A Simplified Approach to Distribution Feeder Protection for Microgrids With Inverter-Based Resources

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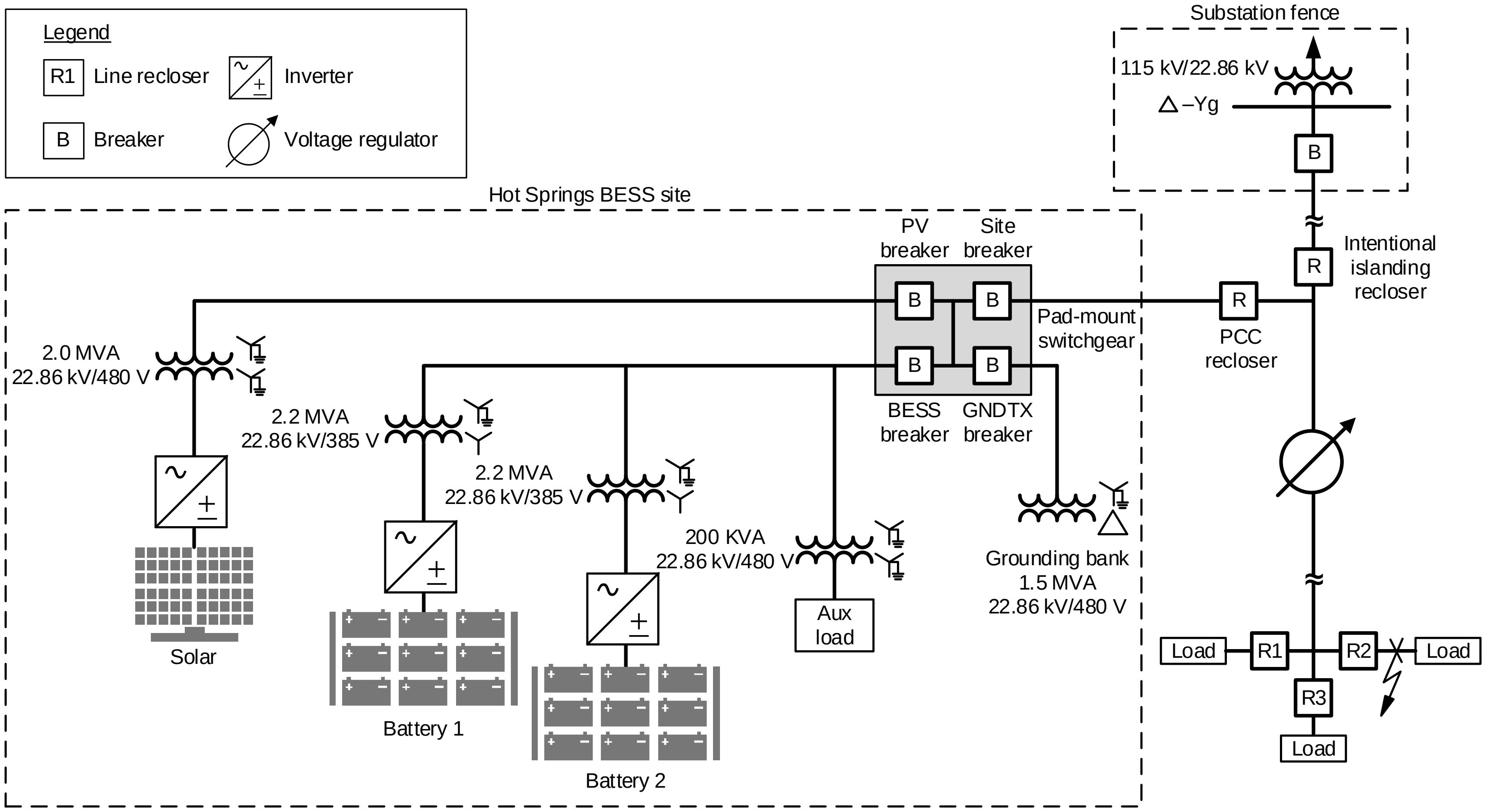
Hot Springs DERs

- Environmental sensitivity and rough terrain limit options to address extended outages
- Non-wires solution provides grid-support functions during grid-parallel operation
- DERs serve as alternate power source during outages
- DERs are combination of 4.4 MW lithium-ion BESS and 1.85 MW PV plant

Simplified one-line diagram

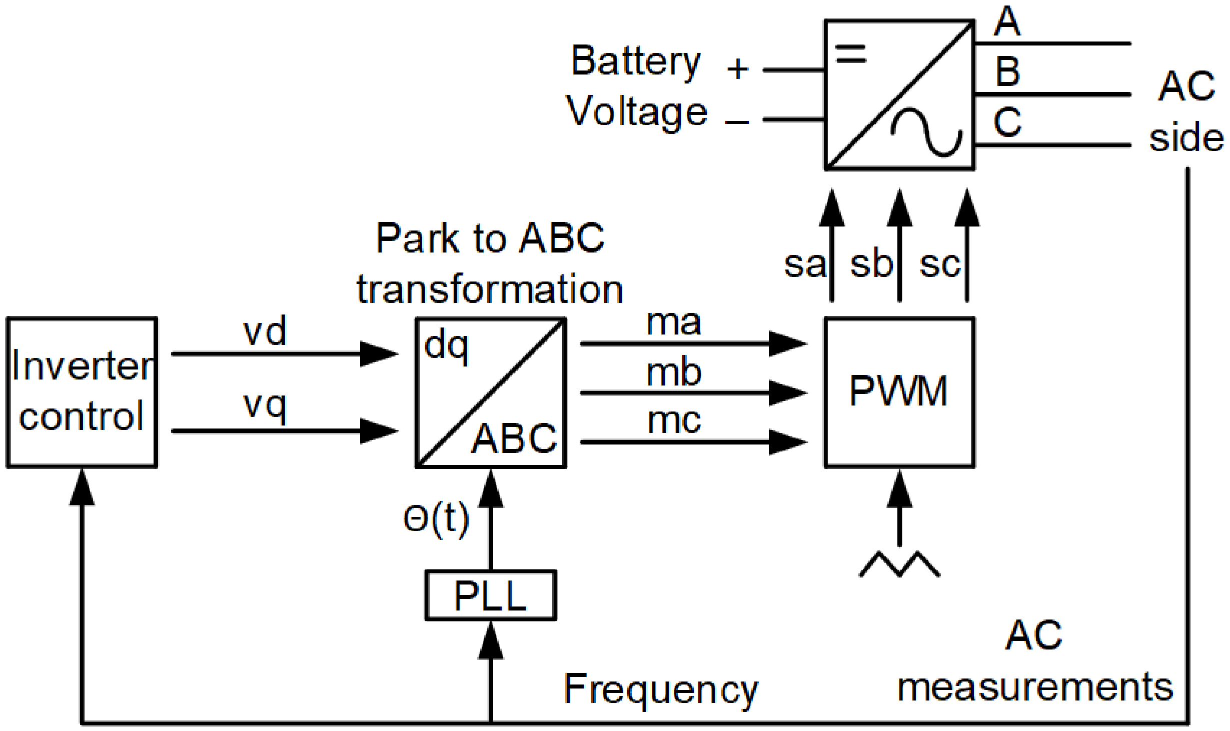
- Single feed to town of Hot Springs from substation
- IID recloser installed for circuit segmentation
- R1 and R2 electronic reclosers sequentially pick up load during black start



Inverter control

Grid-following (GFL) mode

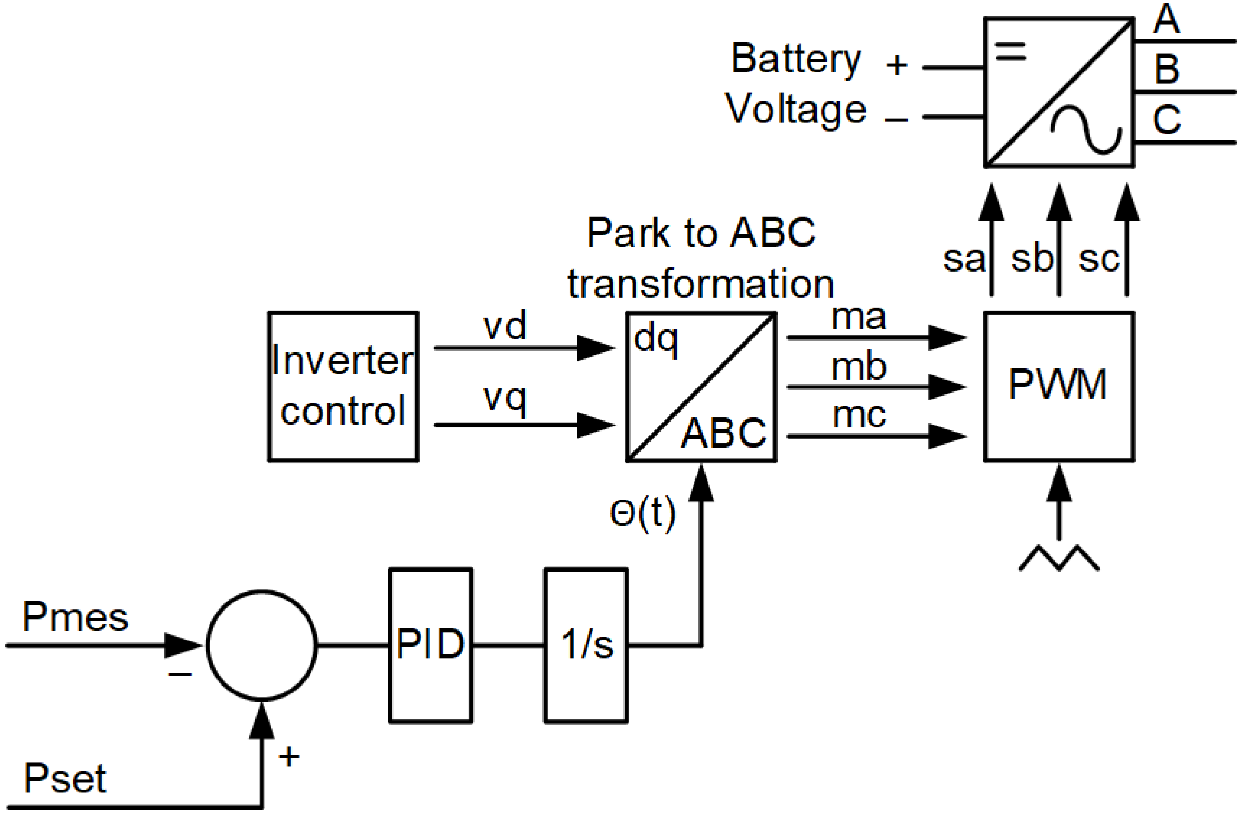
- Uses PLLs
- Requires a source to follow
- Injects currents relative to voltage obtained from PLLs based on desired P and Q; acting as current source
- Trips offline via anti-islanding schemes upon loss of grid



