Introduction to Grid Enhancing Technologies

Presentation to ERCOT Technology and Security Committee

Anna Lafoyiannis
Deputy Program Manager & Co-Lead GET SET

August 19, 2024

© 2024 Electric Power Research Institute, Inc. All rights reserved.

Benefits of Expanding Transmission System

01 Reliability, Resilience and Resource Adequacy

02 Integrate Renewable Generation

03 Reduce Congestion and Curtailment

04 Support Electrification and Decarbonization Efforts

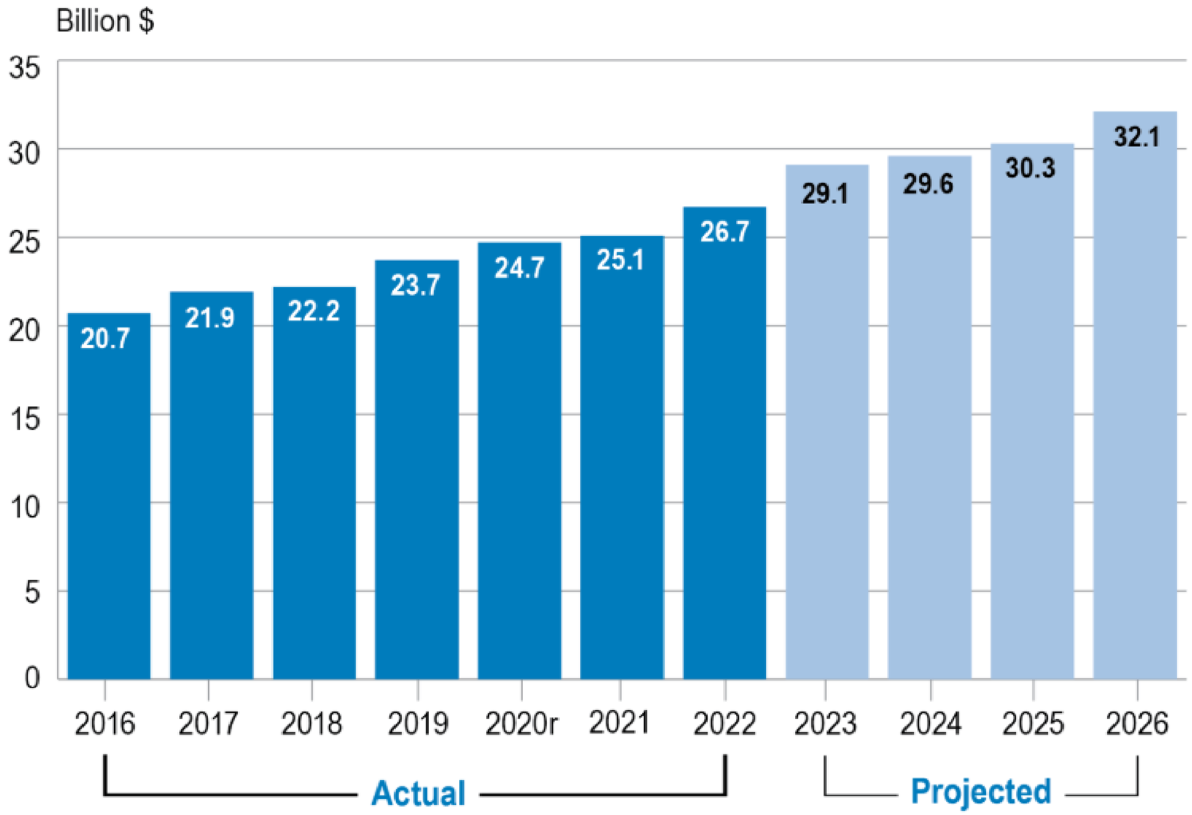
05 Enable Energy Justice by Reaching Energy Burdened Regions

All of these benefits come with the cost of increasing transmission capacity

© 2024 Electric Power Research Institute, Inc. All rights reserved.

Investments in the Transmission System

Annual Transmission Investment Reported to FERC



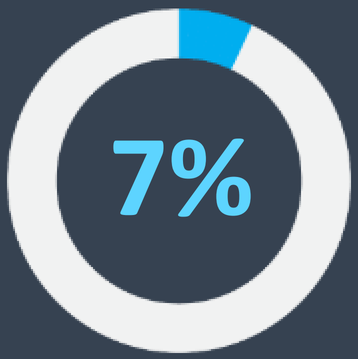
Source: [EEI Actual and Projected Transmission Investment]

- **90% of all transmission build in the US based on reliability assessment**
  - Meet local reliability issues
  - Meet generation interconnection needs
- Other benefits from transmission buildouts are generally not evaluated.
- Resulted in smaller piece meal transmission projects that don't focus on economic benefits
- *Importantly, expansion planning might determine that curtailment is a cheaper (optimal) overall solution considering CAPEX and OPEX than building a line*

© 2024 Electric Power Research Institute, Inc. All rights reserved.

Today's Transmission Investments

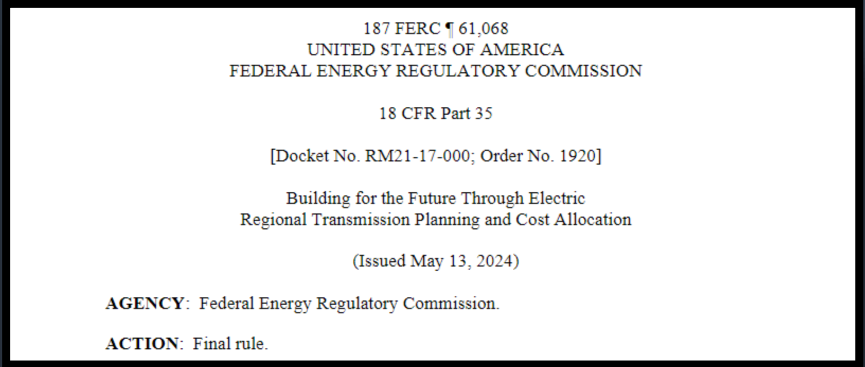
Transmission



Source: EEI Business Analytics 2022 surveys.

Advanced Technologies

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



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.

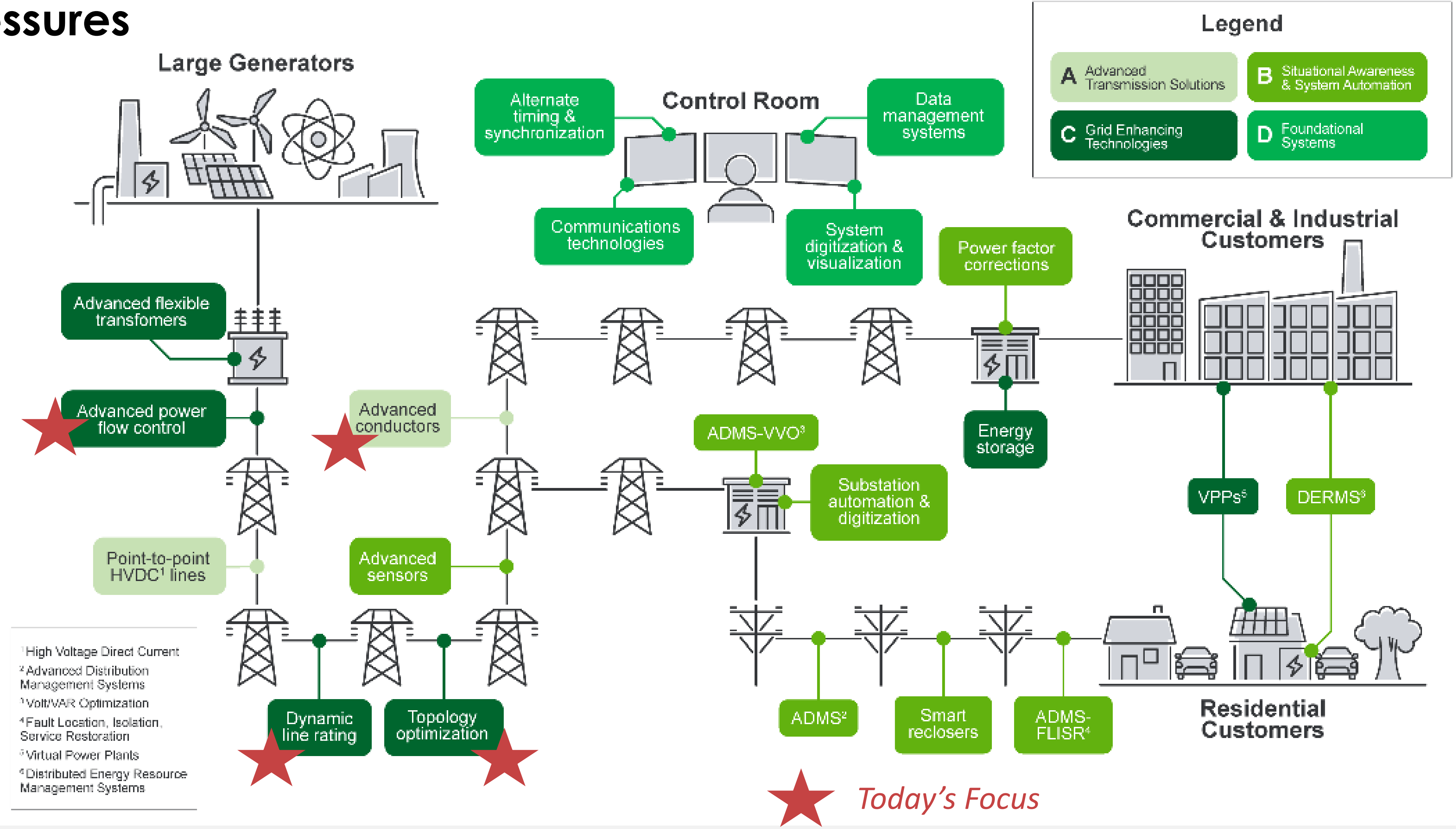
A rarely used technique to upgrade old power lines could play a big role in fixing one of the largest obstacles facing clean energy, two reports found.

