Grid-Parallel and Islanding Operation Challenges of a Large Battery Energy Storage System at Cape Cod

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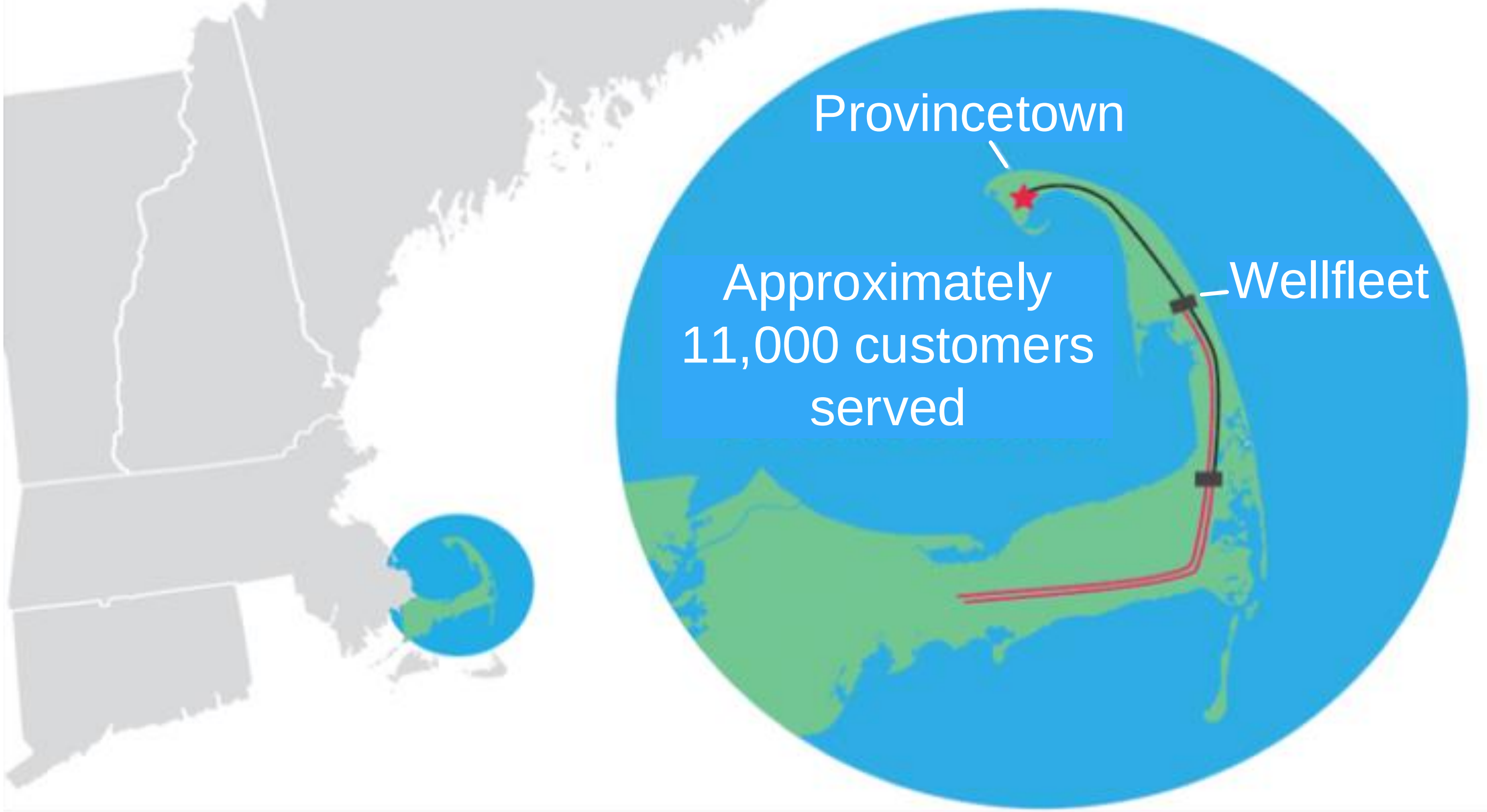
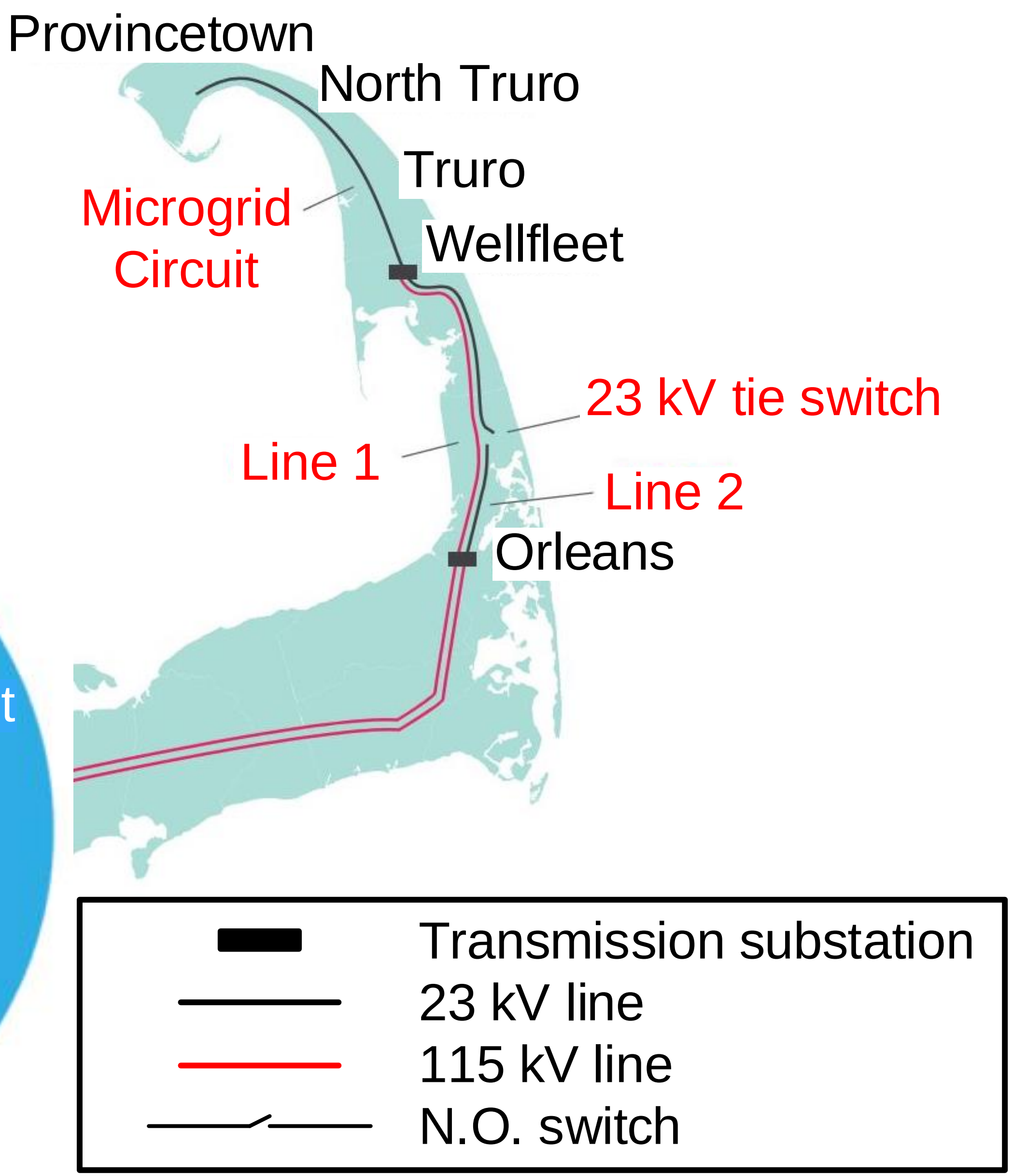
Provincetown battery energy storage system (BESS)