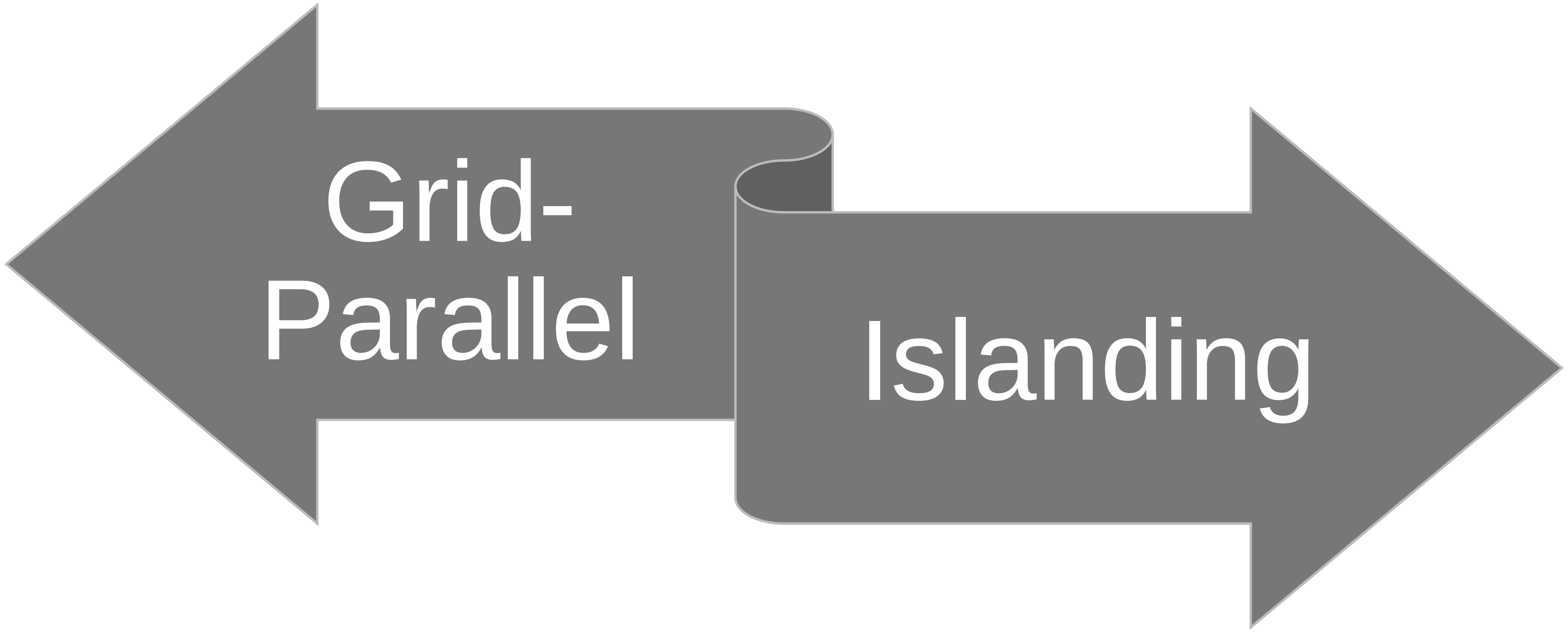
Inverter control

Grid-forming (GFM) mode

- Generates its own voltage and frequency
- Provides droop control for P-Q dispatch
- Acts as voltage source
- Is required for islanding operation
- Is capable of black starting microgrids



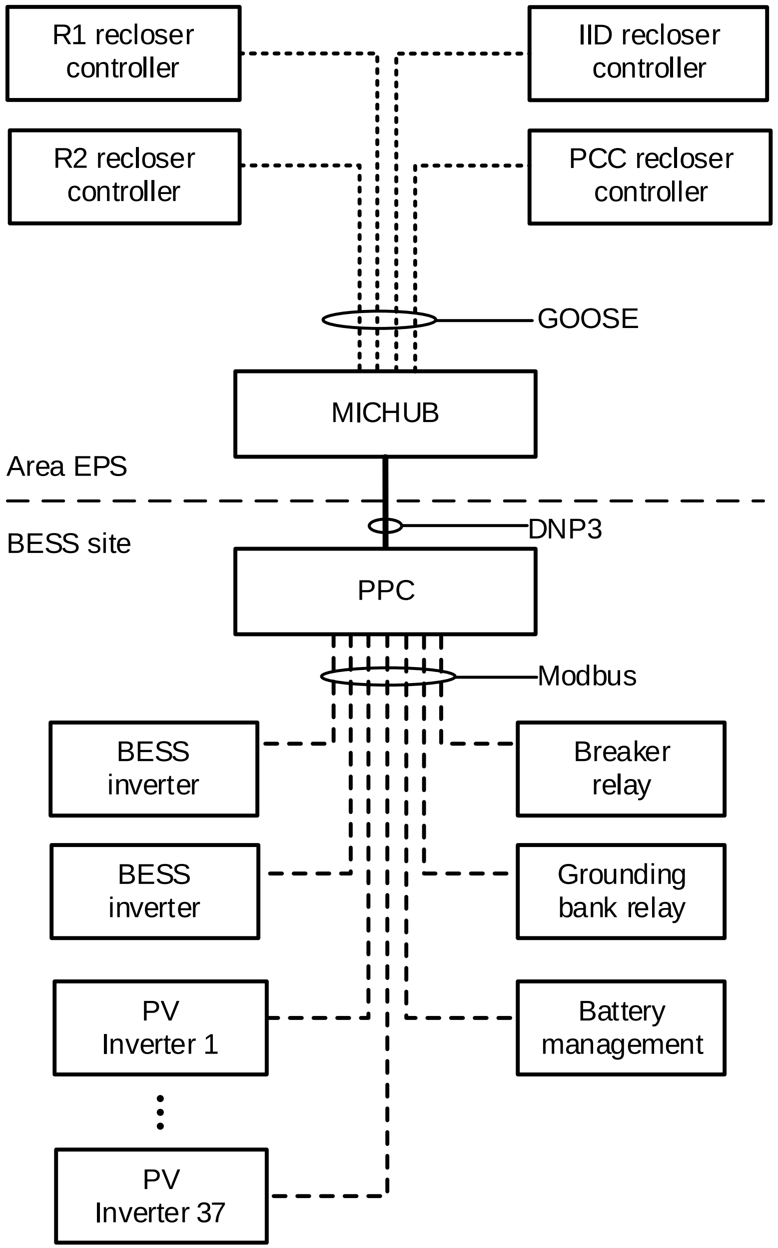
Control system transition



- Performs break-before-make transition
- Requires successful completion of multiple steps within transition sequence

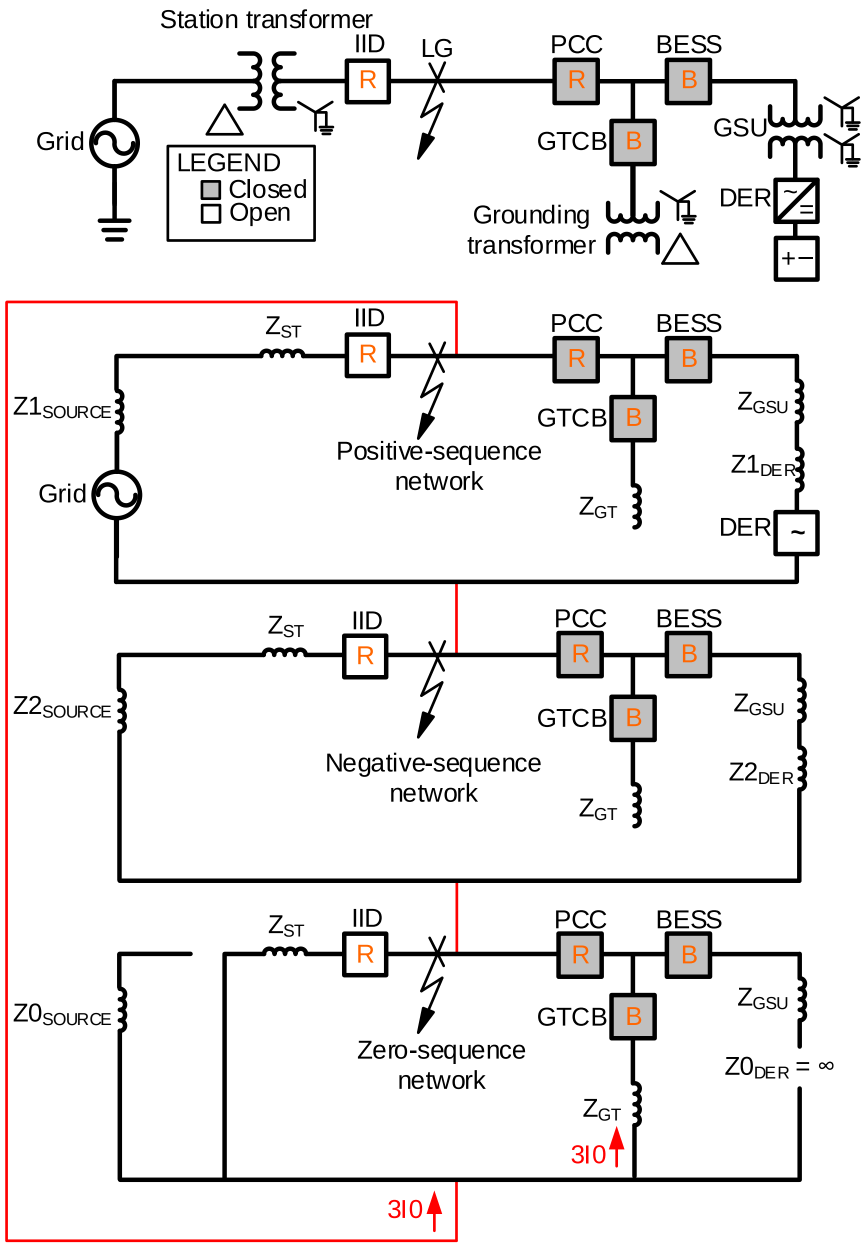
Microgrid automation

- PPC interfaces with plant relays and inverters
- MICHUB interfaces with distribution circuit reclosers
- PPC puts inverters and grounding transformer in grid-parallel and islanding configurations
- MICHUB puts distribution circuit reclosers in grid-parallel and islanding configurations



