Interconnection of Batteries as Distributed Energy Resources on the Electric Distribution System

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Presentation Overview

How do distribution planning engineers address the addition of battery energy storge on the system?

Background & Context

- Background Information & Motivation
- Characteristics of BESS as a DER
- Dependency on Location for Value of BESS
- Investment in Distribution by Electric Utilities

DER Interconnection Process for BESS

- 3^{rd} Party DER Application & Screening
- Pre-Study Coordination: Scoping Requirements and Data Exchange
- Modeling Process
  - Mitigations of Impacts on the Distribution System (Interconnection Criteria & Standards)
- Safety & Protection

Background Information & Motivation

Driving motivators for the interconnection of battery energy storage on the system

•The global clean-energy transition is the leading trend within the modern power system; currently, a **record amount** of renewable generation (solar, wind, etc.) is being added onto the electrical system, shifting it away from large, fossil-fuel baseload plants and towards distributed, weather-dependent resources.

•Though these renewable sources are clean and increasingly cost-effective, they are **intermittent:** their output fluctuates depending on weather (solar irradiance, wind speeds) or time of day (daylight vs. nighttime hours). This creates challenges for reliably matching supply to demand instantaneously.

•Energy storage can help extend the hours of capacity met by clean resources by adding **flexible capacity** in tandem with renewables, making the system more reliable and resilient.

•Acting as a **"shock absorber"** for the grid, energy storage can mitigate "temporal mismatch between generation and consumption" by storing electricity when generation exceeds demand and releasing it when demand is higher than supply [1].

Solar Farm 2.0

Characteristics of Battery Energy Storage Systems as a DER

Distributed Energy Resources (DERs) and their utility system value

- What are **Distributed Energy Resources**?

  "A DER is a resource sited close to customers that can provide all or some of their immediate electric and power needs and can also be used by the system to either reduce demand or provide supply to satisfy the energy, capacity, or ancillary service needs of the distribution grid. The resources, if providing electricity or thermal energy, **are small in scale, connected to the distribution system, and close to load**."

- In short: **DERs are decentralized, small-scale resources (generation, storage, or demand-side) connected at the distribution level or behind meter.**

- Some resources included under the term "DER" include **solar photovoltaic (PV), wind, combined heat and power (CHP), energy storage, demand response (DR), electric vehicles (EVs), microgrids, and energy efficiency (EE).**

- When interconnected at a **specific poin**t in the system, these DERs can **provide numerous benefits** to the grid, especially deferred or avoided distribution upgrades, reduced energy and generation costs, avoided transmission and distribution losses, peak-demand capacity, improved voltage and power quality, and enhanced flexibility and resilience for renewable integration [2].

- Accurately and fairly assigning these benefits a dollar value (to compensate DER owners) is a **difficult** task and the topic of much discussion.

Characteristics of Battery Energy Storage Systems as a DER

The value that BESS can provide as a Distributed Energy Resource (DER)

- **Energy Arbitrage:**
  Charges during low-price periods and discharges during high-price periods to capture price spreads

- **Peak-Load Shaving:**
  Lowers demand charges and defers costly infrastructure upgrades by reducing maximum load when discharging

- **Lower System Operating Costs:**
  Enables more efficient unit commitment and dispatch, reducing need for expensive peaker plants
  Minimizes generator cycling and allows baseload units to run at optimal output

- **Support of other DERS (Wind/Solar):**
  Smooths intermittent solar/wind generation and stores excess energy that would otherwise be curtailed
  Enables higher renewable penetration without compromising grid stability

- **Ancillary Services:**
  Frequency regulation maintains grid at 60 Hz with fast response (<20 ms)
  Voltage support provides reactive power and black start capability

- **Enhances Reliability & Resilience:**
  Short-duration (<24 hrs): Backup power, microgrid operation, and power quality improvement with fast response
  Long-duration (>24 hrs): Protection against catastrophic events; can defer major infrastructure (Non-Wire Alternative, NWA)

