Sustainable Solutions for Industrial Energy Management

Integrating Microgrid Controllers with Local Utilities: Evolutions in IEEE Standards and BESS Integration Challenges

Presenter: Dr. Xinsheng Lou, ISA Fellow

IEEE GREEN ENERGY CONFERENCE (Virtual)

Date: March 22, 2024

Agenda

- Microgrid Controller
- IEEE 1547 and IEEE 2030
- NERC Standards
- BESS Integration and Challenges
- MG Controls – Resilience with DBs
- Q&A

Microgrid Controller

Definition

- Microgrid controllers are sophisticated systems designed to manage and control microgrids
- They are localized groups of electricity sources and loads that can operate independently from the traditional, centralized electrical grid or in parallel with it.

Here's an illustration showing a simple microgrid layout. this image includes a central control unit connected to various distributed energy resources such as solar panels, a wind turbine, and a small-scale battery storage system. (picture created by GPT 4.0)

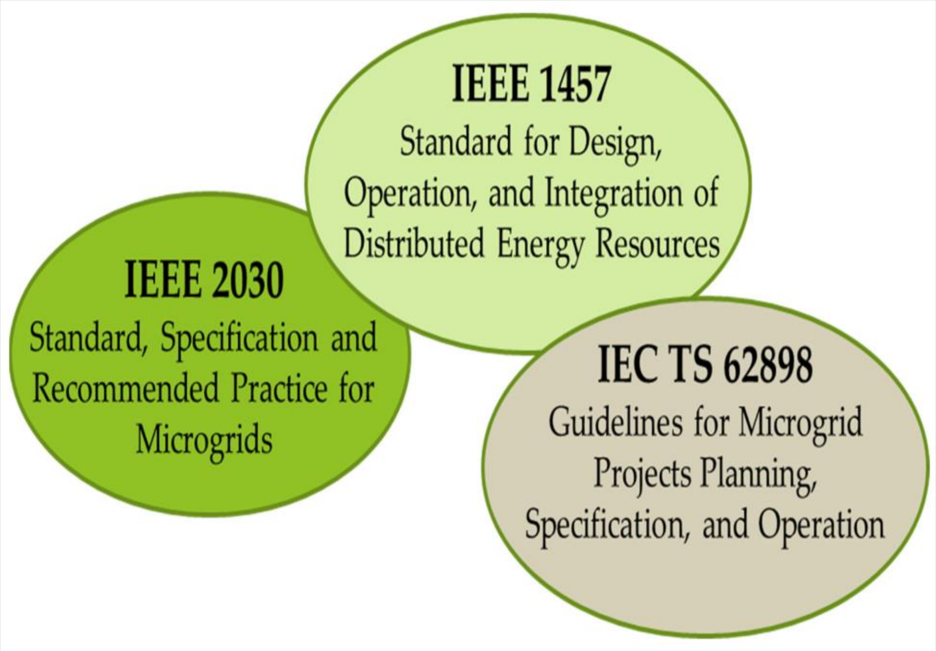
Microgrid Controller
Crucial Roles

- **Managing Energy Resources:** They efficiently manage the energy production from various sources within the microgrid, such as solar panels, wind turbines, and conventional generators, ensuring that the energy supply meets the demand.
- **Ensuring Reliability and Stability:** Microgrid controllers maintain the stability of the microgrid by managing voltage and frequency, ensuring a reliable supply of electricity, especially important during grid disturbances or outages.
- **Optimizing Performance:** They optimize the performance of the microgrid by minimizing energy costs, reducing emissions, and maximizing the use of renewable energy sources.
- **Automating Operations:** Through automation, these controllers can instantly respond to changes in energy demand or supply, perform grid reconfigurations, and manage energy storage systems.

IEEE Standards
IEEE 1547 and IEEE 2030

The **IEEE 1547** and **IEEE 2030** standards are critical for the integration of distributed resources with the electric power system, focusing on interconnection and interoperability of distributed energy resources (DERs) with the electrical grid.

- **IEEE 1547** provides the standard for the interconnection and interoperability of DERs with electrical power systems and their associated interfaces. Recent updates to this standard have focused on enhancing the grid-support functionalities that DERs can provide, such as voltage regulation, frequency stability, and the ability to support the grid during disturbances.
- **IEEE 2030** provides a guide for smart grid interoperability of energy technology and information technology operation with the electric power system (EPS), end-use applications, and loads. It outlines the architectural framework for developing, analyzing, and implementing smart grid functionalities and interoperability.



Source: https://pub.mdpi-res.com/energies/energies-16-02893/article_deploy/html/images/energies-16-02893-g001.png?1679448903

Microgrid Applications and Technical Challenges—The Brazilian Status of Connection Standards and Operational Procedures: https://www.mdpi.com/1996-1073/16/6/2893