Grounding transformer for microgrids

- Effective grounding is key to microgrid operation (COG <=0.8, TOV=1.38 pu)
- Grounding transformer provides path for zero-sequence currents to flow
- Grounding transformer is in service only during microgrid operation to limit desensitization of ground fault protection during grid-parallel operation
- Optimal zero-sequence impedance may not be practical for large-scale deployments



Protection philosophy

Grid-parallel operation

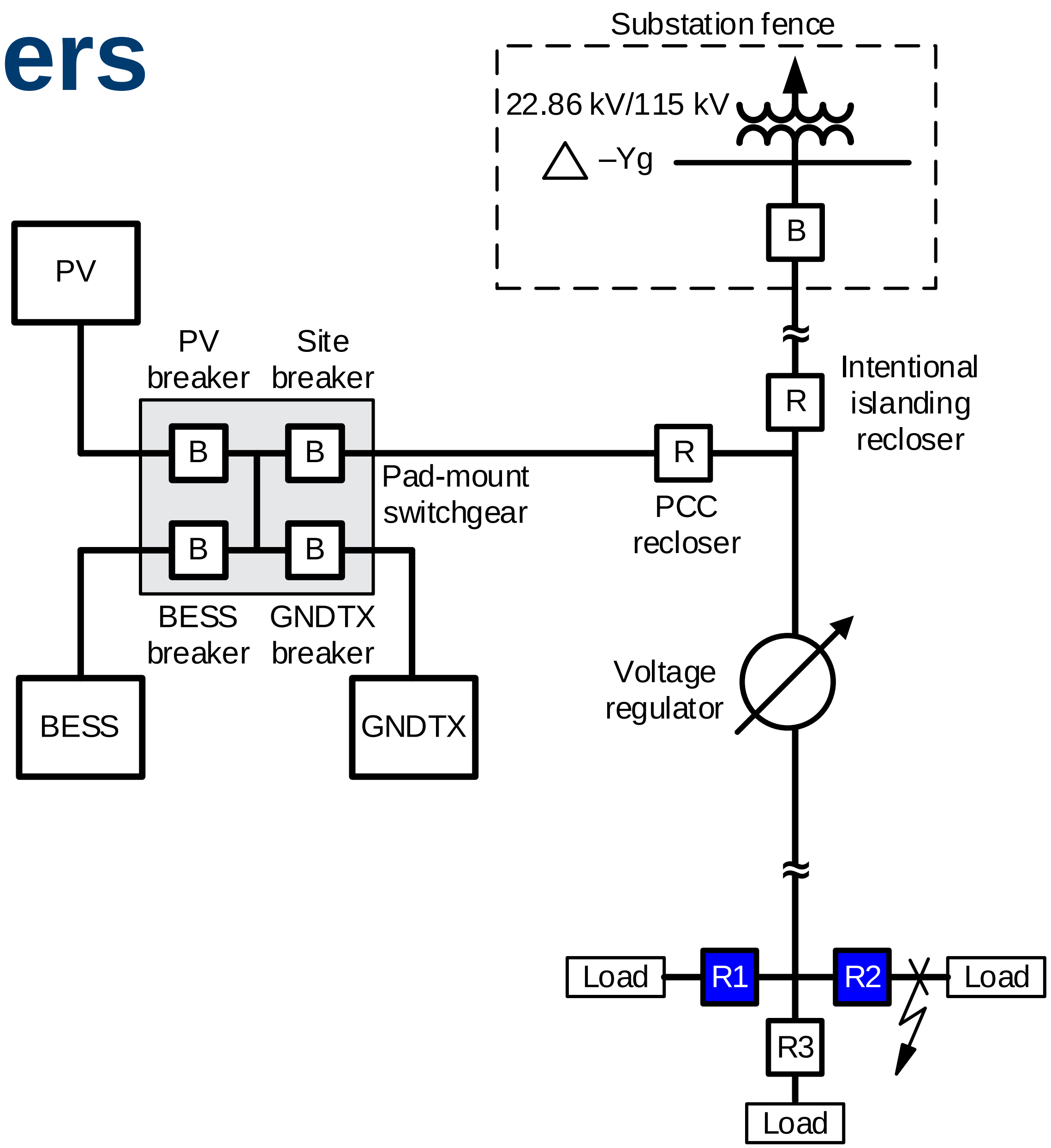
- Distribution circuit uses traditional protection schemes
  - Fuse-saving
  - Trip-saving
  - Multishot reclosing
- Inverters do not source sustained fault currents when operating in GFL mode
- DER plant switchgear relaying and PCC recloser controller protection philosophy is based on IEEE 1547 voltage and frequency excursions

Microgrid operation

- GFM inverters source limited faulted currents based on their rating (1 to 1.2 pu)
- Inverters oversized to maintain large sensitivity margins are not financially feasible
- Inverters source their rated fault current for faults within microgrid boundary
- Project-specified inverter can source sufficient negative-sequence currents to be used for protection

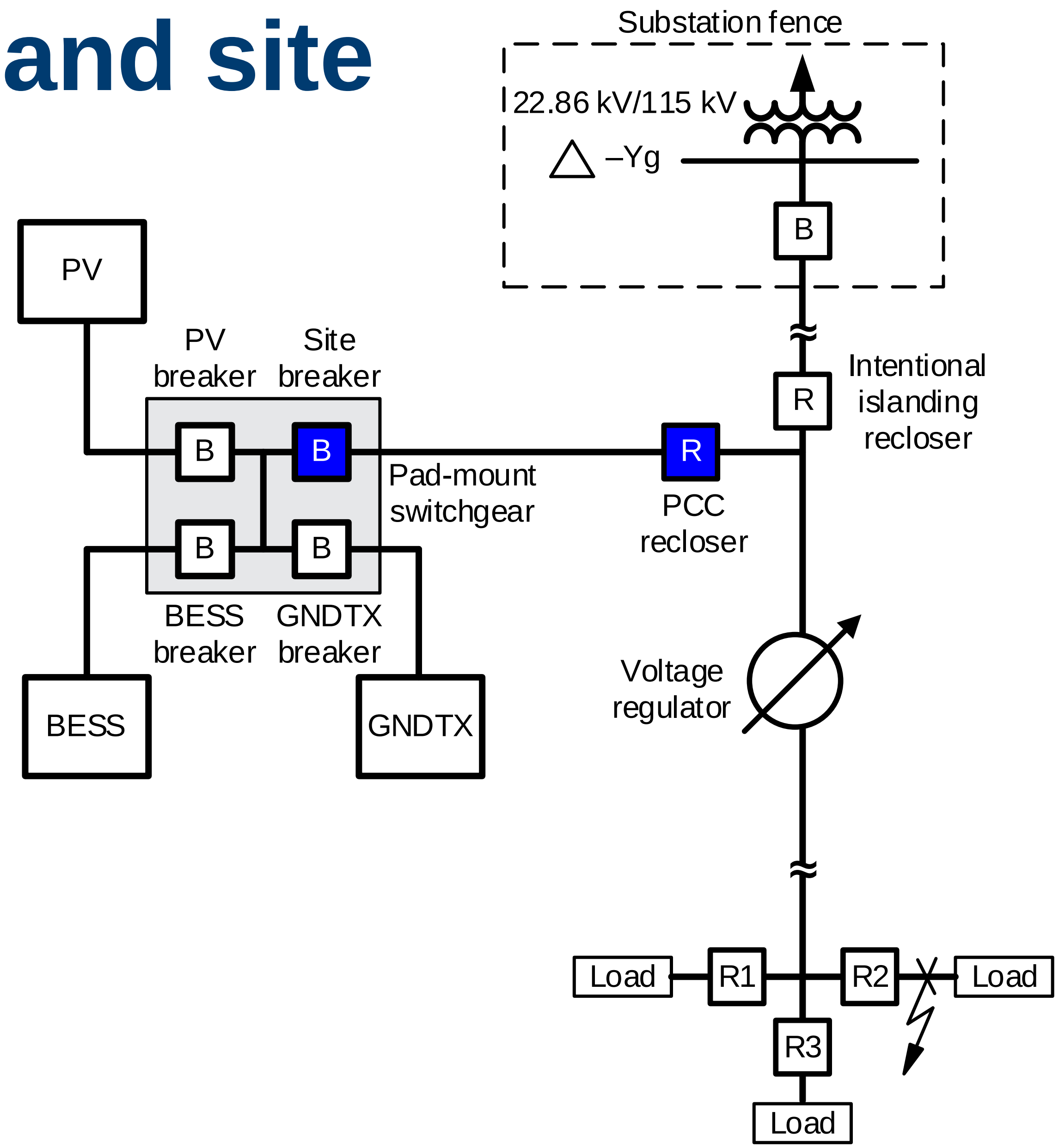
Feeder electronic reclosers

- 50PT elements set to 1.5 pu of maximum load current seen by recloser and supervised by 2nd harmonic blocking
- 50QT elements set to 0.5 pu of minimum LL 3I2 fault current and above maximum feeder imbalance
- 50GT elements set to 0.3 pu of minimum LG and LLG 3I0 fault currents and above maximum feeder imbalance
- Elements have 0.3-second time delay



