	Splight AI	Sumitomo DLR	ThermalRate	TopoloNet	Utility Weather Stations	WindSim	

Key:	Software based	Hardware based	OPGW / FO connection
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Current State of the Science for DLR

- DLR technology providers have different methods to establish the wind speed used for ratings calculations
 - This influences cost, reliability, risk, accuracy, maintenance, cyber requirements etc.
- Utilities have many tradeoffs to find right size and no-lose scenarios
 - Weather-based DLR can be used as a baseline for cost and performance that commercial DLR should improve upon to merit adoption
- Compared to GETs like advanced conductors, DLR has not been as rigorously evaluated and has fewer standards/industry guides for best practices



Adoption Barriers Reported by Utilities / Challenges Observed in Field Trials

Accuracy concerns	Lack of error / risk management	Complete failure in under a year	Communication dropouts	Poor calibration methods / high maintenance	Battery explosions
Corona and audible noise issues	Failed or missing weather seals	Differences in performance when hardware and software updates are performed	Physical attachment issues	Accuracy drop off due to line maintenance	Accuracy drop off due to structure movement (wood poles)
Capacity reduced significant portion of time	Improper installation issues / damage	Damage from improper maintenance	Copper theft (of ground leads)	Dropouts during low solar or line load conditions	Capacity limited by other factors (DLR gains not actionable)

Knowledge Gaps

Acquisition

- Understanding accuracy & uncertainty of ALL available technologies
- Requirements for specifications and validation
- Life cycle costing (CapEx + O&M)
- Performance ranked against alternative upgrades

Planning & Operations

- Defining then managing uncertainty/risk of rating and forecast
- Automatic 'bad data' management
- Models/processes for decisions
- Industry-wide practices and tools
- Training

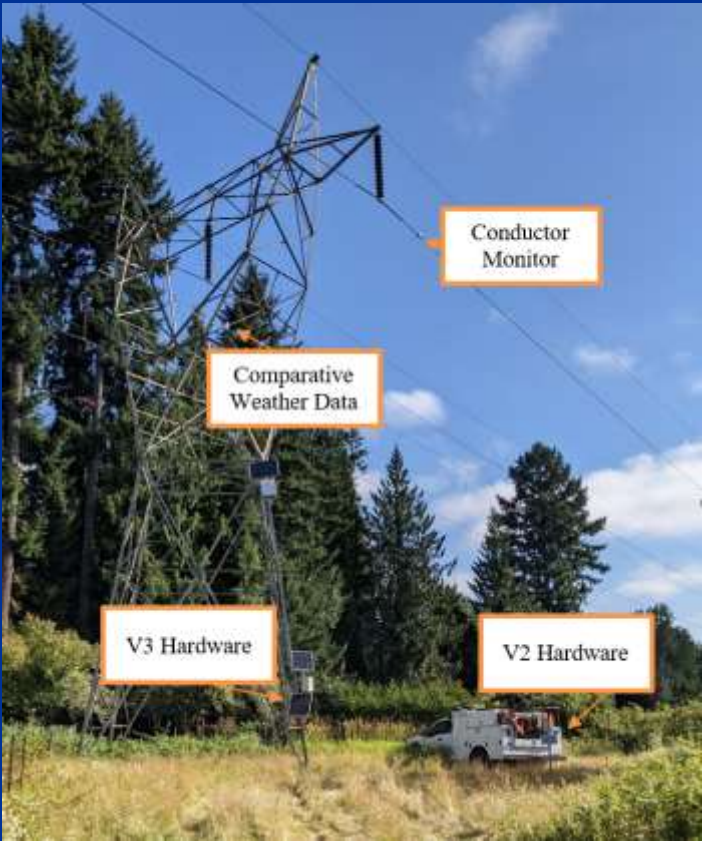
Maintenance

- Expected failure / outage rate
- Failover procedures and spares strategy
- Quantity & skills of resources needed
- Degradation & failure modes
- Life expectancy
- Disposal / end of life treatment