Project Needs





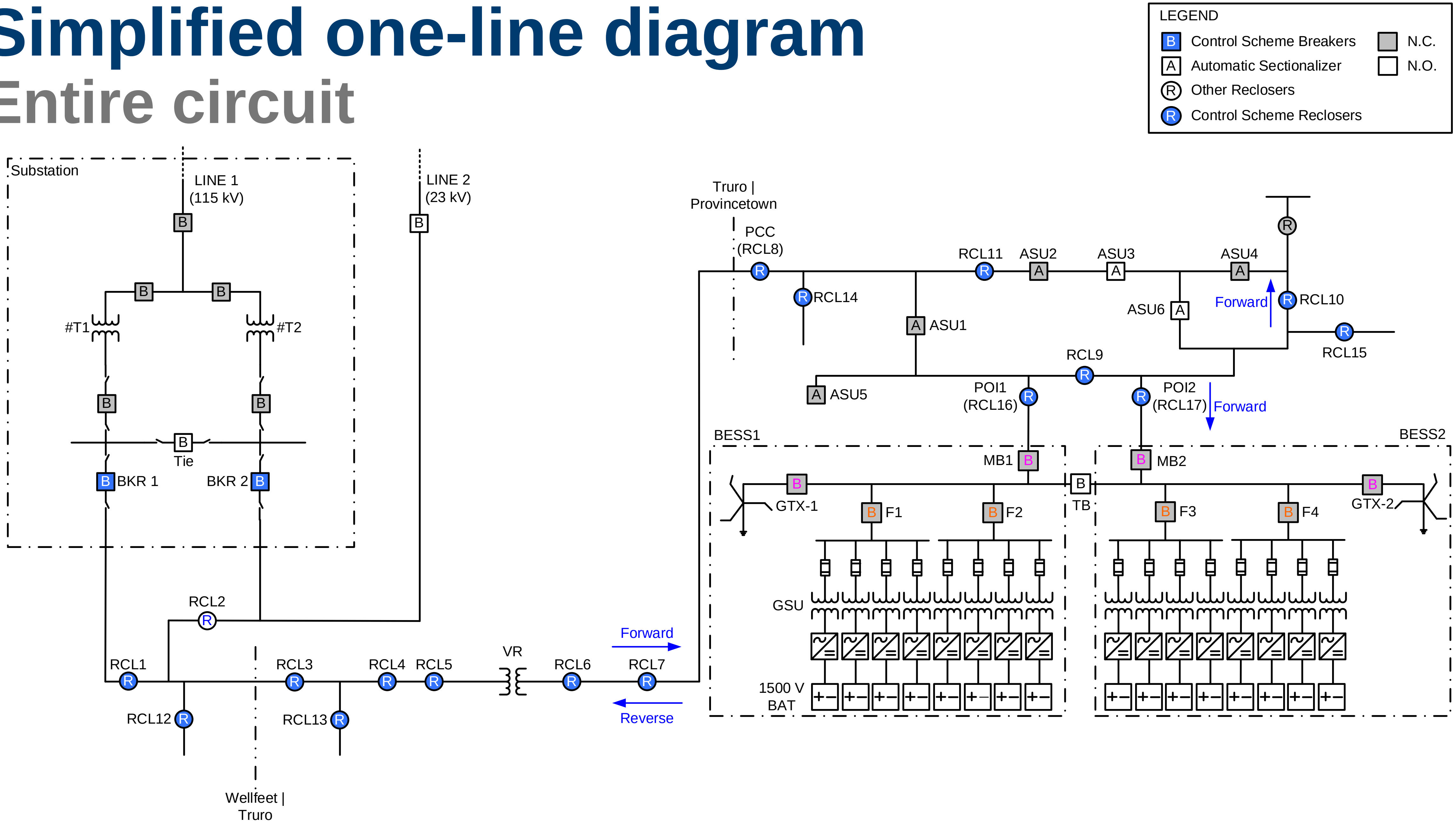
BESS plant statistics


Building size	: ~10,000 square feet
Battery size	: 25 MW / 38 MWh
Battery type	: Lithium ion
Charge time	: ~8 hours (10 max)
Discharge time	: 1.5–3 hours (peak) 10 hours (off-peak)
Battery life	:12 years

Battery modules total	: 6,048
Battery modules / rack	: 14
Battery racks / inverter	: 27
Inverters	: 16
Generation step-up (GSU) transformers	: 16
Grounding transformers	: 2

