Integration of Distributed Energy Resources Into the Electric Grid: Some Issues and Solutions

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Spirae
Not only possible. Proven.

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Outline

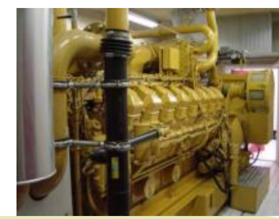
- Introduction to Spirae and our flagship project
- Advantages of distributed energy resources (DER)
- Key issues relating to DER
  - Changes to traditional radial distribution system
  - Operation of traditional voltage control devices
  - Variable energy sources such as wind and solar
  - Protection of distribution system and DER
  - Islanding, unintentional and intentional
  - Synchronization
  - System stability

Outline (continued)

- Solutions include
  - DER autonomous operation strategies
  - Coordination of DER with traditional voltage control devices
  - Protection system settings and upgrades

Spirae Introduction

- Based in Ft. Collins, Colorado
- Established in 2002, Privately Owned
- Spirae Virtual Development Center in Kochi, India
- Danish subsidiary, Spirae.dk, established in 2010
- BlueFin® – Spirae's microgrid control system
- Co-Own and Operate InteGrid Laboratory with CSU
- Launching CSGA – Center for Smart Grid Advancement



Industry initiatives:

- **Smart Grid Live 2012 – September 25-27, 2012 (Live Demos of the Smart Grid in Action)**
- NERC Smart Grid Task Force
- Colorado CleanTech Industry Alliance and Colorado Clean Energy Cluster
- Fort Collins Zero Energy District (FortZED)
- Active participation and frequent speaker at Industry events

Energinet.DK Cell Controller Pilot Project

- Prepare for higher penetration renewable DER (current 20%, goal 30% 2020, 50% 2025, carbon neutral by 2050)
- Ensure grid reliability through intentional islanding
- Enable additional value streams through ancillary services
- Provide replicable model