Existing Pathways to Address & Accelerate DLR Solutions

- Full Scale Field Trials

Compare against known reference



- DLR Specification and Lab Evaluations



MEASUREMENT
ACCURACY



ELECTRIC &
MAGNETIC FIELDS
WITHSTAND



POWER CYCLING



ATTACHMENT
SLIP / VIBRATION



ENVIRONMENTAL
EXPOSURE



SWITCHING AND
LIGHTNING



Lightning and switching
surge test area

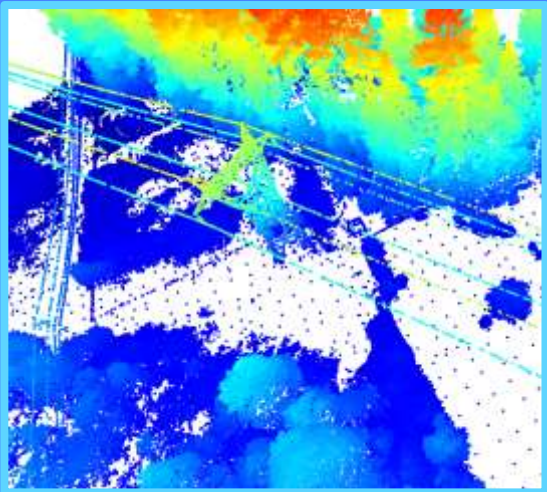
EMF withstand test area

Corona cage / RFI test area

Full scale test lines

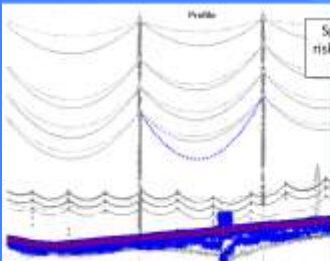
Accelerated aging areas

- Critical Span Identification and Coverage Area

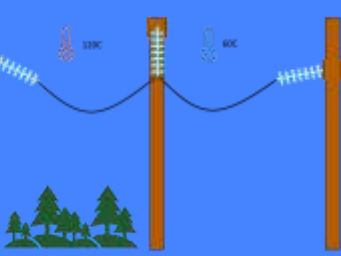


LiDAR and Cadd analysis tell us what spans will hit sag limits IF the conductors are hot

Critical span analysis tells us which spans **WILL** run hot



Spans most at risk or in need of upgrade





Incentives for Efficient Investment and Operation

Can our Transmission system GET a little relief?

Estimated Congestion Costs (\$M)

ISO/RTO	2016	2017	2018	2019	2020	2021	2022
ERCOT	497	976	1,260	1,260	1,400	2,100	2,800
ISO-NE	39	41	65	33	29	50	51
MISO	1,402	1,518	1,409	934	1,181	2,849	3,700
NYISO	529	481	596	433	297	551	1,000
PJM	1,024	698	1,310	583	529	995	2,500
SPP	280	500	450	457	442	1,200	2,000
National Estimate	6,501	7,266	8,776	6,379	6,686	13,353	20,777

Grid Strategies, “Transmission congestion costs rise again in U.S. RTOs,” July 2023. Available:
https://gridstrategiesllc.com/wp-content/uploads/2023/07/GS_Transmission-Congestion-Costs-in-the-U.S.-RTOs1.pdf

How much relief can we GET?

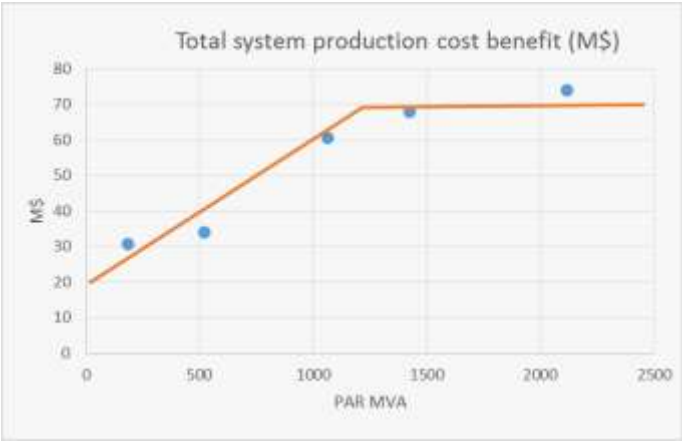
PJM Example

Total Transmission Congestion Costs (USD millions) for RTOs from 2016 - 2022

RTO	2016	2017	2018	2019	2020	2021	2022	2023 (*)
PJM	1024	698	1310	583	529	995	2500	1069

Source: Grid Strategies, Transmission Congestion Costs Rise Again in the U.S. RTOs, July 2023

(*) Source: 2023 Annual State of the Market Report for PJM



Benefits and Value of New Power Flow Controllers, EPRI, Palo Alto, CA: 2018. 3002013930. Available: <https://www.epri.com/research/products/000000003002013930>

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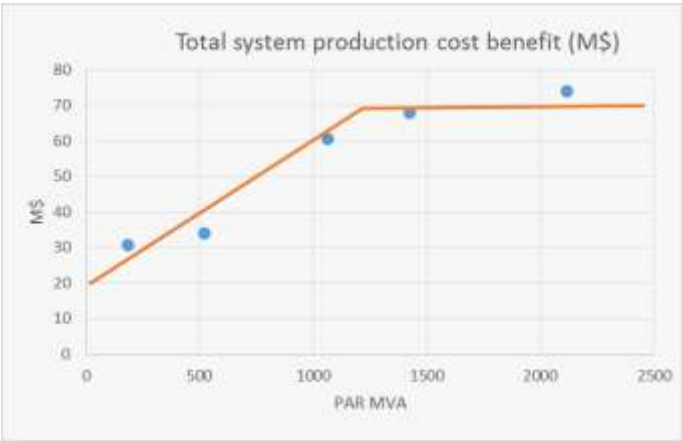
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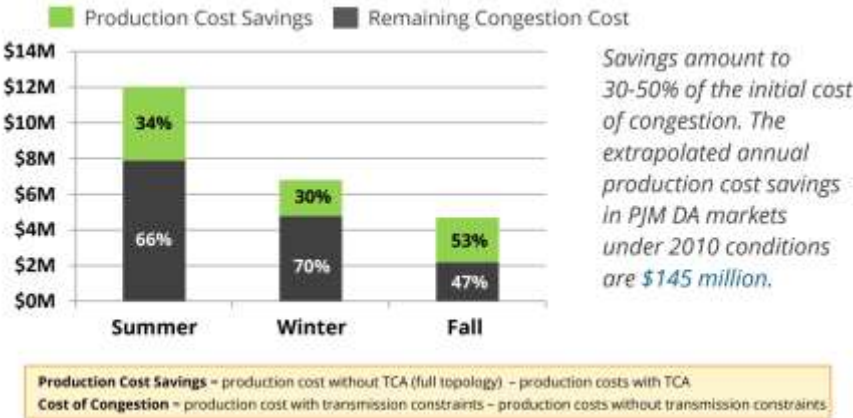
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P. Ruiz et al, "Transmission topology optimization: simulation of impacts in PJM day-ahead markets," presented at FERC Tech. Conf. on Increasing Market Efficiency through Improved Software, Docket AD10-12-007, Washington, DC, June 2016. Available: <https://www.ferc.gov/sites/default/files/2020-08/T-4B-2-Ruiz.pdf>



