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SESP Deliverable 2.3

Österbottens förbund
Pohjanmaan liitto

Regional Council
of Ostrobothnia

AC Microgrid with high penetration of renewable DGs and central BESS

Fault protection studies using average type of models

SESP WP2: Task 2.3

Aushiq Memon

Electrical Engineering

SESP- Smart Energy Systems Platform

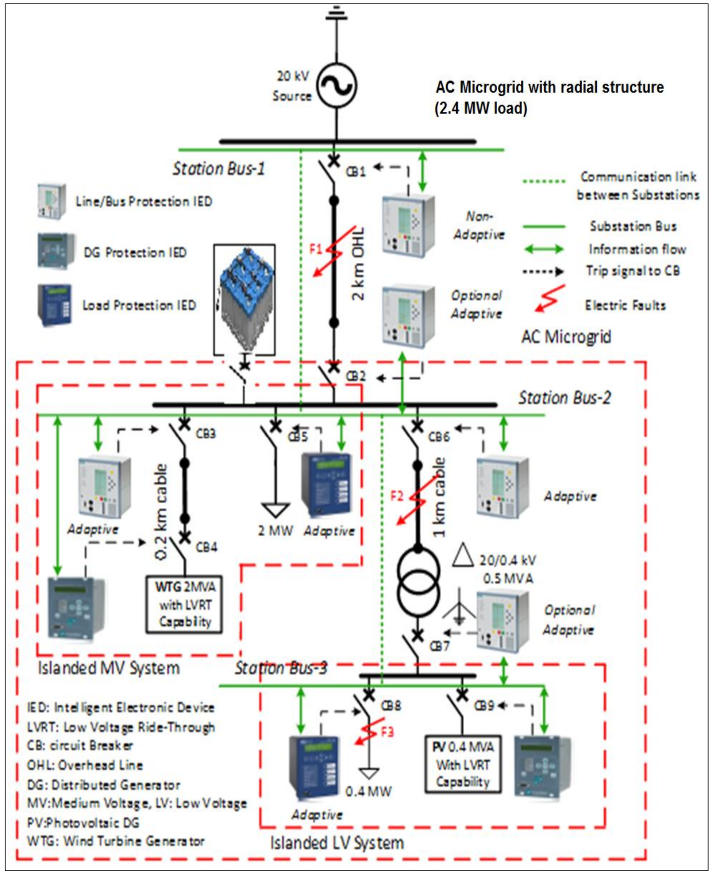
WP2: Protection and automation

Task 2.3 Report about AC Microgrid protection

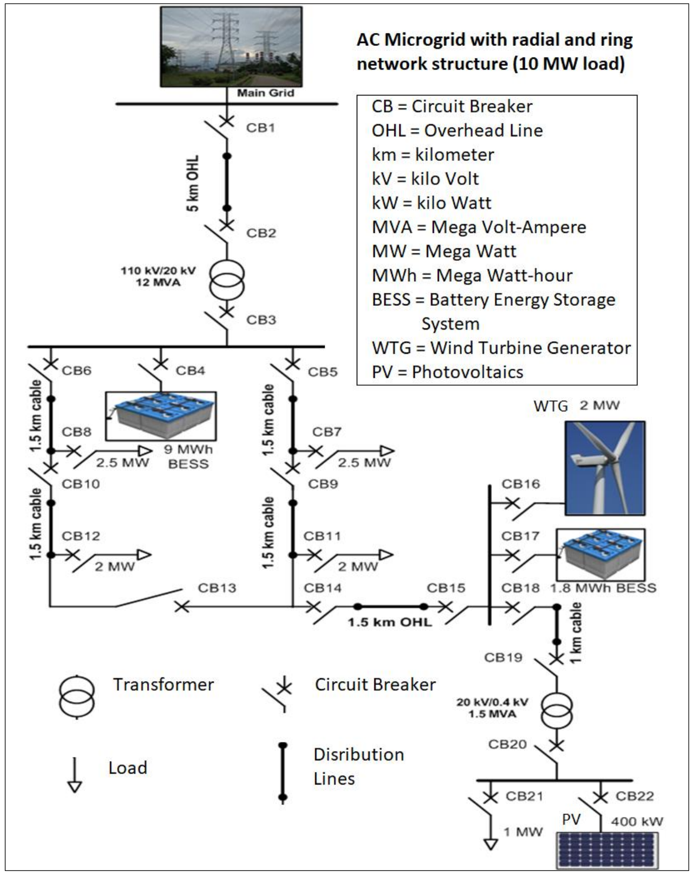
- The report highlights the results of fault studies of AC Microgrids in both grid-connected and islanded modes of operation.
- Adaptive OC protection is generally required for that type AC Microgrid which could also be operated in islanding mode.
- After islanding only local DGs have to provide the fault contribution during faults. If the local DGs are converter-based DGs (PV/WTG) then they can provide very limited fault current contribution (1-2 p.u.). For islanded operation some or all converters of DGs in AC Microgrid should operate in grid-forming mode in order to regulate the local voltage. In this study, central BESS has been used as grid forming source whereas PV and WTG are operated in grid-following mode.
- Transfer trip signals are used to change relay settings from grid-connected mode settings to islanded-mode settings.