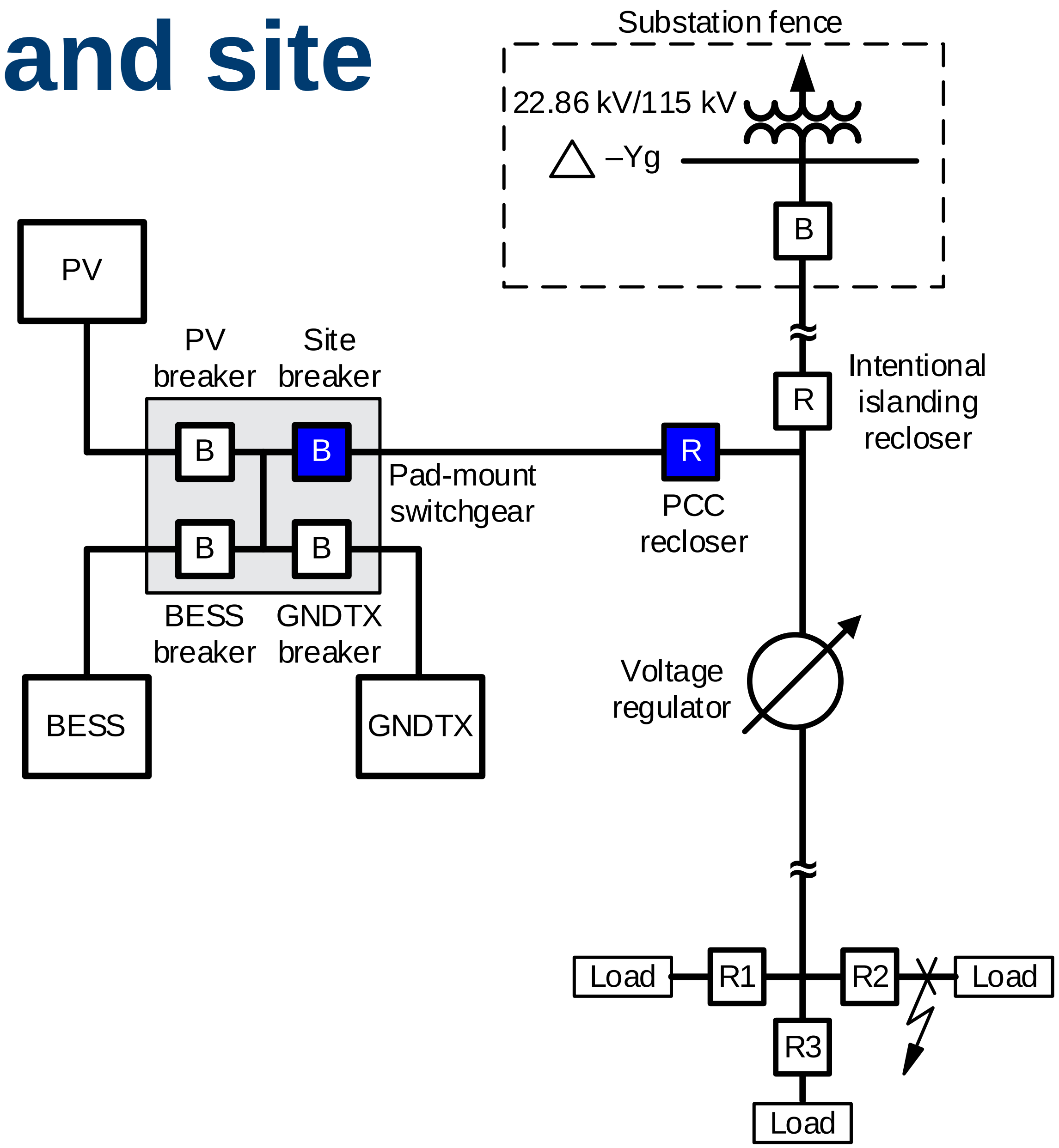
PCC recloser controller and site main breaker relay

- Inverter full current capability is used and not constrained by load current
- 50PT elements are set equal to rated inverter output (1 pu) and supervised by undervoltage elements (0.8 pu)
- Phase elements are supervised by 2nd harmonic blocking for security during cold-load pickup



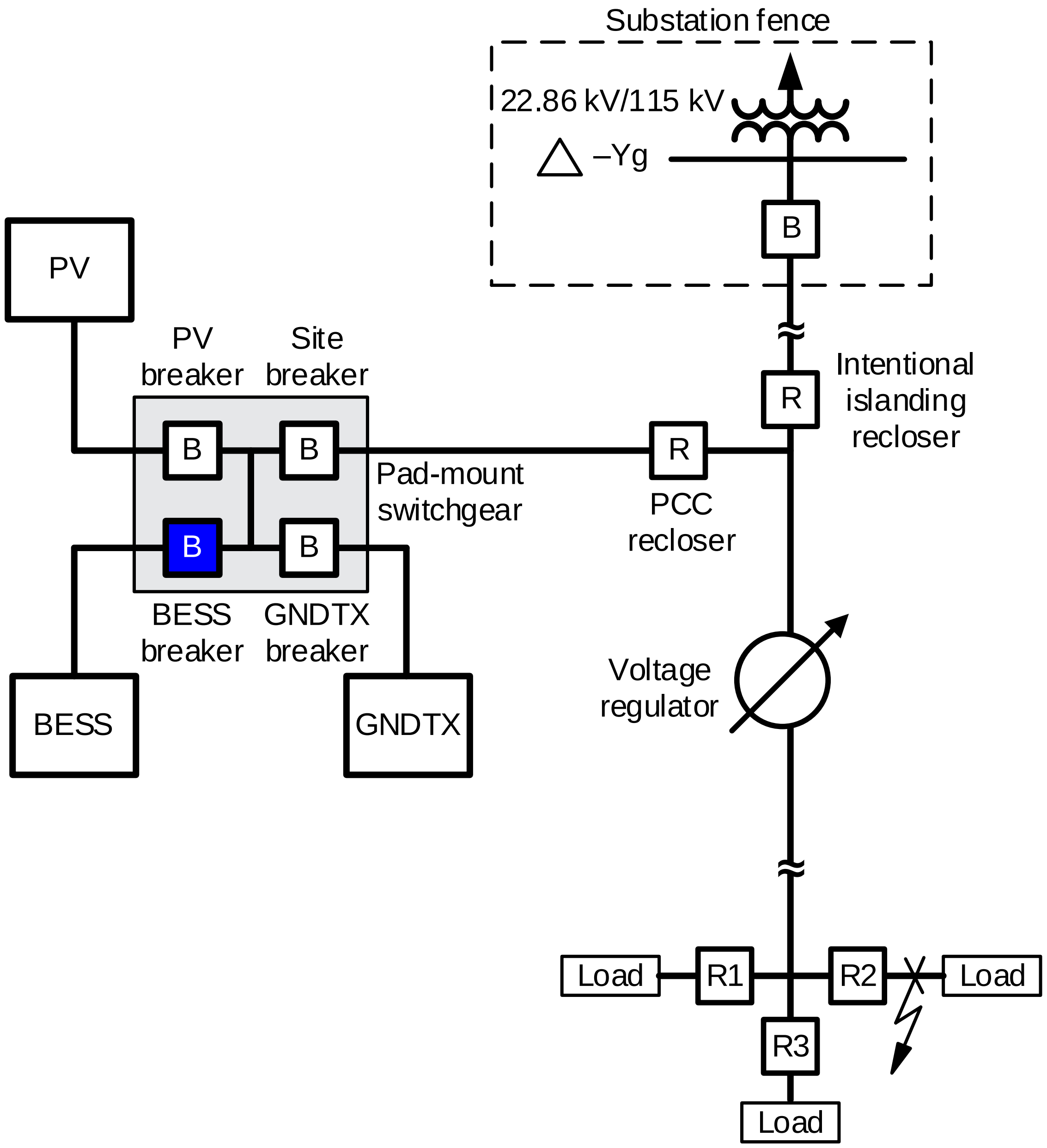
PCC recloser controller and site main breaker relay

- 50QT elements set to 0.5 pu of minimum LL 3I2 fault currents and above maximum feeder imbalance
- 50GT elements set to 0.3 pu of minimum LG and LLG 3I0 fault currents and above maximum feeder imbalance
- PCC maintains 0.3-second CTI with R1 and R2
- Site breaker maintains 0.3-second CTI with PCC



