FREEDM SYSTEMS CENTER

Distribution Inverter Based Microgrid System Impact Study

Kevin Chen, Duke Energy

2/20/2023

Duke Energy Overview

Our Company

One of the **LARGEST** energy holding companies in the U.S.

8.2 MILLION
Retail electric customers in **six** states

1.6 MILLION
Natural gas customers in **five** states

28k* **EMPLOYEES**

Headquarters: *Charlotte, N.C.*

We own and operate diverse power generation assets in North America, including a portfolio of **renewable wind, solar, energy storage, nuclear, hydro and microgrid projects.**

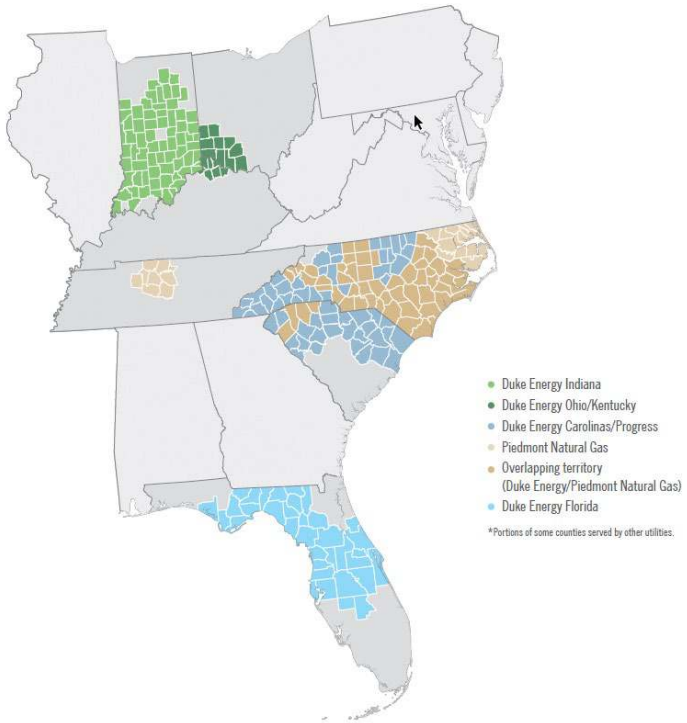
10,500 megawatts (MW) wind and solar owned, operated or contracted. With a goal of **24,000 MW** wind and solar by 2030.

$63 BILLION
CAPITAL PLAN**

82% ($52 billion) include investments in our generating fleet's transition to low- and zero-carbon resources and a modernized grid.

* 27,605 employees as of December 31, 2021.
** Investment over the next five years to accelerate the clean energy transition.

Utility Service Territories*



DUKE ENERGY®

Electric Utilities and Infrastructure

Generation Diversity (percent owned capacity)[1,2]

42% Natural Gas/Fuel Oil
32% Coal
18% Nuclear
8% Hydro and Renewable

Generated (net output gigawatt-hours (GWh))[2,3]

39% Natural Gas/Fuel Oil
37% Nuclear
22% Coal
2% Hydro and Renewable

Speaker Bio

Kevin Chen, PhD, PE
Manager, Renewable Engineering
DG Interconnection
Duke Energy
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- Kevin is currently the manager of DG Interconnection team in Customer Delivery Department at Duke Energy, Raleigh, NC. His team conducts system impact studies for DER projects ranging from 20kW to multi-megawatt scale, including PV, Battery Energy Storage System, Microgrid. Kevin also supports company's interconnection policy, technical requirements, and compliance for DER integration.

From Duke Energy
Neil Bhagat, Jaclyn Whiteman, Bryan Hoffman, Trent Miller contributed to the presentation materials.