Holsted Cell

≈ 1,000 km^2

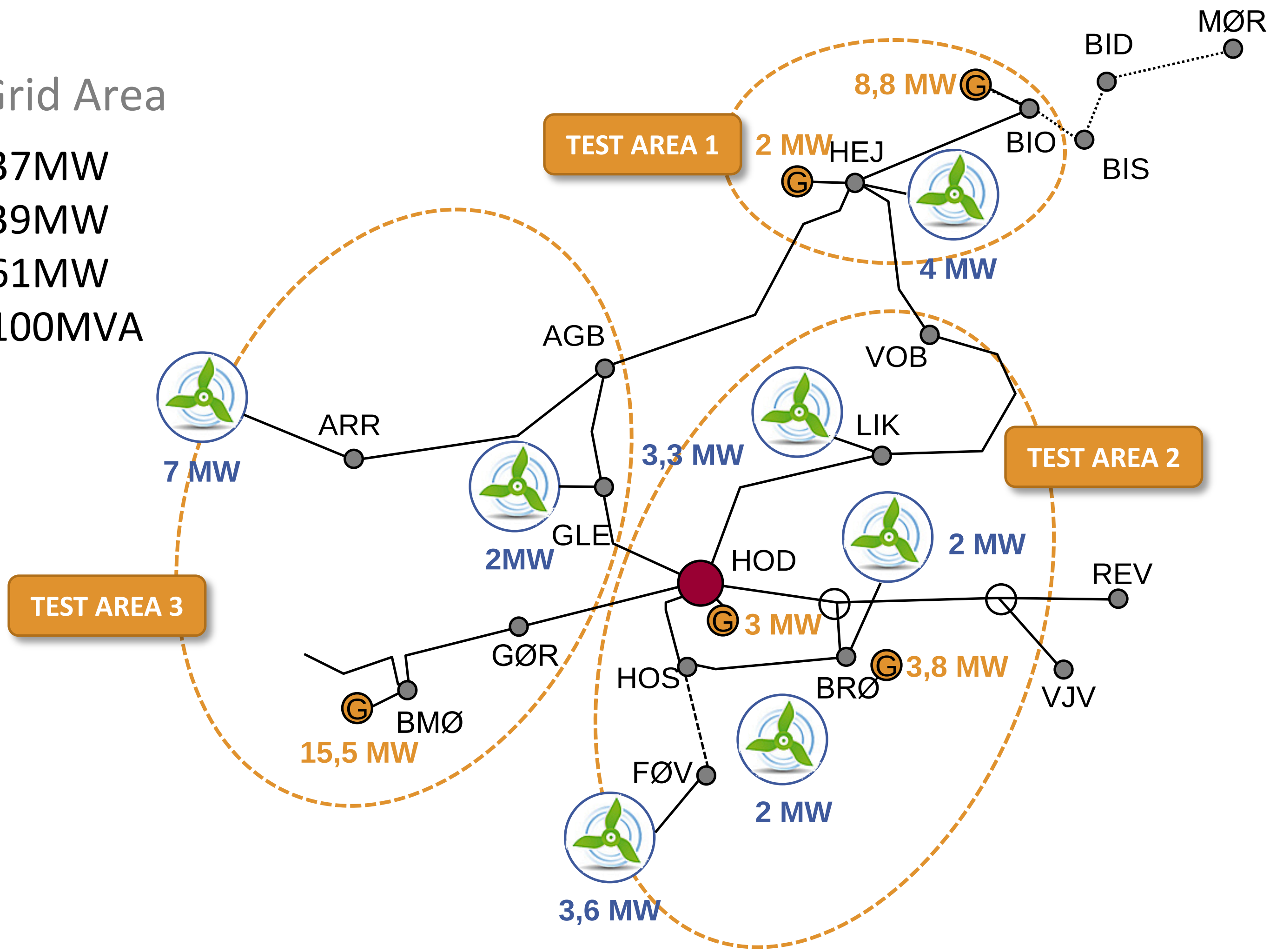
≈ 28,000 customer meters

Energinet.dk Cell Controller Project Test Area

Pilot Cell:

SS Holsted 60kV Grid Area

Installed CHP:	37MW
Installed Wind:	39MW
Max Load:	61MW
150/60 kV Trafo:	100MVA



Cell Controller Capabilities

Islanding of the cell requires an extensive capability set to handle variations in current operating conditions when the island command is received:

- Load shedding to achieve controllable conditions in the case of importing power when islanding.
- Generation shedding in the case of exporting power when islanding.
- Black start in the event no generation is available within the cell when islanded.
- Load restoration when sufficient generation is brought online.
- Frequency and voltage control during island operation.
- Under frequency load shedding.
- Maintenance of frequency and voltage reserves.
- Master synchronization to reconnect to the grid.

Advantages of Distributed Energy Resources

- For electric energy suppliers:
  - Beneficial supplement to centralized generation
  - Reduces power losses
  - Defers distribution system upgrades
- For consumers:
  - Low cost
  - High reliability
  - Improved power quality
  - Independence of energy supply
- For the environment
  - Renewable energy sources
  - Lower emissions

Issues from Distributed Energy Resources

Traditional distribution systems are designed to operate radially. In radial systems, power flows from upper voltage levels down to customers located along the radial feeders. In this case short circuit and overcurrent protection is straight forward as the fault currents flow in only one direction. When DER is introduced in increasing levels of penetration, more complex protection schemes are required. Each system therefore, requires its own interconnect study to insure adequate protection is made available.