How much relief can we GET?

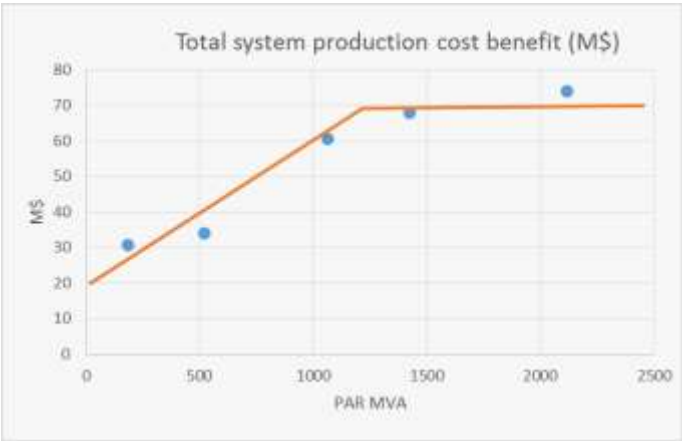
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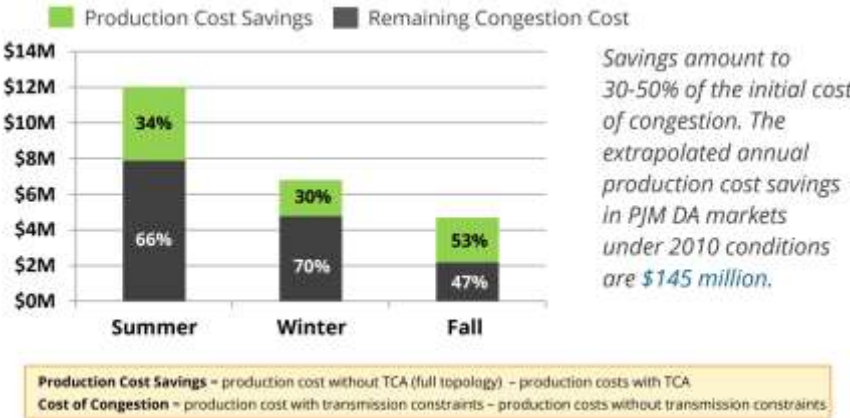
Source: Grid Strategies, Transmission Congestion Costs Rise Again in the U.S. RTOs, July 2023

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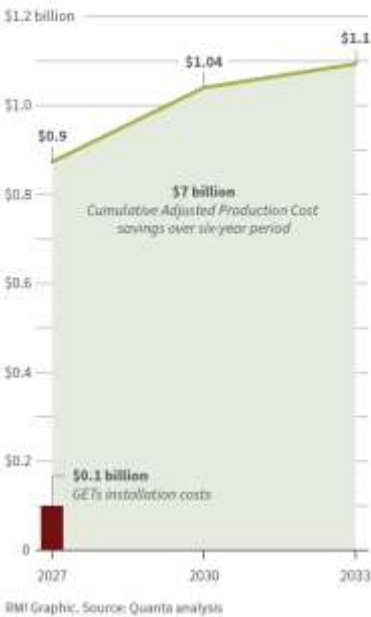


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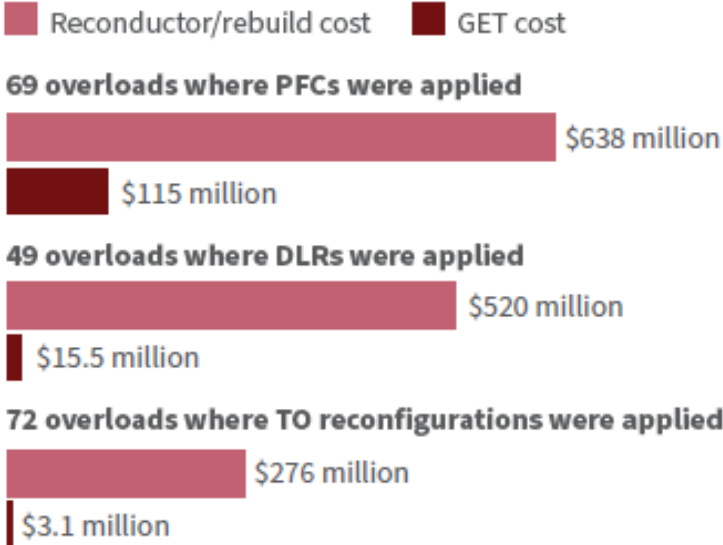