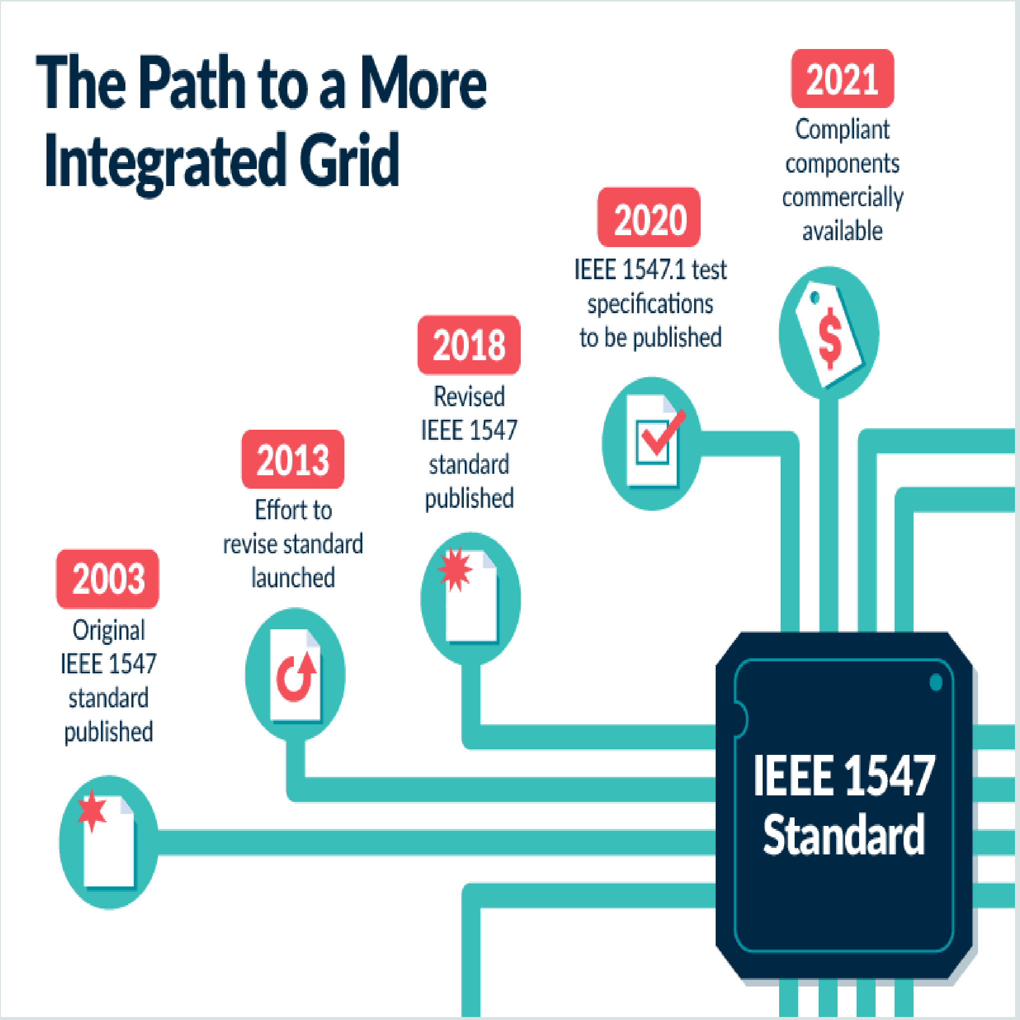
IEEE Standards

Evolution of IEEE 1547

Established to standardize the interconnection and interoperability of distributed energy resources (DERs) with electric power systems.

- **Timeline:**
  - **2003:** Initial release of IEEE 1547, setting the foundation for DER integration into the electric grid.
  - **2014:** Amendment 1 added, introducing modifications to accommodate evolving grid capabilities and DER technologies.
  - **2018:** A significant revision, IEEE 1547-2018, was released to address advancements in technology and grid management needs.
  - **2021:** Compliant components commercially available

- **Key Milestones:**
  - First to provide a uniform set of technical criteria for DERs.
  - Emphasis on safety, reliability, and quality of service.
  - Evolving with technological advancements and grid modernization efforts.

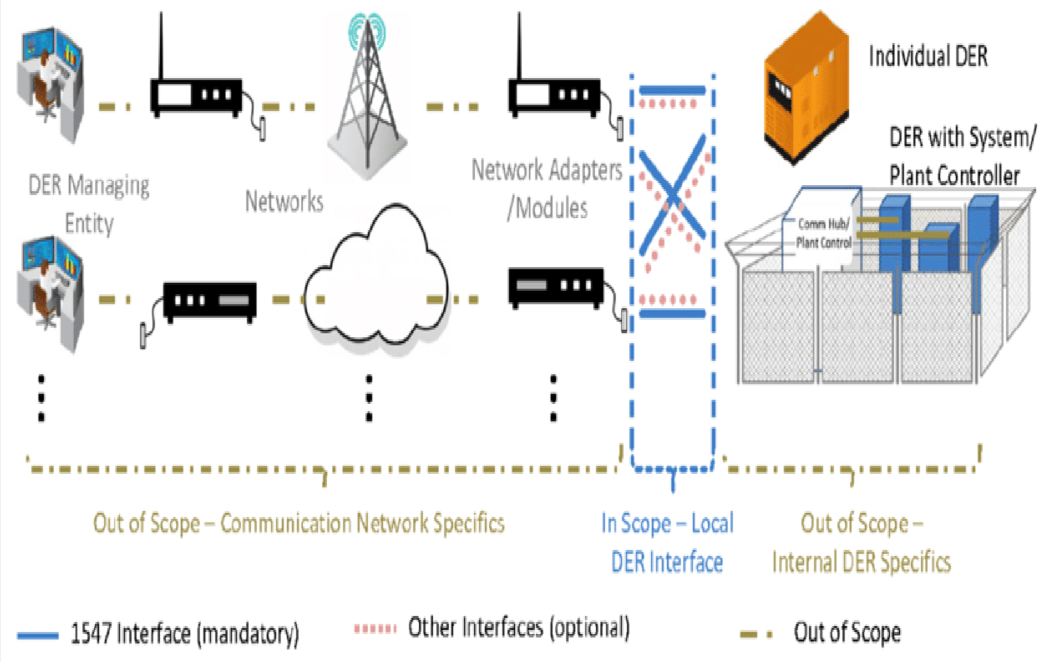


Source: https://eprijournal.com/wp-content/uploads/2019/04/integrated-grid-timeline-v6-corrected.png

IEEE Standards

Scope of IEEE 1547

- **Objective:** To provide technical standards for the connection, operation, and interoperability of DERs with electric power systems.
- **Coverage:**
  - **Technical Specifications:** Voltage, frequency, power quality, and islanding.
  - **Testing and Certification:** Procedures for DER systems to ensure compliance.
  - **System Design:** Guidelines for the physical and logical integration of DERs.
- **Applies To:**
  - Solar photovoltaic systems, wind turbines, battery storage, and other DER technologies.
  - Utilities, DER developers, and regulatory bodies involved in DER integration.