Listen to this article · 8:04 min Learn more | Share full article | 875

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

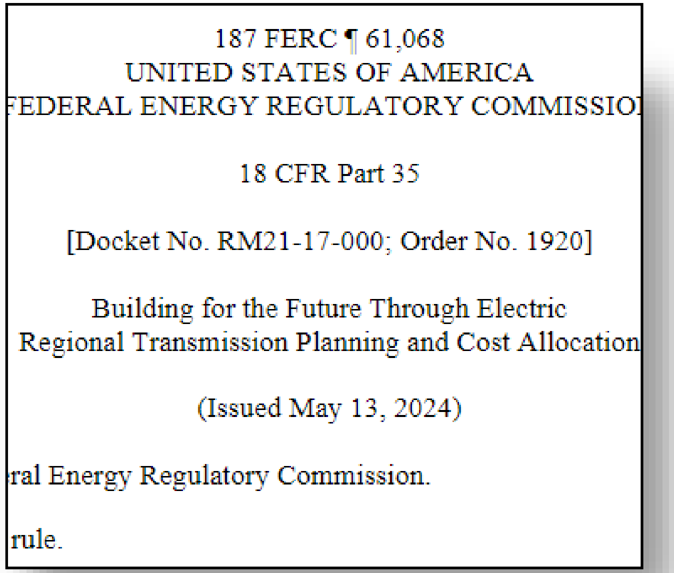
© 2024 Electric Power Research Institute, Inc. All rights reserved.

DOE's Innovative Grid Deployment Lift-Off Report identified GETs amongst 20 advanced grid solutions that can help quickly respond to accelerating grid pressures



© 2024 Electric Power Research Institute, Inc. All rights reserved.
EPRI

Grid Enhancing Technologies (GETs) can be deployed on the bulk system to improve transmission limits


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

18 CFR Part 35

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

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

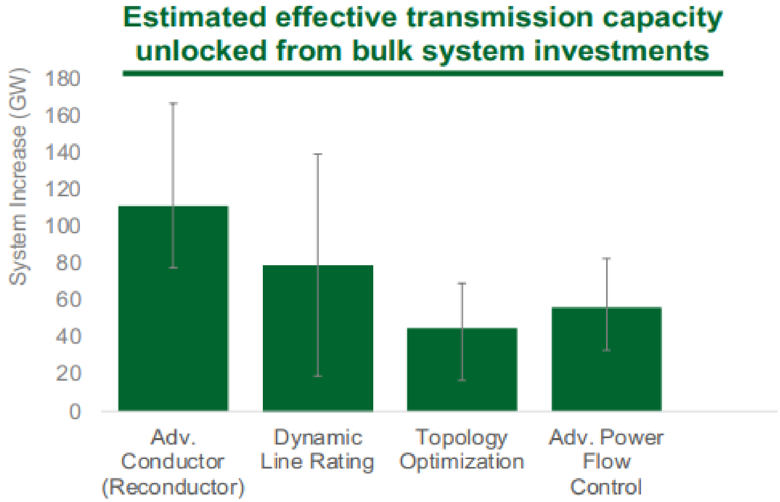
(Issued May 13, 2024)

ral Energy Regulatory Commission.

rule.

Grid-Enhancing Technologies (GETs) are hardware and/or software that can increase the capacity, efficiency, reliability, or safety of existing transmission lines

1 Increases Transmission Capacity and Reduces Congestion



HVDC is a critical part of the transmission solution set – while it has more limited use cases on existing ROW infrastructure, there are strong opportunities for new build corridors not captured here

2 Can be deployed quicker than building new transmission

Source: DOE Innovative Grid Deployment Lift-Off Report

© 2024 Electric Power Research Institute, Inc. All rights reserved.

Each technology can address different transmission challenges

Advanced Conductors

Operates at higher temperatures, allowing more power to flow

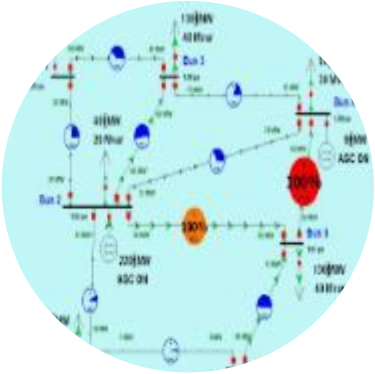
Dynamic Line Ratings

Updates thermal ratings of lines in proactively through forecasting and in real time

Power Flow Controllers

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

Transmission Topology Optimization



Reconfigures network to efficiently manage congestion

© 2024 Electric Power Research Institute, Inc. All rights reserved.

Technology #1: Advanced Conductors

Comparison of Advanced Conductors to Traditional Conductors

- Lower unit weight
- Higher core strength
- Sags less at high temperatures
- More aluminum for same diameter
- Sags more under ice loading
- More care needed when handling and installing
- No core inspection tools (non-steel core)
- Higher cost
- No long-term operational experience

© 2024 Electric Power Research Institute, Inc. All rights reserved.

Technology #1: Advanced Conductors
Application by Western Area Power Administration

Challenge

- During high power flow conditions, WAPA's transmission system and Bureau of Reclamation's Shasta hydroelectric power plant were not capable of operating at maximum potential
- Needed to double the ampacity of both substations to remain compliant with reliability standards and increase electrical capacity to meet the growing demand

Conventional Alternatives Considered

- Increase the substation ampacity to increase the conductor bus size. However, because these substations were designed for 795 ACSR conductors, an increase in the conductor size would mean a total replacement of the major structures in the substations.
- Cost and outage time would be significant.

Solution

- Reconductored with Aluminum Conductor Composite Core (ACCR) conductor

Benefits

- Meet original sag at higher current and full output of Shasta (710 MW)
- Satisfied increased power flow requirements and potential emergency conditions
- No structure modifications needed and reduced outage time savings

© 2024 Electric Power Research Institute, Inc. All rights reserved.