Dependency on Location for Value of BESS

The locational value that BESS can provide at given position on the system

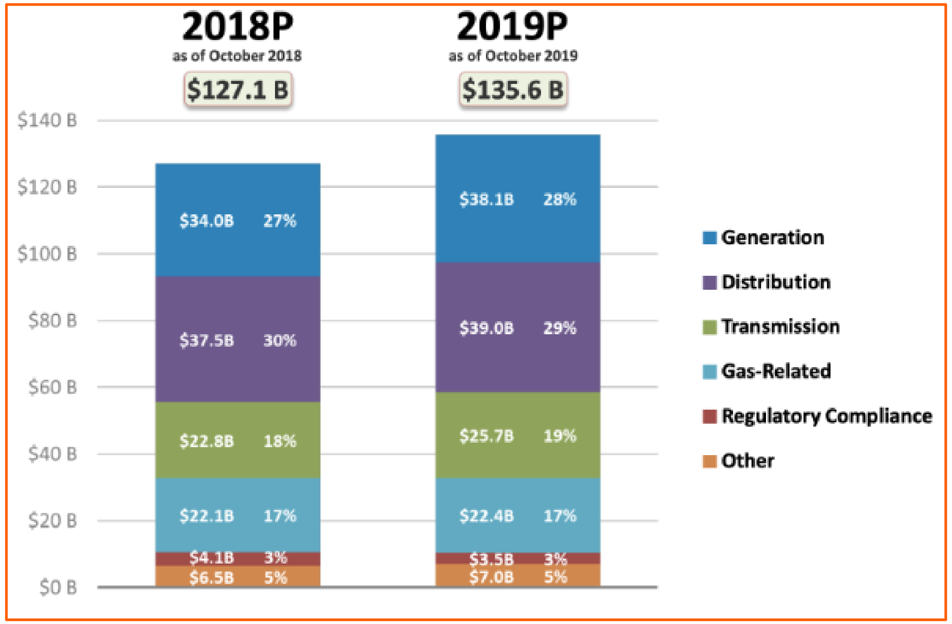
From the Ameren Locational Value of DERs study [4]:

- The value a BESS provides depends significantly on **where it is placed on the distribution system** (e.g., feeder, lateral, or substation).
- When placed on a distribution feeder, these resources mainly provide value to the system **downstream** of their location on the grid.
- Placing storage near **load pockets** can reduce or defer upgrades to feeders, transformers, and voltage-regulation equipment by supplying capacity exactly where constraints occur (i.e., a Non-Wire Alternative).
- Storage sited closer to customers **reduces losses**, supports **local voltage regulation**, and provides **peak capacity** at the exact nodes driving system stress.

From "Understanding the value of energy storage" [3]:

- Energy storage is **highly scalable and flexible**, unlike large traditional resources that cannot be deployed deep in the distribution system.
- At specific distribution locations, BESS can provide unique **distribution-based services**, including voltage support, local congestion relief, and reliability benefits.
- To properly utilize BESS, **effective value stacking** (accounting for technical limits, ownership constraints, and site-specific operational requirements) is dependent on deploying BESS at locations where the services needed can realistically be delivered.
- A battery **cannot provide all services simultaneously** since using stored energy for one service reduces availability for others.
- Proper valuation requires **co-optimizing services** the BESS can provide (e.g., capacity relief + voltage support).

Investment in Distribution by Electric Utilities



Distribution System Upgrades account for the largest portion of capital investments (2019)

Distribution System Investments

Utilities are making rapidly growing investments in the electric grid as they work to modernize aging infrastructure, integrate increasing amounts of distributed energy resources (DERs), and meet emerging reliability and resilience needs.

According to the Lawrence Berkeley National Laboratory report *Locational Value of Distributed Energy Resources* [2], U.S. utilities are collectively investing $39 billion dollars (2019) each year in distribution system upgrades, including capacity expansions, equipment replacements, and grid modernization technologies such as advanced metering, automation, and sensing. These investments are driven not only by load growth and electrification, but also by the need to manage two-way power flows, host more customer-sited DERs, and address locational constraints on feeders and substations.

To aid in this process, electric utilities **need experienced technical experts in consultancy** who can help with this growth in investment. This includes distribution planning engineers knowledgeable in DER Interconnection.