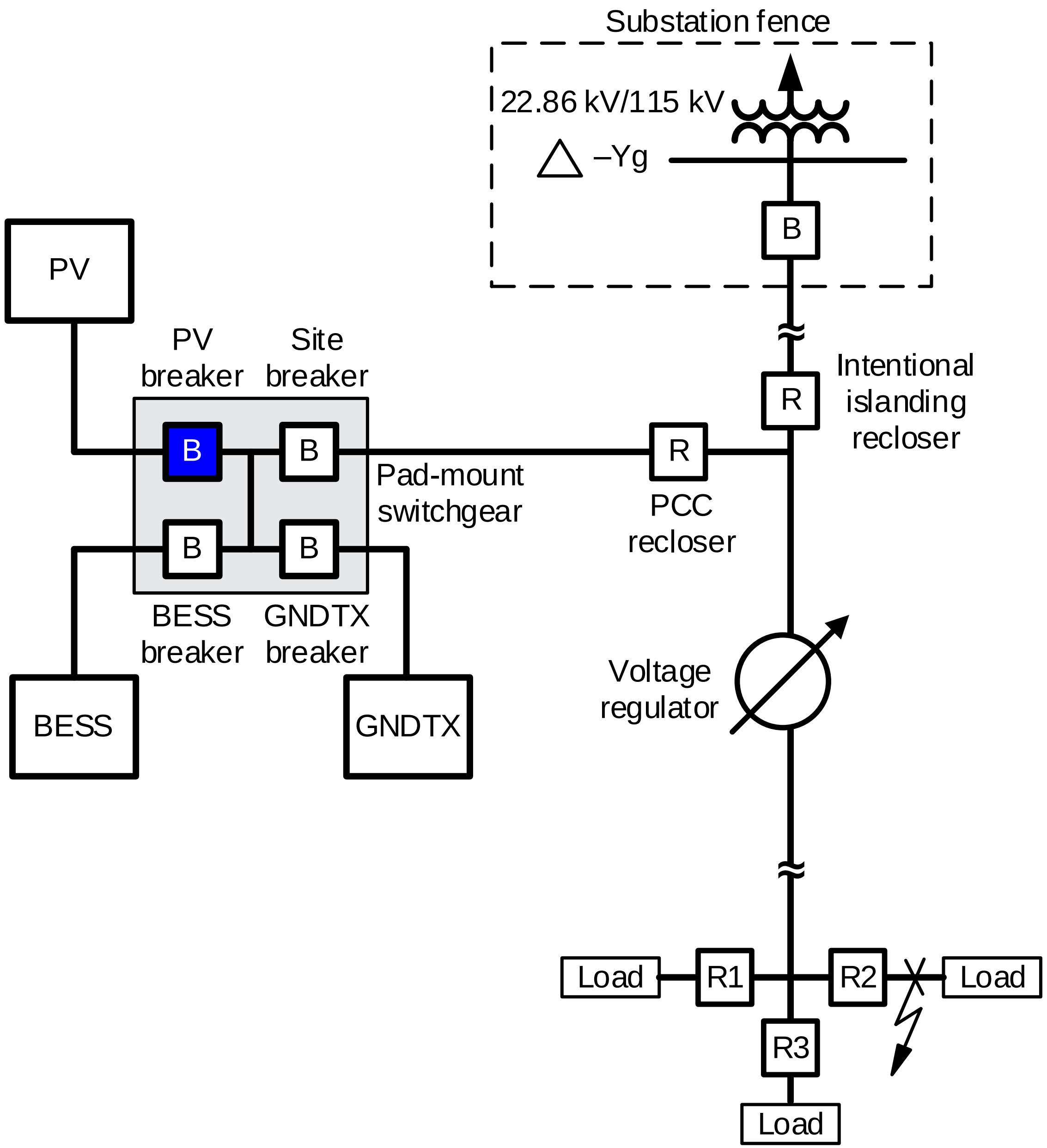
BESS breaker relay

- BESS inverters only source I1 and 3I2 currents for faults on distribution feeder
- 50PT and 50QT pickups are set same as site breaker with CTI of 0.3 seconds
- BESS breaker relay only sees 3I0 currents for ground faults between breaker and GSU
- 50GT set to 0.3 pu of the minimum LG and LLG 3I0 fault currents for faults between breaker and GSU with 0.3-second delay



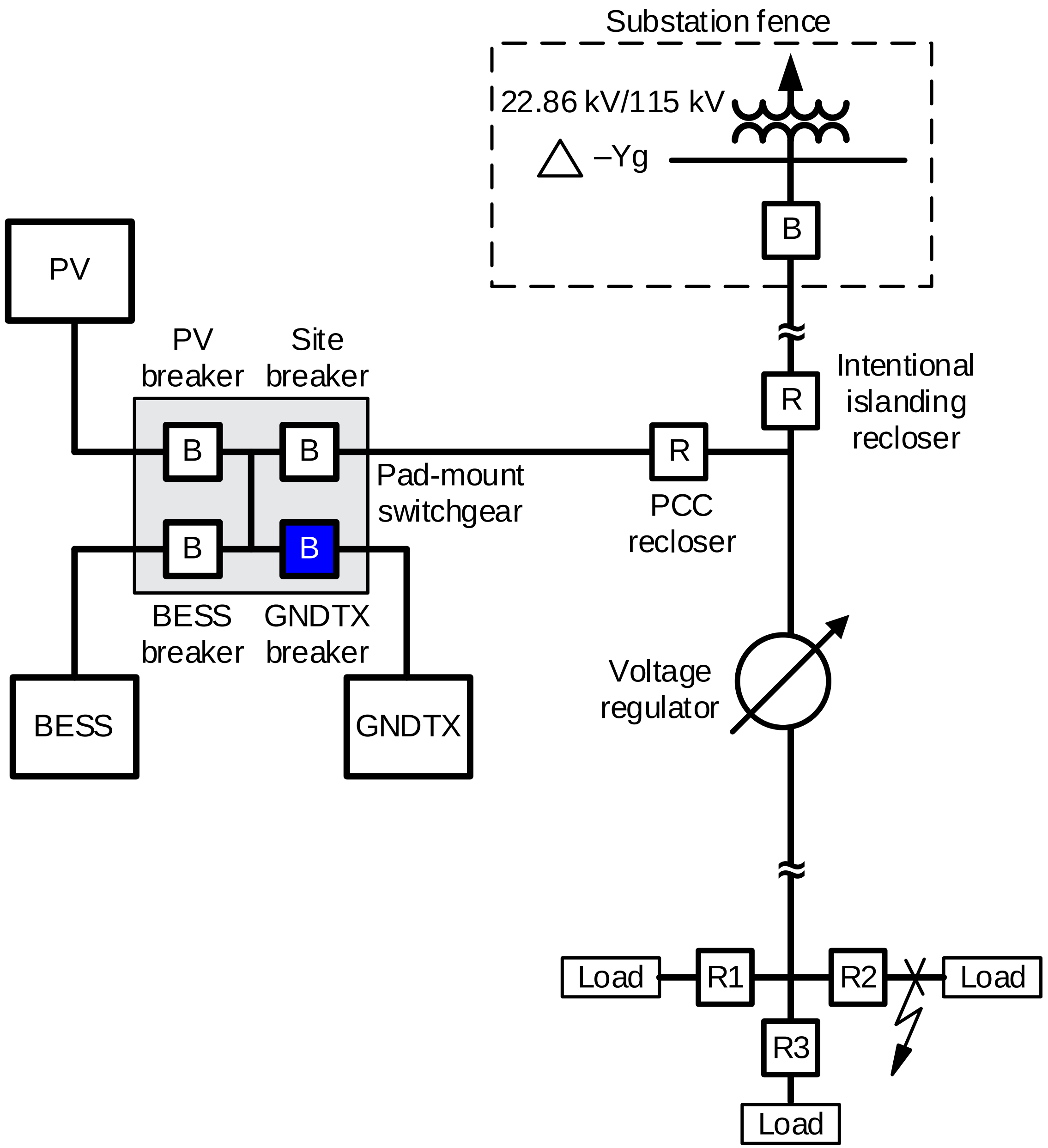
PV breaker relay

- PV inverters do not source sustained fault currents, so PV breaker relay sees fault currents for faults downstream of PV breaker
- 50PT set to 1.2 pu of maximum PV plant output and supervised by 2nd harmonic blocking with 0.3-second delay
- 50QT set to 0.5 pu of minimum LL 3I2 fault currents and 50GT set to 0.3 pu of minimum LG and LLG 3I0 fault currents with 0.3-second delay



GNDTX relay

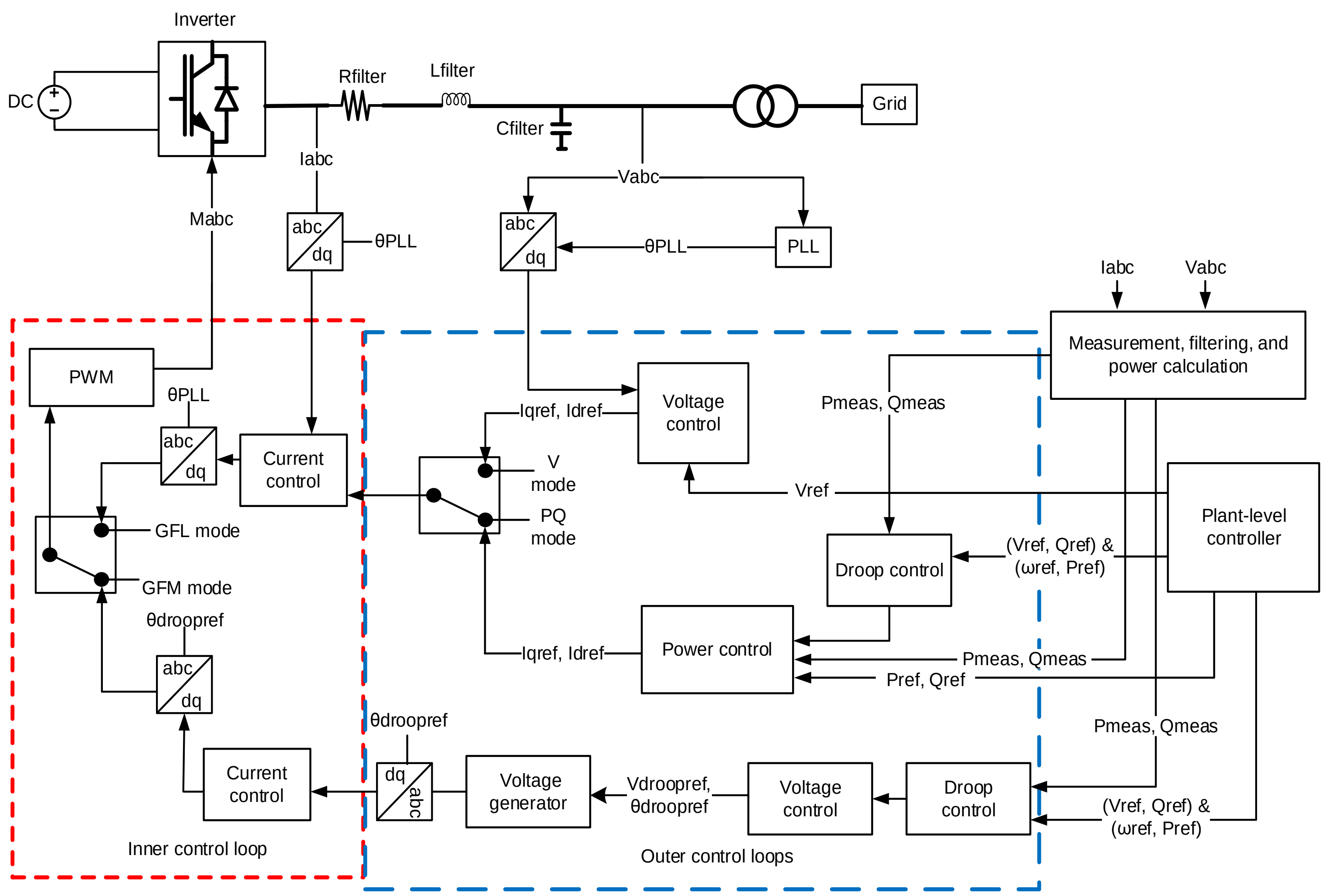
- GNDTX relay sees phase and 3I0 fault currents for distribution circuit ground faults
- 50GT set to 0.3 pu of minimum LG and LLG 3I0 fault currents and above maximum load imbalance
- 50PT set to 0.5 pu of minimum phase fault currents between GNDTX breaker and GNDTX, and above maximum phase imbalance
- GNDTX relays maintain 0.3-second CTI with BESS breaker relay



