Impacts of Distributed Energy Resources and Case Study on Network Protectors
EAPA Presentation, March 20, 2018
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Agenda

• Overview of the Existing Power System
• Distributed Energy Resources (DER)
• Impact of DER in Regards to Existing Power System
• Eaton Case Study: DER and Network Protectors
Overview of the Existing Power System

High-Level Summary: Central Power Station Model

- The current model for electricity generation and distribution in the United States is dominated by centralized power plants. The power at these plants is typically combustion (coal, oil, and natural gas) or nuclear generated.
- Centralized power models require distribution from the center to outlying consumers.
- Current substations can be anywhere from 10mi to 100mi of miles away from the actual users of the power generated. This requires transmission across the distance.
- Utility-scale generation units generate power in capacities 100’s to 1,000s of MW
Overview of the Existing Power System

Although electrical power systems vary in size and structure, they all currently have the same basic primary characteristics:

- Power systems are comprised of 3-phase alternating current (ac) operating at near-constant voltage and frequency
- Generation and transmission use 3-phase equipment whereas loads use both 3-phase and 1-phase equipment
- Power systems use synchronous machines for generation by means of a prime mover that converts energy (fossil, nuclear, hydro) to mechanical power that is in turn converted to electrical power
- Power is transmitted over significant distances to consumers spread over a wide area. This requires a transmission system comprising subsystems operating at different voltage levels
Overview of the Existing Power System

Response of a Power System

• A response of the power system to a disturbance may involve much of the equipment/components
  • For example, a fault on a critical element (e.g., bus, line), followed by its isolation by protective relays will cause variations in:
    o Power flow
    o Network bus voltages
    o Machine rotor speeds
    o Generator and transmission voltage regulators
    o Prime mover controls
    o System loads MW and Mvar consumption

• If, following a disturbance, a power system is stable, then:
  o It will reach a new equilibrium point with the system integrity preserved
    ▪ e.g., with practically all generators and loads connected through a single contiguous transmission system
    ▪ Some generators or loads may be disconnected by the isolation of the fault or intentional tripping to preserve the continuity of the operation of the bulk system

• If, following a disturbance, a power system is unstable, then:
  o It will result in a run-away or run-down situation
    ▪ e.g., with a progressive increase of angular separation of generator rotors AND/OR a progressive decrease of system voltages
  o An unstable condition could lead to cascading outages and a shutdown of major portions of the power system

Overview of the Existing Power System
Definition of Power System Stability

Voltage Stability

• The ability of a power system to maintain steady voltages at all buses in the system after a disturbance depends on the ability to maintain/restore equilibrium between load demand and generation
  ▪ Instability that may result occurs in progressive voltage drop (loss of generation) or rise (loss of load)
  ▪ Possible outcomes; Tripping of transmission lines and other equipment leading to cascading outages; Loss of load; Loss of generators
  ▪ Voltage instability commonly occurs as a result of reactive power deficiency

Rotor Angle Stability

• The ability of synchronous machines in an interconnected power system to remain in synchronism after a disturbance
  ▪ Under steady-state conditions there is equilibrium between the input mechanical torque and the output electrical torque
  ▪ If the system is perturbed, the equilibrium is upset resulting in acceleration or deceleration of the rotors of the machines

Frequency Stability

• The ability of a power system to maintain steady frequency following a severe disturbance resulting in a significant imbalance between load and generation
  ▪ Instability that may result occurs in the form of sustained frequency swings leading to tripping of generators and/or loads

Overview of the Existing Power System
Transmission Line Loading – Clothes Line Analogy

- Clothes Line Elevation = Transmission Line Voltage Profile
- Amount of Laundry = Transmission Line Loading
- Distance of Clothes above ground = Stability Margin
- Main supports (brown poles) = On-Line Generation
- Red Props = Static and/or Dynamic Shunt Compensation (SVC)
Distributed Energy Resources
High-level Summary and Definition

- Distributed energy resources (DER) is an approach that employs technologies to produce electricity close to the end users of power. DER technologies often consist of modular (and sometimes renewable-energy) generators.

- In contrast to the use of a few large-scale generating stations located far from load centers, the approach used in the traditional electric power paradigm, DER systems employ numerous, but small plants and can provide power onsite.

- DER technologies yield power in capacities that range from a fraction of a kilowatt to about 100 megawatts
Distributed Energy Resources

Challenges associated with DER

**Behind the meter DER definition**
- A DER generating unit or multiple generating units at a single location (regardless of ownership), of any nameplate size, on the customer’s side of the retail meter that serve all or part of the customer’s retail load with electric energy.