Source: https://www.researchgate.net/publication/340716687/figure/fig9/AS:881346239016962@1587140726210/IEEE-1547-Standard-Scope-IEEE-2018a.png

IEEE Standards

IEEE 1547: Challenges and Future Trend

- **Current Challenges:**
  - **Cybersecurity:** Ensuring secure communication and control mechanisms for DERs.
  - **Regulatory Compliance:** Aligning state and federal regulations with the updated standards.
  - **Technical Integration:** Managing the complexity of integrating a growing number of DERs without compromising grid reliability.
- **Future Directions:**
  - Ongoing updates to address emerging technologies and grid modernization needs.
  - Enhancing resilience against natural disasters and cyber-attacks.
  - Fostering collaboration among stakeholders to facilitate smooth integration of DERs.

Source: https://www.nrel.gov/news/program/2020/images/ieee-1547-hp.jpg

IEEE Standards

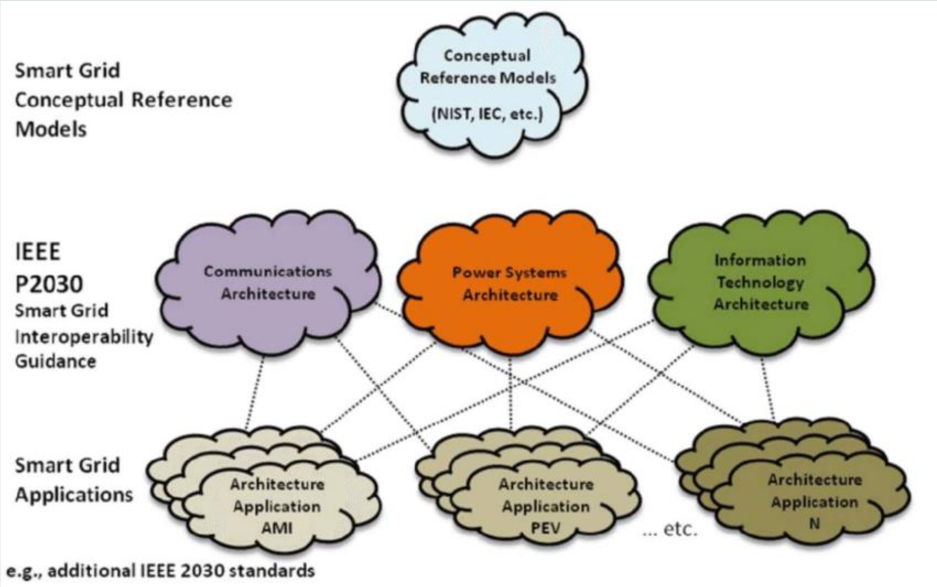
Evolution of IEEE 2030

- **Introduction:** Developed to guide the interoperability **of "Smart Grid"** - energy technology and information technology in operation with the electric power system (EPS), end-use applications, and loads.
- **Timeline:**
  - **2011:** The initial IEEE 2030 standard is introduced, aiming to facilitate the integration of energy and information technology with the electric power system.
  - **Subsequent Updates:** Reflecting the rapid advancement in **Smart Grid** technology, including communication protocols and integration frameworks.
- **Key Milestones:**
  - Established a framework for **Smart grid** interoperability.
  - Addressed the integration of renewable and distributed resources, electric vehicles, and smart appliances.
  - Promoted the development of smart grid technologies that enhance grid reliability, efficiency, and sustainability.

IEEE Standards

Scope of IEEE 2030

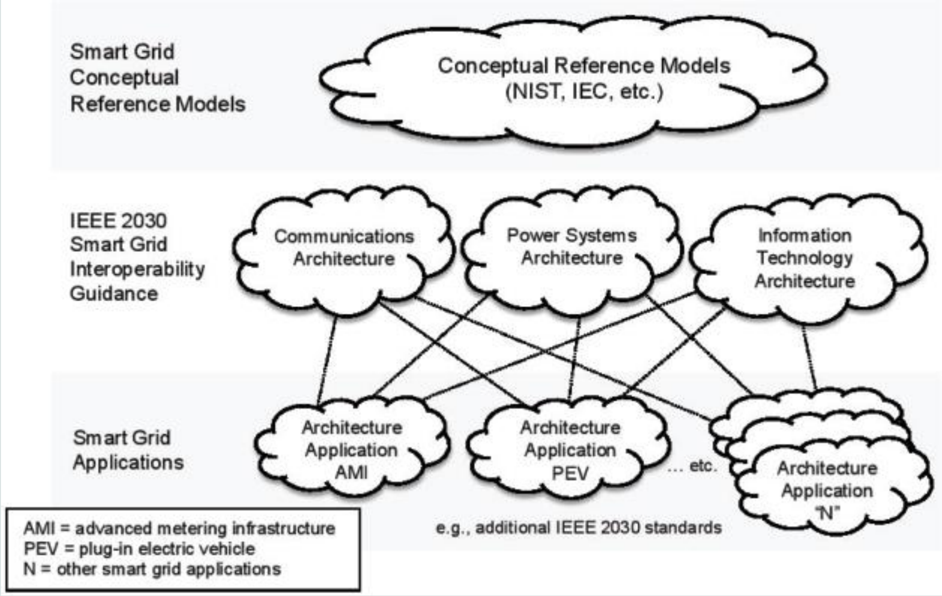
- **Objective:** To provide a common framework for the design, operation, and integration of <u>**Smart Grid**</u> technologies.
- **Coverage:**
  - **Interoperability Standards:** Guidelines for seamless integration and communication between diverse systems and technologies in the smart grid.
  - **Architectural Framework:** Design principles for building scalable, flexible, and secure smart grid networks.
  - **Integration of Renewable Energy:** Facilitating the connection of solar, wind, and other renewable energy sources to the grid.
- **Applies To:**
  - Utilities, energy service providers, and technology developers.
  - Regulatory bodies and policy makers involved in smart grid deployment.
  - End-users and consumers benefiting from enhanced grid capabilities.



