ESIG
ENERGY SYSTEMS INTEGRATION GROUP

Scale, Speed, and Supply Chain - Success Factors for Sustainable Electrical Energy Delivery

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March 19, 2025

The Electrical Grid's Value in the Energy Ecosystem

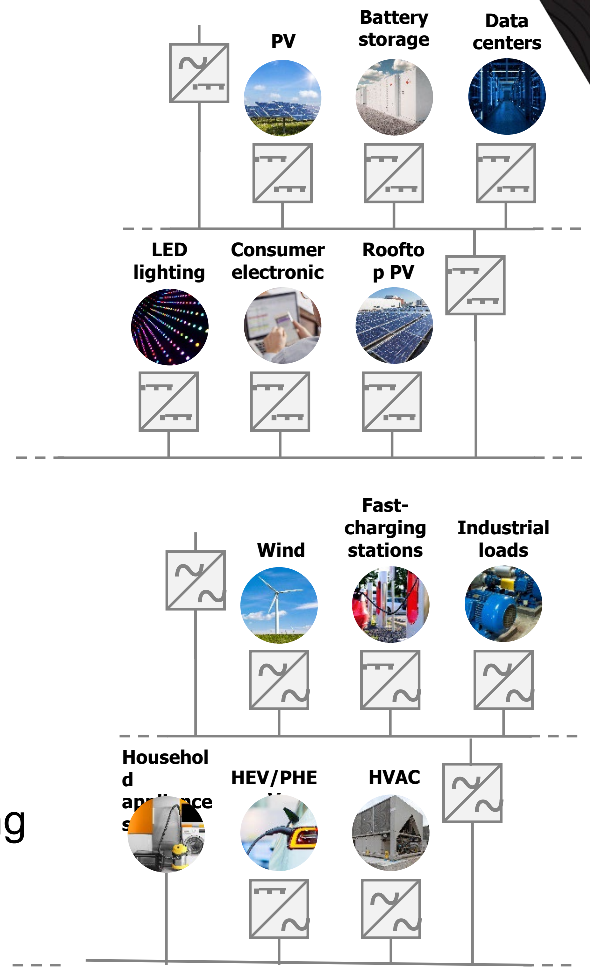
The grid is the customer's physical connection to the energy system and the basis for integrating system information and control. It requires a balance of consumer/supply and T&D grid investments.

The objective of renewables is to **reduce carbon footprints by replacing carbon-emitting generation.**

Both renewables and the T&D grid are carbon-free and complement each other high levels of renewable integration are not possible on an aging and non-functioning infrastructure or outdated operations.

The grid design needs to change to accommodate renewables and electrification, **but the grid and generation need to be planned in a coordinated way for reliable, resilient, safe, and cost-effective electrical energy delivery.**

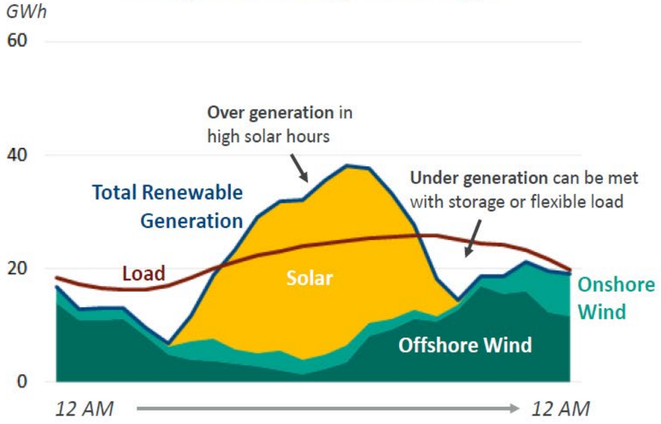
The interplay between the grid's "hosting capacity" (ability to accommodate DERs, resulting in grid upgrade needs) and the value of DERs (ability to avoid grid upgrades) shows that **both grid upgrades and Non-Wire Alternatives are part of the same solution.**