Technology #2: Dynamic Line Ratings
Review of the General Types of Ratings

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

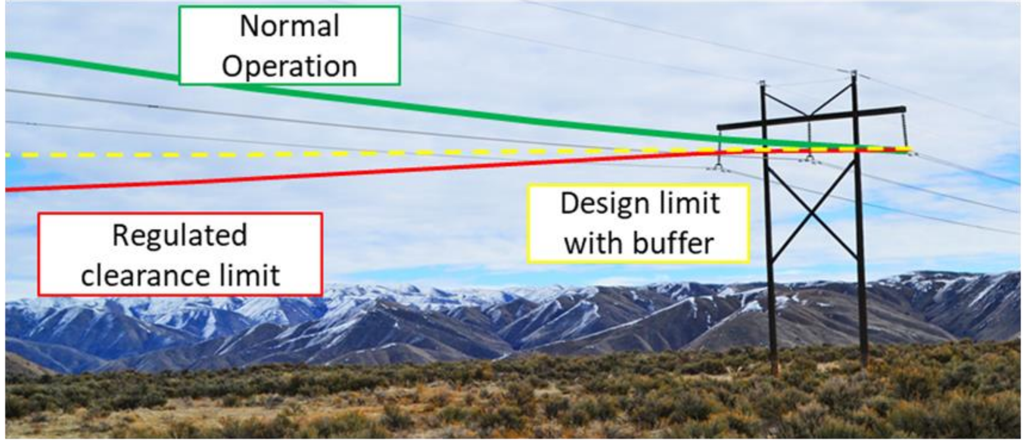
Few models accurately predict (small errors in forecasts can have big effects)

Dynamic line ratings (DLR)

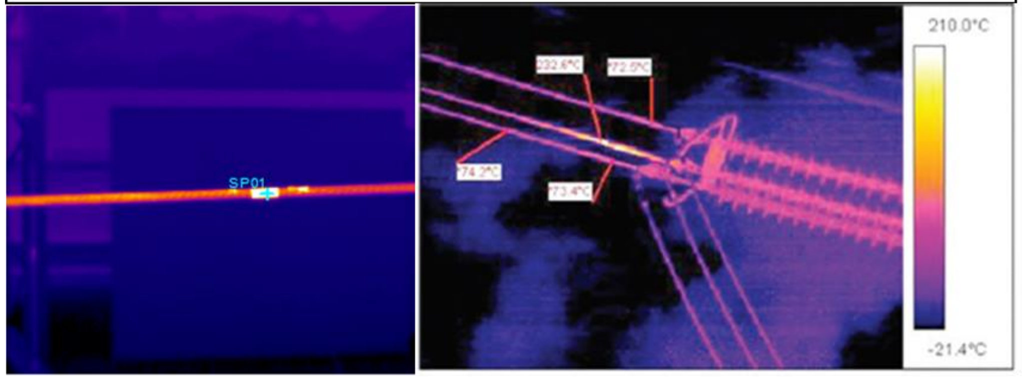
Change every 15-30 minutes based on wind speeds

Very difficult to predict beyond a few hours

Prevents clearance issues and flashovers



Prevents failures due to loss of strength (annealing)



© 2024 Electric Power Research Institute, Inc. All rights reserved.

Technology #2: Dynamic Line Ratings

State of Deployments

- In the US mainly pilot projects which have not been incorporated into day-to-day operations to get experience
  - Exception: PP&L has units installed on select circuits and provides ratings to PJM
  - There are over 30 commercial DLR technologies and pilots have not sufficiently addressed all vendors
  - Pilots do not address the lack tools, guides, etc. needed to accelerate adoption

- Utility Pilots typically fall into two categories
  - Getting experience on installation, maintenance and what the ratings provided are
  - Doing evaluation on the uncertainty in the ratings by comparing against research grade instrumentation and back-casting

- Adoption rates and tolerance varies regionally
  - In Europe different market structures provide sufficient ROI with DLR in more scenarios
  - QA/QC is often performed by vendors, utilities in areas with tighter regulations may not prefer this
  - Some utilities choose only to adopt DLR that does not apply AI/ML or "Black box" methods

Examples of DLR Deployments

SentriSense Transelec	PrismaPhotonics Israel Electric	Ampacimon PPL	SUMO ELES	Weather Station Red Eléctrica	Heimdall GRE	Linevision NGET

© 2024 Electric Power Research Institute, Inc. All rights reserved.

Technology #2: Dynamic Line Ratings
Questions from Utilities

Acquisition

Challenges

Advisor: "There are no industry standards related to performance, specification or selection"

Advisor: "There is no accuracy or performance test process utilities can use to ensure accuracy and longevity"

Gaps

- Understanding accuracy & uncertainty
- Requirements for specifications

Operate

Challenges

- Evolving Cybersecurity Landscape

Uncertainty, & Complexity of Integration
- Realtime Operations
- Short Term (Operations) Planning

Integration into Longer Term Planning

Gaps

- Understanding of Uncertainty
- Industrywide Practices & Tools
- Training
- Understanding of Increased Risk

Maintain

Challenges

Advisor: "How do we ensure the performance of field systems in the harsh right of ways?"

Advisor: "What is the level of effort & expertise needed for maintenance?"

Advisor: "Do we know how to manage asset life cycle?'

Gaps

- Expected failure / outage rate?
- Quantity & Skills of resources needed?
- Degradation & Failure modes / Rates
- Life Expectancy

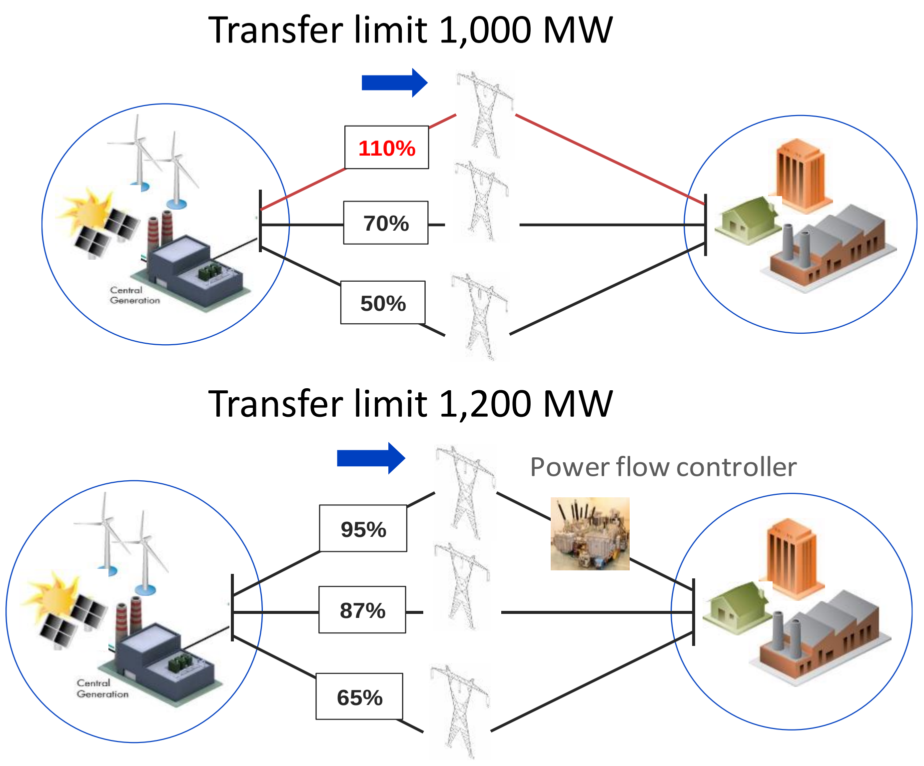
Significant Diversity in Solution Approaches Increases Complexity & Unknowns

© 2024 Electric Power Research Institute, Inc. All rights reserved.

Technology #3: Advanced Power Flow Controllers
Comparison with traditional power flow control

Traditional Power Flow Control
- Includes phase-angle regulators/phase shifting transformers (PSTs), flexible AC transmission systems (FACTS), and high-voltage DC (HVDC) technologies

Advanced Power Flow Controllers (APFC)
- Power electronic based
- Modular and scalable, more responsive, faster deployment



Power Flow Control devices allow better utilization of existing transmission assets by balancing flows by actuating on high voltage devices connected in series or in shunt

© 2024 Electric Power Research Institute, Inc. All rights reserved.