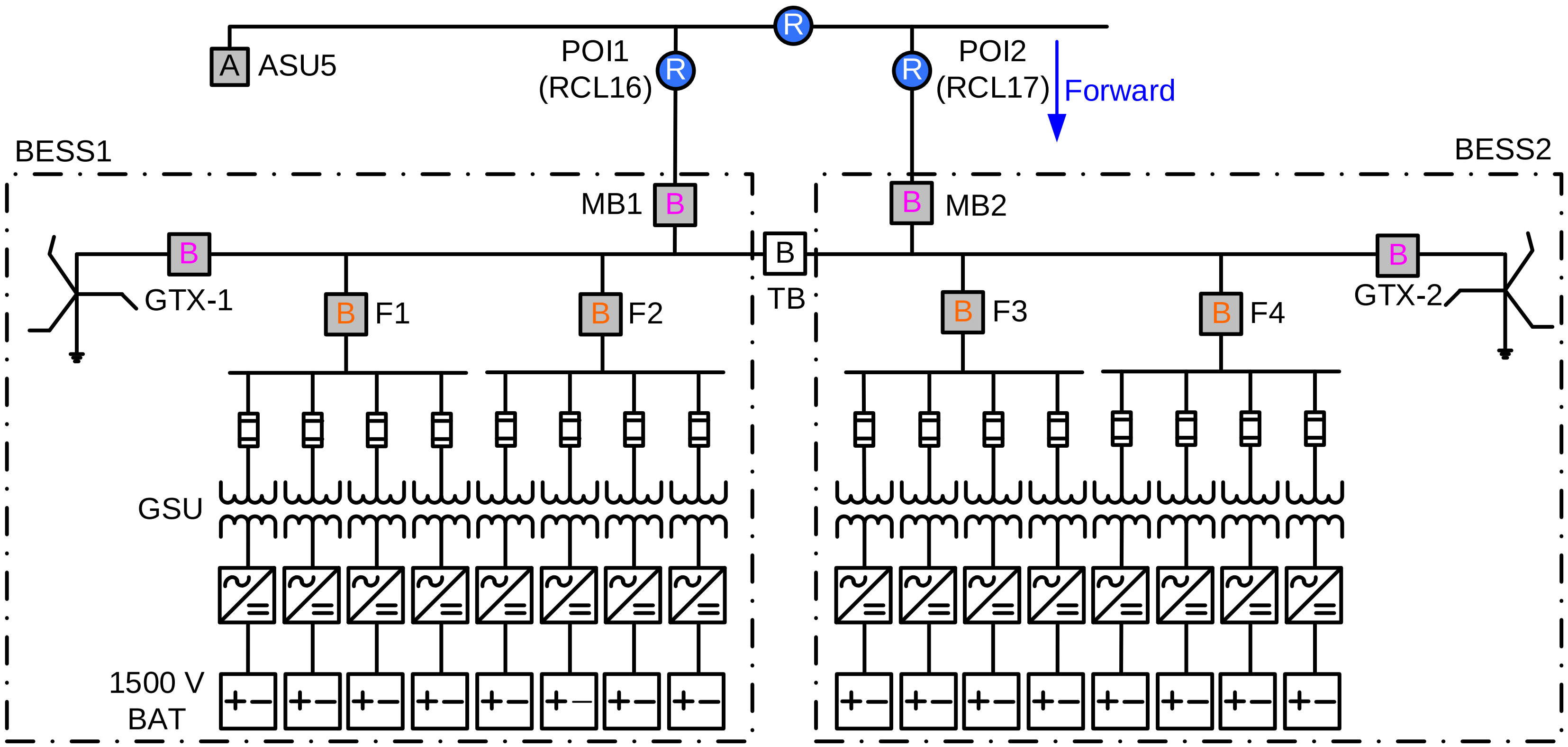

Simplified one-line diagram

Entire circuit



Simplified one-line diagram

BESS plant



LEGEND

- B Control Scheme Breakers
- A Automatic Sectionalizer
- R Other Reclosers
- R Control Scheme Reclosers
- N.C.
- N.O.

Inverters	: 16
Inverter rating	: 3600 kVA
Plant capacity	: 57.6 MVA
Inverters / breaker	: 4
Inverters / POI	: 8
Tie positions	: 2

Grid-tie inverter controls

Grid-following (GFL)

- Phase-locked loops (PLL)
- Current source
- P-Q set points
- Stiff source required

Grid-forming (GFM)

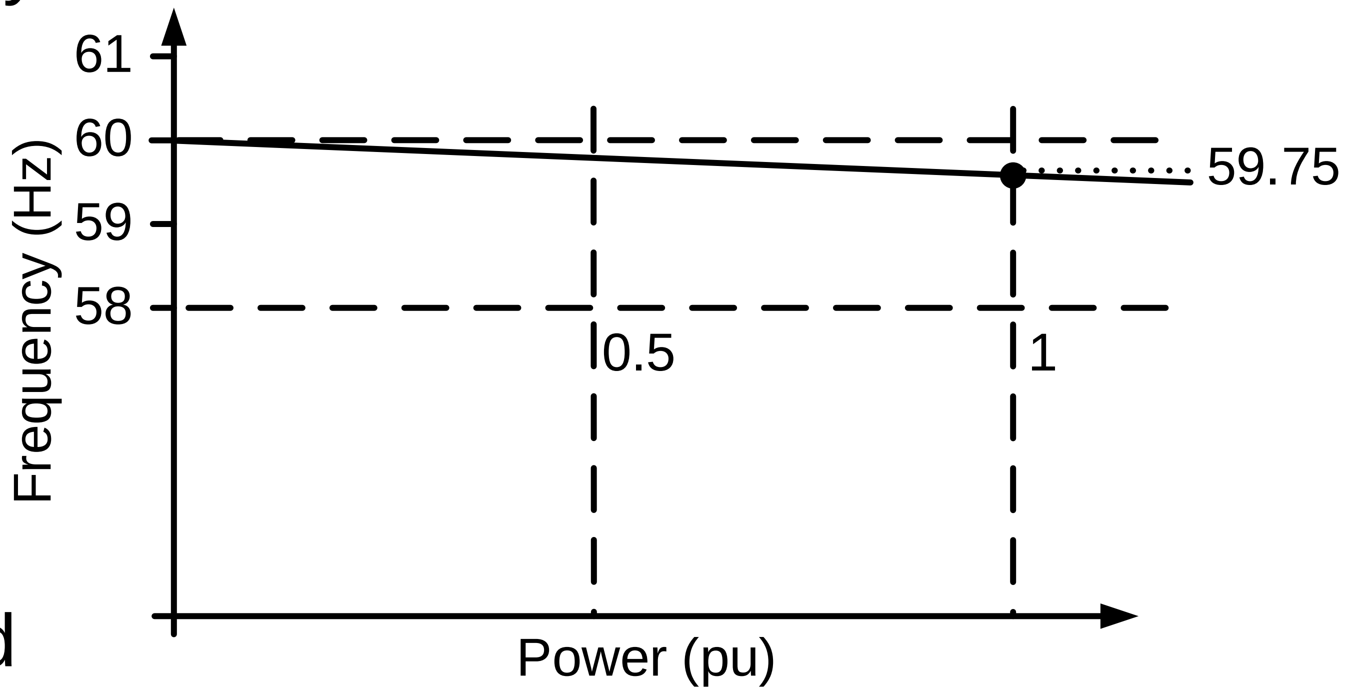
- Voltage reference and frequency reference required
- Droop control for P-Q dispatch
- Needed for islanding
- Black-start capability