RTDS modeling and test results

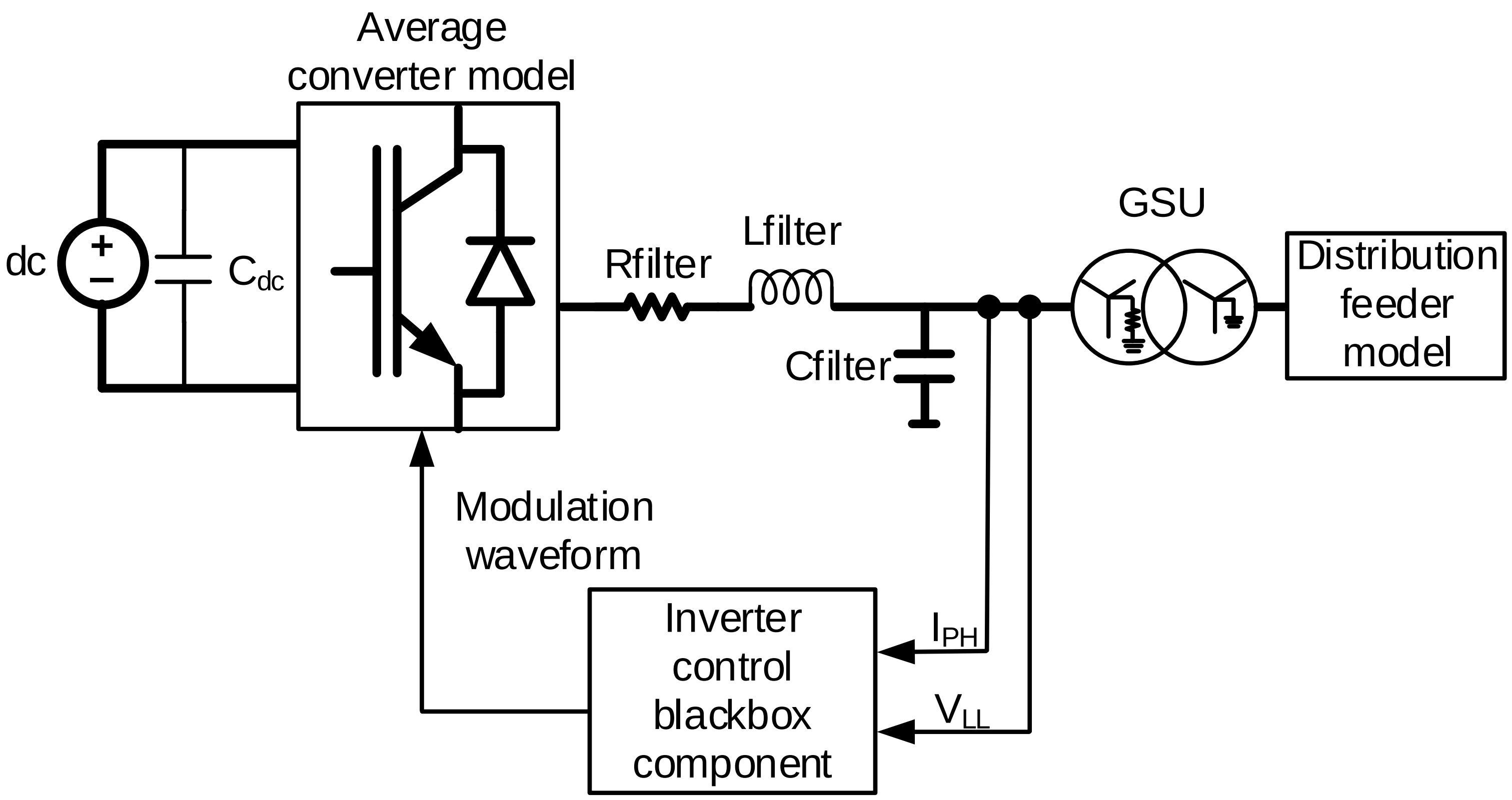
Inverter model using EMT software

- EMT inverter models are important in understanding interactions with power system
- EMT models use two control layers; an inner fast control loop and outer slow control loop
- Generic inverter models tuned to match inverter current specifications may be acceptable for radial applications



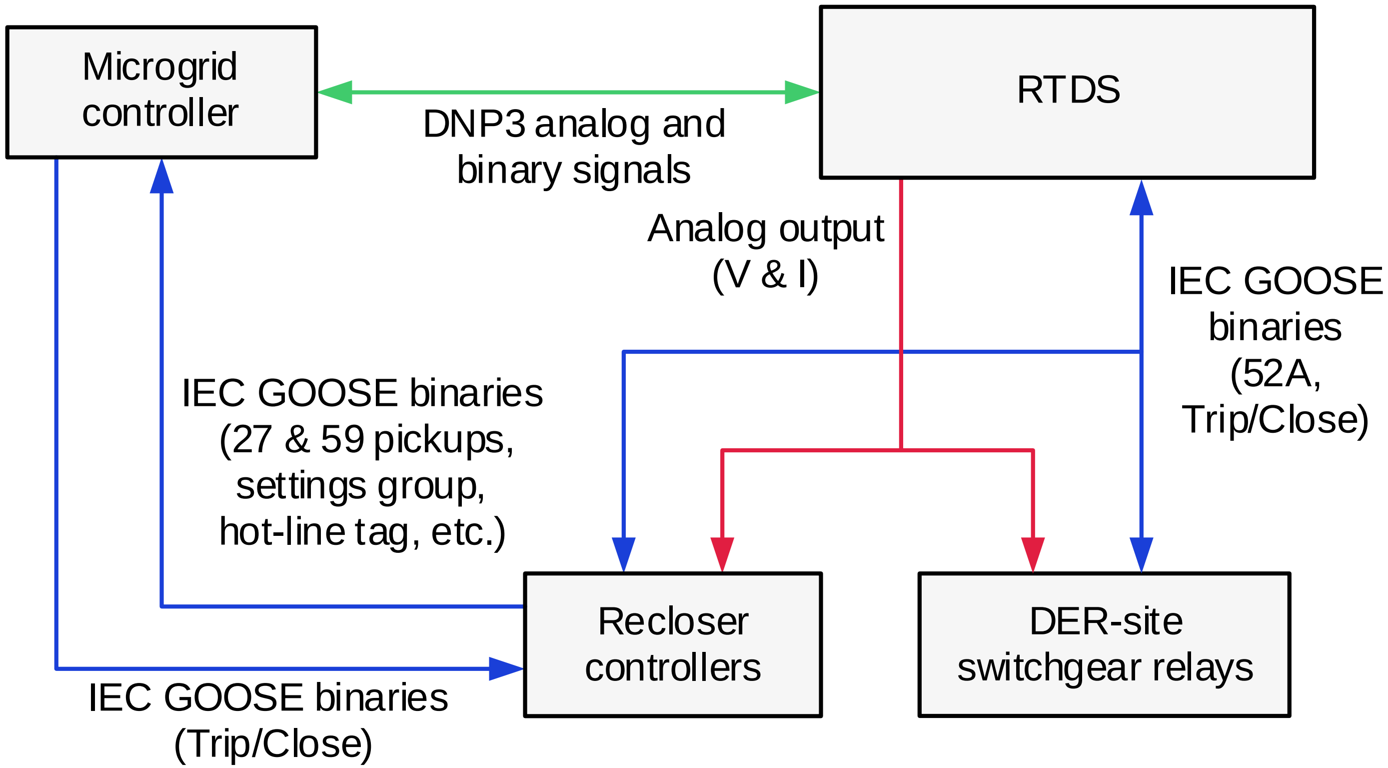
Inverter controls integrated in RTDS

- Inverter black box model with field parameters was used directly in RTDS test environment
- Filtered inverter phase current (I_{PH}) and LL voltage (V_{LL}) were inputs to inverter control components
- AC filter (R_F, L_F, and C_F) and dc capacitor (C_{dc}) were modelled to suppress higher-order harmonic with vendor-recommended values