Grid Flexibility and "Coordinated" Resource^2 and T&D Planning

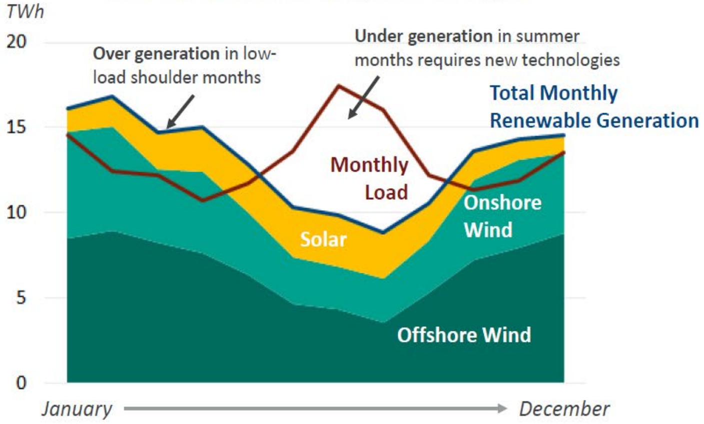
- **Flexibility as capability of the power system to maintain balance between generation and load under uncertainty -** Value of flexibility and corresponding investments vary depending on business, regulatory, and regional differences; evolving trends and technologies; and consumer needs.
- Ensure **resource adequacy,** in coordination with market design and regulation to achieve **affordability** despite increasing infrastructure needs – **new metrics** to support **reliability and resilience** (*weather, security, and system*) targets.
- **Advanced automation, Data mgmt., AI, and Grid Enhancing Technologies (GETs)** are beneficial for effective monitoring, control, and protection of dynamic changes with DER, storage, and loads, and weather changes.
- ***"Coordinated"* Resource^2 & T&D planning** as systematic analysis of the benefits provided to the grid and its participants.

Hourly Balancing Challenge



Batteries and load flexibility can provide short-term balancing.

Seasonal Balancing Challenge

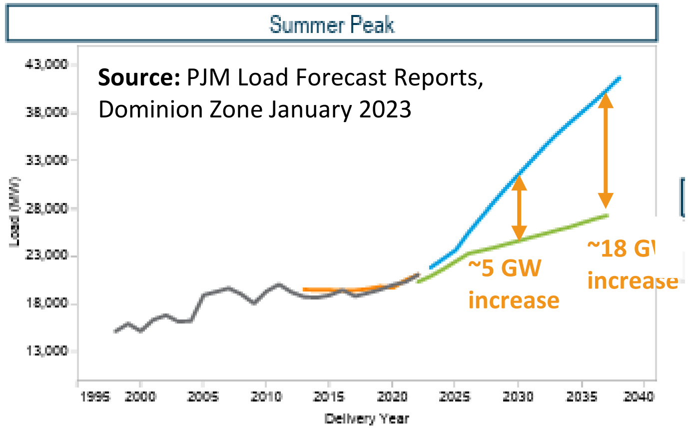


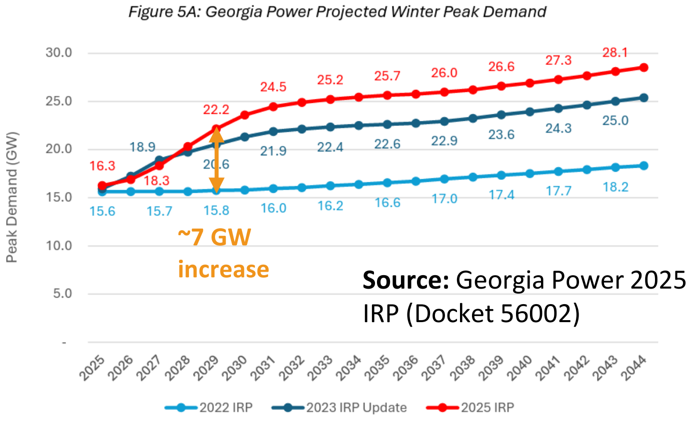
Seasonal balancing is the more difficult challenge, requiring <u>new technologies</u> such as seasonal storage or zero-emission dispatchable generation.