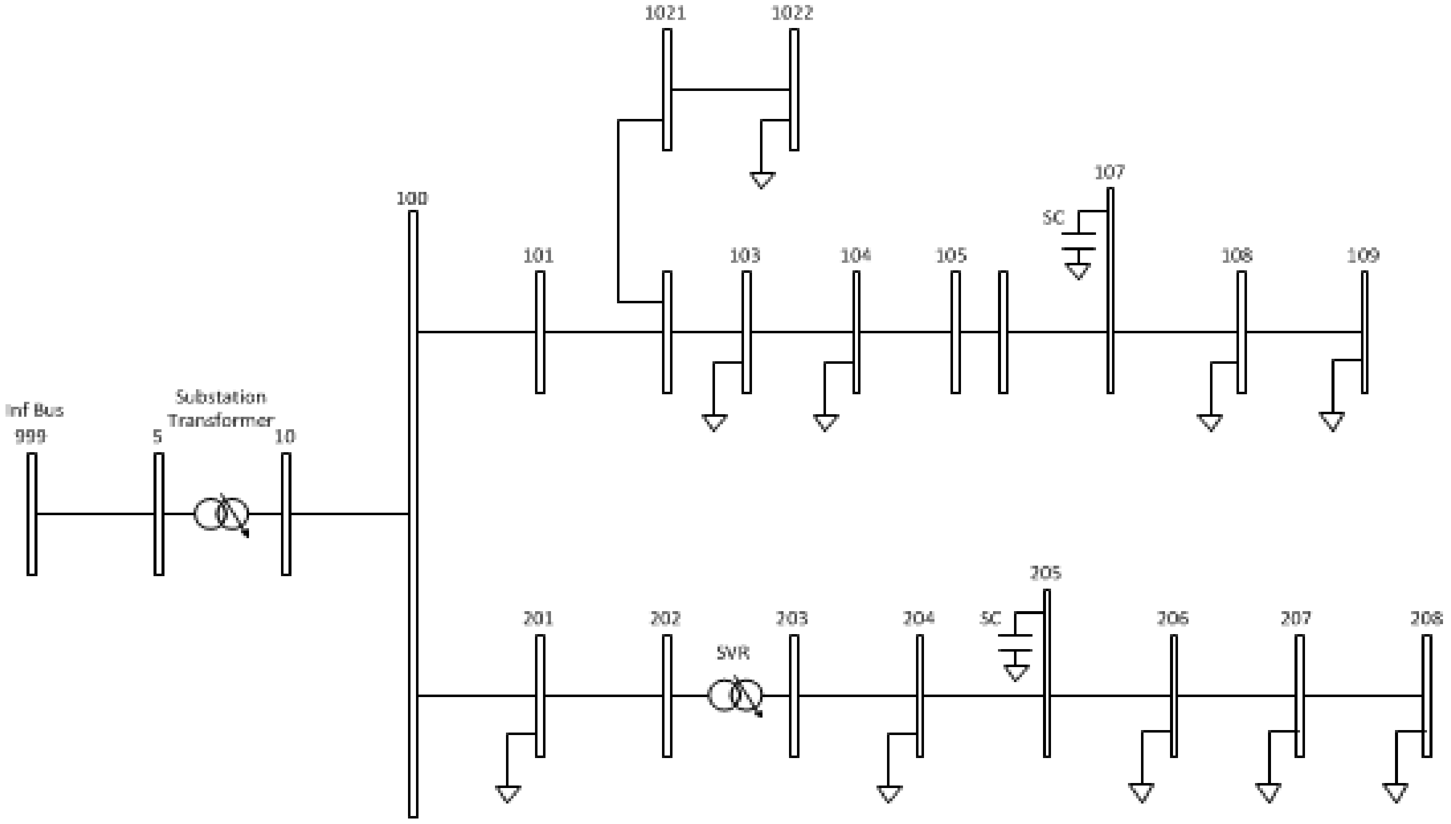
Distributed generation changes the system voltage and var profiles that may require some form of coordination of traditional voltage and var control devices with DER operation. The type of DER equipment utilized, penetration level and location of DER have different impacts on they systems, so each system requires individual assessment.