3rd Party DER Application & Screening

Beginning the process of interconnecting BESS to a utility distribution system

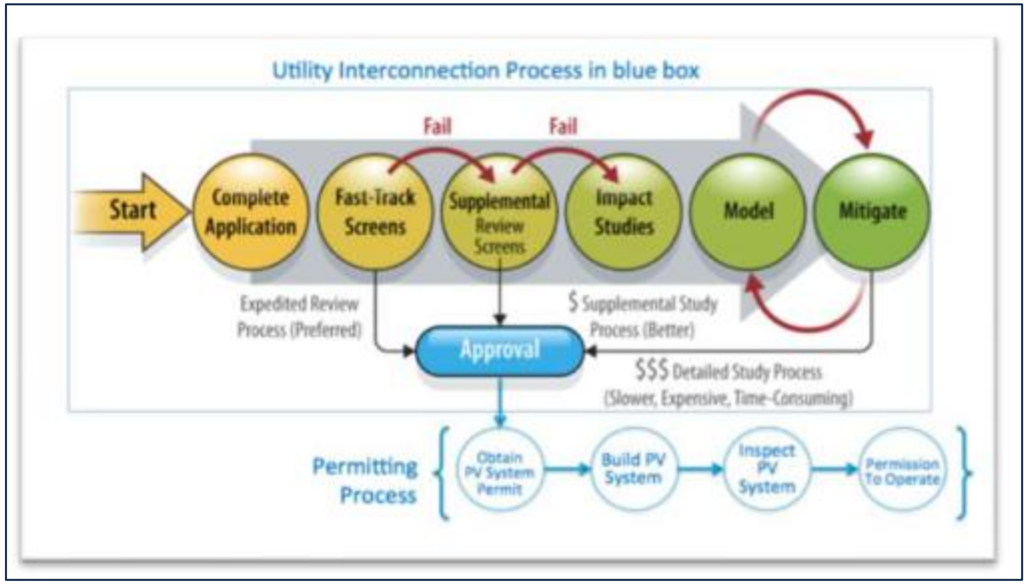
- The current energy market mainly follows a **deregulated/restructured** market that follows **PUHCA 2005**, where certain state laws may require:

  Functional unbundling: separation of generation, transmission, and distribution
  Divestment from generation assets: former utility generation resources sold to independent power producers
  Utilities be "wires only": utilities can only own transmission/distribution

- To join online, 3rd party DER owners must go through a **Utility Interconnection Process** to gain approval; there are several steps in this process, but the main steps relevant to distribution planning engineers are: **Complete Application, Review Screens, Impact Studies, Model, and Mitigate.**

- The interconnection process begins with an **application** by the 3rd party DER owner to the electric utility. These interconnection applications are unique to each utility but are commonly structured to mitigate confusion for both the applicant and utility and promote workflow efficiency.

- The collection, management, and transfer of **accurate** data is a critical aspect of the interconnection process. The utility will collect and store information, such as one-line diagrams, site plans, and hosting capacity maps, to evaluate whether interconnection at a given location is low-cost/high-value [5].



Typical Utility Interconnection Process via NREL

3rd Party BESS Application & Screening

Technical Screening Process for DER Interconnection from the Federal Energy Regulatory Commission [5]

- **FERC Small Generator Interconnection Procedures (SGIP)**
  Foundation: FERC Order No. 2006 (2005) established 10 initial technical screens that most states have adopted or incorporated into their interconnection rules
  Purpose: FERC intended these screens to identify "proposed interconnections that clearly would not jeopardize the safety and reliability of the Transmission Provider's electric system"

- **Level 1: Simplified Process (≤10 kW)**
  Streamlined approval for inverter-based systems using UL 1741 certified equipment
  Fast-track timelines: 10 business days for completeness, 15 business days for technical review

- **Level 2: Fast Track Screening**
  Applications undergo 10 technical screens as "quick-check questions" to identify systems that clearly pose no safety or reliability concerns
    - **If all screens pass** → Immediate approval without detailed study
    - **If any screen fails** → Supplemental review or detailed impact study required

- **The 10 FERC Technical Screens Evaluate:**
  System jurisdiction - Connection to distribution vs. transmission
  Spot networks - Limits on secondary network interconnections
  Short circuit capability - Equipment not to exceed 87.5% of rating
  Shared secondary - ≤20 kW on single-phase shared circuits
  Transient stability - ≤10 MW in areas with known limitations
  Penetration - DER capacity ≤15% of peak load (the "15% rule")
  Fault current contribution - ≤10% of maximum fault current
  Primary line configuration - Proper grounding and connection type
  Service balance - ≤20% imbalance on 240V center-tap services
  No construction required - No utility system upgrades needed

Pre-Study Coordination: Scoping Requirements and Data Exchange

After the initial screening and application process is completed, a detailed study process can begin

- Once an electric utility has approved the application by the 3rd party DER owner and gone through an initial set of screenings, the utility may require **additional studies** to be performed to move forward in the approval process.