**Challenges associated with behind-the-meter DERs**
- At a substation: net load = load – DER
- Potential sudden changes in the substation net load due to variability and intermittency of DERs will cause great challenges to the bulk power system ramping needs

*Courtesy: ANL*
Distributed Energy Resources
Transmission Line Loading – Clothes Line Analogy

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- Red Props = Shunt Compensation and/or DER
Impact of DER in Regards to Existing Power System
FERC Involvement

- **Demand Response**- State now FERC asserted jurisdiction when DR used in wholesale market through its March 2011 Final rule on Demand Response Compensation in Organized Wholesale Energy Markets
- **Aggregation of Behind the Meter Distributed Resources**- February 2018 FERC Notice of Proposed Rulemaking (NOPR) on Participation of Distributed Energy Resource Aggregations in Markets Operated by Regional Transmission Organizations and Independent System Operators and upcoming April 10-11 FERC Technical Conference
- **Critical Infrastructure Assets**- Does the nature of these assets require additional requirements and/or coordination with other entities?
- **Impact of State Subsidies on Competitive Wholesale Markets**- FERC convened a May 1-2 2018 FERC Technical Conference to build the record as it decides on varied proposals filed by RTOs to address the issue
Impact of DER in Regards to Existing Power System

NERC has identified the following factors on bulk system reliability associated with DERs:

- Need for establishing requirements to regulate the aggregated voltage at the point of interconnection to the transmission
- Potential over-generation during minimum load periods due to DER plus grid connected base load and non-dispatchable generation
- Need for developing standards for DERs wishing to participate in ancillary service markets
- Coordination and reconciliation of IEEE 1547 interconnection standards with proposed DER grid codes on fault current, low-voltage ride-through, frequency ride-through etc.
- Disconnecting DER during under-frequency load shedding can further reduce frequency
- System restoration coordination between transmission/distribution resources
- Potential system protection coordination due to current flow reversal

*NERC Distributed Energy Resources Workshop: Clyde Loutan, Sr Advisor - Renewable Energy Integration, Market Analysis and Development
Impact of DER in Regards to Existing Power System

Operational Challenges

Operational challenges on the grid associated with large scale DERs and loads:

- Lack of visibility of distribution system
- Uncontrollable nature of DER output
- PV inverters in large amounts can affect the frequency response and voltage profile of the system
- Forecast assumptions of “net load” seen by operators
- Variability of “combined heat and power” production due to load, natural gas prices, real-time energy prices etc.
- Predicting price responsive loads behavior to real-time prices
- Demand response variability and forecast uncertainty
- Uncertainty/assumptions associated with commercial, industrial and residential storage

*NERC Distributed Energy Resources Workshop: Clyde Loutan, Sr Advisor - Renewable Energy Integration, Market Analysis and Development*
Impact of DER in Regards to Existing Power System

What is being asked and studied in the industry?

How do we adapt to the high penetration levels of DER?

- Develop technical interconnect requirements as part of grid codes for DER
- Develop new planning and operating guidelines so system operator can better understand the impacts of DERs
- Identify areas where current reversal due to DER can result in thermal overloads on the grid
- Develop and incorporate day-ahead and real-time forecast for aggregated DERs production in applicable market applications
- Analyze areas with high levels of inverter-connected DERs to identify potential transient and small signal stability problems
- Coordinate transmission planning/operating studies with DERs, demand response resources, plug-in vehicles (PEVs), distributed storage etc.

*NERC Distributed Energy Resources Workshop: Clyde Loutan, Sr Advisor - Renewable Energy Integration, Market Analysis and Development*
Impact of DER in Regards to Existing Power System
What is being asked and studied in the industry?

Should and how might we adapt existing tools that address load and generation variability / forecast errors to better integrate DERs?

- Demand response resource
- Load modifying resource
- Energy storage
- Load forecasting & monitoring

What additional solutions (interconnection requirements or market products) are or aren’t needed?

- Primary frequency response
- Volt/Var implications
- Market pricing dynamics & estimating responses

* NERC Distributed Energy Resources Workshop: Observability and Control, MISO, Jessica Harrison, Director of R&D, Market Services
Impact of DER in Regards to Existing Power System
What is being asked and studied in the industry?

How might distribution-level technologies / capabilities ultimately shape the profiles viewed in the aggregate at the bulk scale and how might that change over time?

- Distribution-level capabilities relative to DER deployment timelines
- Controllability versus observability

What kinds of capabilities, requirements or roles, if any, can we define independent of:

- DER penetration (total penetration and mix of DERs)
- State policies
- Supporting resource portfolio makeup

*NERC Distributed Energy Resources Workshop: Observability and Control, MISO, Jessica Harrison, Director of R&D, Market Services
Impact of DER in Regards to Existing Power System

What is being asked and studied in the industry?

What metering / telemetry might be required or would be helpful?

• Situational awareness or forecasting support (day ahead to real time)
• Appropriate regional samples, data collection processes?
• Appropriate requirements (security, time delays, accuracy)?
• Accuracy required?
• Visibility to behind the meter generation production?

What additional system needs will there be?