Duke Energy BESS Investments

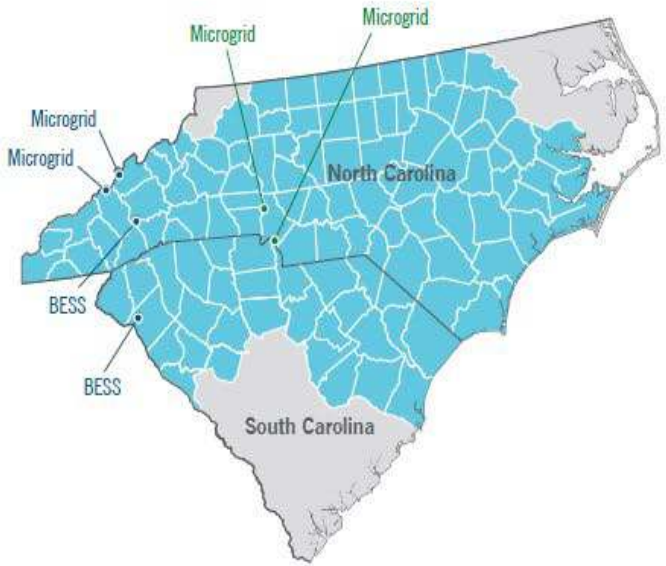
- In 2018, Duke Energy announced to invest $500 million in battery storage in the Carolinas over the next 15 years. (Link)
- In 2019, Duke Energy Florida committed to investing an estimated $1 billion to construct or acquire a total of 700 megawatts of cost-effective solar power facilities and 50 megawatts of battery storage through 2022. (Link)
- Distribution connected battery energy storage system (BESS) can form a microgrid (MG) improve overall reliability for surrounding communities during grid outage

BESS/MG Deployment

Regulated Battery Energy Storage Sites

DUKE ENERGY®

Carolinas

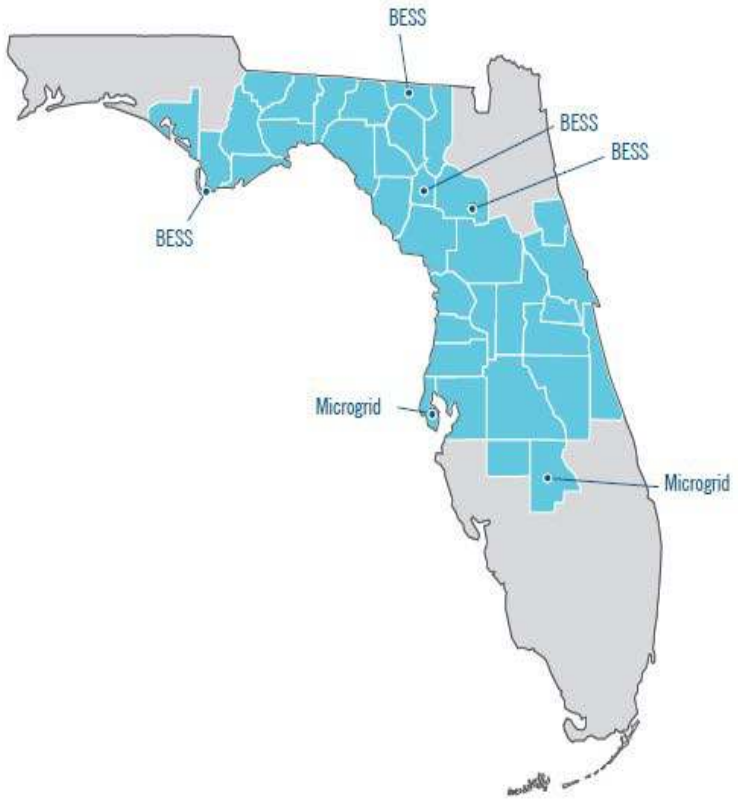


Duke Energy Service Territories

Legend: ● Regulated Battery Energy Storage Site
● Research and Demonstration Microgrid Site

Midwest

Florida



Successful Story

Site Specs:

- Power Capacity: 4.4MW
- Energy Capacity: 4.4 MWh
- PV Capacity: 2MWac

Use Cases:

- Islanding Reliability
- Frequency Response

Site Status:

- Energized: Dec 2021
- COD Parallel: July 2022
- COD Islanding: Jan 2023

Duke Energy Hot Springs Microgrid
Hot Springs, Madison County, North Carolina

News: *Duke Energy places advanced microgrid into service in Hot Springs, NC* (Link)

Energy Storage Project Process

Post Interconnection Request

Project Identification
- Business development
- Preliminary Design
- Cost Benefit Analysis
- Distribution Planning

Cluster Study
- Power Flow
- Stability
- Facility study
- Interconnection Agreement

Islanding Study
- Software Modeling
- Black Start
- Transient Analysis

Deployment
- Detailed Design
- Procurement
- Construction
- Commissioning

Operations
- Control
- Maintenance

File Interconnection Request

Microgrid System Impact Study

Regular DER grid-parallel studies

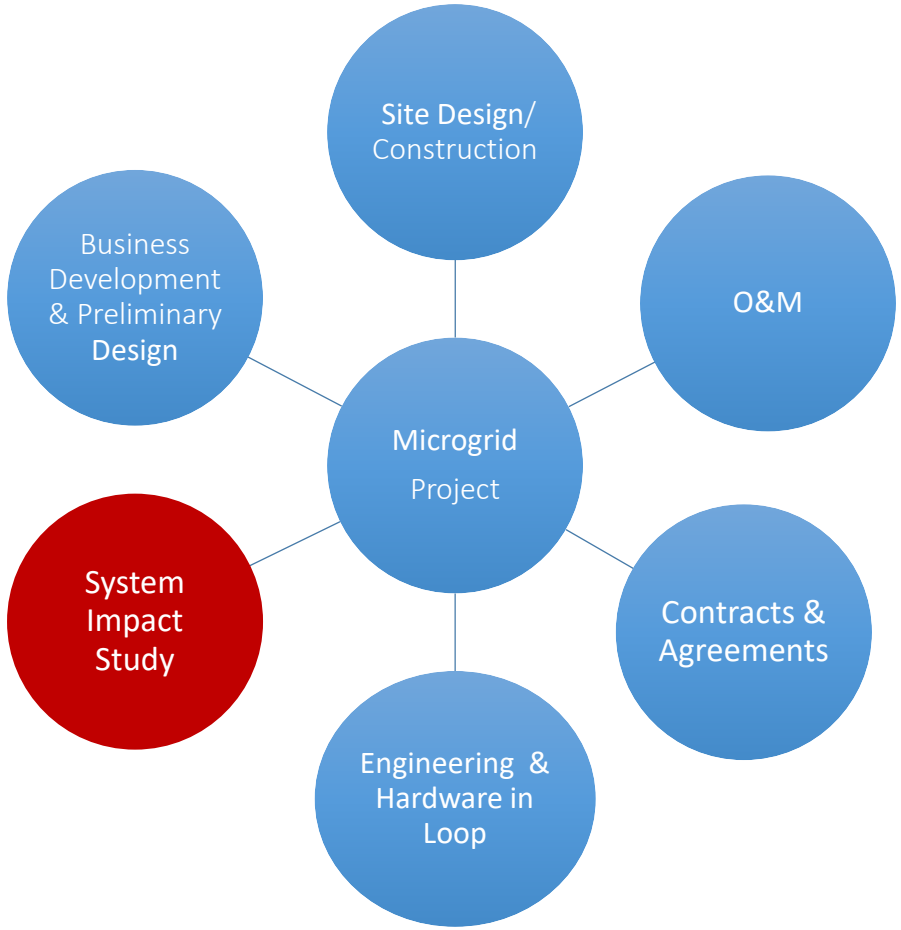
- Established practice (for PV)

BESS grid-connected studies

- Required for BESS projects

MG islanding studies

- Unique for microgrid



Microgrid Technical Standard Committee (MGTSC)