Issues from Distributed Energy Resources

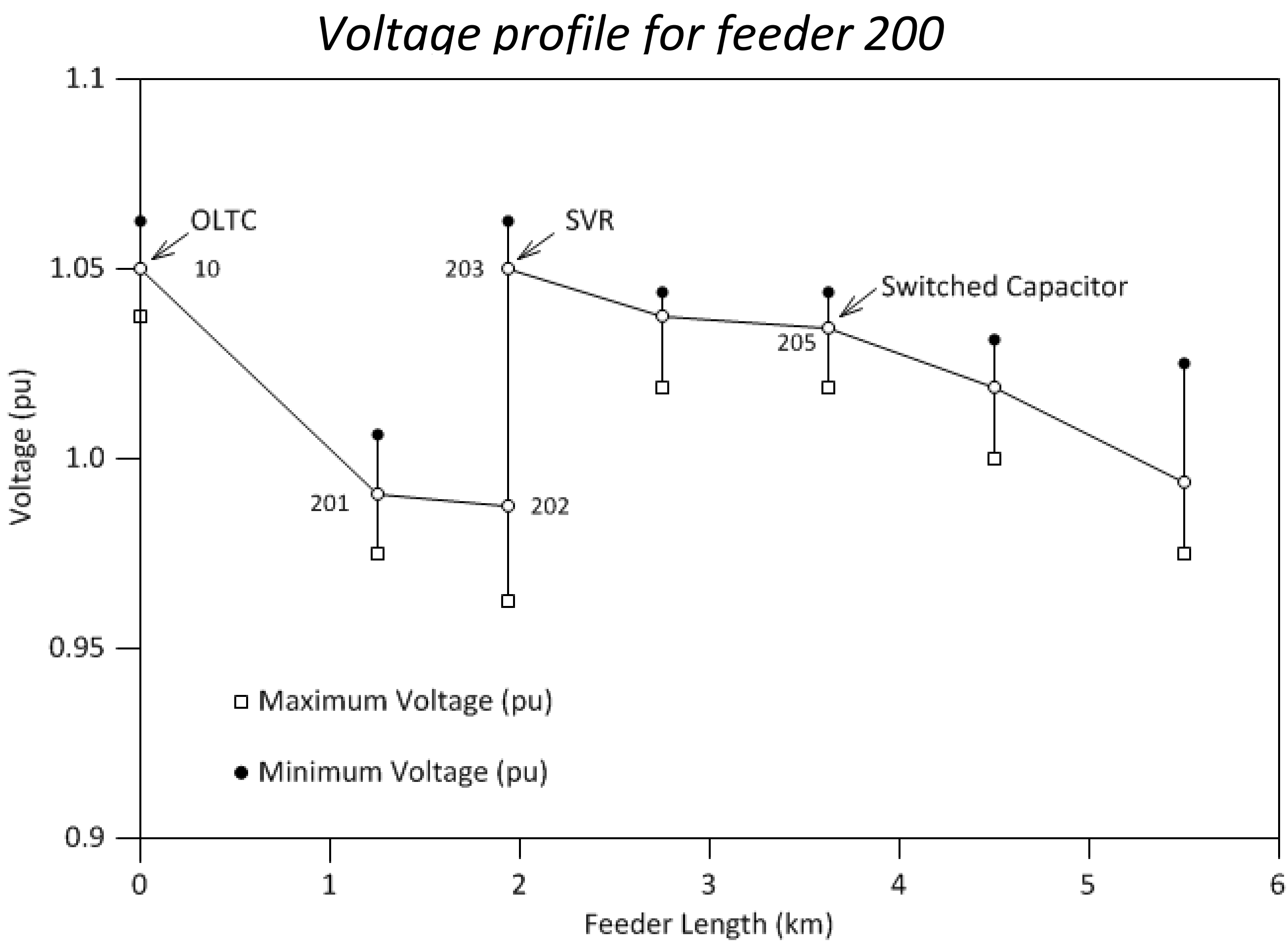
Distributed generation changes the way traditional radial distribution systems are operated.

- Traditional voltage control devices
  - Load tap changing (LTC) transformers
  - Step voltage regulators (SVR)
  - Switched capacitors (SC)
- Traditionally controlled by voltage, load, or time of day using load and voltage studies to determine settings.
- Inverter connected DER may inject harmonics into the system.
- DER may cause over-voltage, fluctuation and unbalance of system voltage.
- Short circuit current levels are changed.