Annual adjusted production cost savings from 2027-33, driven by GETs and the new generation enabled to interconnect

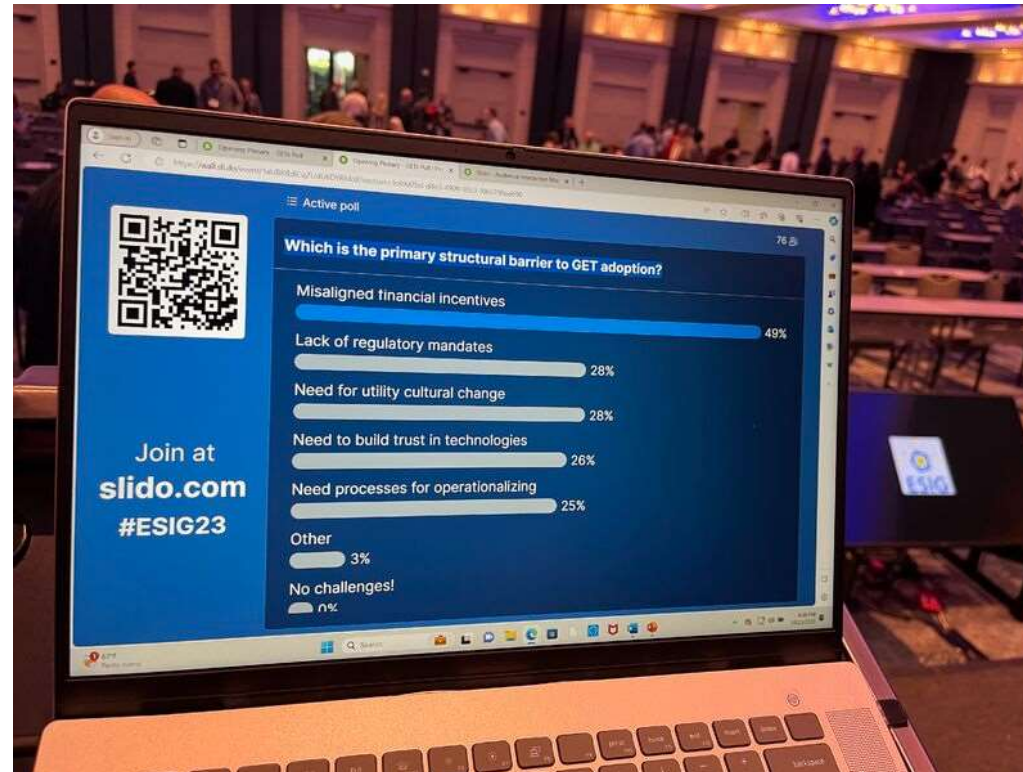


Katie Siegner, Sarah Toth, Chaz Teplin, and Katie Mulvaney, *GETting Interconnected in PJM: Grid-Enhancing Technologies (GETs) Can Increase the Speed and Scale of New Entry from PJM's Queue*, RMI, 2024, <https://rmi.org/insight/analyzing-gets-as-a-tool-for-increasing-interconnection-throughput-from-pjms-queue/>.

Comparison of the typical network upgrade costs vs the cost of the GET alternatives