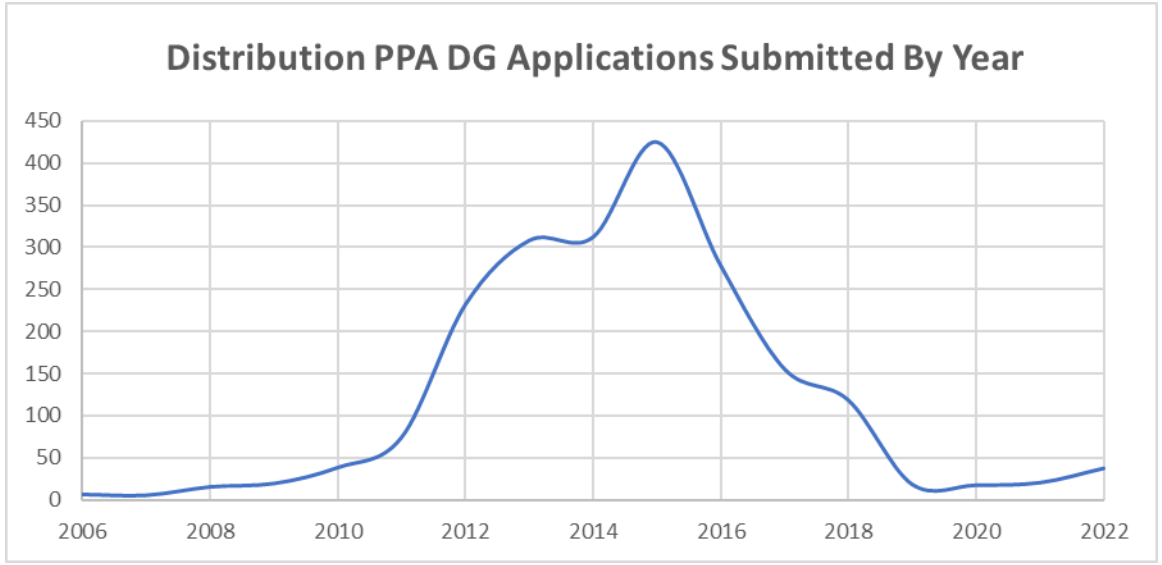
- Distribution Planning
- Distribution Standards
- DER Technical Standards
- Policy Requirements
- Power Quality
- Protection and Automation
- DG Interconnections

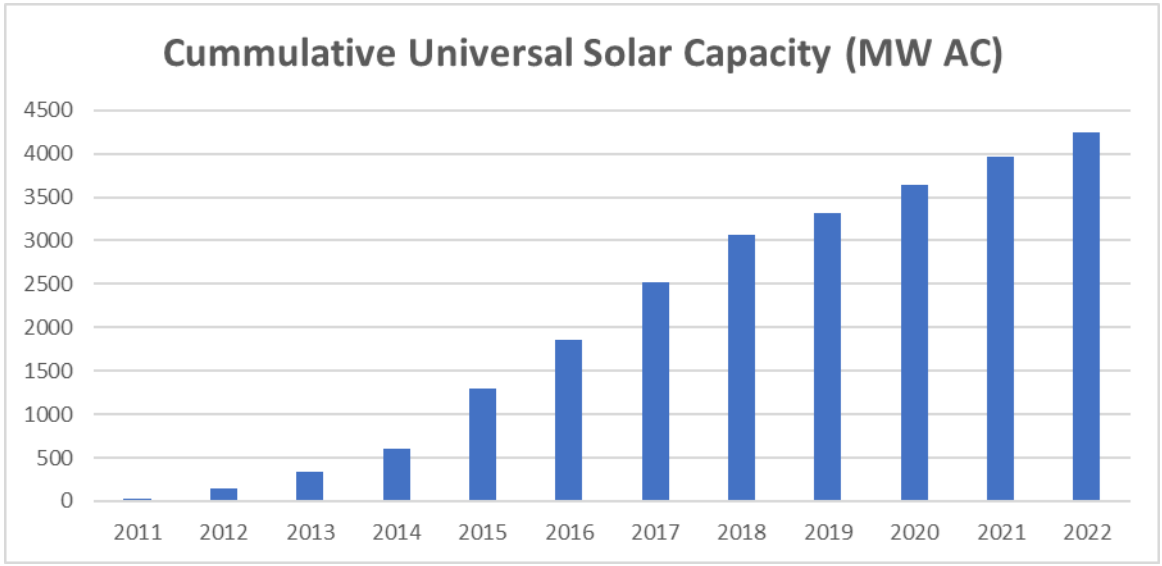
DEC/DEP Interconnection Queue

System Impact Studies:

a. Performed for projects in the queue
b. Determine network upgrade needed to connect the project
c. Power flow, protection, Transformer inrush