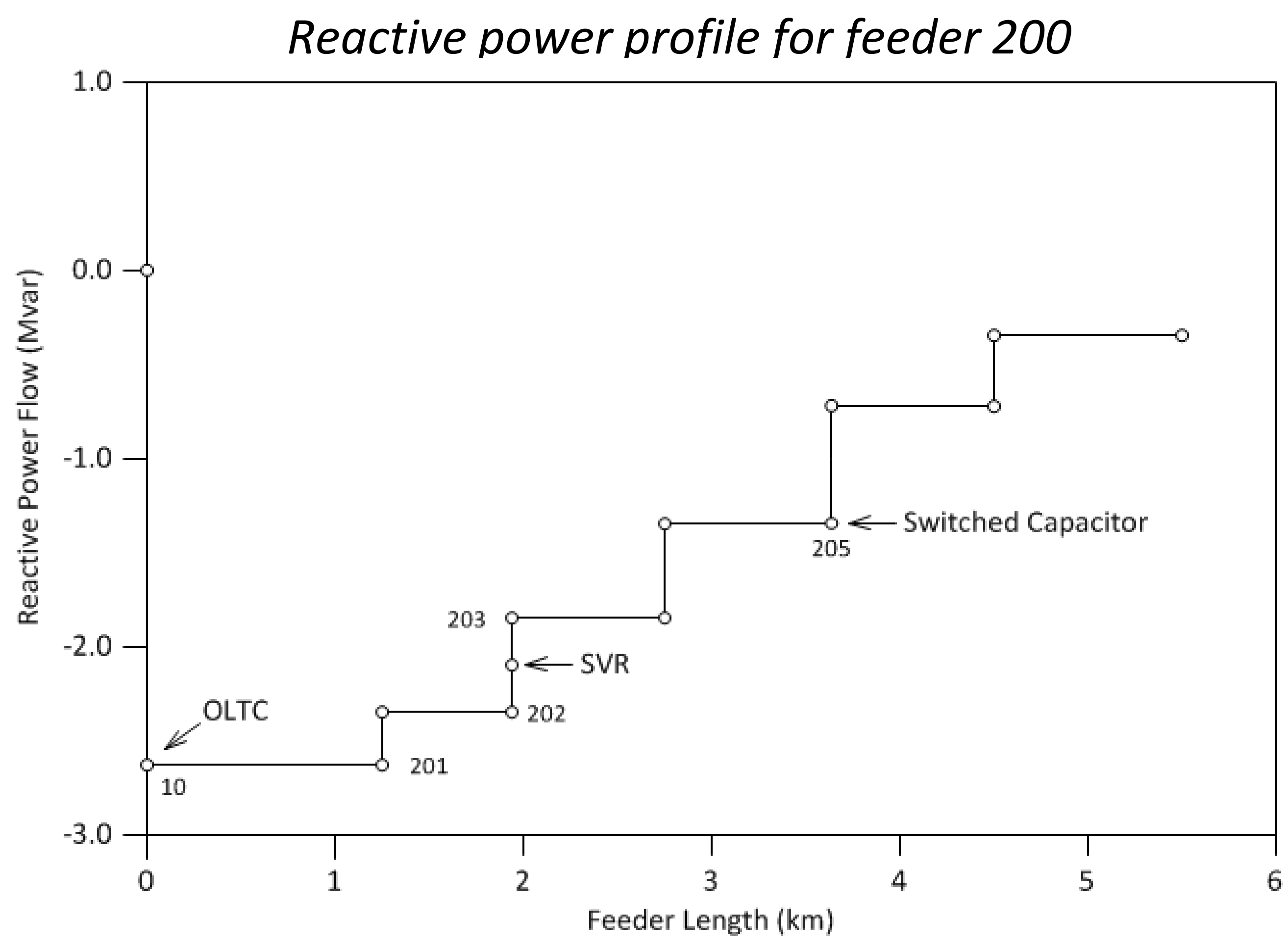
Example Traditional Radial Distribution Feeder



Traditional Feeder Voltage Profile



Traditional Feeder Reactive Power Profile



Issues of Distributed Energy Resources

DER changes voltage and var profiles depending on penetration level

- Injection of real power into the distribution system reduces voltage drop due to lowered losses.
- DER operation at unity power factor can cause power factor issues at the substation. Real power may flow in the reverse direction while the grid must supply the reactive power.

Power quality can be affected by intermittent or variable DER, especially PV.

- Voltage sags and surges due to excessive rate of change in real power.

Basic solutions to voltage and var issues

- Modify LTC, SVR, and SC controls for new operating conditions.
- Allow DER control voltage in droop mode to supply local var load.
- When variable sources of DER such as wind turbines and PV are installed, modern inverters capable of sourcing and absorbing reactive power can be utilized.
- Storage can reduce effects of high variability sources such as PV.