Source: https://www.researchgate.net/publication/262302425/figure/fig2/AS:399681147424770@1472302819806/Evolution-and-scope-of-IEEE-2030-standardization-process-14.png

IEEE Standards
IEEE 2030: Challenges and Future Trends

- **Current Challenges:**
  - **Technology Integration:** Ensuring compatibility and interoperability among an increasingly diverse set of technologies and grid participants.
  - **Regulatory and Policy Alignment:** Updating regulations and policies to keep pace with technological advancements and standard updates.
  - **Resilience and Reliability:** Enhancing the grid's resilience to withstand and recover from natural disasters, cyber-attacks, and other disruptions.
- **Future Directions:**
  - Continuous evolution of the standard to address the dynamic nature of smart grid technologies and the global energy landscape.
  - Fostering innovation and collaboration among stakeholders to overcome integration challenges and realize the full potential of smart grids.



Source: https://www.researchgate.net/publication/254994410/figure/fig3/AS:669255246835716@1536574293206/Evolution-of-smart-grid-interoperability-Source-IEEE-Std-2030.png

IEEE Standards

IEEE 2030: Recent Updates

- **Cybersecurity Enhancements:**

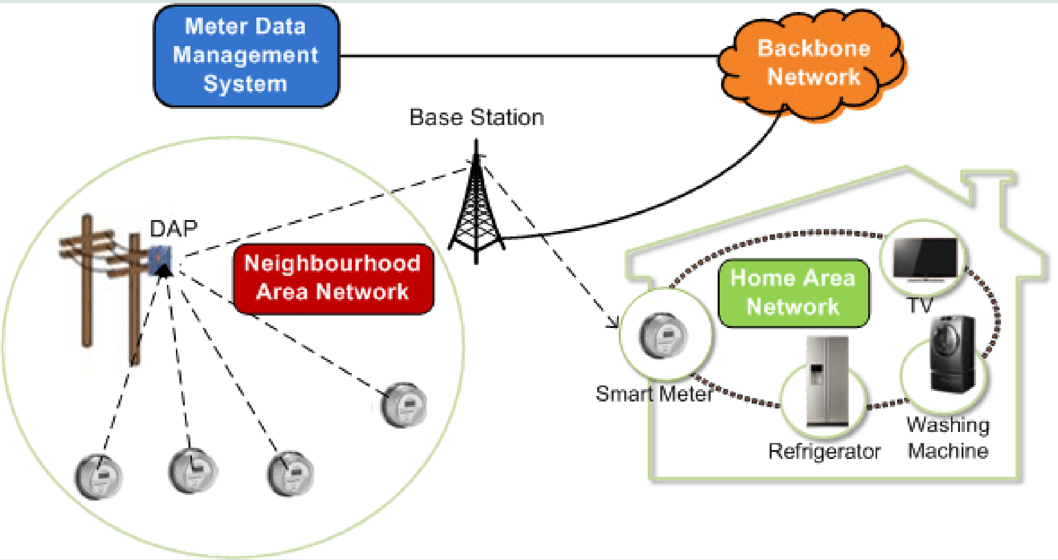
  Addressing the growing threats to grid security with robust protocols and standards.

- **Advanced Communication Technologies:**

  Incorporating new communication standards to support real-time data exchange and grid management.

- **Greater Emphasis on Sustainability:**

  Integrating more comprehensive guidelines for renewable energy and energy efficiency measures.



Source: https://www.researchgate.net/publication/259911781/figure/fig3/AS:667663059669001@1536194686509/Modes-of-connectivity-within-an-AMI-system-according-to-the-IEEE-2030-standard-for-smart.ppm

IEEE Standards

Practical Considerations for Microgrid Control Design

- **Harmonizing Technical and Operational Requirements:** Use IEEE 1547 to ensure that all DERs meet the necessary technical requirements for safe grid interconnection. Concurrently, apply IEEE 2030 guidelines to design the communication and control architecture of the microgrid, ensuring that operational data can be effectively managed and utilized for real-time control and decision-making.

- **Designing for Flexibility and Scalability:** Consider the scalability of the microgrid control system to accommodate future expansions or modifications. IEEE 2030's focus on interoperability and information technology can guide the selection of modular and flexible control systems that can adapt to changing needs and technologies.

- **Ensuring Cybersecurity and Resilience:** Given the emphasis on communication and data exchange in IEEE 2030, cybersecurity becomes a critical consideration in microgrid control design. Implementing robust security measures to protect the control systems and data is essential for maintaining the reliability and integrity of the microgrid.

- **Compliance and Testing:** Both standards emphasize the importance of testing and certification to ensure compliance. Design the microgrid control system with these requirements in mind, planning for necessary testing and certification processes to validate that the microgrid meets all relevant standards and regulations.

Other Standards: NERC

NERC Standards for Microgrid Integration

Overview:

- NERC standards ensure the **reliability and security** of the North American bulk power system. While primarily focused on the bulk power system, certain NERC standards indirectly support the objectives of IEEE 2030 and IEEE 1547, particularly in the domains of cybersecurity, protection and control, and system modeling. These intersections enhance the integration and operation of **microgrids and distributed energy resources (DERs) within the broader grid framework**.

NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Coordination for Grid Reliability and Security:

- Effective integration of **microgrids and DERs** requires adherence to both **NERC** and IEEE standards to ensure that these resources do not compromise the reliability and security of the broader power system.
- Compliance with NERC standards complements the technical and operational guidelines provided by IEEE standards, offering a comprehensive approach to secure and reliable grid integration.

Other Standards: NERC

NERC Standards and Intersection with IEEE 2030 & IEEE 1547 for Microgrid

NERC Key Points:

- **Critical Infrastructure Protection (CIP) standards**:

  Standards such as CIP-002 to CIP-014, provide a cybersecurity framework that can guide secure communication and control practices for microgrid controllers and DERs, complementing IEEE 2030's emphasis on interoperability and IEEE 1547's focus on safe DER integration.

- **Protection and Relay Standards (PRC)**:

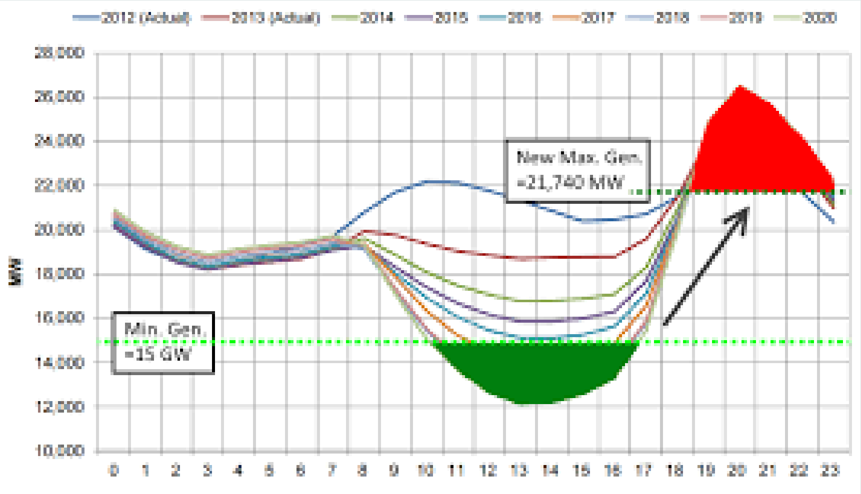
  Standards like PRC-005, underscore the importance of protective relays and systems maintenance, which is crucial for the reliable operation of microgrids and DERs, aligning with IEEE 1547's safety and reliability requirements.

- **Modeling, Data, and Analysis (MOD) standards**:

  They support accurate system planning and operation, ensuring that the integration of microgrids and DERs into the grid is reflected in system models, resonating with IEEE 2030's goal of seamless energy technology integration.

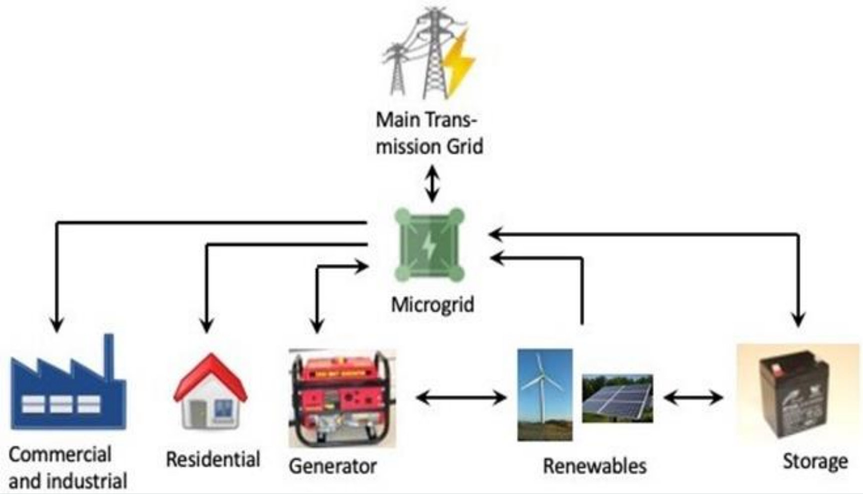
Growing Importance of BESS in Renewable Energy

Increasing need for flexibility



Power System Flexibility:

- Increasing reliance on wind and solar energy in power systems
- Growing Challenges of instability and unpredictability in grid operations
- BESS as a solution for consistent energy supply