Technology #3: Advanced Power Flow Controllers
Application in Central Hudson

Challenge

- NYISO identified deliverability constraints during its generation interconnection process
- Upstate New York/ Southeast New York interface transfer capability needed to be improved by 185 MW to ensure the deliverability of the class year projects

Conventional Alternatives Considered

- A fixed series capacitor (FSC) installed at Central Hudson's Hurley Avenue substation, to provide a 21% series compensation on the Leeds-Hurley line
- However, the screening study identified potential for sub-synchronous resonance issues (protections issues)

Solution

- Installed 15 Smart Wires SmartValve10-3600i units

Benefits

- An immediate impact to the current flow on the line was noted
- Potential to expand the deployment to increase the compensation level
- Local and remote control of the units, with NYISO determining when the system is place in or out of service
- Bypass bay allows maintenance without taking line out of service

© 2024 Electric Power Research Institute, Inc. All rights reserved.

Technology #4: Transmission Topology Optimization (TTO)
Application in MISO

Challenge

- Increased congestion and congestion costs resulted in reconfiguration requests from non-transmission owners/operators
- Market participants used TTO to run studies to identify reconfiguration options; submitted requests to MISO and TO/TOPs
- MISO performed studies and sent results to the appropriate TOs for evaluation; largely rejected by TOs
  - Reliability/other concerns cited
  - Lacking a process for how to handle these requests

Solution

MISO worked with stakeholders to create a process to accept and evaluate the requests including both reliability and market impacts

Implementation Considerations and Learnings

- Four requests approved since start of process in 2023
- Coordination between system operator and transmission owner/operator is time intensive (therefore not replicable in real-time under the existing process)
- Important to study and analyze impacts, using full market simulation (e.g SCUC/SCED) and as accurate a representation of system conditions and market benefits
- Topology has changed so optimization of commitment and dispatch should and will be impacted as well

Limitations

- Not applied when it may impact stability impacts
- Limited ability to assess benefits of the reconfiguration and market impacts of re-dispatch
- Feasibility of conducting frequent topology changes

Adapted from MISO presentation to EPRI members, March 2024

© 2024 Electric Power Research Institute, Inc. All rights reserved.
EPRI

Technology #4: HVDC

Today's Implementation Considerations

1

Lack of Vendor Capacity

Demand for HVDC has skyrocketed, already in Europe, and now the US is catching up. However, vendors capacity is limited, build times are ballooning.

2

Multi Terminal HVDC / DC Grids

Offshore, onshore. In Europe, in the US. Multi-terminal, multi-vendor HVDC is taking off. Will it work?

3

Standards, standardization and education

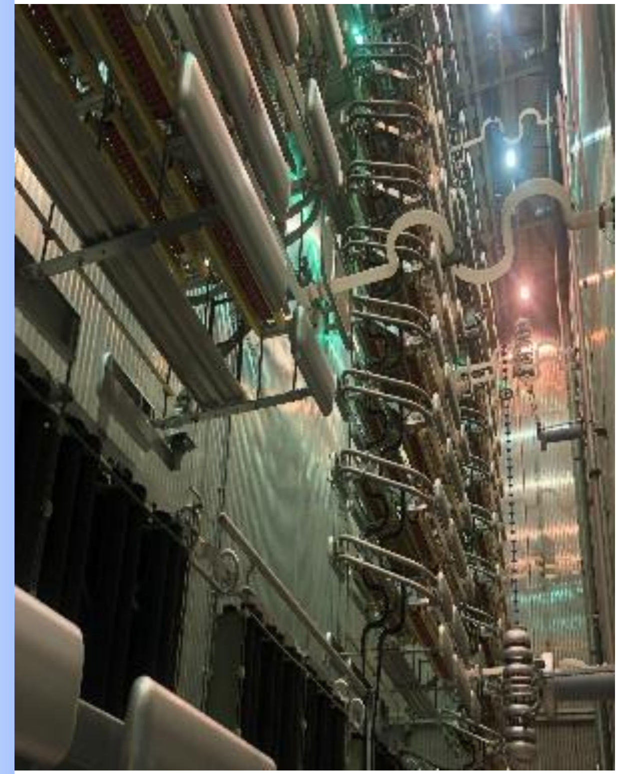
Standards to tackle; performance, interoperability and testing. Standardization to reduce engineering effort. Education to increase industry knowledge of HVDC.

4

Operation with multiple HVDC links

Increased number of embedded HVDC links may create reliability and operation security concerns.

HVDC Deployment At a Glance



Today's deployments

- HVDC has been in use since 1954
- Used primarily for long-distance bulk system delivery
- Over 250 GW of HVDC globally at 170 locations
- In North America, 34 major HVDC projects in-service with a total nameplate capacity over 24 GW
- Since 2013, 7 new HVDC commissioned
  - 5 in Canada
  - 2 in US

Future of HVDC deployments

- Renewed interest for interconnecting off-shore wind to on-shore AC transmission
- 14 projects are 'ready to go' in U.S. (*see appendix for more)*

© 2024 Electric Power Research Institute, Inc. All rights reserved.

Activities for System Owners and Operators to Incorporate GETs

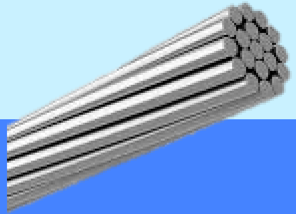
- **01** Test and Validate Technology Options
- **02** Specify, Acquire, Install Applicable Technologies
- **03** Develop Tools and Processes to Operate in Real-Time
- **04** Consider market designs and policies to incentivize efficient investment and operation of GETs
- **05** Monitor Reliability and Effectiveness to Quantify Dependable Impact for Planning

© 2024 Electric Power Research Institute, Inc. All rights reserved.

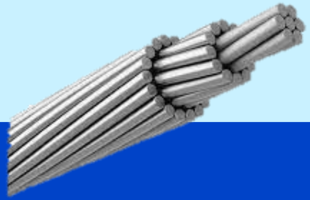
Appendices

Traditional Conductors

Initially, bare, stranded copper was utilized as an overhead transmission conductor due to its high conductivity and good tensile strength. The aluminum 1350-H19 replaced copper as the main conductive material due to its lower cost and lower density.



All Aluminum Conductor (AAC)



Aluminum Conductor Alloy Reinforced (ACAR)

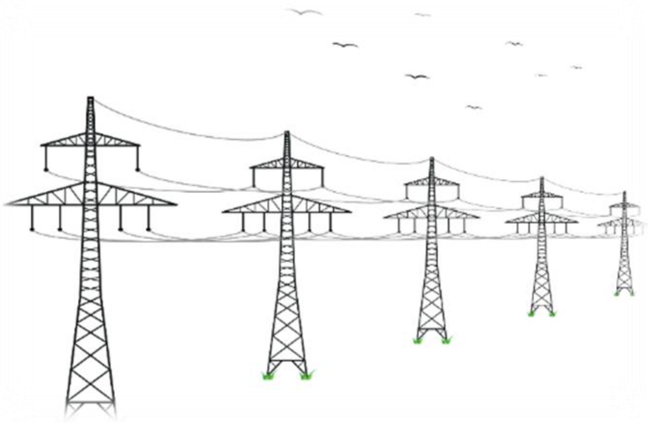
All Aluminum Alloy Conductor (AAAC)

Aluminum Conductor Steel Reinforced (ACSR)

© 2024 Electric Power Research Institute, Inc. All rights reserved.

Conductor Design Evolution

Copper Conductors → 1899: All-Aluminum 1350-H19 Conductors (less dense and expensive than copper) → 1907: Aluminum Conductor Steel Reinforced Conductors (need for higher strength) → 1939: All-Aluminum Alloy Conductors & Aluminum Alloy Conductor Steel Reinforced Conductors → 1973: Aluminum Conductor Steel Supported with galvanized steel (demand for more ampacity) → 1990s: Aluminum Conductor Steel Supported with mischmetal steel coating and trapezoidal strands → 2003: Aluminum Conductor Composite Core & Aluminum Conductor Composite Reinforced

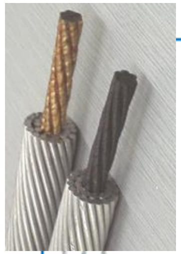


© 2024 Electric Power Research Institute, Inc. All rights reserved.
EPRI

Advanced Conductors

ACSS

Aluminum Conductor Steel Supported



ACFR

Aluminum Conductor Fiber Reinforced

ACCR

Aluminum Conductor Composite Reinforced

ACCM

Aluminum Conductor Composite Multistrand

ACCS

Aluminum Conductor Composite Supported

HVCRC

High Voltage Composite Reinforced Conductor

LSCC

Low Sag Composite-core Conductor

TS

Total Solutions

ACCC

Aluminum Conductor Composite Core

© 2024 Electric Power Research Institute, Inc. All rights reserved.