Has the probability of wide area system blackouts increased?

Source: *NYISO*

Data Center Opportunities and Economic Growth

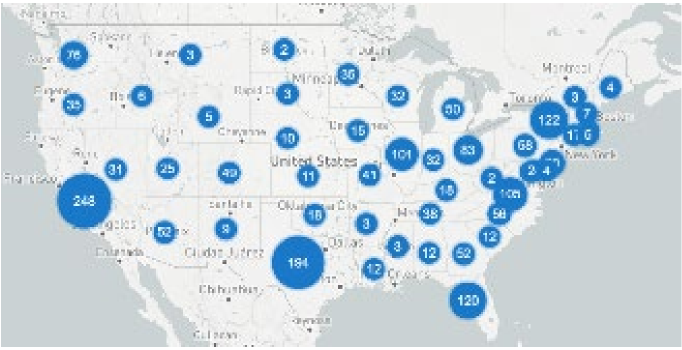




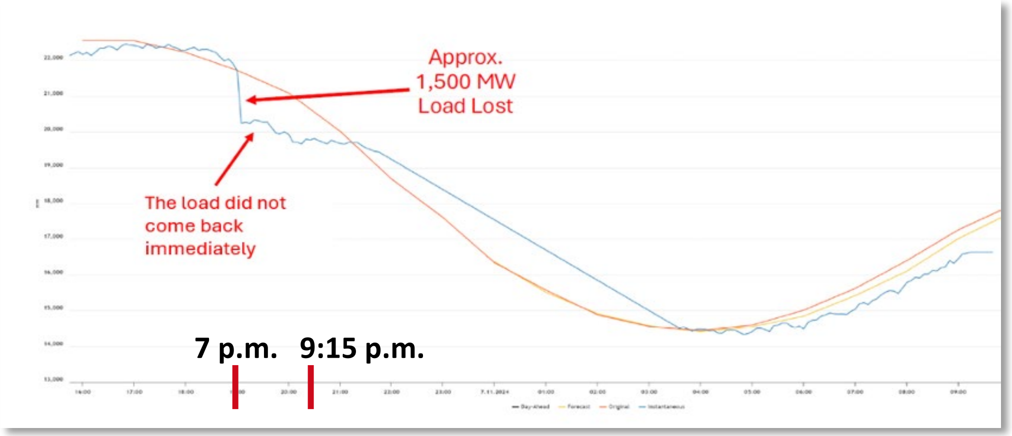
U.S. data centers might use 25% of all electric energy by 2055

- Load exceeds 100 MW and plans for **multi-GW loads** at single sites resulting in load growth for individual utilities of 50-100% or more in 5-10 years
- Need for **advanced forecast model** based on various parameters – grid connection, market size, incentives, power and land cost, and the purpose of individual DCs
- New DCS are often **clustered** with existing data centers
- Significant **investments in generation and transmission** are required
- DCs recently seek to **co-locate with various new or existing** (e.g.., Amazon and Constellation) generation, including renewable resources (distant from data centers)
- AI large loads impose **stresses and risks** for reliable and cost-effective grid operation

Map of data centers in the U.S.