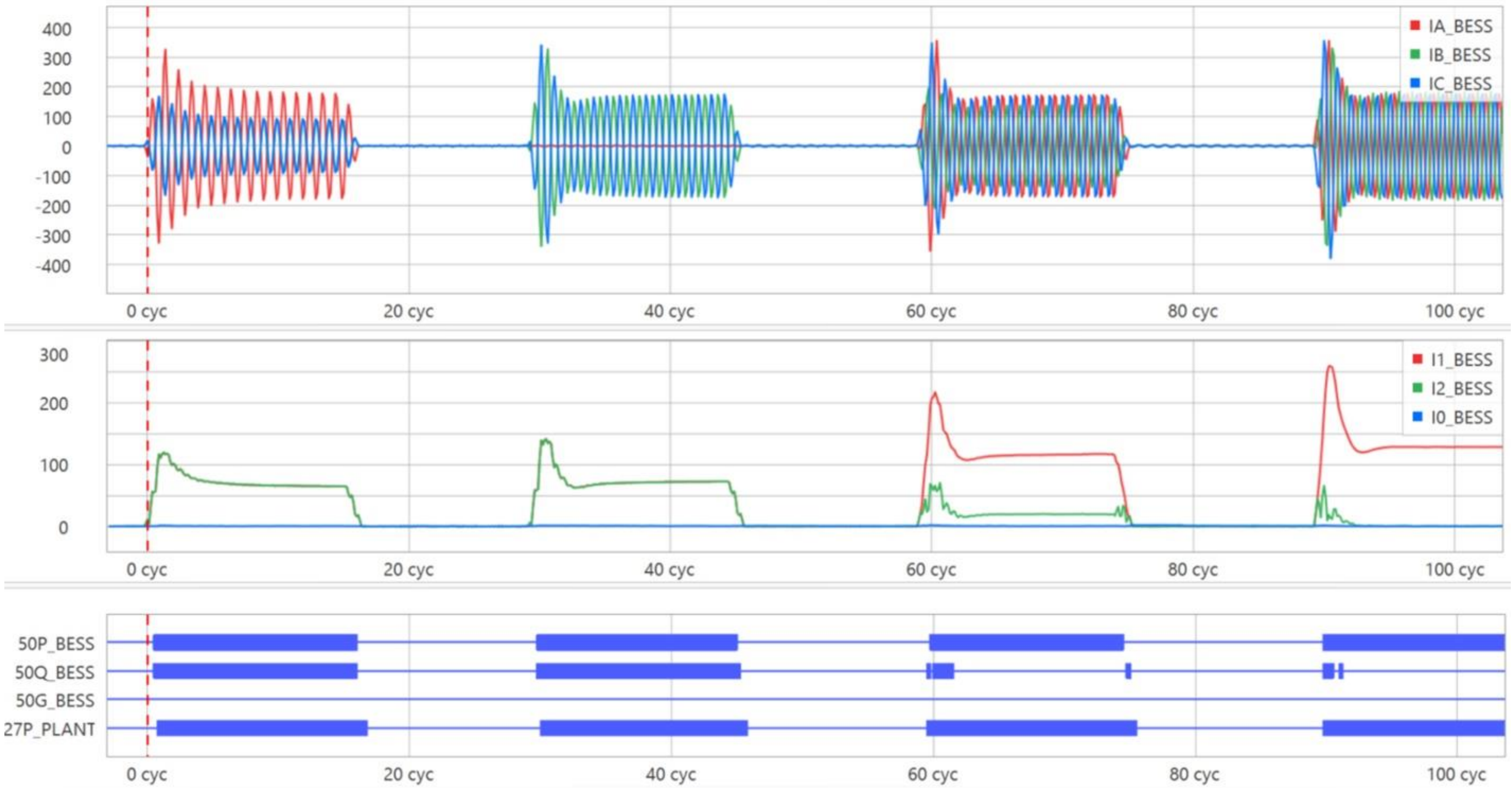
CHIL testing

- Distribution circuit was reduced to boundary equivalent and integrated with inverter model in RTDS test environment
- Distribution circuit recloser controllers, plant relays, and microgrid controller were interfaced with RTDS for CHIL testing
- Various loading conditions and system contingencies were simulated to validate protection and control schemes