Next Steps for Advanced Conductors

Material Behavior

Selection and Application

Installation Practices

Long Term Performance

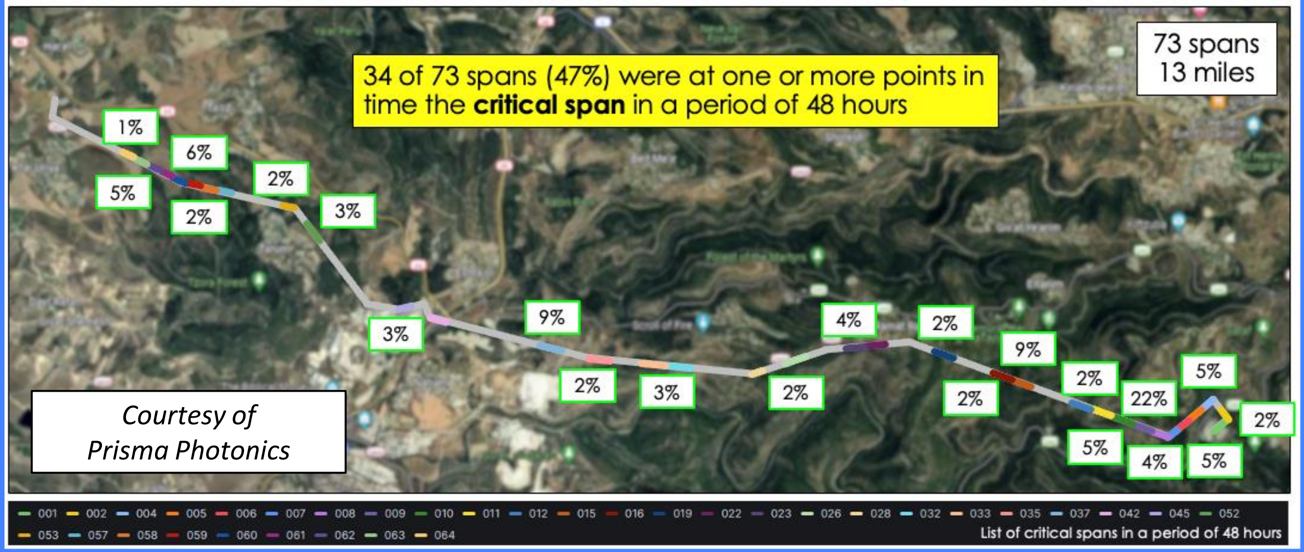
Inspection, Assessment and Maintenance

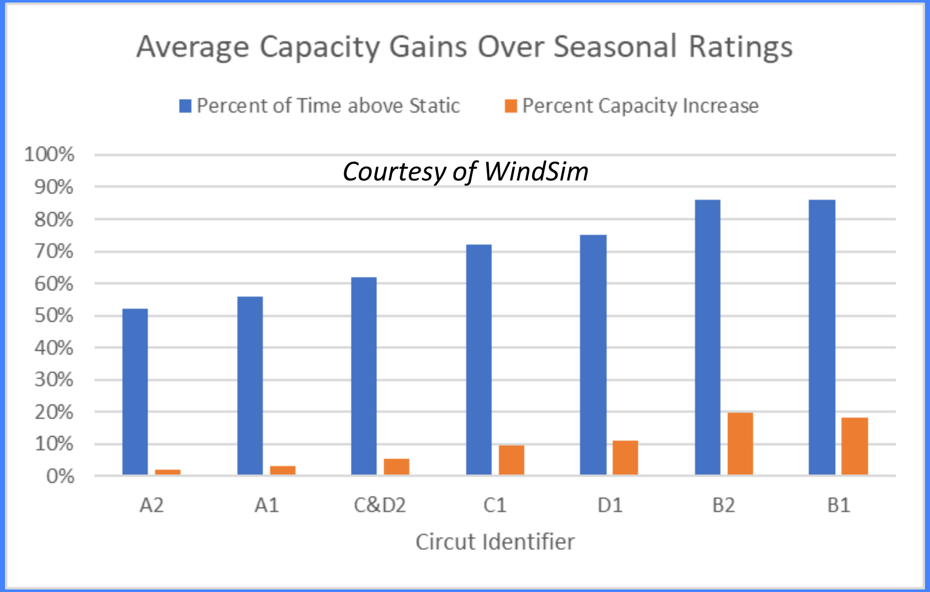
Life Expectancy

© 2024 Electric Power Research Institute, Inc. All rights reserved.

Pairing DLR with Traditional Upgrades to Address Limiting Spans

- To achieve the expected benefits from DLR we may need
  - Site modifications to account for at-risk spans
  - Added monitoring for critical spans and redundancy
  - Substation upgrades
  - Added storage capacity
- Part of applying DLR is understanding what technologies do and do-not do

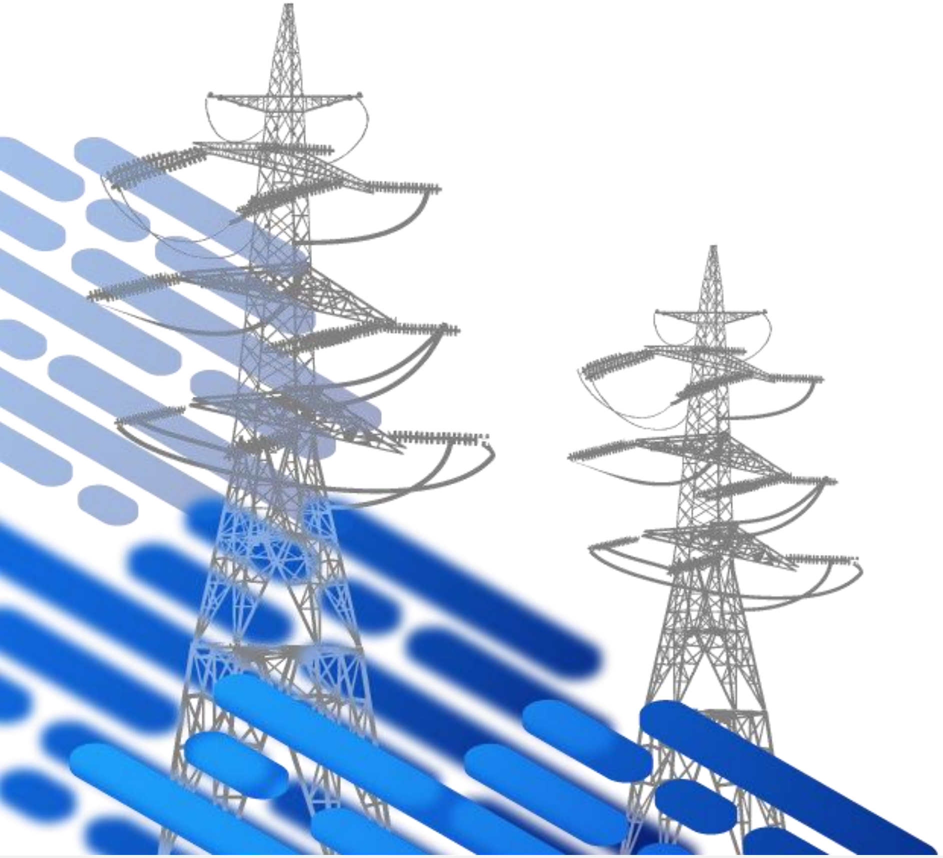




© 2024 Electric Power Research Institute, Inc. All rights reserved.