Advanced solutions to voltage and var issues

- Coordination of DER and traditional voltage and var control devices
  - Minimize tap operations to prevent excessive wear and resulting maintenance expenses.
  - Prevent instability or hunting between devices
  - Prevent opposite control operations from cancelling each other and reaching a stable solution. Example is LTC increasing voltage and DER absorbing vars to reduce voltage.

General DER Operational Constraints

It is desirable to maximize utilization of renewable energy resources. In the case of high penetration of these sources, operation of the system within thermal and voltage limits of system elements is required. Thermal limit solutions include:

- Curtail higher emission DER first, e.g., diesel, natural gas, bio-fuel before wind and solar.
- Reconfigure the distribution network to route the supplied energy to less loaded circuits.
- Operate circuits in their upper voltage range to maximize real power delivered. Isolate local loads with SVRs to prevent overvoltage.
- Curtail renewable generation (least desirable solution.)

Advanced Distribution Management Systems

Advanced distribution management systems allow real-time monitoring of system voltages and thermal limits to actively control DER and network configuration to maximize renewable energy production.

Capabilities

- Real and Reactive Power Import/Export using DER at remote interties
- Firm wind production using DER
- Aggregated market participation for DER
- Feeder Volt/VAR control using DER
- Fast islanding and resynchronization

Advanced Distribution Management Systems

Benefits

- Maximize value of DER by exposing multiple value streams
- Distribution system operator (DNO) can enable new services to multiple parties
- Transmission system operator (TSO) leverages assets on distribution network for reliability and optimization
- Market Operators can aggregate and dispatch DER to market
- Same portfolio of DER can be used for multiple applications

Protection overview

The system should have a well designed and practically coordinated protection scheme. The protection requirements must take into account:

- The ability of the protection system to operate correctly and reliably.
- Minimum operating time to clear a fault to avoid damage to equiment.
- Disconnect the minimum section to isolate the fault.
- Achieve maximum protection at the least cost.

Protection Issues

General Protection

- DER with inertia, such as synchronous generators, increase the short circuit current and may shadow the substation overcurrent protection devices.
- Reverse power protection at the substation may be required to avoid opposite power flow as required. If reverse power flow is desired, to provide frequency reserves to the grid for example, reverse power protection limits must be set to allow this condition.
- Distance relays can be affected depending on the location of the DER with respect to the relay.

Overcurrent protection relays must be coordinated to prevent unnecessary outages on healthy segments of the system. Interconnection studies must be made to determine proper settings of overcurrent relays and that short circuit currents are sufficient to trip the relays on under all operating conditions.

Protection Issues

Unintentional Islanding Issues

- DER that powers lines external to the facility
  - Maybe be a safety issue to personnel servicing the outage
  - Re-synchronization to the grid required
  - Auto-reclosers must be disabled when voltage is present on the load side to prevent closing out of synchronization.
  - Power quality degraded due to overload conditions.
- Anti-islanding protection is desirable to disconnect the DER from the grid.
- Synchronization required to reconnect synchronous DER to the grid.

Intentional Islanding

Intentional islanding of a DER powered facility or microgrid can be desirable from a power reliability standpoint.

- Emergency power in the event of grid failure.
- Lower cost energy during high congestion periods.
- High reliability power in the case of an unstable grid.

Operation in island mode places additional requirements on the DER. Frequency and voltage control must be maintained within limits. Additional equipment may be required to achieve this in the event existing resources are not capable of meeting these limits.

- Battery energy storage system (BESS) to maintain frequency and voltage
- Synchronous condenser to control system voltage and supply reactive power to loads.
- Load balancing equipment to provide frequency control by matching load to generation.

Synchronizer, synchronous condenser, and secondary load controller used for intentional islanding

Containerized SC and SLC

SC – Synchronous Condenser

Control Cabinet

SLC – Secondary Load Controller

SC Transformer

Master Synchronizer

Summary

Distributed energy resources offer many economic and operational benefits. Important reasons are:

- Potential reduction of emissions through renewable energy sources
- Deferment of distribution system upgrades in congested areas
- Increased reliability of energy supply

Major issues with distributed energy resources include:

- Voltage rise, controllable with voltage and var control at the resource level in many cases. In higher penetration systems, advanced controls to coordinate traditional voltage control devices with the DER is desirable
- Protection systems require careful study and installation to insure a safe and reliable system.

Questions?

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