• What volume of data / constraints might our system need to handle and how might we best manage that?
• Cybersecurity implications under different integration models?
• What levels should we model to?
  ▪ Depends in part on answers to above questions

*NERC Distributed Energy Resources Workshop: Observability and Control, MISO, Jessica Harrison, Director of R&D, Market Services
Case Study: DER and Network Protectors

Dan O’Reilly
Engineer Specialist
Case Study Overview

- Customer was interested in installing on-site generation (microturbines).
- What makes this installation challenging is that the building is supplied from a spot network utilizing network protectors.
- When the microturbines are paralleled with the power system, the surplus generated power cannot be exported back onto the grid because the network protectors would open on reverse current.
- Network protectors prevent reverse power flow from the secondary network to network feeder primaries. Network protectors do not interrupt fault current.
- A study was conducted by Eaton in regards to the feasibility of connecting the customer’s proposed generation.
Network Protectors

- Network protectors are special switching devices used to interconnect low voltage incomers into so called spot (or street) networks.

- They are commonly close-coupled with step-down transformers converting medium voltage to the network utilization voltage 120/208V or 277/480V.

- The role of the network protector is to automatically disconnect the supplying feeder from the network side when the medium voltage supply-end circuit breaker opens.

- This is accomplished by network protector relay that senses the reverse current, from fraction of ampere of the reverse transformer magnetizing current to several tens of kA of the fault current.

- Opening of the network protector can be practically instantaneous. Network protectors are designed to automatically reconnect to the network when the supply voltage (on the line side of the protector) is higher than the network voltage.
Secondary Network
Customer System Overview

• Peak building load equals 1480 kW; minimum load equals 440 kW

• Network Protectors trip on reverse power within 30 cycles

• Building Management System (BMS) has an old system where all HVAC switches on/off at once
Existing Electrical System

3 x Network Protectors

System Peak Load = 1420 kW
System Min. Load = 410 kW
Proposed Electrical Design

3 x Network Protectors

System Peak Load = 1420 kW
System Min. Load = 410 kW

8 x 65 kW Capstone Microturbines = 520 kW
Installation of Capstone Microturbines C65 With Heat Recovery

- 8 x 65 kW Capstone Microturbines = 520 kW
- Sized to source the heat transfer and electric load to gain 99% efficiency
- Ramp rates for increasing and decreasing the Capstone units is 1.15 kW/Second for a single unit.
  - With eight units on line ramping capability is **9.2 kW/second**.
# Load Flow Study

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<th>Building Load</th>
<th>Parking Garage Load</th>
<th>Total Load</th>
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<td>Min Load in kW</td>
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<tr>
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LF Measurements: Worse Case Scenario

Current Drops from 1,330 Amperes to 890 Amperes in 1.192 Seconds
Turbine Ramping Time

Worse Case Scenario:
- \{\text{Microturbine Full load}\} – \{\text{Time HVAC shuts off}\} – \{\text{Remaining Parking lot load}\} = \text{Excessive Output of Microturbine}
  - \(1330A – 890A – 149A = 291A\)
- 291 A injecting into the network protectors (i.e., reverse current)
  - \(291A \times 0.48 \times 1.732 = 241.93 \text{kVA}\)
  - \(241.93 \text{kVA} \times 0.8 = 193.54 \text{kW}\) (reverse power)
- \(193.54 \text{kW} / 9.2 \text{kW/Sec} = 21.04 \text{ Seconds}\)
  - 21.04 seconds calculated ramping time of the microturbines with all 8 turbines on

Take-away – the network protectors will trip off line within 0.5 seconds when reverse current is detected
Impacts of Microturbine Addition

Real Power Flows

- Building Loading
- Parking Log Loading
- Forward to Reverse Powerflow (Zero Threshold)
- Building A Loading
- Microturbine Output 520 kW

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Three Remedial Proposals

Three remedial proposals, listed in the order of their cost to implement:

1. Limiting microturbine array output (440 kW)
2. Install a resistive load bank with a solid state switch
3. Install an energy storage system
Limit Microturbine Output

Real Power Flows

- Building Loading
- Network Protector Loading
- Parking Log Loading
- Forward to Reverse Powerflow {Zero Threshold}
- Microturbine Output 440 kW

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Resistive Load Bank

System Peak Load = 1420 kW
System Min. Load = 410 kW

Add a resistive load bank and a solid state switch to be able respond within cycles.

8 x 65 kW Capstone Microturbines = 520 kW
Resistive Load Bank

Real Power Flows

- Building Loading
- Network Protector Loading
- Parking Log Loading
- Resistive Load
- Microturbine Output 520 kW
- Forward to Reverse Powerflow (Zero Threshold)

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Add a energy storage system would require an inverter, firewall protection, control scheme which would require a larger footprint.

3 x Network Protectors

System Peak Load = 1420 kW
System Min. Load = 410 kW

8 x 65 kW Capstone Microturbines = 520 kW
Energy Storage
Recommendations

• Lower the output of microturbine; if not desired purchase load block/solid-state switch or energy storage device (i.e., mitigation device)

• Utility reset network reverse current relay to 1 second delay to provide margin for switching on mitigation device

• Interlock M1 Breaker with the three network protectors.
  • M1 opens if any network protector opens and reclosed after 5 minutes after all three network protectors have been closed.

• Upgrade BMS so large loads have staggered on/off function to allow the microturbine to have ample time to