Finding the Right Size Solution & Combination

The optimal solution (rapid, reliable, ROI, etc.) will vary based on generation mix, design practices, and demand profiles. Often better results are obtained by pairing DLR with other GETs



DLR

PFC

Topology

Storage

Li·ion

Example 1
Wind farm serving a large residential area
Congestion typically 5-10% during daily peaks

Li·ion

Example 2
Mixed industrial and residential load increasing with electrification, served by a mix of generation types

Example 3
An interconnection is relied on more heavily during system maintenance

© 2024 Electric Power Research Institute, Inc. All rights reserved.
EPRI

Examples of Questions from Utilities & Challenges Observed in Field Trials

Uncertainty concerns	Unexpected capacity reductions	Communication dropouts	Battery leaks/ explosions	Change in performance after hardware / software updates
Accuracy drop off due to line maintenance	Improper installation	Copper theft (of ground leads)	Unexpected costs for maintenance & outages	Recalibration interval cost and resource prohibitive (sometimes multiple per year)

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

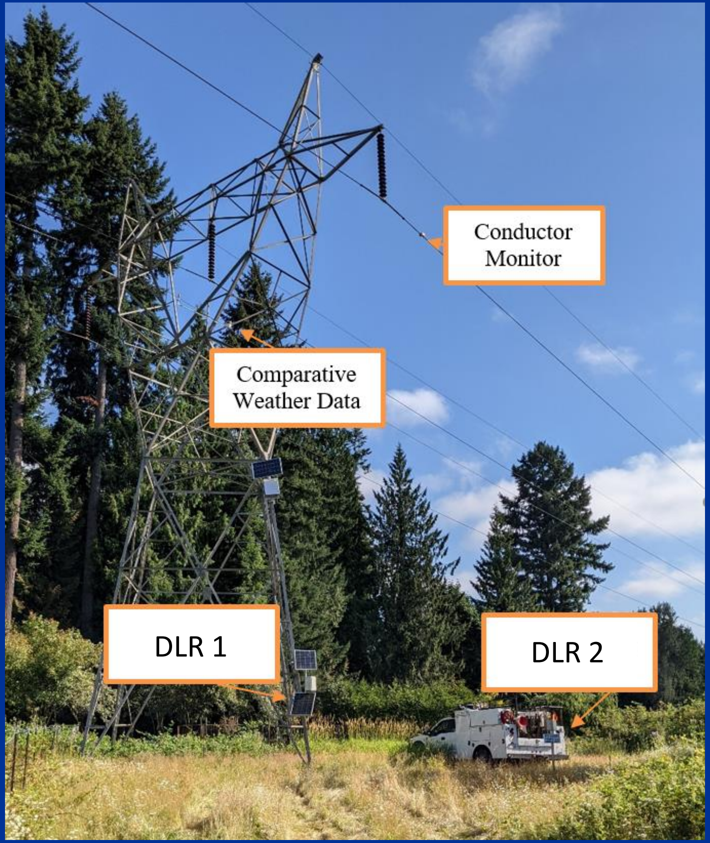
- Expected failure / outage rate
- Failover procedures and spares strategy
- Quantity & skills of resources needed
- Degradation & failure modes
- Life expectancy
- Disposal / end of life treatment

© 2024 Electric Power Research Institute, Inc. All rights reserved.

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

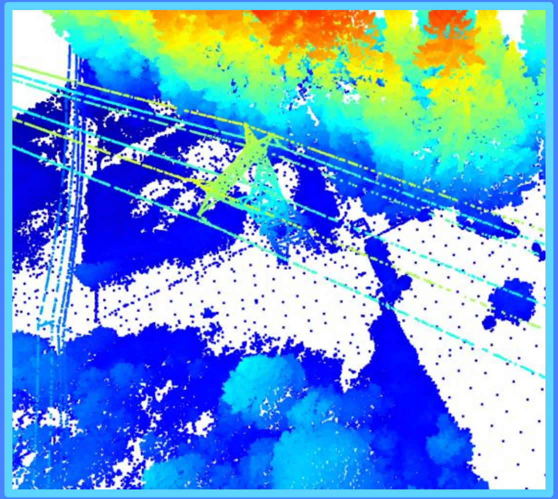
POWER CYCLING

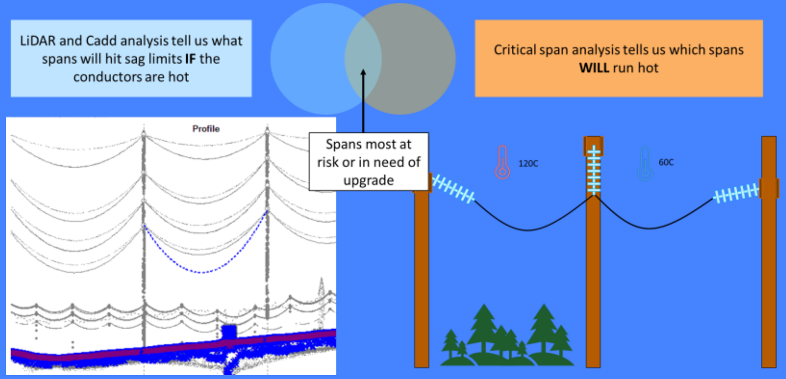
ATTACHMENT SLIP / VIBRATION

ENVIRONMENTAL EXPOSURE

SWITCHING AND LIGHTNING

- **Critical Span Identification and Coverage Area**





© 2024 Electric Power Research Institute, Inc. All rights reserved.

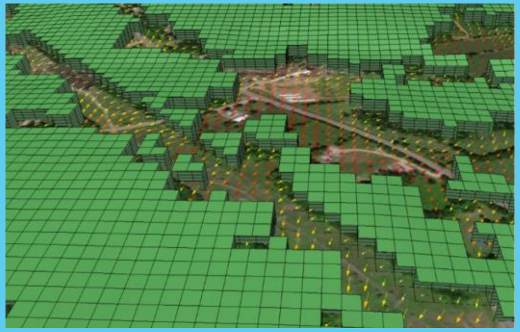
How Can Tools with Different Methods be Compared?

Vendor approach	Intermediate steps they take					
Conductor Temperature	Take average or peak value from multiple points	Estimate wind speed				
Measure sag or clearance	Perform site survey measurements	Estimate sag to tension relationship	Estimate tension to temperature relationship	Estimate line temperature	Estimate wind speed	
Measure line tension	Perform site survey measurements	Estimate tension to temperature relationship	Estimate line temperature	Estimate wind speed		
Measure line EM-Fields	Perform site survey measurements	Model EMF to clearance relationship	Estimate sag to tension relationship	Estimate tension to temperature relationship	Estimate line temperature	Estimate wind speed
Measure vibration properties	Perform site survey measurements	Estimate vibration to tension relationship	Estimate tension to temperature relationship	Estimate line temperature	Estimate wind speed	

© 2024 Electric Power Research Institute, Inc. All rights reserved.
EPRI

We Must Get Ahead of GETs

- Closing the knowledge gaps will take a focused effort over multiple years
  - Accelerated lab testing
  - Field deployments
  - CybserSec evaluations
  - Evaluations that merge multiple gets
  - Experiencing different conditions in a statistically significant way
  - Developing and applying training





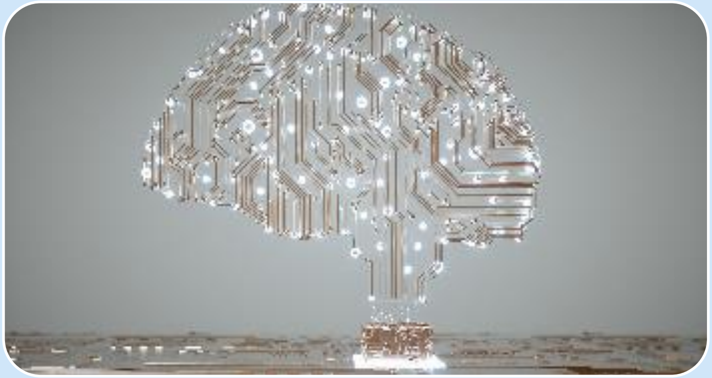


© 2024 Electric Power Research Institute, Inc. All rights reserved.
EPRI

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

© 2024 Electric Power Research Institute, Inc. All rights reserved.

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?

© 2024 Electric Power Research Institute, Inc. All rights reserved.

GETting Investments Right

Benefits to Consumers

Return on Equity

Risks and Challenges

- Planned Benefit vs. Actual Benefit
- Congestion Revenue Allocation
- Shared Incentives

© 2024 Electric Power Research Institute, Inc. All rights reserved.

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.

© 2024 Electric Power Research Institute, Inc. All rights reserved.