Technology to Address Reliability Needs



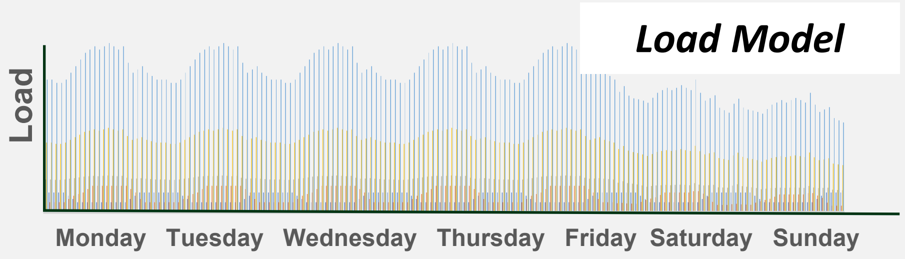
Source: NERC Incident Review 1/8/2025

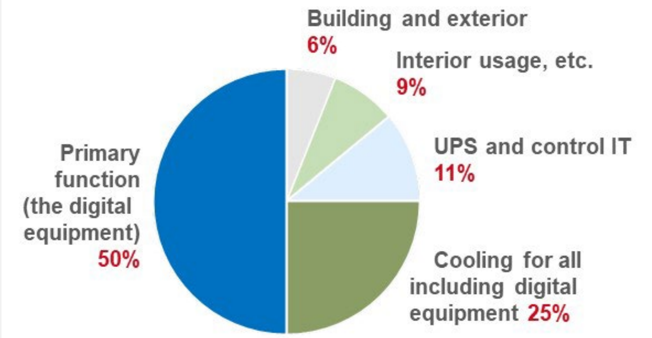
Size of data center load influences overall grid reliability

- *1.5 GW of DC load tripped following 230 kV faults*
- *Load return delay, caused by data center UPS equipment, was not anticipated by the system operators and should be addressed*

Key success factors:

- Technology selection, configuration, and testing for data centers to optimize cost and reliability performance
- Modeling the behavior of complex and dynamic loads
  - Unexpected load behavior can put a utility system at risk
  - Lack of load models can cause overly conservative requirements from utilities for interconnection
- Coordination between utilities and data center to facilitate interconnections addressing technology solutions and performance requirements.





Address-Level Process to Estimate Load Impact of Medium & Heavy-Duty Vehicles and Study Results

Finding Facilities & Vehicle Counts → *Answer's Where*

- Data Analytics
  - Public Data (DMV)
  - Purchase Data for added fidelity

Categorizing Facilities & Adoption Curves → *Estimates When*

- Facility Type
  - Vehicle Class & Type
  - Charging Window
- Adoption Curves
  - Regulations
  - Facility & Vehicle Type

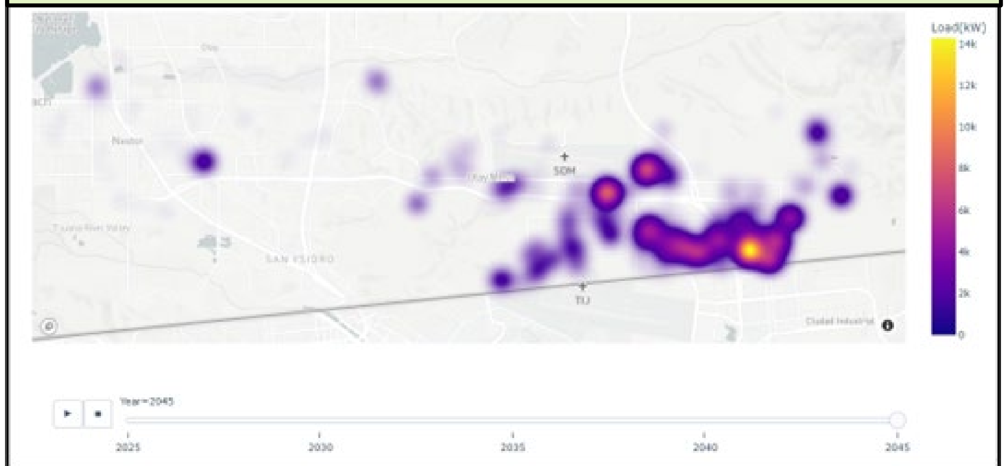
Creating Facility Load Shapes → *Determines How Big!*