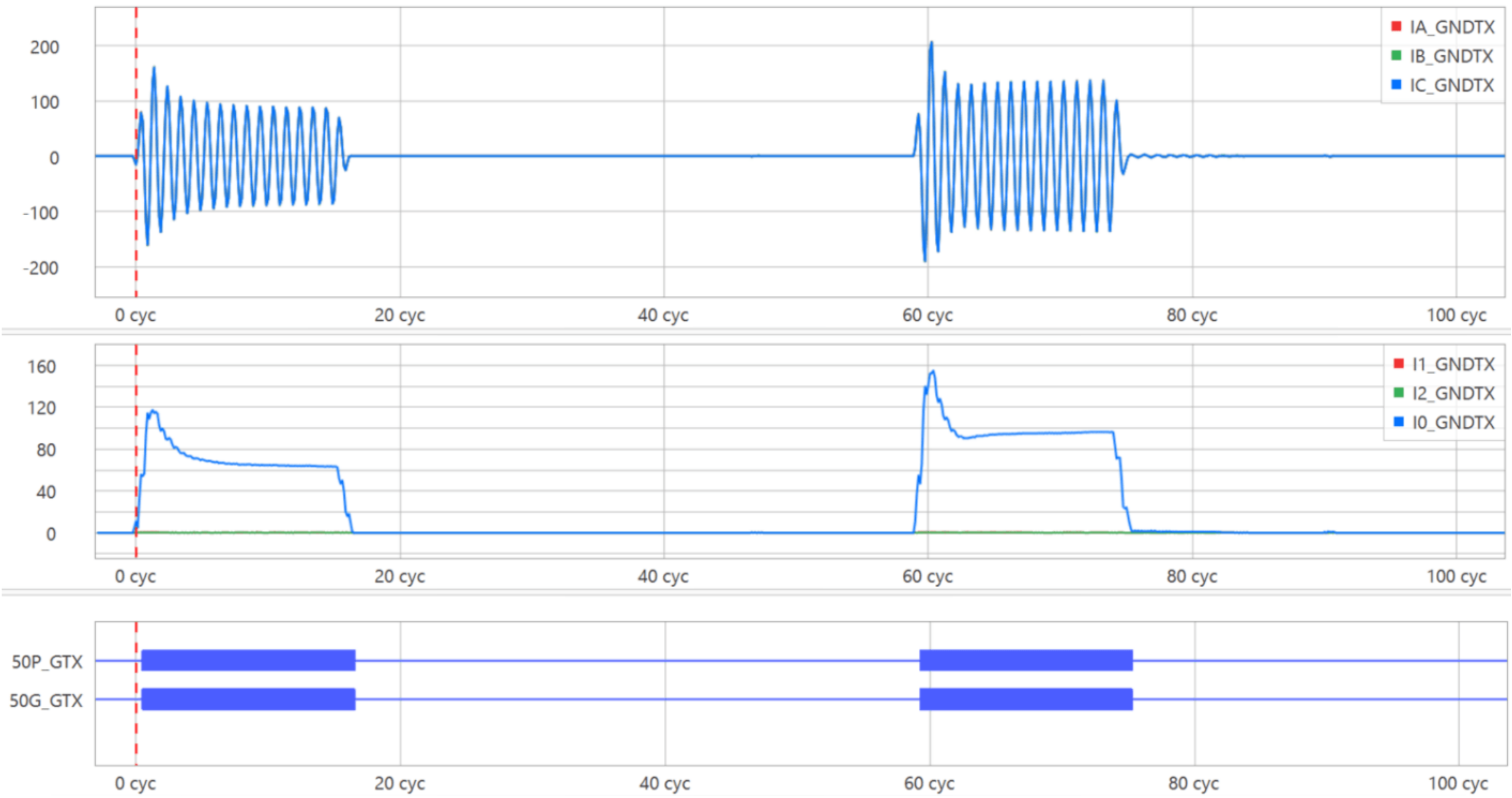
RTDS test results – protection testing

BESS



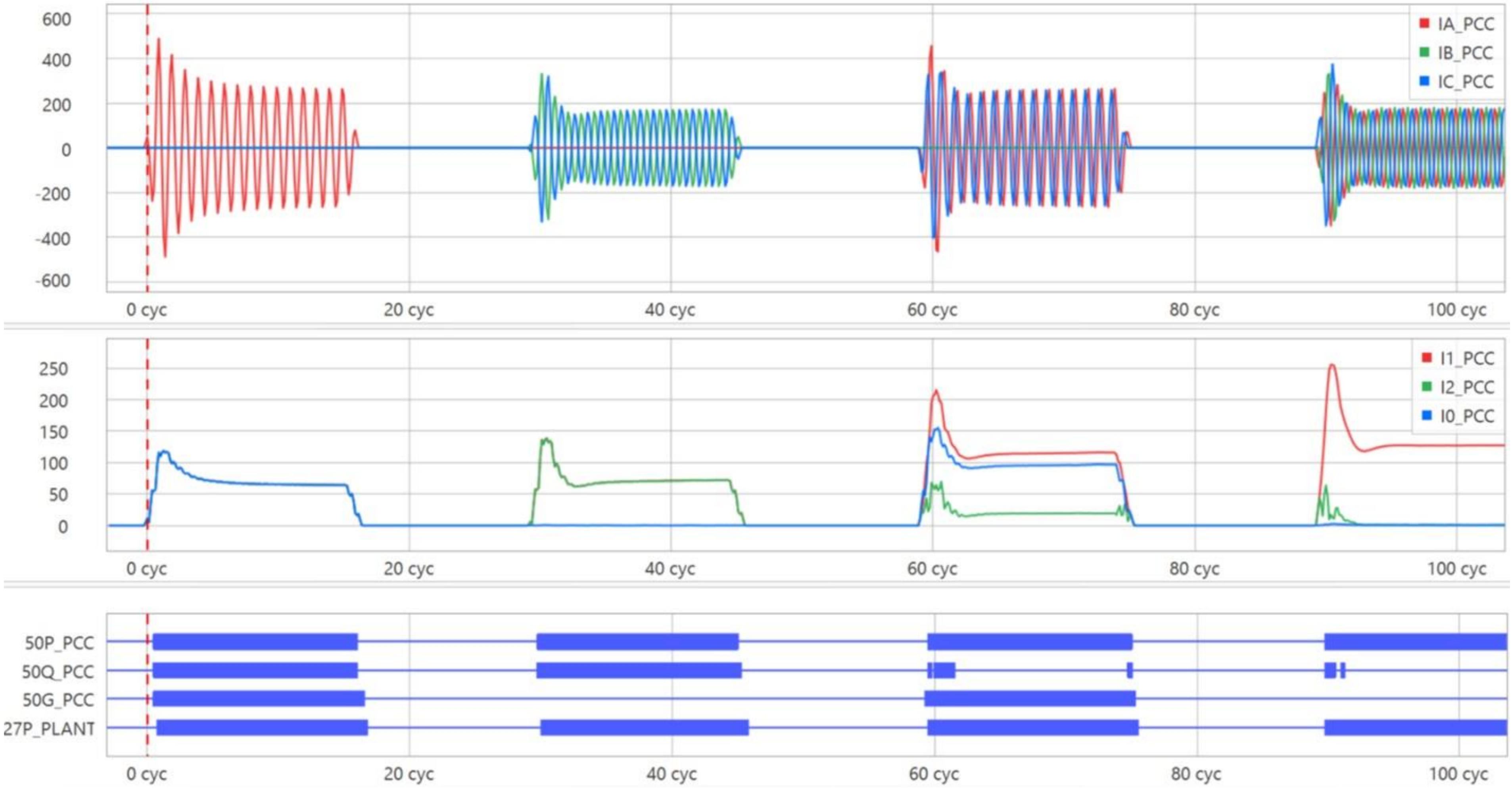
RTDS test results – protection testing

GNDTX

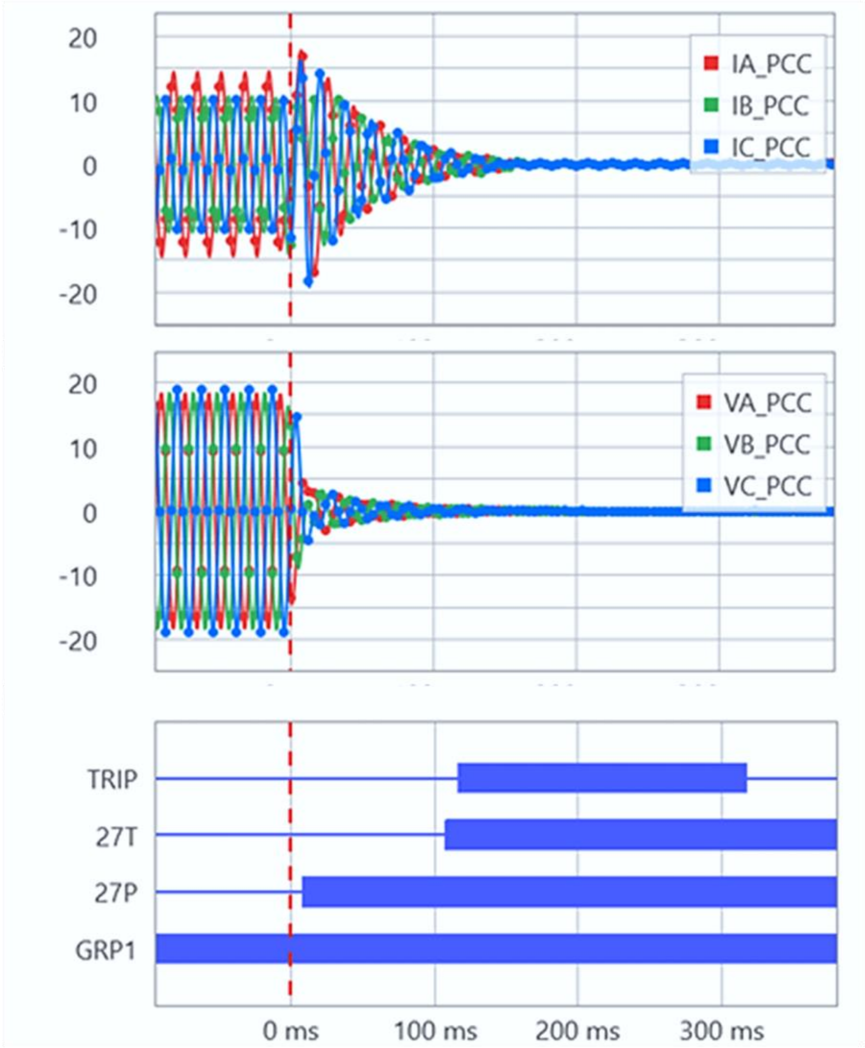


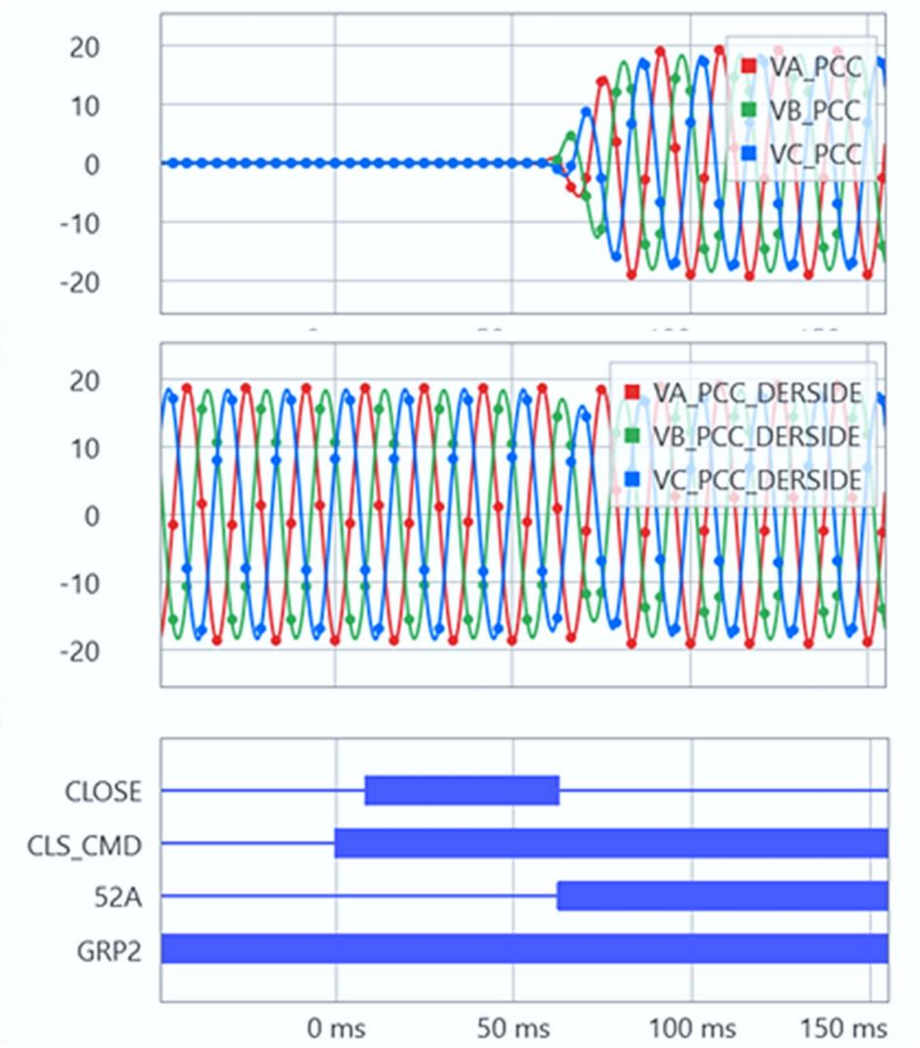
RTDS test results – protection testing

PCC



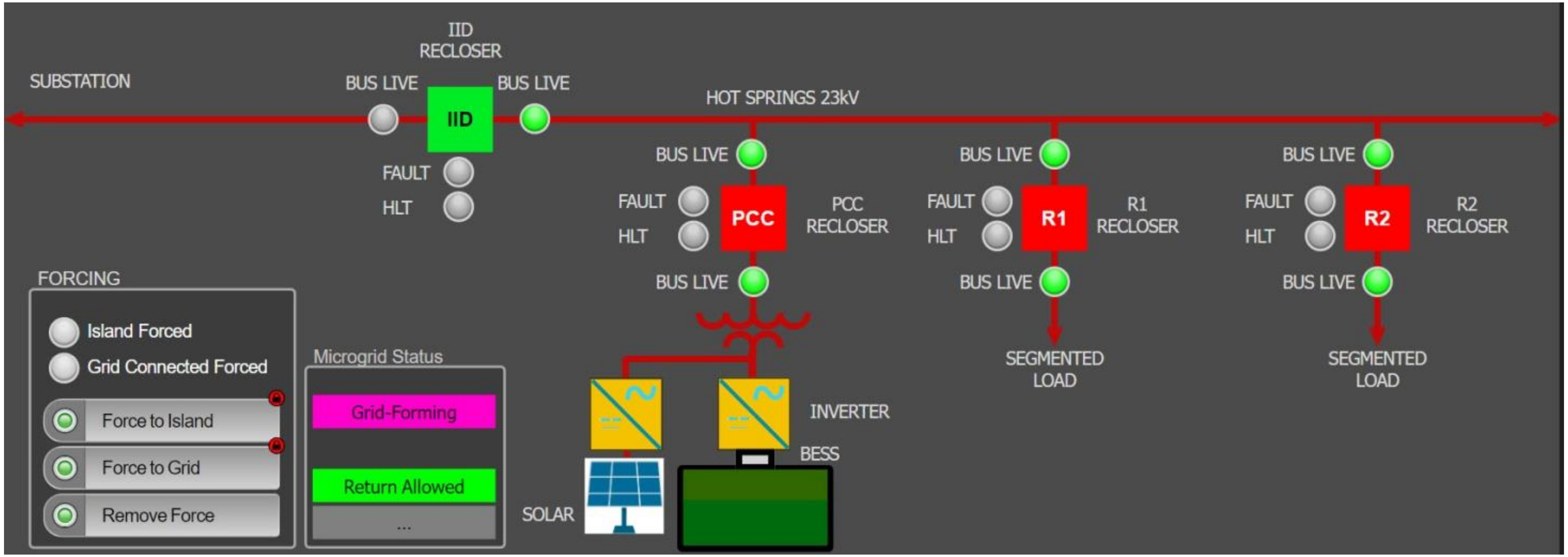
RTDS test results – automation testing





MICHUB HMI

- Provides visualization of plant and distribution circuit states during transitions between grid-parallel and islanding operations
- Aids in troubleshooting unmet conditions during transition sequences



Conclusion

- DERs offer viable non-wires alternatives to building new distribution feeds
- Microgrids fed solely by IBRs present protection and control challenges
- Manufacturer-provided inverter models are important for accurate EMT simulations, especially in applications where seamless islanding is needed
- Break-before-make strategy, where grounding transformer is switched in only during islanding operation, simplifies the protection philosophy but results in temporary customer outages
- Time-coordinated definite-time overcurrent protection provides secure and dependable protection for microgrid applications
- CHIL testing with RTDS provides high degree of confidence for protection and automation schemes prior to field deployment

Questions?