Grid-tie inverter controls

- GFM inverters can seamlessly island microgrid load upon loss of grid

- GFM inverters were configured to use droop control

- Grounding evaluation needed to serve single-phase loads

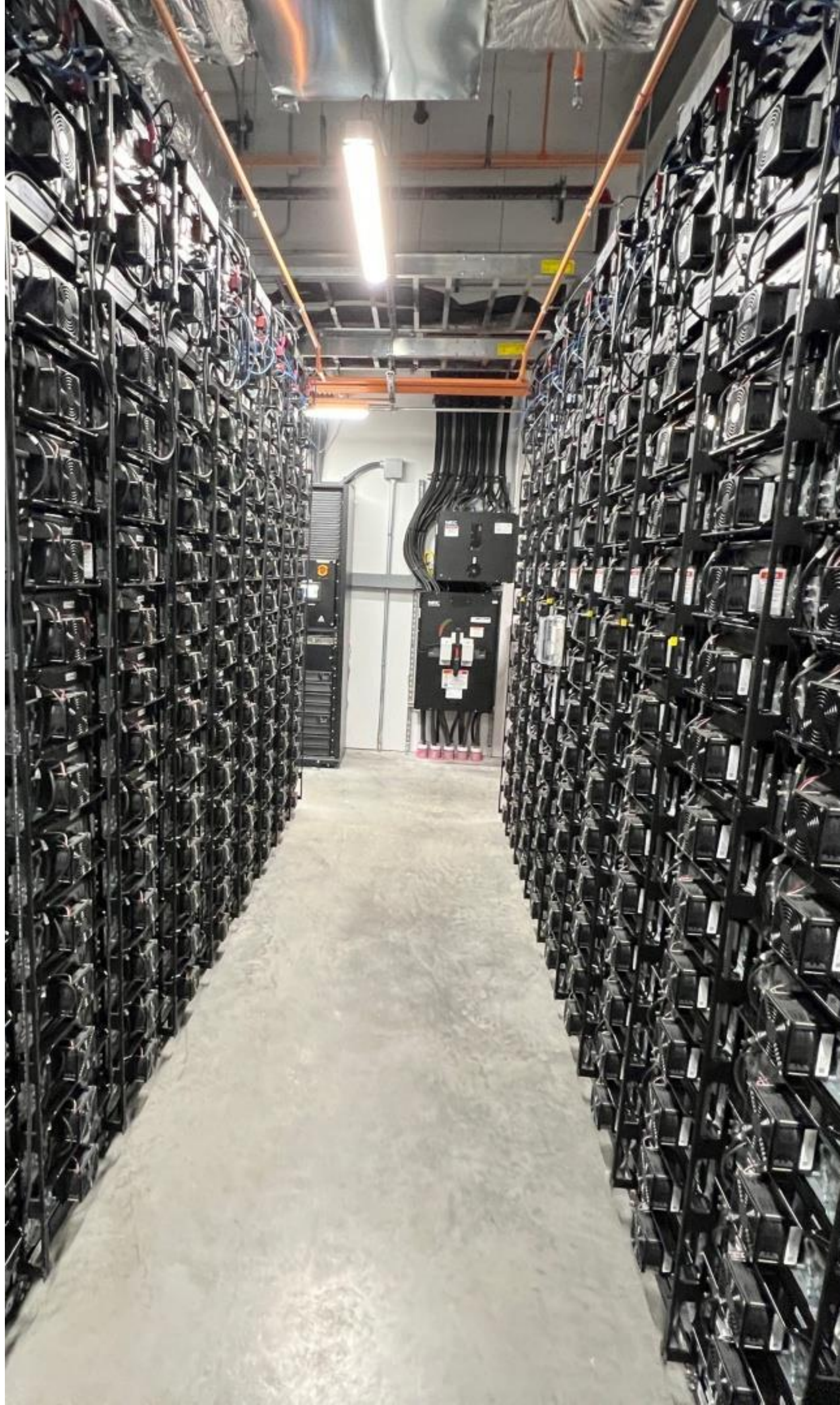


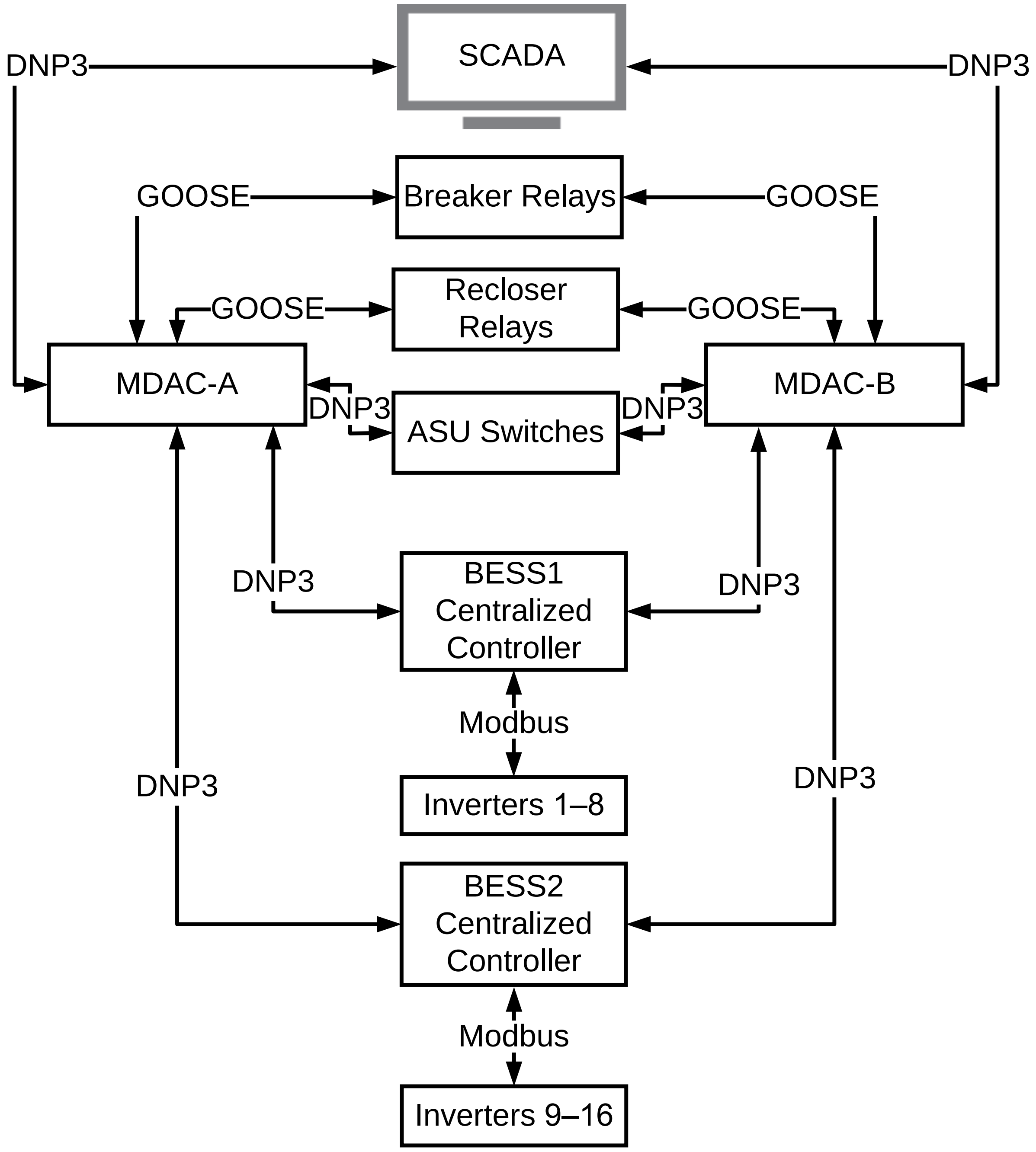
Microgrid Distribution Automation Controller (MDAC)