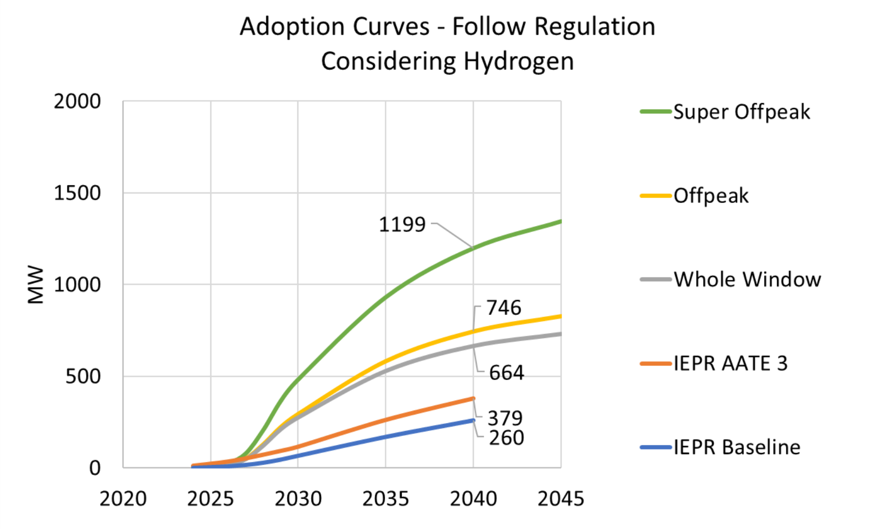
- Estimate Charging Needs
  - Miles per day
  - Miles/kWh
- Create Load Profiles
  - Scenario Analysis
  - Create 8760 profile
  - Fit into required format

Map Facility Locations to Substations

- Loads profiles are aggregated for Regions
- Geocoded data links to feeders and substations

Impact Heat Map - Importance of Granular Approach





Charging Load Scenarios

IEPR - California Integrated Energy Policy Report Scenarios

- **Baseline**
- **Achievable Transportation Electrification (AATE) Regulation**

Source: Quanta Technology

Grid-Enhancing Technologies (GETs)

Category	Advanced Grid Solutions
Advanced Transmission Technologies	Advanced Conductors Point-to-point High Voltage Direct Current (HVDC)
Situational Awareness and System Automation Solutions	Advanced Distribution Management Systems (ADMS) and ADMS applications Distributed Energy Resource Management System (DERMS) Advanced Fault Location, Isolation, Service Restoration (FLISR) Volt/VAR Optimization (VVO) Smart Reclosers Power Factor Corrections Substation Automation & Digitization Advanced Sensors
Grid-Enhancing Technologies and Applications	Dynamic Line Rating (DLR) Advanced Power Flow Control (APFC) Topology Optimization Virtual Power Plants (VPPs)[1] Energy Storage (as a T&D asset)[2] Advanced Flexible Transformers
Foundational Systems	Communications Technologies Data Management Systems System Digitization and Visualization Alternate Timing and Synchronization

Dynamic Line Ratings (DLRs)

Advanced Power Flow Control (APFC)

Topology Optimization (TO)