AC Microgrid Protection studies

AC Microgrid with radial network



AC Microgrid with radial and ring network



AC Microgrid Protection Studies

Radial network model (2.4 MW load)

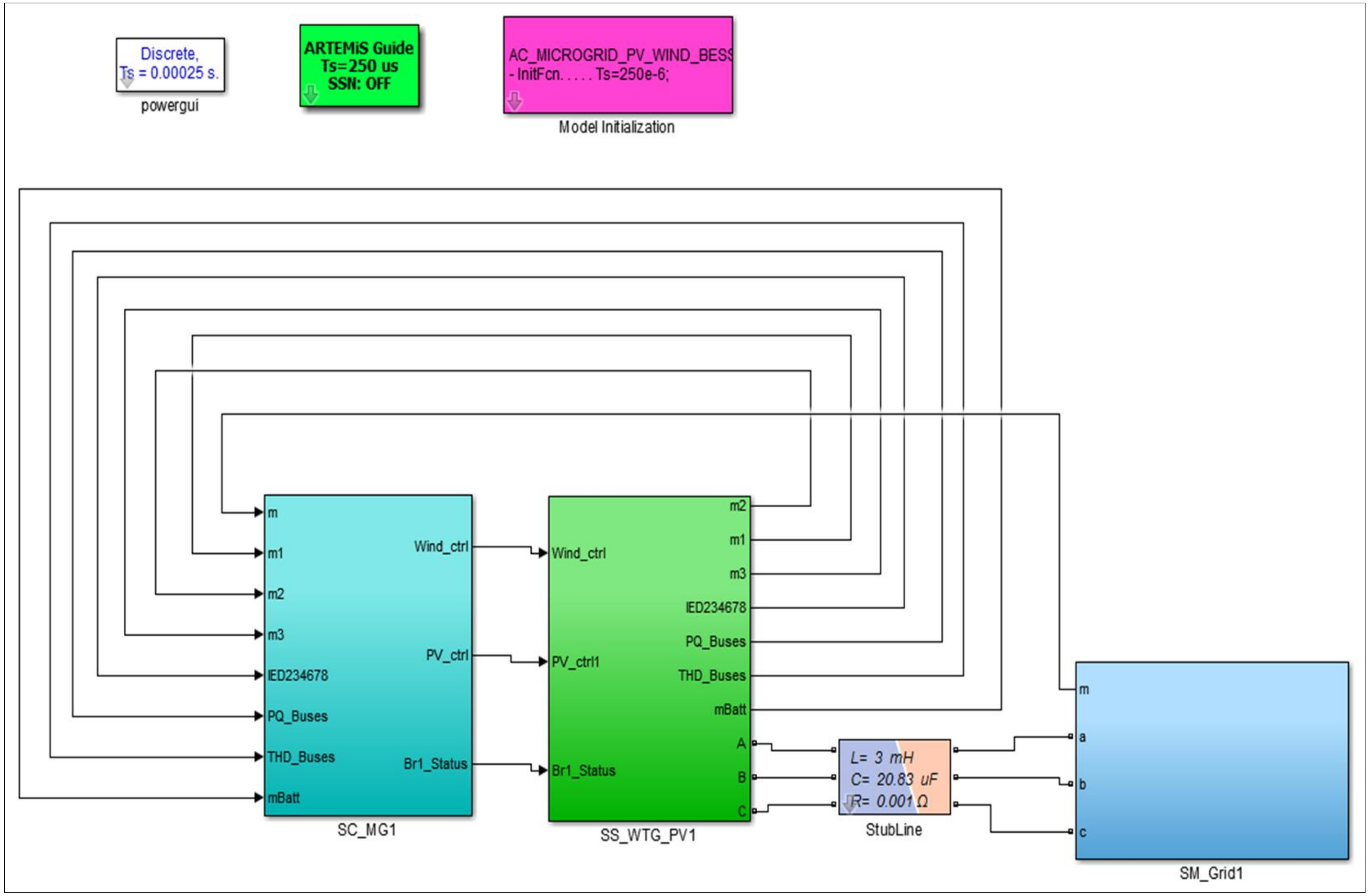