- Electric utilities work alongside power system consultancies to perform these DER Interconnection and System Impact studies, which are done by **Distribution Planning Engineers**.

- **Relationship between Electric Utilities & Consultancies:**

  Request for Proposals (RFP) Process: A utility will issue an RFP with a scope of work, deliverables, timeline, and evaluation criteria; multiple consultancies submit competitive bids with their unique technical approach, qualifications, and pricing; the utility will select one of these bids based on cost, expertise, reputation, and methodology.

  Contractual Arrangement: The utility and consultancy will then discuss the defined scope of work, deliverables, hourly billing rates, and other aspects of the study to begin designating work among the planning engineers.

  Data Transfer & Management: The utility will transfer a significant amount of information and data over to the planning engineers, such as: BESS nameplate capacity, one-line circuit diagram for each substation feeder, system addresses, pole & grid numbers, the inverter specification sheet & settings (Volt-Var Curve Compatibility), transformer nameplate/settings/configuration, historical system data (SCADA, GIS), etc. Throughout the study, the two-parties will continue consistent communication over the project for potential clarifications and the need for additional data (RFIs).

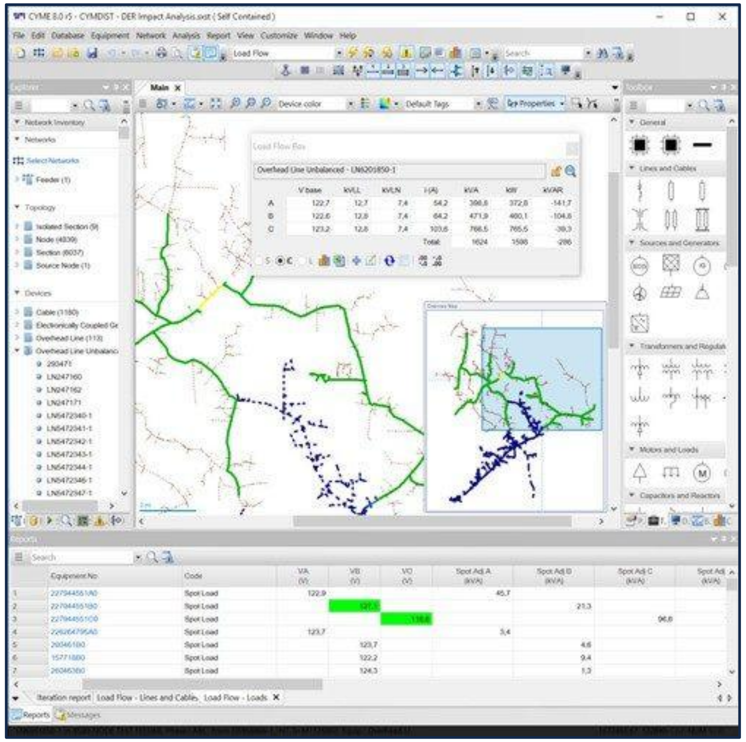
Modeling Process

DER Interconnection: Model Building, Power Flow & Load Allocation Checks, Adding BESS

Define Objectives & Boundary Cases: Depending on the DER being studied for interconnection, only specific boundary cases may be relevant to fully understand the impacts and needs of the system; **for BESS, the resource can operate as both a load and source** which requires data collection for both a peak-load scenario (Max MVA) and minimum load scenario (Min MVA) from the SCADA data; understanding how the system should behave at these grid conditions is essential for accurate system modeling and verifying the data transferred.

Data Collection & Cleanup for Base Model: It is possible that when transferring the model into software (e.g., CYME) there may be some inaccurate or defaulted values that need to be corrected; a planning engineer will use their intuition on how the system will operate at the minimum and maximum load conditions (e.g., capacitor bank status on/off) and correct/verify the model to best represent the physical system; this model **does not** include the BESS at this stage, as the base model must be vetted for accuracy with initial Load Allocation and Power Flow checks.

DER Interconnection, Load Allocation, & Power Flow: Once the base model is established, the BESS can now be added onto the system to see how it influences the behavior of the system. Load Allocation (to determine how demand is spread across the feeder) and Power Flow (to visualize voltage, reactive power, and real power values on various points on the system) is performed to ensure **system conditions are within an acceptable range**.