Advanced Conductors

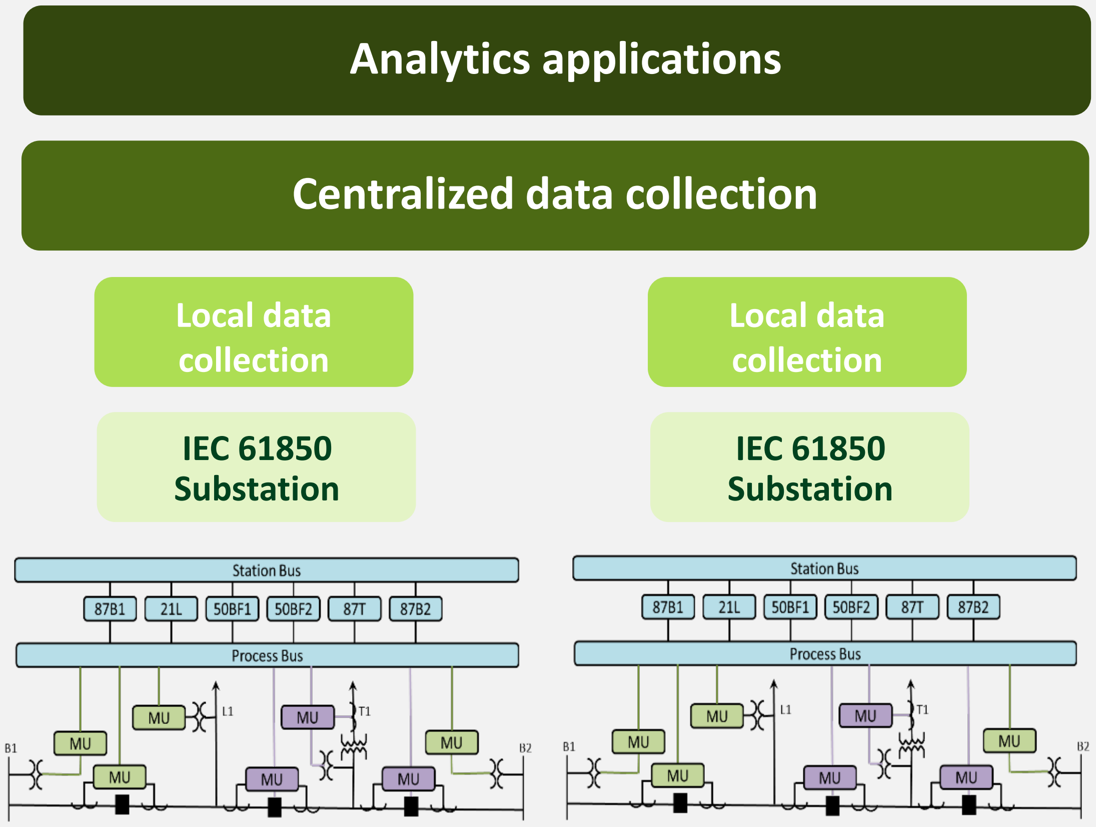
HW & SW solutions to enhance and optimize the throughput, efficiency, and reliability

- Enable grid operators to address congestion, improve power flow, and integrate higher levels of renewable energy while optimizing large-scale infrastructure investments.
- Not a one-size-fits-all solution:
  - Different technology values for operations and planning.
  - Carefully select the appropriate use cases where these technologies can have the most impact.

Digital Substation and Distributed Sensors Offer New Options for an Evolving Grid

Inputs:

- IEDs (e.g., digital relays, digital reclosers, capacitor bank controllers)
- IEC 61850 network data
- Synchronized measurements
- PQ meters
- Field sensors (e.g., FCIs, line sensors)
- Smart meters and AMI headend systems
- SCADA, GIS, and Lightning data
- LIDAR/satellite imagery
- System model
- Protection settings



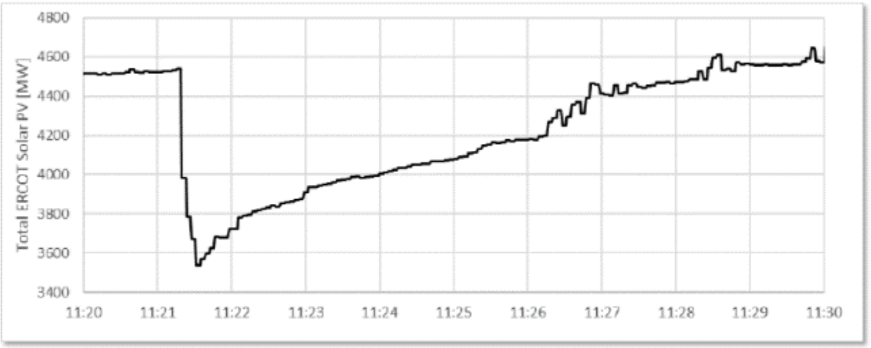
Outputs:

- Event analysis
- Fault location
- Grid situational awareness and modeling (T&D)
- Model and Settings validation
- 61850 network monitoring
- Compliance
- Asset monitoring, predictive maintenance
- Dynamic ratings
- Reliability and resilience indices and metrics

The Changing Landscape: Operational Challenges of High Penetration of IBRs and Data Center Growth

Intermittency:
- Short period – short-term (e.g., five minutes) forecast
- Long period – solutions are still work-in-progress

Unexpected tripping:
- Avoid unnecessary tripping (e.g., time delays, measurement accuracy)
- Capture events for analysis and mitigation
- Importance of modeling and testing