Questions from System Operators

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

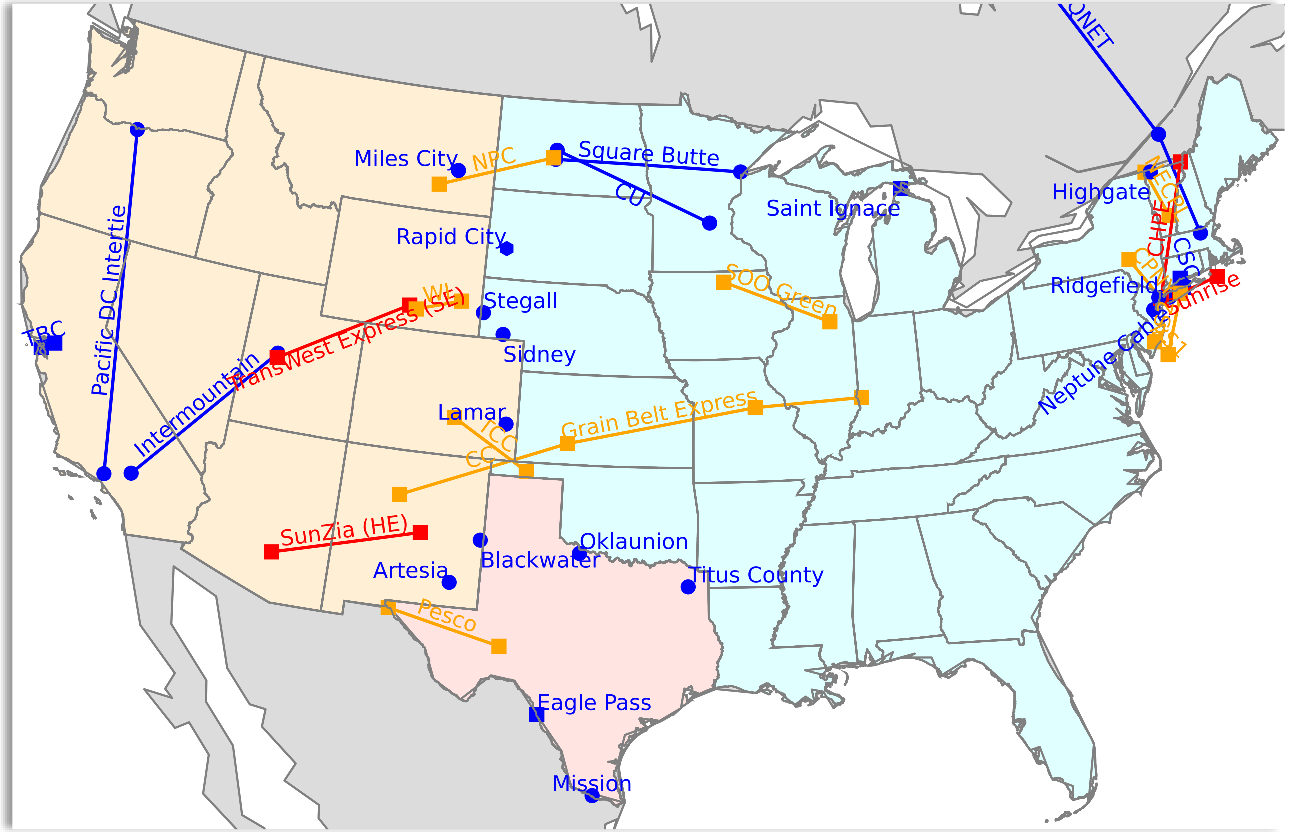
Mechanisms to better hedge congestion with GETs in forward auctions

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

© 2024 Electric Power Research Institute, Inc. All rights reserved.

Current US HVDC schemes

- Only one new HVDC scheme was commissioned in the US in the last 10 years (not including upgrades)
- Americans for a Clean Energy Grid* identified four projects under construction:
  - SunZia, HE Arizona/ New Mexico
  - TransWest SE Wyoming/Utah
  - Champlain Hudson Power Express CHPE HE Canada/New York
  - Sunrise SE NY/offshore
- Americans for Clean Energy Grid suggests ten projects are “ready to go” (approved or near approval, getting to financial closure).



*Z.Zimmerman et al. Ready to Go Transmission Projects 2023, Americans for a clean energy grid

© 2024 Electric Power Research Institute, Inc. All rights reserved.

What do transmission planners and operation engineers need to evaluate and operate HVDC?

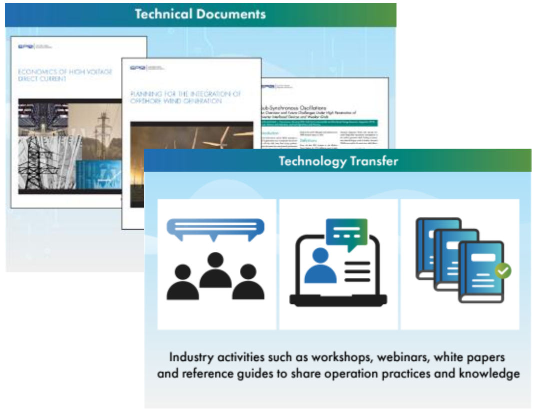
- Understanding of technology principles
- Trends and emerging technologies
- Understanding of the technology benefits
  - Comparison of alternatives
  - Metrics and approaches for comparing alternatives
- Basic/reference data: parameters, cost
- Modeling, methodologies and tools
- Reliability and system impact: control interactions, special protection schemes, stability issues, control strategies
- **Performance and planning standards**

Increased number of HVDC connections will impact system operations and planning

© 2024 Electric Power Research Institute, Inc. All rights reserved.

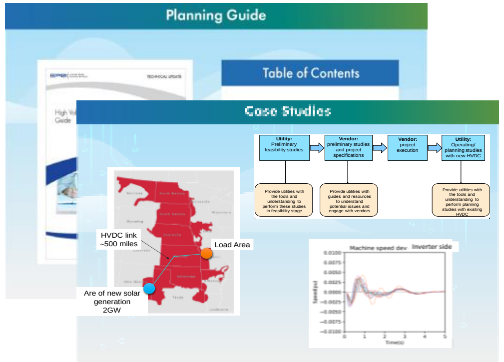
EPRI efforts related to HVDC planning

Understanding of technology, new trends (MTDC, DC Grids), benefits, implementation and operation challenges



Technical documents / White papers / Workshops/webinars/ Participation in external project (i.e. HVDC WISE)

Systematic approach and guideline for planning and assessment of HVDC

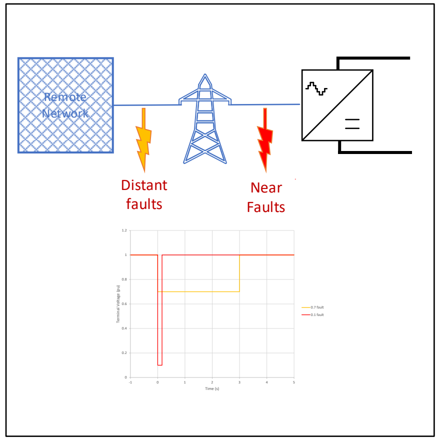


HVDC Planning Guide / Case Studies /

Models and simulation and analysis tools

Guidance on the use of models / Handy tools to perform specific studies and analysis

Comprehensive performance and planning standards



Recommendations for grid code requirements for HVDC systems

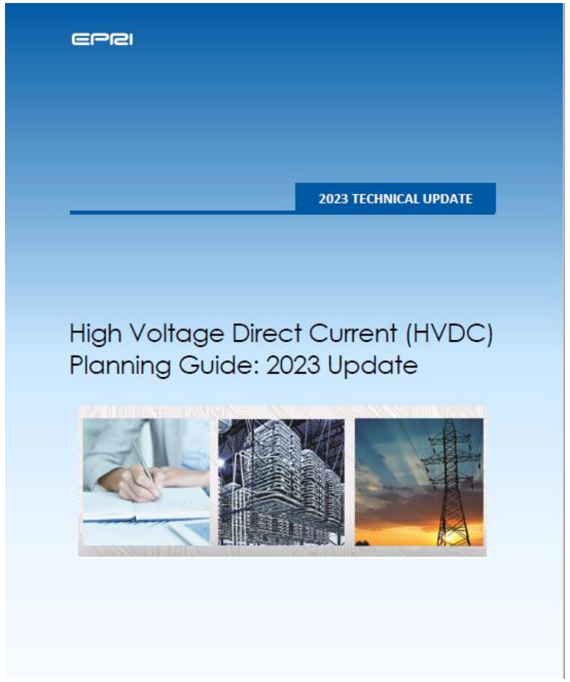
Basic/reference data: design parameters, cost