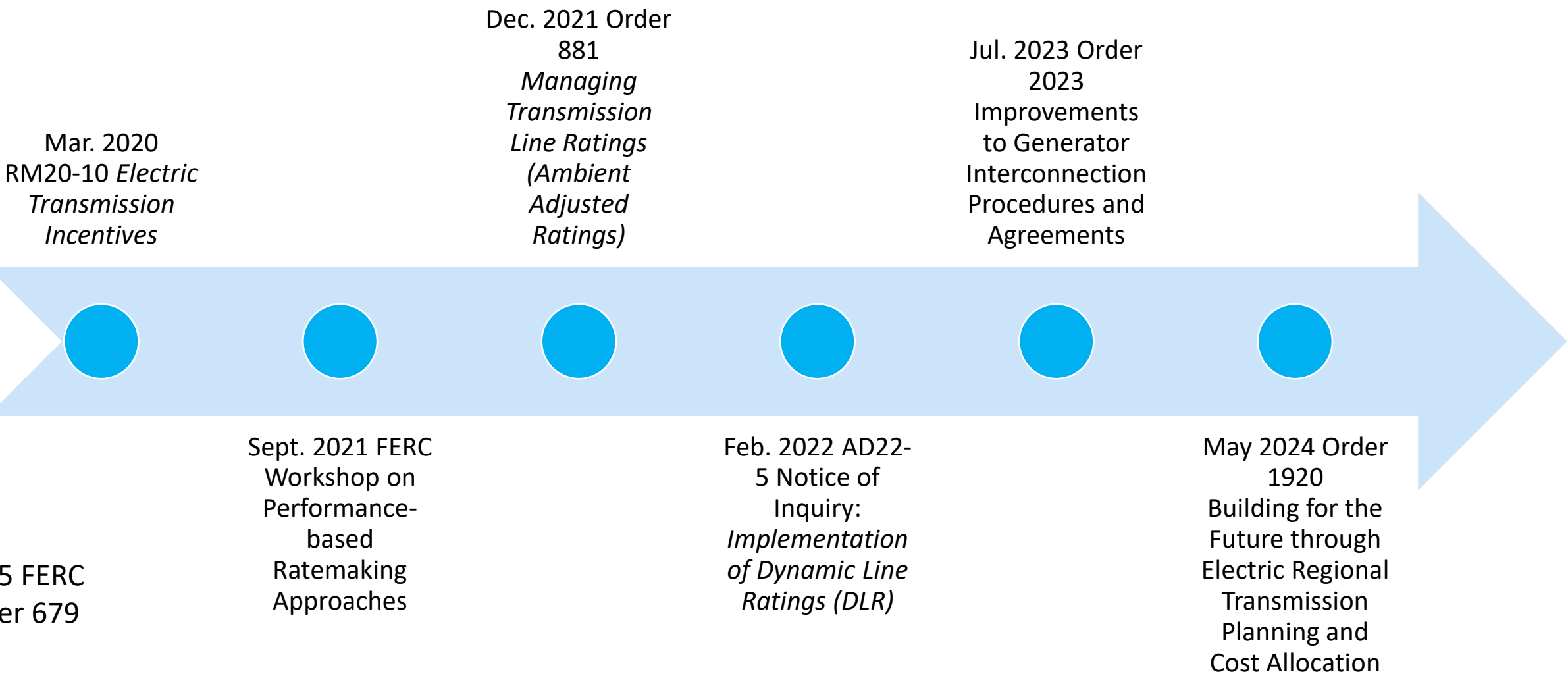


What are the important issues to GET addressed?



Julia Selker, WATT Coalition (Linkedin)
Polls from 2023 ESIG Fall Technical Workshop

How did we GET here?



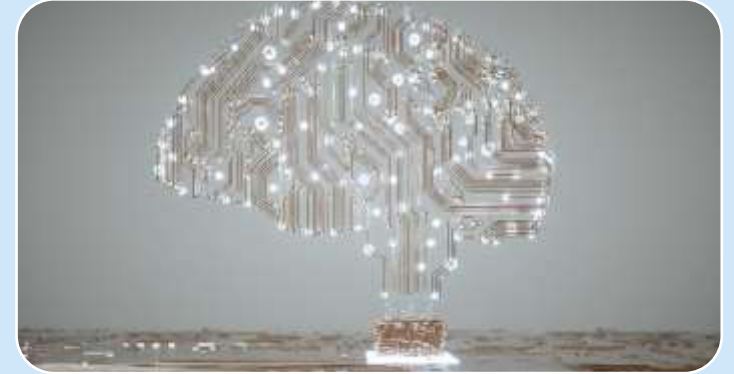
What do well designed incentives GET us?



Efficient
investment; cost-
effective
infrastructure and
energy suppliers



Efficient
operation; Truthful
participation and
behavior that
supports a reliable
system operation

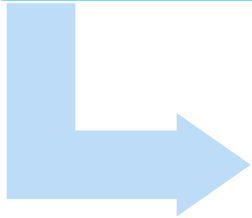


Innovation; and
new technologies
that can do things
better and cheaper
than what exists

What types of incentive will GET important?

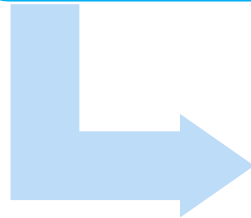
Innovate

- Is there a means for new technologies to enter and compete?



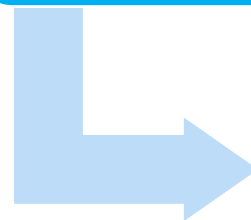
Invest

- If it is a better alternative, is there an incentive for buyer/user to install?