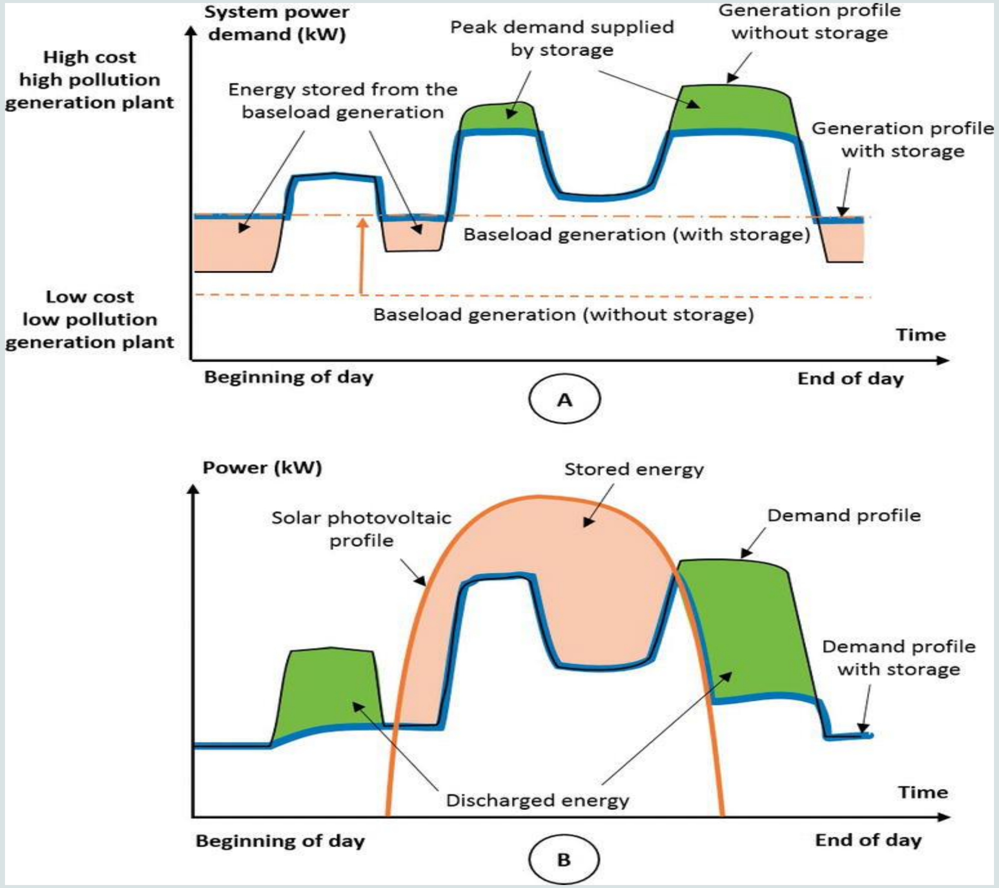


Growing Importance of BESS in Renewable Energy

Optimizing Energy for Demand and Cost

Addressing the Challenges:

- Balancing supply with increasing demand for grid operating flexibility
- Reducing operational costs using energy management system (EMS)
- Achieving optimal storage capacity and Operating & Maintenance (O&M) costs



Impact of Energy Storage on Economics

Other Standards: UL and IEC

BESS Integration with Microgrids

For the integration of Battery Energy Storage Systems (BESS) into microgrids (MGs), please also refer to the following technical standards (UL and IEC):

- **UL 9540 and UL 9540A:** These are not IEEE standards but are relevant for BESS integration into microgrids. UL 9540 covers the **safety** of energy storage systems and equipment, while UL 9540A provides a test method for evaluating the **thermal runaway fire propagation** in battery energy storage systems, ensuring that BESS integrated into microgrids meet safety requirements.

- **IEC Standards:** International Electrotechnical Commission (IEC) standards, such as **IEC 62485** (**Safety** requirements for secondary batteries and battery installations) and **IEC 62933** (Electrical energy storage (EES) systems), also provide comprehensive guidelines relevant to BESS integration in microgrids, focusing on **safety, performance, and interoperability** aspects.

These standards collectively cover various aspects of BESS integration into microgrids, from safety and performance to interoperability and control functions. It's essential for engineers and designers to consult these standards when planning and implementing BESS solutions within microgrid projects to ensure compatibility, safety, and optimal performance.

BESS Integration with Microgrids

Relevant Items in IEEE 1547 and IEEE 2030

For the integration of Battery Energy Storage Systems (BESS) into microgrids (MGs), IEEE 1547 and IEEE 2030 provide general guidance applicable to various DERs, including BESS as well as other technical standards (UL and IEC):

- **IEEE 2030.2:** This standard is specifically designed to guide the interoperability of **energy storage** systems integrated with the electric power infrastructure, covering aspects of BESS such as integration, operation, and communication within microgrids and the broader grid. It provides a framework for energy storage systems to ensure they can effectively participate in electric power systems and services.
- **IEEE 2030.7:** Focused on the standard for the specification, design, and operation of a microgrid's control functions, this standard addresses how various components of a microgrid, potentially **including BESS**, are controlled and managed to ensure stable and efficient operation.
- **IEEE 2030.8:** This standard provides guidelines for the design and operation of microgrids, including how to integrate and **manage BESS** within microgrid architectures. It touches upon the essential roles that BESS plays in terms of energy management, stability, and reliability of microgrids.
- **IEEE P2800:** Although not exclusively focused on microgrids, IEEE P2800, a standard for interconnection and interoperability of **inverter-based resources** with associated transmission electric power systems, is relevant for BESS integration as it addresses technical requirements for **large-scale battery storage systems** connected to the transmission grid, which can have implications for microgrid designs, especially regarding stability and control strategies.

Microgrid Controls

Resilience in Microgrid (MG) Operations

Resilience in microgrid operations refers to the ability of the microgrid to prepare for, withstand, recover from, and adapt to adverse conditions, disturbances, or attacks. This includes natural disasters (such as hurricanes, earthquakes, and floods), human-made events (such as cyber-attacks and physical sabotage), and technical failures within the grid infrastructure. Key aspects of resilience in microgrids include:

- **Robustness:** The strength or ability of the microgrid to absorb shocks without significant degradation or loss of functionality.
- **Redundancy:** Having multiple pathways or backup systems that can take over in case of a failure, ensuring that essential services and functions can continue.
- **Resourcefulness:** The capacity to manage and mobilize resources effectively in response to disturbances or emergencies.
- **Rapid Recovery:** The ability to return to normal operations quickly after a disruption, minimizing downtime and its associated impacts.
- **Adaptability:** The capability to learn from past events and adapt operational practices to prevent future failures or to mitigate their effects.

Resilience in microgrids is achieved through a combination of system design, operational practices, and technologies such as distributed energy resources (DERs), advanced control systems, and automated switchgear, which can isolate faults and maintain power supply to critical loads.

Microgrid Controls
Dynamic Boundaries

The concept of a **dynamic boundary** in microgrid operations refers to the ability of the microgrid to adjust its operational boundaries in real-time based on various factors, including load demand, availability of distributed generation, grid conditions, and economic considerations. This flexibility allows the microgrid to optimize its performance and resilience by dynamically selecting which loads and generation sources are included within its operational scope at any given time. The Key features include:

- **Scalability:** The microgrid can scale its operations up or down by including or excluding certain DERs or loads based on current needs and conditions.
- **Flexibility:** Operational flexibility allows the microgrid to respond to changes in the external grid conditions, such as grid outages or fluctuations in electricity prices, by altering its boundaries.
- **Islanded and Grid-connected Modes:** A dynamic boundary enables the microgrid to seamlessly transition between being islanded from and connected to the main grid, enhancing its ability to maintain reliable power supply.
- **Optimization:** By adjusting its operational boundaries, the microgrid can optimize for energy efficiency, cost, reliability, and resilience, taking into account real-time data and forecasts.