Transmission Infrastructure Cost Estimating Guide

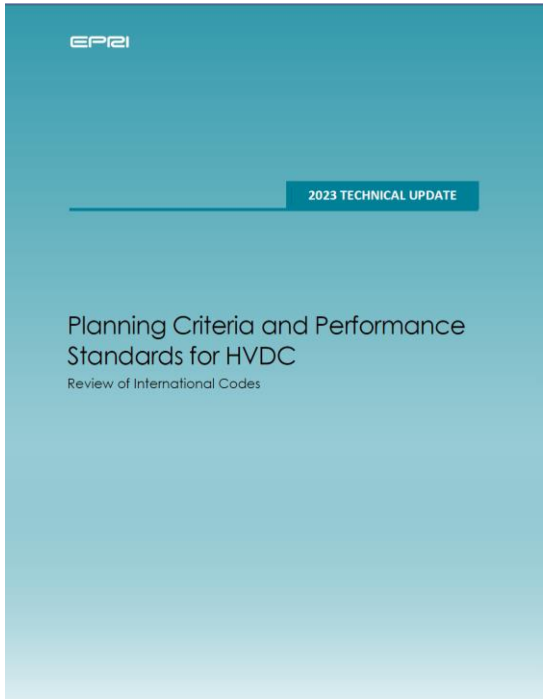
What do planners/engineers need to evaluate HVDC projects?

© 2024 Electric Power Research Institute, Inc. All rights reserved.

2023 Deliverables



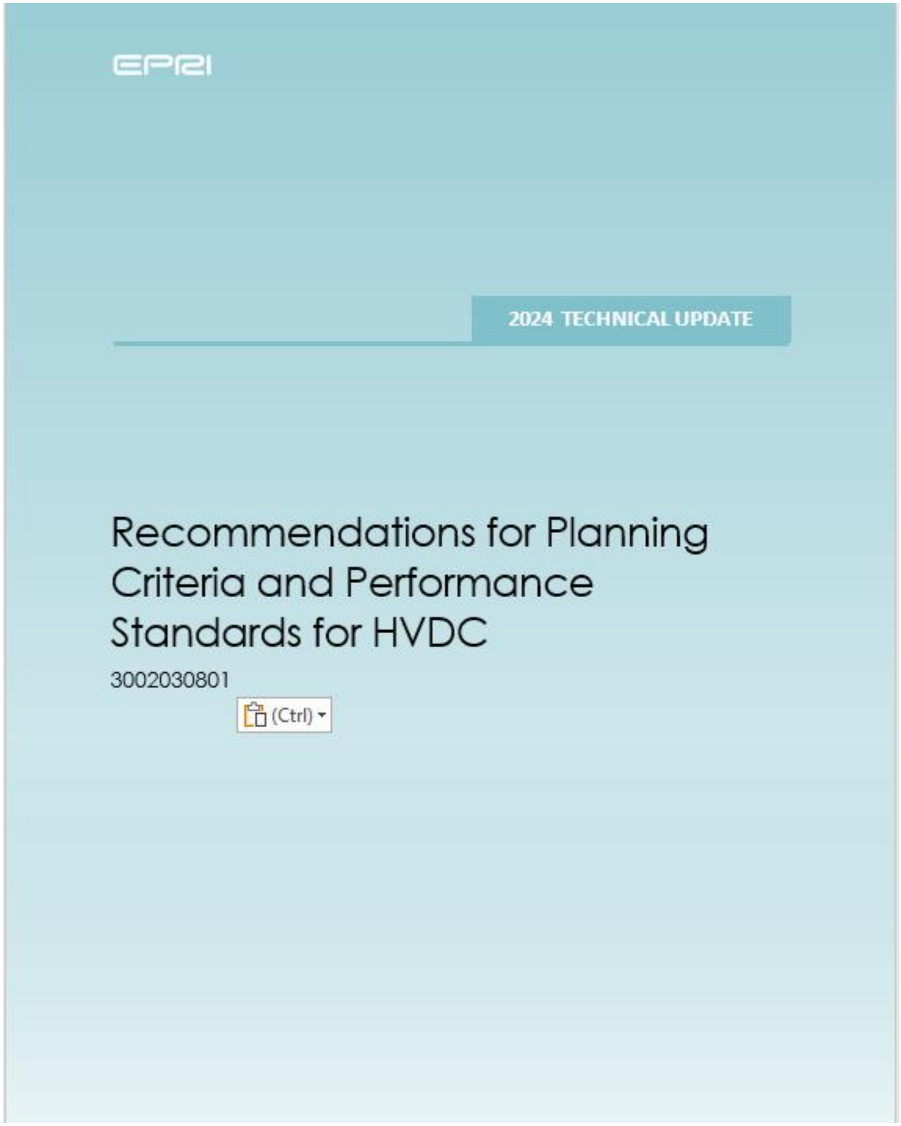
HVDC Planning Guide: 2023 Update. EPRI, Palo Alto, CA: 2023. 3002027098



Planning Criteria and Performance Standards for HVDC: Review of international codes. EPRI, Palo Alto, CA: 2023. 3002027099.

© 2024 Electric Power Research Institute, Inc. All rights reserved.

Planning Criteria and Performance Standards for HVDC

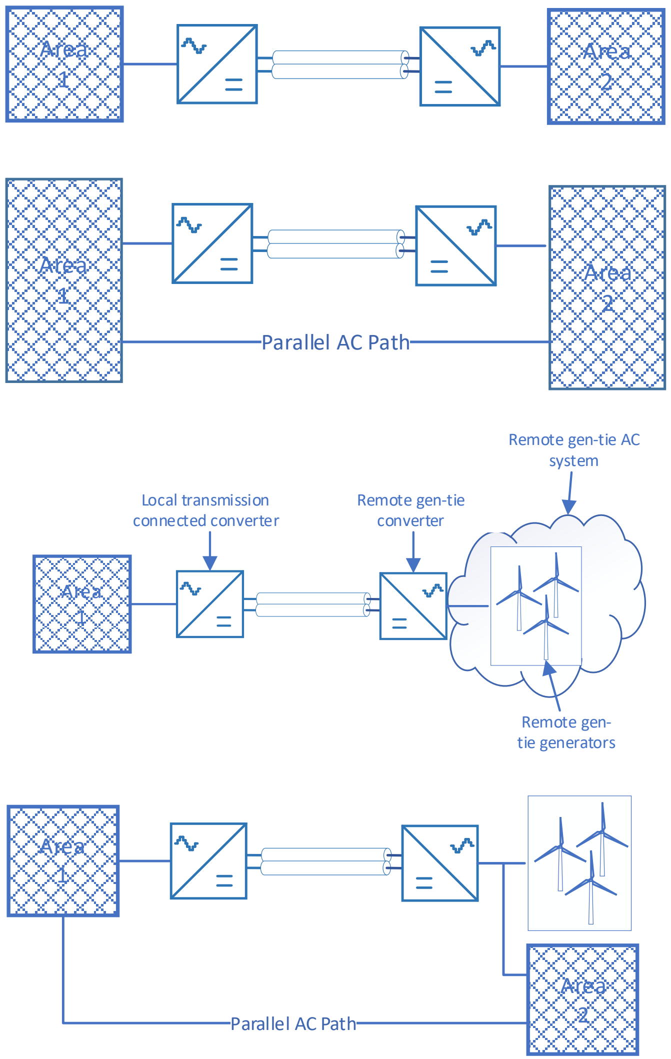

EPRI

2024 TECHNICAL UPDATE

Recommendations for Planning Criteria and Performance Standards for HVDC

3002030801

Scope



Content

1. Introduction
2. Recommendations for Planning Criteria and Performance Criteria for HVDC Projects
3. Recommendations on Studies
4. Recommendations on Network Models Supplied by the system operator
5. Recommendations on Model Requirements and Simulation Tools
6. References

This is a very important piece of work that we developed primarily for SPP but we made it publicly available

© 2024 Electric Power Research Institute, Inc. All rights reserved.