Hedge

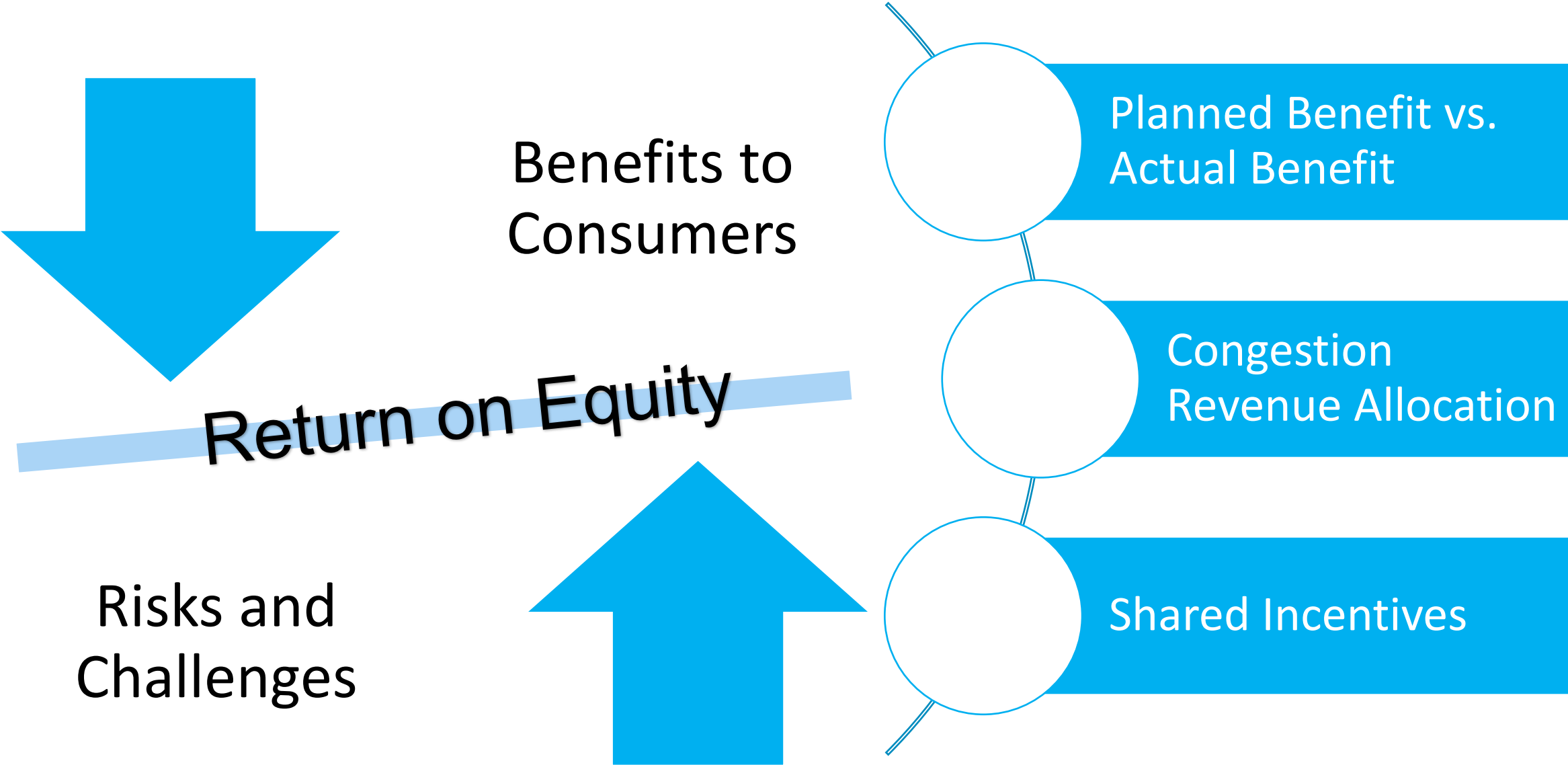
- If efficiency causes uncertainty, can participants hedge?



Operate

- Is there incentive to operate the facility in the most efficient manner possible?

GETting Investments Right



Things can GET challenging

	Current Practice	Operator Confidence	Cost	Market Model and Computation	Congestion Hedging / Revenue Adequacy
DLR	Use of AAR in some regions; planned in all FERC ISOs; DLR pilots	Moderate	Low	Easy	Moderate
Advanced Power Flow Controller	PST in Day-ahead in few markets; no others in US	More	Moderate	Moderate	Easier
Topology Optimization (for economics)	Not for economics	Low	Low	Challenging	Challenging
Internal HVDC	NYISO, Soon SPP	High	High	Moderate	Easy

Between Long Island and New York City, the day-ahead scheduling of the PAR-controlled lines (i.e., the 901 and 903 lines) was highly inefficient with power scheduled in the inefficient direction in 97 to 98 percent of hours in 2014, which was comparable to the results in recent years. The use of these lines *increased* DAM production costs by an estimated \$14 million in 2014 because prices on Long Island were typically higher than those in New York City where the 901 and 903 lines connect.

-Potomac Economics, NYISO State of the Market Report, 2014.