Model of a Distribution System in CYME

Mitigations of Impacts on the Distribution System (Interconnection Criteria & Standards)

The criteria that needs to be met for BESS interconnection approval [5]

Voltage Limits (ANSI C84.1)
Range A - Normal Operation:
Nominal voltage ±5%
120V systems: 114V - 126V
Equipment performs best within Range A; may be damaged if operated outside this range for extended periods

Power Quality Requirements
Voltage Flicker (IEEE 1453):
Voltage fluctuation must be within acceptable limits as defined by IEEE Standard 1453
Limits rapid voltage changes that cause visible light flicker
Protects sensitive customer equipment

Harmonic Distortion (IEEE 519):
Harmonic levels must meet IEEE Standard 519 limits
Total Harmonic Distortion (THD) typically <5% for voltage
Individual harmonic limits specified by frequency

Reactive Power & Power Factor
Power Factor Requirements:
Typical minimum PF ≥0.90 (lagging or leading)
Reactive power capability: ±0.44 vars per watt of real power
IEEE 1547-2018 requires DER to have leading and lagging reactive power capability

Advanced Inverter Modes:
Constant power factor mode
Volt-var control (autonomous voltage regulation)
Volt-watt control (active power curtailment for over-voltage)
Constant reactive power mode

IEEE 1547-2018 Key Performance Requirements
Ride-Through Capability:
Must stay online during voltage/frequency disturbances (Categories I/II/III)
No 5-minute wait after disturbance (unlike IEEE 1547-2003)
Anti-Islanding:
Detection and disconnect ≤2 seconds
Response Time:
Advanced inverters: <20 milliseconds for voltage support

Mitigations of Impacts on the Distribution System (Interconnection Criteria & Standards)

Advanced Inverter Solutions [5]

Reactive Power Control Modes

Volt-Var Control:

Inverter actively controls reactive power output as a function of voltage following a volt-var curve

Autonomous operation - responds to local voltage measurements

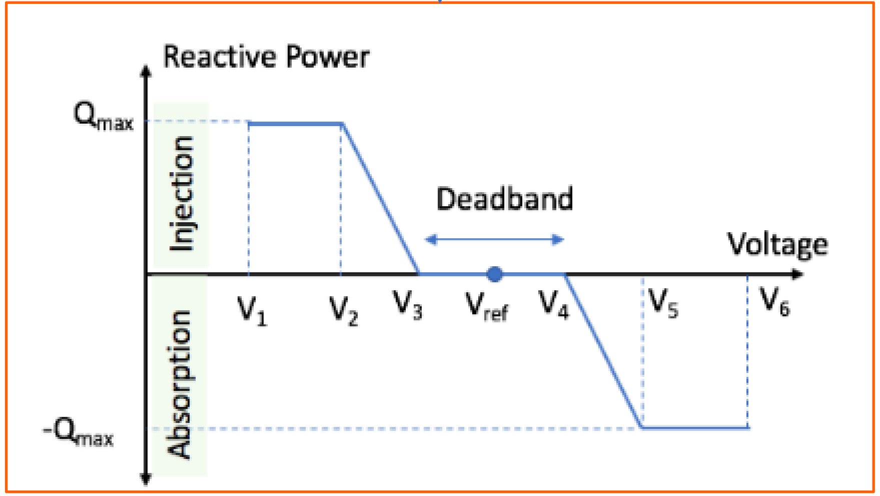
Absorbs vars to lower voltage, injects vars to raise voltage

Volt-Watt Control:

Inverter actively controls active power output as a function of voltage; typically used as backup when voltage moves into abnormal range

Curtails real power during over-voltage conditions

Default threshold: 1.06 p.u. to minimize economic impact



Fixed Settings:

Constant PF mode - Operates at fixed power factor (typically PF ≥0.90)

Constant reactive power mode - Maintains fixed var injection/absorption

Implementation Considerations

Advantages:

Low to no cost if set at install

Fast response (<20 ms)

Scalable with DER deployment

Limitations:

Retrofits of old inverters typically prohibitively expensive

At high penetrations, advanced inverters may need to be used in concert with other voltage-regulation solutions

Mitigations of Impacts on the Distribution System (Interconnection Criteria & Standards)

Traditional Utility Equipment Solutions [5]

Voltage Regulators

Modifications:

- Modify voltage-regulator controls for bidirectional or co-generation mode for desired operation with reverse power flow
- Modifying device bandwidth may help with voltage flicker