- Centralized controllers for entire system
- High-speed communications to distribution circuit devices and BESS plant devices
- Microgrid actions
  - BESS plant status detection (grid-parallel versus grid-disconnected)
  - Dispatch of BESS plant
  - Synchronization
- Distribution automation actions
  - Fault detection and isolation
  - Temporary fault and permanent fault reconfiguration

BESS plant controller

- Control inverter output via Modbus over TCP / IP
- Sixteen inverters divided into two BESS (BESS1 and BESS2)
- Battery asset management
- State-of-charge (SOC) management
- Load management or energy balancing at battery rack level
- Plant equipment and network monitoring and alarms





BESS and distribution circuit data flow

- MDAC; 23 kV power system control
- BESS centralized plant controller
  - Inverter control
  - Battery asset management
- High-speed fiber-optic network
  - IEC 61850
  - DNP3

MDAC
Microgrid

- Grid-Parallel mode
  - V_{ref} = 1.03 pu
  - f_{ref} = Measured filtered frequency of grid
  - Real power modes are standby, peak shaving, real power dispatch, and SOC
- Grid-Disconnected mode
  - V_{ref} = 1.0375 pu
  - f_{ref} = 60.05 Hz
  - System is islanded and follows load

Grounding transformer selection and design

- Grounding transformers are key to microgrid or island power system operation
- Unit(s) must always be connected to prepare for seamless islanding
- Island configuration control and complexity in multi-point grounding had grounding transformer installed for each BESS and all GSU transformers neutral connections are ungrounded

Grounding transformer selection and design

Criterion

- Higher overall short-circuit MVA
- Temporary overvoltage (TOV) regulation during island condition
- Ground relaying desensitization and complexity of relaying protection on distribution circuit
- Surge arrester sizing and application

Grounding transformer selection and design

Zig-zag transformer specification

Parameters	Value	Comments
Line-to-Line Voltage (kV)	22.8 kV	Distribution circuit line-to-line (LL) voltage
Impedance (Ohms / Phase)	6.4 Ohms	Value was selected to satisfy TOV requirements based on PSCAD simulations, while factoring impact on ground relaying sensitivity
Continuous Neutral Current	140 A	Highest continuous system current unbalance considering largest single fuse operation
Thermal Rating Current	6000 A	Highest fault current through the grounding transformer under any operation
Frequency	60 Hz	System frequency for grid-parallel and islanded operations

Protection system requirements

System stability

<10 cycle or high-speed decoupling of BESS from utility grid

Fault clearing

Detection of weak or inverter–based source in grid-parallel or islanded configuration

Reliability

Protective devices coordination and proper sectionalization of faulted areas

Protection scheme
Fault detection

- Island configuration inverter-based or weak source short-circuit limitations

- Total inverter ratings twice the maximum circuit load

- Island size limited by inverter availability

- Custom logic torque controlled forward directional phase overcurrent elements

Protection scheme
Fault detection

The following relay elements supervised forward directional overcurrent:

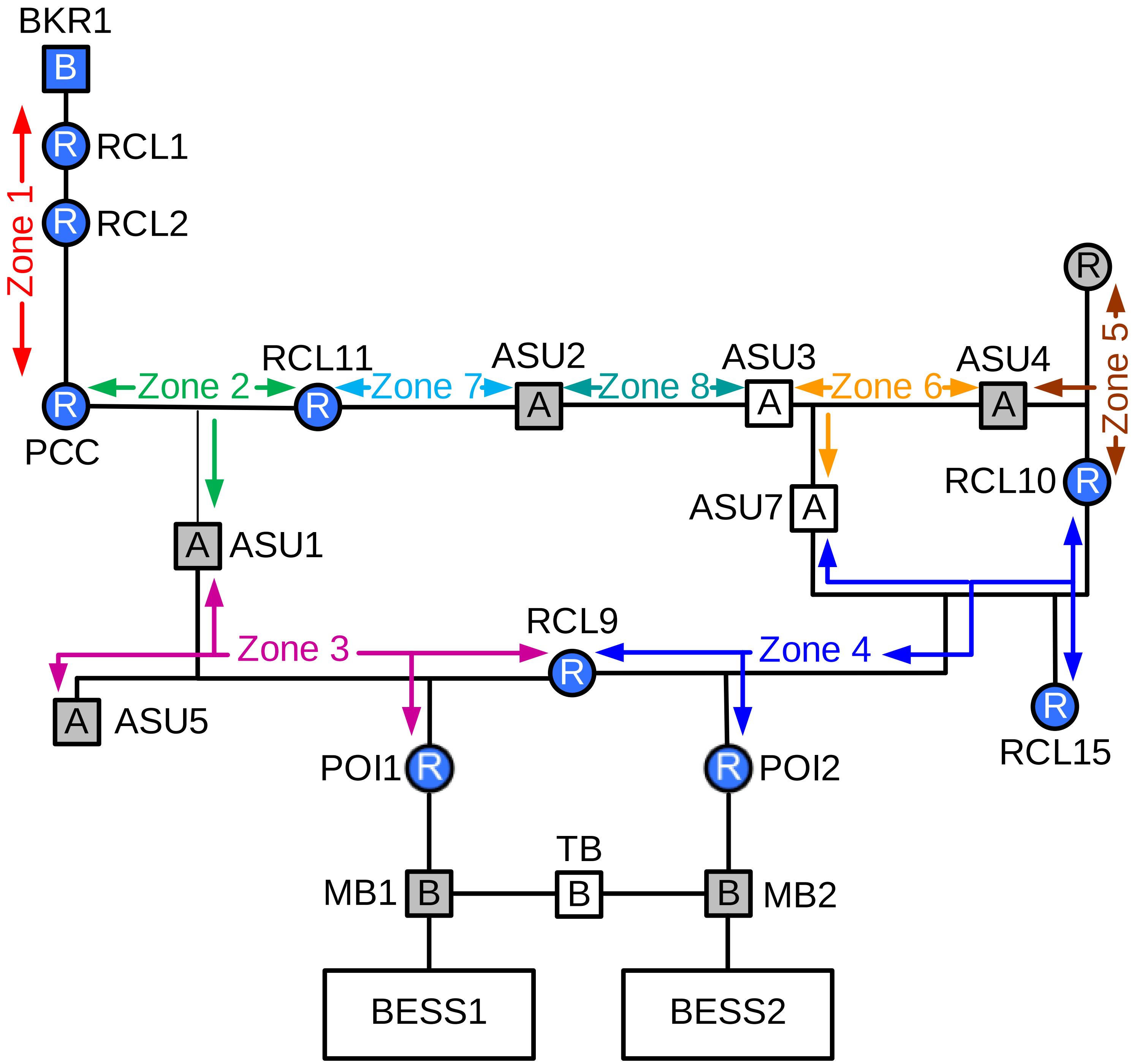
- Directionality: 32PF OR 32QF OR 32GF
- Load region: ZLOAD impedance observed by a particular recloser controller within load encroachment region
- Unbalance condition: 50Q negative-sequence current fault detector
- Ground current: 50G zero-sequence current fault detector
- Voltage measurement: LOP indicates a loss-of-potential to a recloser controller voltage input