Duke Energy Generate Your Own Energy (Link)

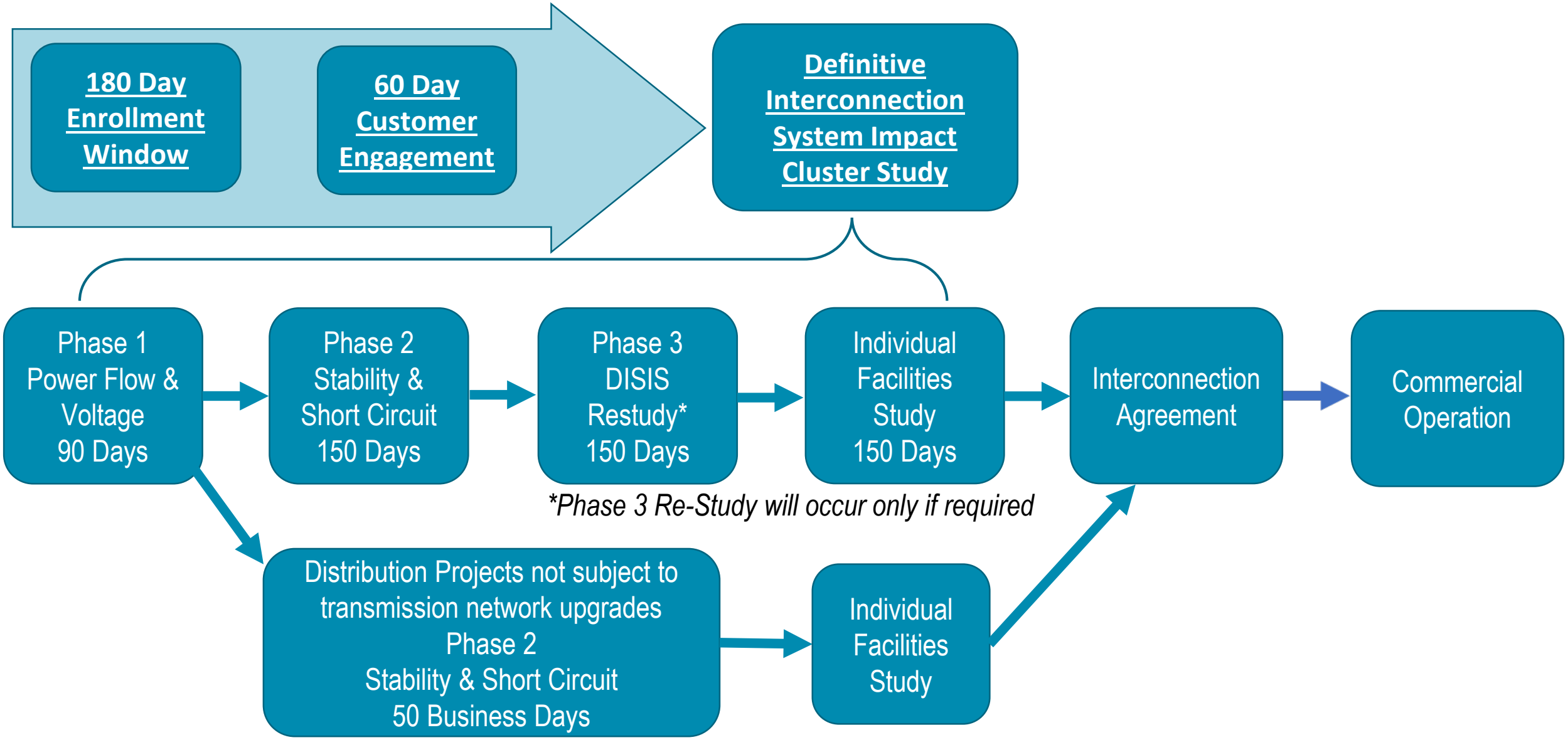




Interconnection Queue Reform

Serial Queue	Cluster
Different rules for FERC, NC, SC	Aligned rules across FERC and State
Distribution & Transmission grid impacts evaluated separately	Distribution & Transmission grid impacts evaluated together
"First come, first served" • Single queue and study process for all projects, no matter readiness • Serial processing of studies for all projects	"First-ready, first-served" • *Informational Study provided for outside of queue* • Definitive Study Process for ready projects includes cluster study on an annual basis merging Feasibility and System Impact Studies, eliminating Optional Studies
No incentive for non-viable higher queue projects to withdraw, clogging queue for years and causing numerous Re-Studies	Increase developer "skin in the game" with Definitive Study Process milestone decisions and payments demonstrating project readiness and site control