ERCOT
Solar resource loss
May 9, 2021

Lower and variable inertia:
- Declining participation of large rotating machines, and major variation of machine/IBR ratio over the day
- Need to understand impact of inertia – no need for "synthetic" inertia

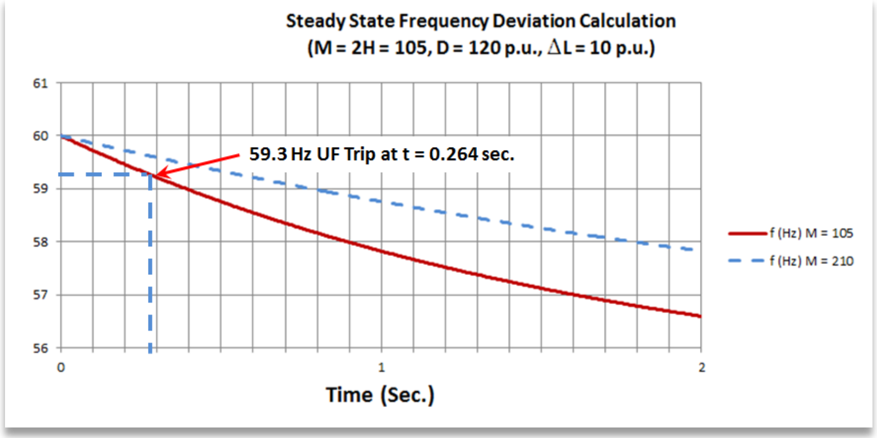
Relay miss-operations:
- Adjusting system protection designs to reliably handle faults
- Need for adaptive protection

Inaccurate system models:
- Overly conservative → Asset underutilization
- Inadequate margins → Increased system failure risk
- Inability to analyze events or respond effectively

Technology Solutions for Grid Modernization

Inverter-based resources (IBRs)
➔ Less inertia ➔ Things happen faster!

Frequency decay for losses of 1,000 MW



Source: *IEEE/NERC report on Impact of Inverter Based Generation on Bulk Power System Dynamics and Short-Circuit Performance*

Frequency excursions:
Rate-of-change of frequency proportional to inertia

$$\Delta P = -k_{in}\frac{df}{dt}$$

Enabling the electric grid to integrate new resources (renewables and storage) and loads (data centers and EVs) while improving the utilization of existing assets

Faster monitoring and controls of renewables and energy storage addresses dynamic changes with IBRs and improving situational awareness for the safe, secure, and reliable operation of modern grids.

Sensors and tools for situational awareness & condition assessment:

- Equipment monitoring (transformers, switchgear, etc.)
- Synchronized measurements
- PQ and GIC monitors
- Drones
- Etc.

Analysis tools and models (i.e., dynamic security assessment; EMT; weather forecasting; electric, gas, and communication interdependencies).

Integrated T&D power flow and market models to handle widespread integration of renewables and energy storage.

Microgrids to address resilience and decarbonization.

Adaptive protection for low fault currents and dynamic system changes.

Communications infrastructure with the necessary speed and latency.

Solutions for the Energy Future

A resilient, modern electric grid is the foundation for our clean energy future, requiring renewables, energy storage, energy efficiency, and electrification.

Electricity is key for achieving societal and economic goals, such as decarbonization and growth:

- Demand for electricity increases electrification and fuel transformation
- Need for clear and balanced societal and regulatory policies

Essential factors for a resilient grid to protect against and recover from any event that would significantly impact the grid:

- Technology advancement
- Educated and diverse workforce
- Standards and sharing global best practices

Coordinated resource and T&D planning and operations for investment prioritization:

- Load, DER, and electrification forecasting
- Accurate system and equipment modeling
- Scenario planning
- Risk- and probabilistic-based investment decisions

Importance of diverse generation mix for uncertainties

Coordinated resource &and T&D planning and operations – tools and processes

Digital transformation through automation - single data source

Automated and adaptive monitoring, protection, and control

Long-term storage

Synthetic gas

Small modular reactors

Hydrogen

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