MDAC
Distribution automation

- Relays detect fault and trip reclosing device
- MDAC determines if fault is temporary or permanent
- Temporary fault
  - Reclosing sequence is successful
  - MDAC restores system to original state by performing automatic synchronization
- Permanent fault
  - Reclosing device goes into lockout
  - MDAC identifies fault zone and isolates fault
  - Fault zone determines reconfiguration

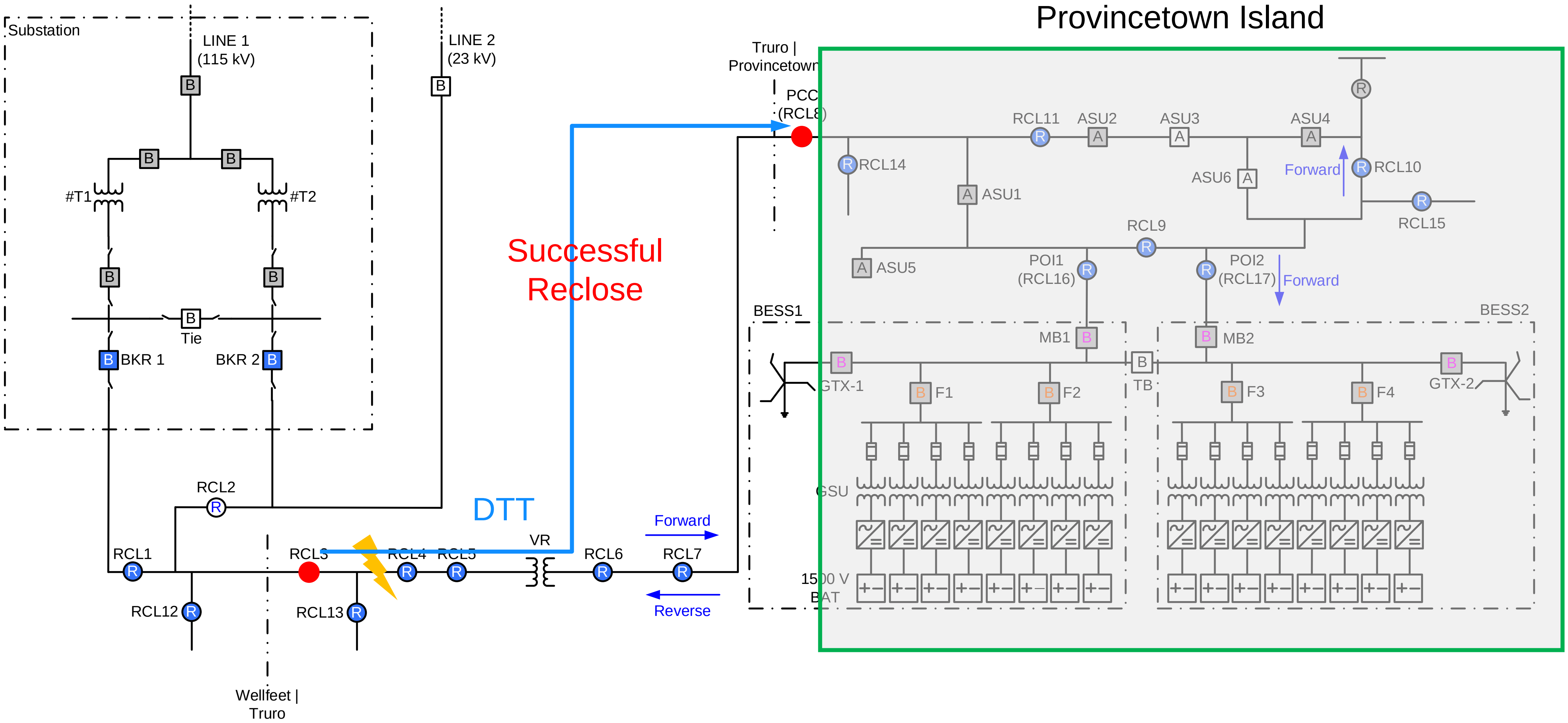
MDAC

Distribution automation zones



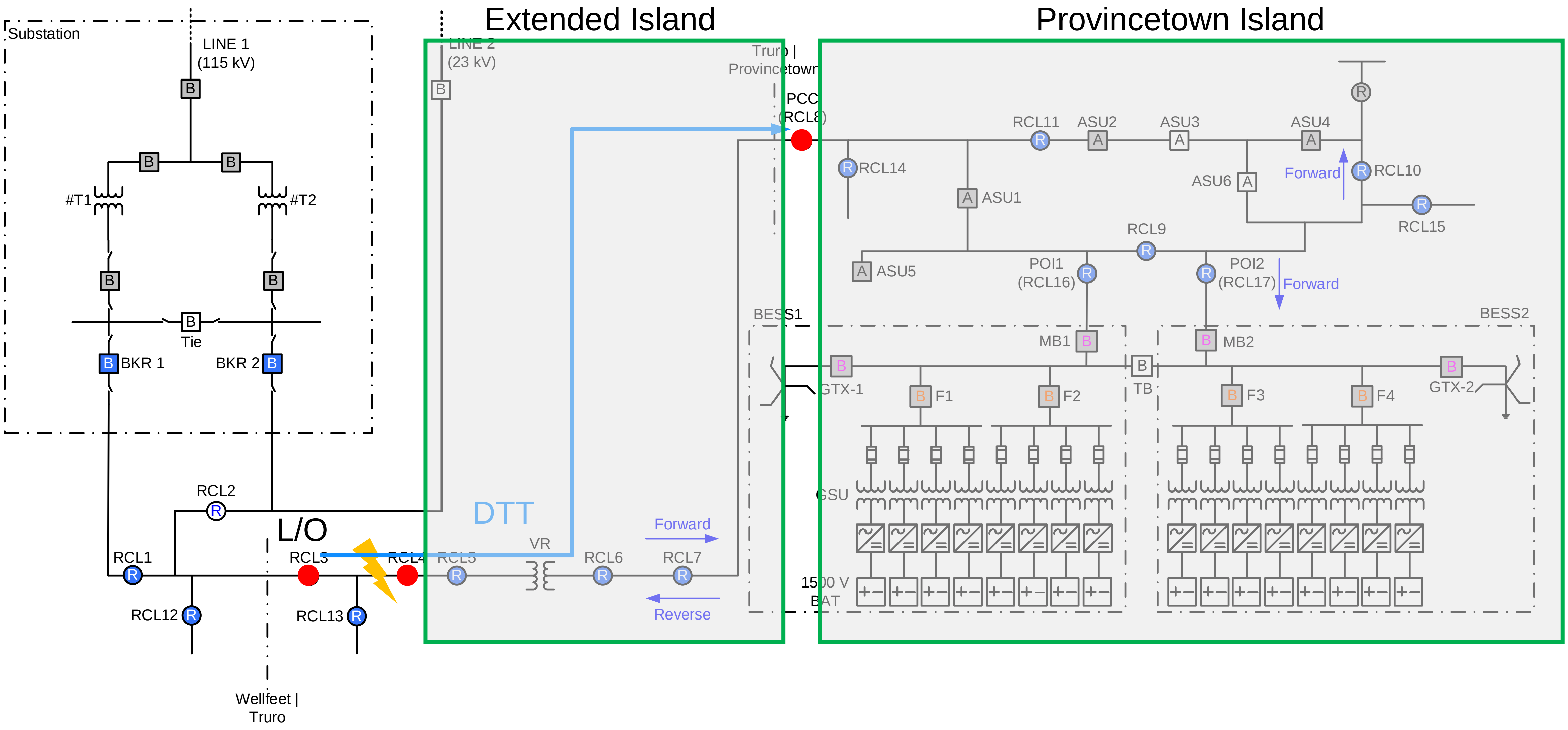
Protection scheme

Temporary fault