"First to impact" network upgrade cost allocation	Shared cost allocation of network upgrades

DISIS Cluster Study



Reference: North Carolina Interconnection Procedure (link)

Additional Studies for BESS

Long-term Dynamic Study

- Quasi-static simulation to evaluate BESS use case of frequency regulation (ancillary service)

Grid-connected Mode EMT Study

- Study model development (power flow validation)
- Stability analysis (varying load, voltage, BESS output)
- Protection (temporary overvoltage, anti-islanding)
- Power quality (frequency scan & harmonic analysis)

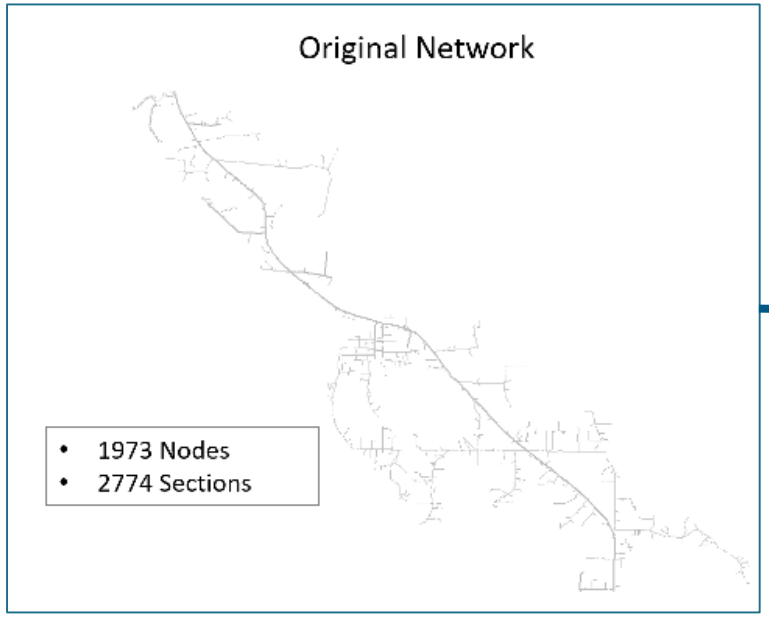
Microgrid Technical Challenges

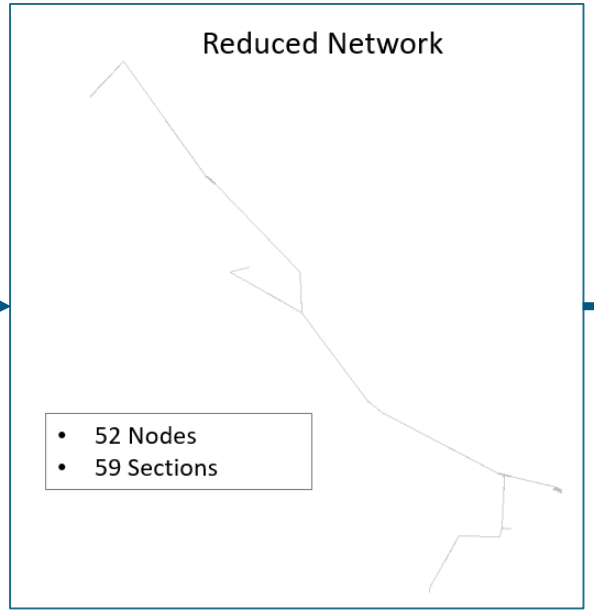
Technical Challenges in Island-mode Operation