Dynamic boundaries represent an **advanced concept in microgrid** design and operation, enabling more responsive, efficient, and resilient energy systems that can adapt to changing conditions and integrate seamlessly with the broader electrical grid.

Methods in Dynamic Boundaries

TECHNICAL ITEMS IN DYNAMIC BOUNDARIES:

- **Real-Time Data Analytics Platforms:** For processing and analyzing data from various sources within the microgrid.
- **Automated Control Systems:** Including PLCs and RTUs for real-time operational adjustments.
- **Distributed Energy Resource (DER) Controllers:** To manage the operation of renewable energy sources, batteries, and other DERs.
- **Energy Storage Systems:** Advanced battery management systems for optimizing storage use.
- **Communication Networks:** Secure and robust communication technologies for grid coordination and control.
- **Smart Sensors and IoT Devices:** For detailed monitoring of grid conditions and resource utilization.
- **Software Tools for Optimization:** Including MIP and machine learning models for predictive control and optimization.

Illia M. Diahovchenko, “Enabling resiliency using microgrids with dynamic boundaries ”, Electric Power Systems Research 221 (2023) 109460

Methods in Dynamic Boundaries

ENHANCING PDS RESILIENCY WITH DYNAMIC BOUNDARY:

- **Introduction to Dynamic Microgrids:** Brief overview of how dynamic microgrids differ from traditional microgrids in terms of boundary flexibility.
- **MILP Approach:** Outline the mathematical foundation of the **MILP** model used for optimizing microgrid configurations. Include a simplified version of the key equation that defines the optimization problem.
- **Switching Actions for Resilience:** Describe the algorithm for selecting optimal switching actions. A flowchart or process diagram illustrating steps from disturbance detection to microgrid reconfiguration would be helpful.

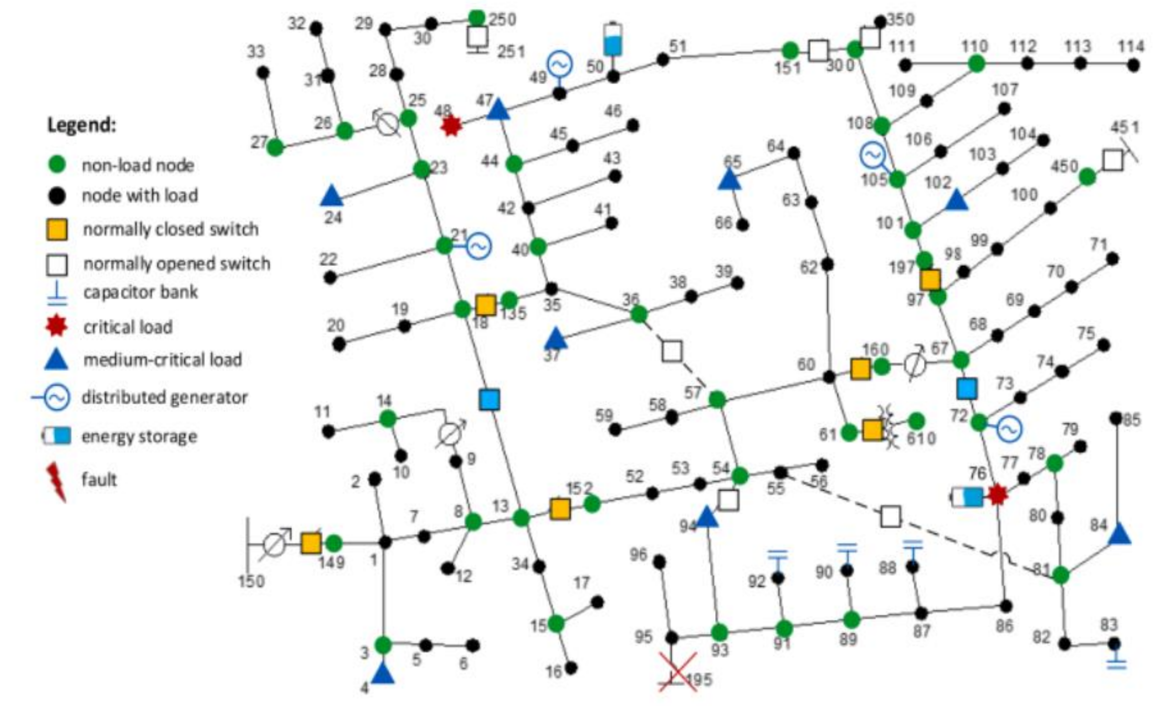
- **MILP:** Mixed Integer Linear Programming

Illia M. Diahovchenko, “Enabling resiliency using microgrids with dynamic boundaries ”, Electric Power Systems Research 221 (2023) 109460

Results in Dynamic Boundaries

KEY RESULTS AND IMPLICATIONS:

- Application of the methodology on the modified **IEEE 123 bus system** to demonstrate effectiveness.
- Comparison of network resilience between traditional fixed-boundary microgrids and proposed dynamic-boundary microgrids.
- Significant improvement in network resiliency and critical load support with dynamic boundaries.



One-line diagram of the modified IEEE 123 node test feeder.