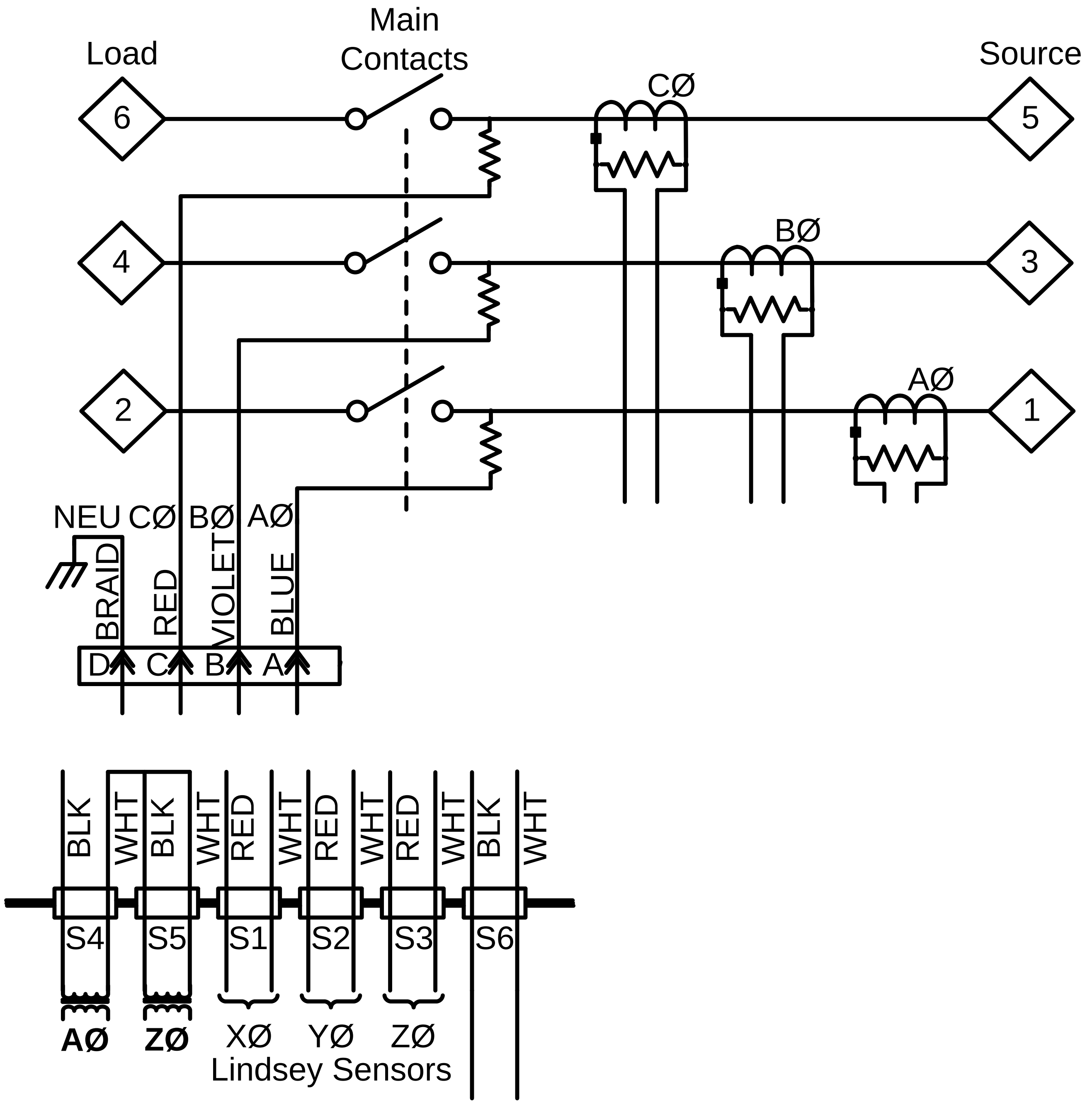
Protection scheme

Permanent fault



Seamless restoration
Synchronization

- Synchronization at multiple nodes
  - Two substation breakers
  - Twelve reclosers
- Relay determines if synchronization is required after receipt of close command
- MDAC adjusts voltage and frequency of BESS plants to match grid
- Relay closes recloser or breaker when sync conditions are met
  - Grid voltage within 0.95–1.05 pu
  - Voltage difference between grid and BESS within 3%
  - Slip frequency difference of –0.03 Hz
  - Phase angle of 10%