Research on incentive solutions is GETting us there

IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 32, NO. 3, MAY 2017

1773

Computationally Efficient Adjustment of FACTS Set Points in DC Optimal Power Flow With Shift Factor Structure

Mostafa Salameh-Andakani, Member, IEEE, and Kory W. Hedman, Member, IEEE

Abstract—Enhanced utilization of the existing transmission network is a cheaper and paramount alternative to building new transmission lines. Flexible ac transmission system (FACTS) devices are advanced technologies that offer transfer capability improvements via power flow control. Although many FACTS devices exist in power systems, their set points are not frequently changed for power flow control purposes, which is mainly due to the computational complexity of incorporating FACTS flexibility within the market problem. This paper proposes a computationally efficient method for adjustment of variable impedance-based FACTS set points, which is also compatible with existing market solvers. Thus, the method can be employed by the existing solvers with minimal modification efforts. This paper models FACTS reactance control as injections in keep the initial shift factors unchanged. Next, the paper formulates a dc optimal power flow that co-optimizes FACTS set points alongside generation dispatch. The resulting problem, which is in a nonlinear program, is then reformulated to a mixed-integer linear program. Finally, an engineering insight is leveraged to further reduce the computational complexity to a linear program. Simulation studies on IEEE 118-bus and Polish 230-bus test cases show that the method is extremely effective in finding quality solutions and being very fast.

Index Terms—FACTS devices, linear programming, optimal power flow, power system economics, power system operation, power transfer distribution factors.

NOTATION

Matrices are represented by upper case bold, vectors by lower case bold, and scalars by lower case characters. Superscript D is used for the diagonal operation, while superscript T represents transpose of a matrix. $\odot$ is used to describe induced matrices and vectors where the elements related to the reference bus are removed. Finally, $\rightarrow$ is used to show the flow on the lines equipped with FACTS without the FACTS impact.

A. Parameters

F Set of transmission elements equipped with FACTS devices.

N_T Number of transmission elements.

Manuscript received November 5, 2012; revised March 12, 2016 and June 9, 2016; accepted July 9, 2016. Date of publication July 19, 2016; date of current version April 12, 2017. Paper no. TPWRS-00780-2015.
M. Salameh-Andakani is with the Department of Electrical and Computer Engineering, University of Utah, Salt Lake City, UT 84112 USA (e-mail: mostafa.andakani@utah.edu).

K. W. Hedman is with the School of Electrical, Computer, and En-

h Index for transmission elements.
 ρ Upper limit vector of power generation.
 μ Lower limit vector of power generation.
 T Vector of transmission elements' thermal limit.
 T^{th} Vector of transmission elements' emergency thermal limit.
 c Vector of generators' marginal costs.
 d Vector of power consumptions.
 $\bar{x}$ Upper limit vector of power injections representing FACTS devices.
 $\underline{x}$ Lower limit vector of power injections representing FACTS devices.
 $\bar{\delta}$ Upper limit vector of FACTS relative susceptance adjustment.
 $\underline{\delta}$ Lower limit vector of FACTS relative susceptance adjustment.
 $\bar{\alpha}_k$ Upper limit for FACTS relative susceptance adjustment on transmission element k .
 $\underline{\alpha}_k$ Lower limit for FACTS relative susceptance adjustment on transmission element k .
 P Generation locator matrix.
 A Adjacency matrix.
 $\bar{A}$ Reduced Adjacency matrix.
 B_{eq} Branch B matrix.
 B Nodal B matrix.
 $\bar{b}_k$ Base susceptance of transmission element k .
 Φ PTDF matrix.
 $\bar{c}_k^L$ LODF representing the change on line k 's flow with respect to the outage of line k .
 $\mathbf{1}$ Vector of ones.
 $\mathbf{0}$ Vector of zeros.
 I Identity matrix.
 M A very large positive number.

B. Variables

p Vector of power generations.
 f Vector of power flows on transmission elements.
 ψ Vector of power injections.
 $\bar{\psi}$ Reduced vector of power injections.
 $\bar{x}$ Vector of power injections representing FACTS devices.
 $\bar{\delta}$ Reduced vector of power injections representing

Modeling of Internal Controllable HVDC Lines in Energy Market Operations

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Abstract—A high voltage direct current (HVDC) line is proposed to be built between upstate New York and New York City (NYC), with both ends inside the control area of the New York Independent System Operator, Inc. (NYISO). This is the first fully controllable internal HVDC line in the United States to be modeled in the energy market. This paper proposes a generalized locational marginal price (LMP)-based energy market model for internal controllable HVDC lines (ICLs). A key advantage of the proposed model is that the ICL operator can bid competitively in the energy market for power flow in both directions. The proposed model is initially demonstrated with a three-bus test system and then simulated in the NYISO's day-ahead energy market. A sensitivity analysis of ICL bids is conducted, and ICL flow's impact on market conditions is illustrated. The simulation results show the proposed model can effectively optimize the ICL schedule for cost-saving and congestion relief.

Keywords—Congestion, contingency, energy market, HVDC, internal controllable line, ISO, transmission losses.

1. INTRODUCTION

To achieve ambitious clean energy goals, many renewable energy resources must be integrated into the power system. However, some renewable generations are located far away from the demand center, thus making transmission losses over long-distance a challenge. HVDC lines are used to alleviate the problem because they incur lower power losses and are more economical than the equivalent AC lines at a long distance [1]. In addition, HVDC lines also have the advantage of more controllability, smaller right-of-way requirements, and suitability for underwater applications [2]–[4]. Although HVDC power electronics and control technologies have advanced significantly in the past decades, the efficient market integration of HVDC lines remains an open question.