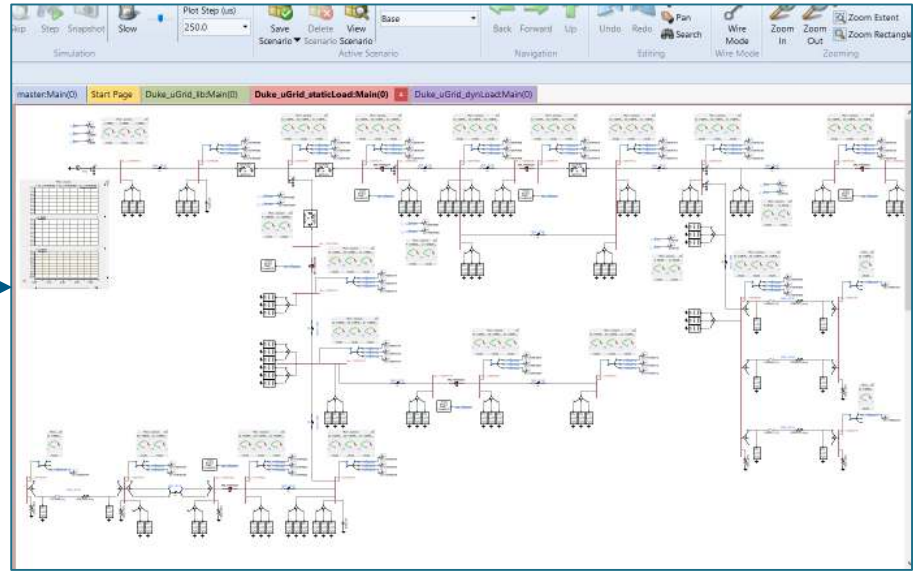
- Weak source introduces risk in system transient stability and power quality.
- Fast inverter control requires Electro Magnetic Transient (EMT) analysis and Hardware In the Loop (HIL) design validation.
- Voltage and overcurrent protection no longer reliable and secure, need more robust designs to identify most common failure modes

Microgrid Islanding Study

- The grid-connected study and islanding study are overlapping and typically take months to complete, in which the islanding accounts for ~70% of the time.
- Microgrid islanding study scope:
  - EMT model development







Microgrid Islanding Study Cont.

- Power flow analysis
  - To ensure the MG operates within standards serving retail customers
  - Results are evaluated against thermal, voltage, imbalance criteria
- Protection and system grounding analysis
  - Adequate fault current availability is needed to ensure protective devices clear faults in a timely manner.
  - Effective grounding of the island is needed to ensure equipment is not damaged from TOV for SLG faults.
  - Approximate high-level specifications for grounding transformers are determined to remediate issues identified.

Microgrid Islanding Study Cont.

- Black start and load restoration study
  - To evaluate if the BESS can energize the island without violating voltage and frequency criteria
  - Service transformer energization
  - Motor starting
- Stability analysis
  - To evaluate if the BESS can handle disturbances
  - Load variation
  - Capacitor switching
  - Fault recovery
  - Voltage reference variation
- Power quality analysis (under development)

Future Opportunities

Business Needs

- Improve the overall development process
- Update the valuation of use cases
- Accumulate operational experience

Technical Needs

- Improve and standardize the microgrid design
- Streamline the studies align with development process and interconnection procedure
- Continue to refine study scope, methodology, and criteria

Q&A