Synchronization challenges

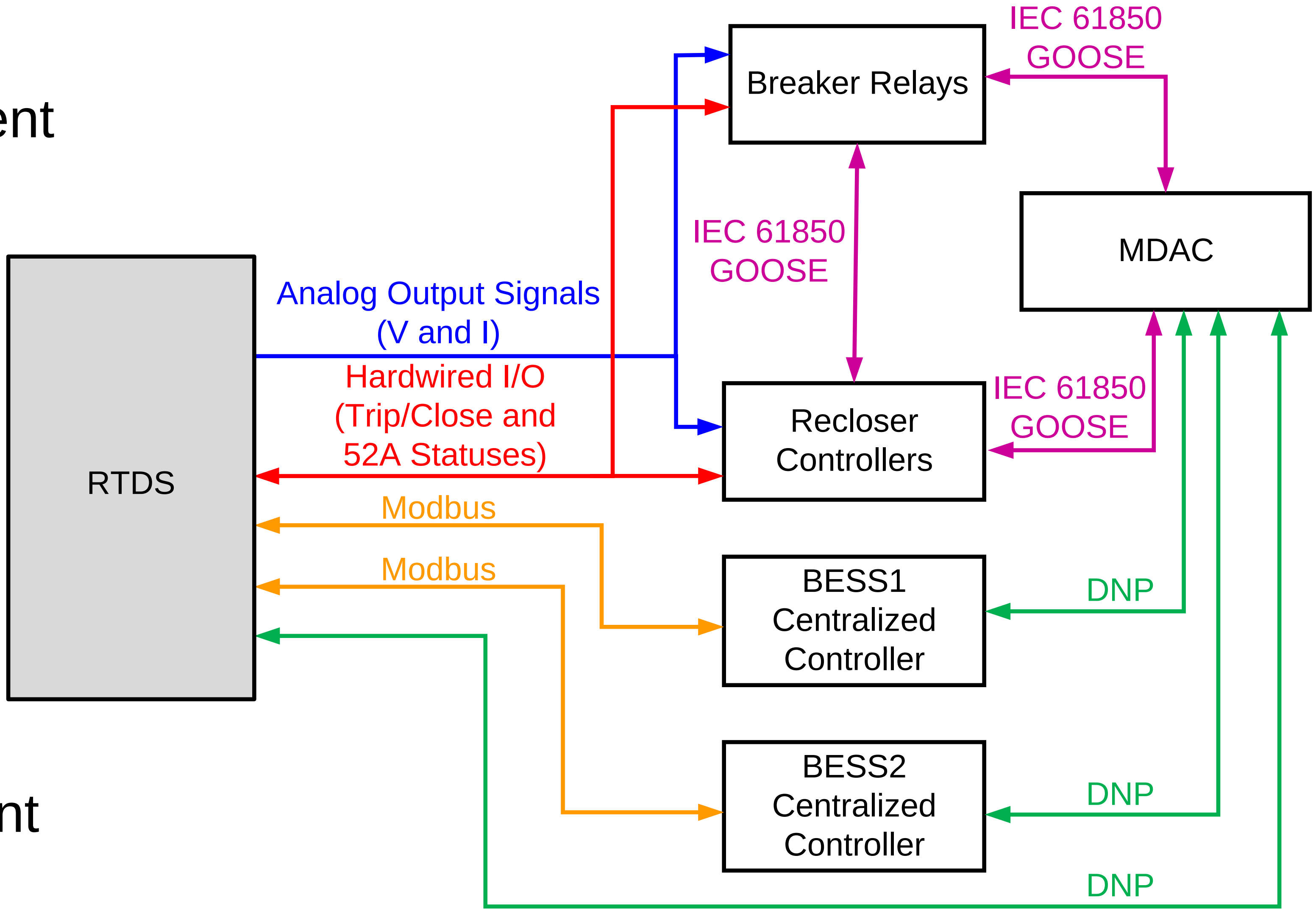
- Voltage sensing on both sides required
- Internal voltage sensor on source side
- External voltage sensor was installed on load side

Synchronization challenges

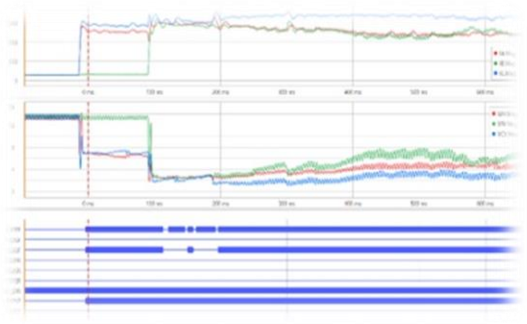
- Separate shielded cable runs were used for voltage cabling to reduce interference
- Measured voltage difference was 6.6% (greater than 3% requirement) during first round of sync testing
- Internal Voltage Sensor (IVS) was replaced with second set of external voltage sensors to meet accuracy requirements

Scheme validation using RTDS and HIL

- RSCAD model development
- Integration testing of microgrid and BESS plant controller
- Hardware-in-the-loop (HIL) testing
- Protection scheme validation; COMTRADE file playback
- Control scheme validation; test-environment configuration HMI

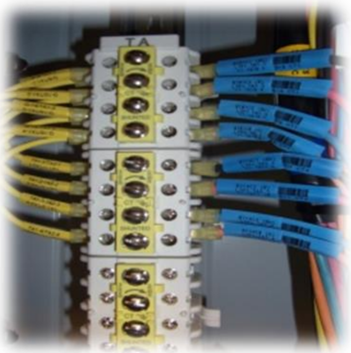


Onsite testing and commissioning



RTDS testing

Simplified based on level of relay scheme testing in RTDS and HIL



Functional testing

GPS-synchronized testing with custom-made recloser interface testing module

Skillset development

Distribution recloser technician performing transmission and substation-level testing

Circuit configuration control

- Significant changes in interconnected distributed energy resources (DERs), load, or operating configuration

- Modeling validation task in work management and / or project approval

- Limitation on DER Interconnection Planning simplified process


Questions?