Several studies explored the problem of HVDC line operation in the power markets. For instance, an operational model for HVDC tie lines was proposed to accommodate renewable integration in Northwest China [5]. The model was able to deal with multiple HVDC lines between interconnected subsystems, but the power flow on HVDC lines was assumed to be lossless and unidirectional. A centrally dispatched multi-

territory or coordinated among multiple regional system operators. However, it was shown in [7] that HVDC interconnectors could be modeled as profit-seeking entities instead of centrally coordinated system assets. An operation paradigm of HVDC interconnectors was introduced that simultaneously allocated energy and frequency response capacity. Lower system operational costs and higher revenues for the interconnectors were observed with the new market-based approach. However, the HVDC lines are assumed to be lossless and always available, which could lead to overestimating the capacity that can be utilized for power transmission. Furthermore, it was found that the inclusion of both AC and HVDC losses in the market clearing resulted in increased social welfare in the Nordic power market [8]. Moreover, piecewise linear loss factor functions were proved to have larger cost savings and better power distribution among HVDC lines [9].

New York State's Climate Leadership and Community Protection Act (CLCPA) aims to deliver 70% of New York's energy from renewable resources by 2030 and 100% emission-free electricity supply by 2040 [10]. However, transmission constraints limit clean-energy technologies in upstate NY from serving southeast New York, where most of the electricity demand is located [11]. This problem of the congested grid is referred to as New York's "Tale of Two Grids." The Clean Path New York (CPNY) project was proposed to alleviate the transmission constraints and deliver clean power to NYC. CPNY is a nominal 1,300 MW underground HVDC line from Delaware County to NYC [12]. Since both ends of CPNY are inside the New York control area, the NYISO will schedule power flows on the HVDC line. It is distinct from HVDC interconnectors between the NYISO and its neighboring ISOs/RTOs, which link two control areas and are not scheduled solely by the NYISO. Therefore, the HVDC line is referred to as an internal controllable line (ICL). It benefits the ICL operator to competitively bid into the NYISO's market to maximize its profit. The NYISO optimizes the ICL schedule to reduce the system's total cost. The ICL can potentially provide ancillary services, such as voltage support service, and added benefits to relieve congestion. All the existing HVDC lines in

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Financial Transmission Rights in Changing Power Networks

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Abstract

Many restructured power markets rely on Financial Transmission Rights (FTRs) as financial constructs that entitle the holder to a stream of revenues (or charges) based on the day-ahead hourly congestion price difference across an FTR-related energy path. Holders obtain FTRs through an auction mechanism relying on the solution of a specially formulated OPF problem. FTR holders then receive or make payments based on the outcome of Day Ahead (DA) energy market. Known FTR properties (revenue adequacy) [1] guarantee that if the auction OPF and the DA market have the same network topology, congestion rent collected in the DA market will be sufficient to pay all FTR holders. DA market topology almost always deviates from the auction topology. This may create underfunding problems. We propose a solution to topology-driven underfunding using Topology Reconfiguration Rights (TRRs) – financial transactions corresponding to topology changes. Combinations of FTRs and TRRs guarantee revenue adequacy.

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Nomenclature

N – number of tradable FTR positions;
 M – number of nontraded transmission constraints. For notational simplicity we assume that each monitored branch is monitored for each contingency; $c(k)$ – contingency corresponding to constraint k ;

$f_{\text{net}}, F (f_{\text{net}} \leq F_{\text{net}})$ – M – vectors of all enforced constraint flows and limits, respectively in the market network;

$\Phi_{\text{net}} = M \times N$ PTDF matrix reflecting the impact of FTR positions on constraint flows in the market network;

B^+ – set of branches that are closed in the auction network but open in the market network (missing branches);

B^- – set of branches that are open in the auction network but closed in the market network (acquired branches);

$\Delta_{\text{net}} = B^+ \cup B^-$ – difference between auction and market topologies;

Φ^c – a PTDF matrix reflecting the impact of FTR positions on branches in B^+ under contingency c in the market network topology;

Φ_{net}^c – a PTDF matrix reflecting the impact of transactions circulating flows for missing branches B^+ on branches in B^- under contingency c in the market topology;

$(I - \Phi_{\text{net}}^c)$ – a self-PTDF matrix reflecting the impact of branches in B^+ on themselves under contingency c ;

Y_c – a vector of flows through missing branches as defined from the power flow solution in the auction network under all contingencies;

Research Gaps that need to GET addressed

Efficient incentive design
to incentivize
technologies that provide
significant benefit/cost
value over their life

Computationally efficient
operational designs to
represent GETs

Participation Models and
Incentives to develop and
operate GETs

Mechanisms to better
hedge congestion with
GETs in forward auctions

Improved confidence in
GETs: demonstrations,
forecast assessments,
backup options



The GET Pun

Upcoming Incentives Panel Discussion at EPRI-ESIG-NERC-NATF workshop



- U.S. Department of Energy Lift Off Report
- Potomac Economics take on incentives for GETs in operation
- Portland General Electric utility perspective

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Updates, deliverables and additional information will also be shared on a dedicated webpage to be launched in June



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