The IEEE 123:

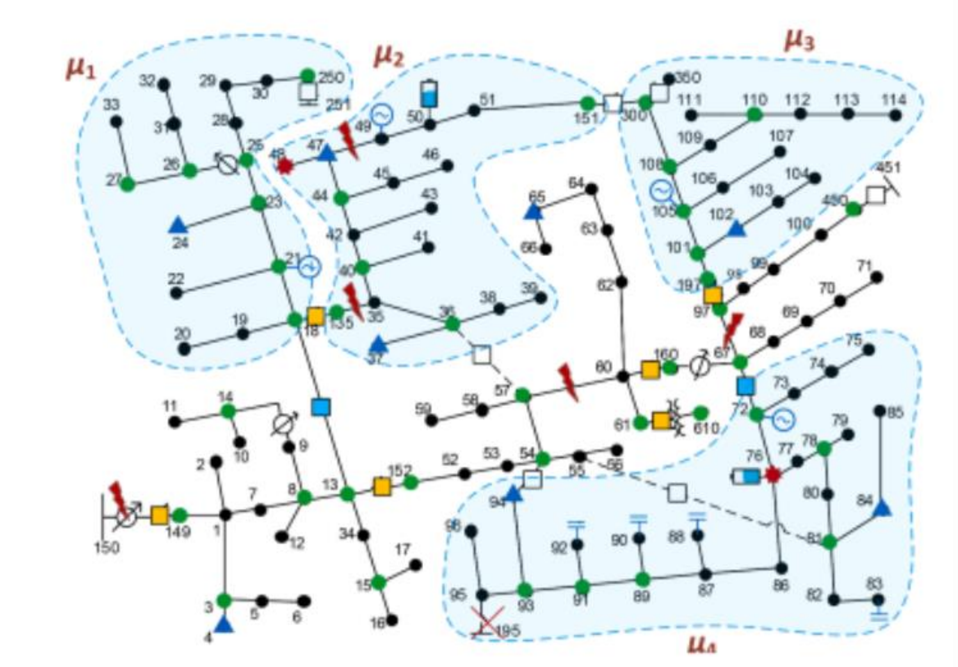
Node Test Feeder represents a typical American small town's distribution system which is used widely in power systems research to test and validate algorithms or models related to electrical distribution systems. It provides a standard and complex enough model that includes residential, commercial, and industrial loads distributed over a network, making it a valuable tool for studying the impact of various technologies like distributed generation, microgrids, and dynamic boundary strategies on the distribution grid.

Illia M. Diahovchenko, “Enabling resiliency using microgrids with dynamic boundaries ”, Electric Power Systems Research 221 (2023) 109460

Results in Dynamic Boundaries

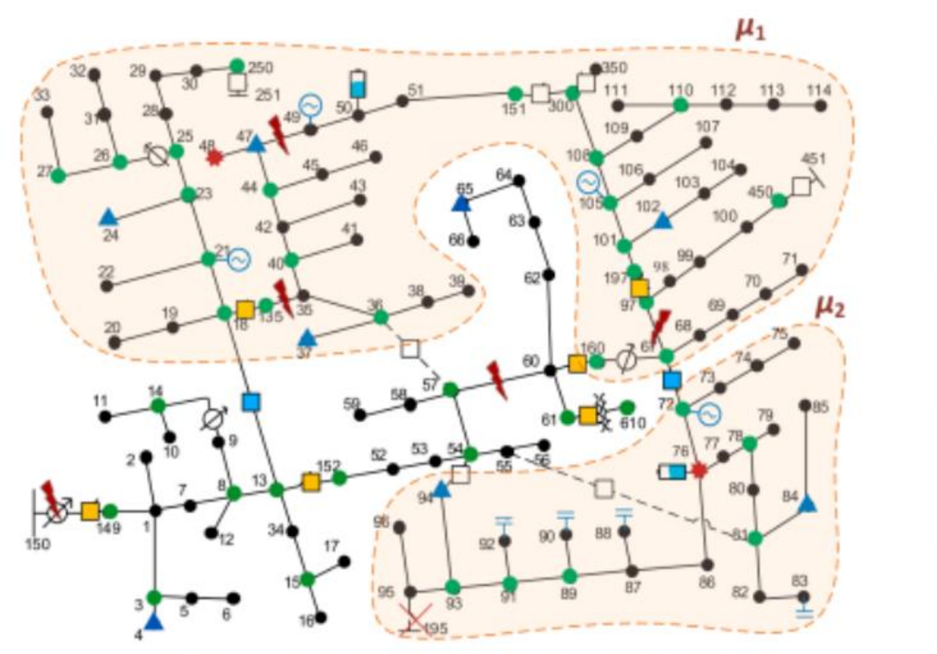
TOPOLOGY FOR PDS FOR DAILY OPERATIONS:

Daytime (4MGs)



The topology of the studied PDS for daytime operation (4 MGs).

Nighttime (2MGs)



4. The topology of the studied PDS for the nighttime operation (2 MGs).

The MGs with dynamic boundaries demonstrated self-healing capability to recover from faults during contingency scenarios, and all the CLs were saved.

Illia M. Diahovchenko, “Enabling resiliency using microgrids with dynamic boundaries ”, Electric Power Systems Research 221 (2023) 109460



Summary

- Microgrid controls will play an increasingly critical role in overall power grid system operations.
- IEEE 1547 series specifies the requirements and recommendations for connecting Distributed Energy Resources (DERs) to the power systems.
- IEEE 2030 series specifies the requirements and recommendations for smart grid connections with microgrids.
- IEEE, NERC, UL and IEC have specific standards on Microgrids and BESS integration.
- Dynamic Boundaries (DBs) management provides new approaches to microgrid resilience enhancement.

Q & A

Thank you!

PPT prepared by:

Dr. Xinsheng Lou

Consultant, Lous Tech and Services LLC

Director-e, ISA Power Industry Division

xinshenglou2016@gmail.com

https://www.linkedin.com/in/xinsheng-lou-57a9233/