Load Tap Changers (LTCs)

Substation-Level Control:

- Modify LTC tap set point to address high or low voltage and excessive device movement
- Install LTC at the substation for high or low voltage mitigation
- Provides voltage regulation at transformer source

Capacitor Banks

Control Modifications:

- Modify capacitor controls for bidirectional or co-generation mode for desired operation with reverse power flow
- Modifying device bandwidth may help with voltage flicker
- Provides reactive power compensation for power factor correction

Conductor Upgrades

Reconductoring:

- Used to address thermal overload and voltage flicker
- Larger conductor size reduces voltage drop
- Improves voltage regulation along feeder
- Higher ampacity for increased capacity

Cost Consideration:

Thermal violations are often most expensive to mitigate; average cost of thermal upgrades over $1.2 million

Safety & Protection

System Protection for DER Interconnection [5]

<u>Fault Current and Protection Coordination</u>

FERC Screen Requirements:
- DER in aggregation shall not contribute more than 10% to circuit's maximum fault current
- DER shall not cause protective devices to exceed 87.5% of short circuit interrupting capability

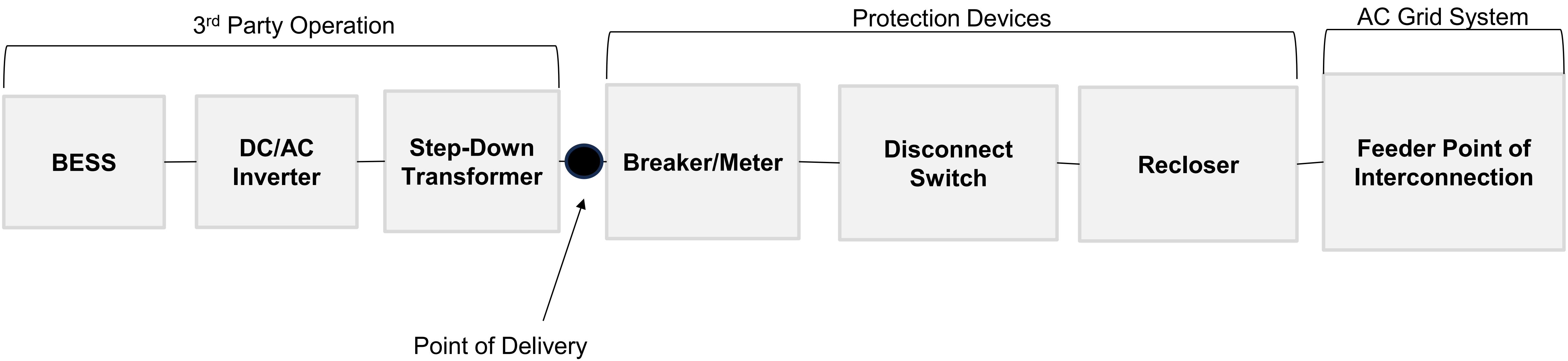
Inverter Characteristics:
- Modern inverters have fault durations typically shorter than synchronous machines and drop offline more quickly
- Different fault behavior requires specialized protection settings

<u>Mitigation Strategies</u>

Protection Upgrades:
- Upgrade protection coordination schemes to address protection violations
- Move protective devices to maintain proper coordination
- Testing and modeling to characterize short-circuit current characteristics of inverters
- Adjust relay settings for bidirectional fault current
- Install directional relays where needed

Safety & Protection

Visual Representation of Model Level Components:



Concluding Thoughts

Balancing Interconnection Rigor with Clean Energy Urgency

The clean energy transition faces a critical challenge: while technical screening ensures safe, reliable, and cost-effective interconnection through rigorous analysis of voltage, protection, and power quality impacts, lengthy study timelines create bottlenecks that slow renewable deployment when speed is essential for climate goals. Fortunately, modern solutions are bridging this gap: online application systems enable over 50% of utilities using them to process applications in less than 2 weeks, automated screening using power flow modeling provides faster, more accurate results, and advanced inverters with IEEE 1547-2018 capabilities offer low-cost mitigation with quick response times while supporting grid stability. By investing in this and other forms of grid modernization, we can dramatically accelerate interconnection without sacrificing safety, proving that rigorous technical studies are not obstacles to clean energy, but essential to meet our climate commitments.

The Ameren Illinois Technology Applications Center (TAC)

Thank You!
Questions?

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