Real-time model and protection results

-Software-in-the-Loop (SIL) results for adaptive OC protection

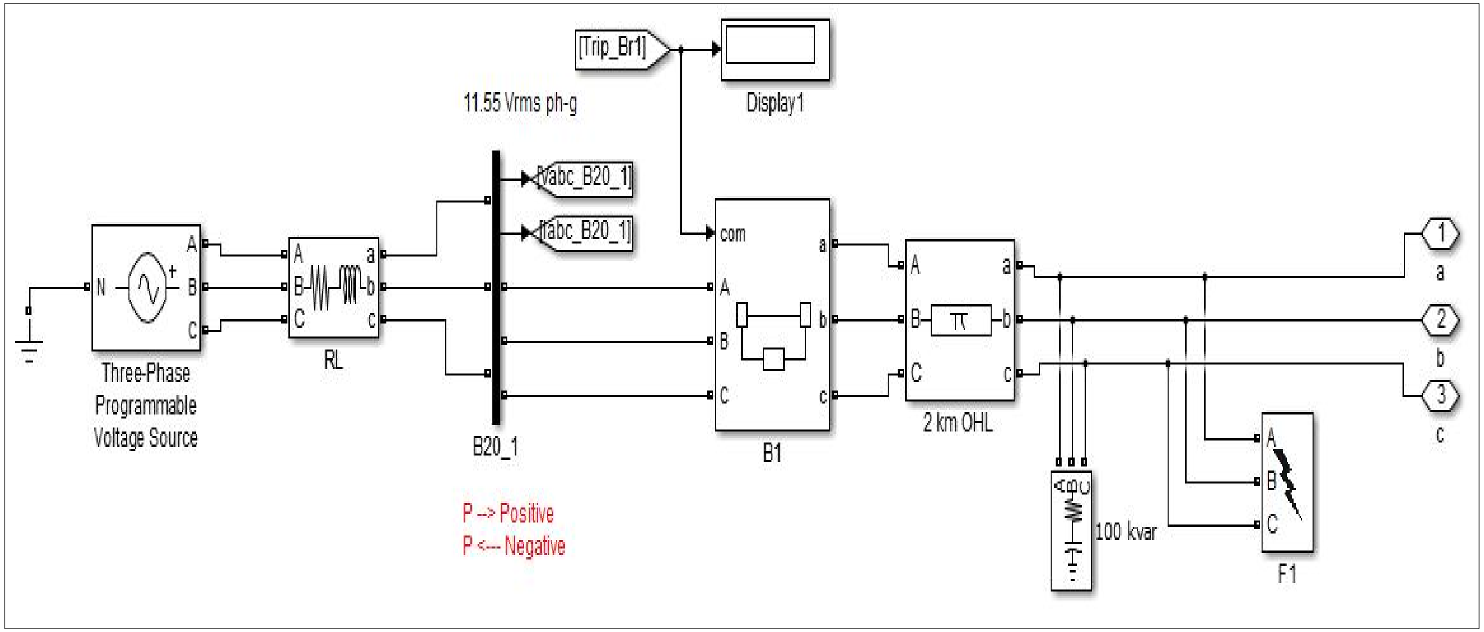
-Hardware-in-the-Loop (HIL) results for IEC61850 Goose testing

Radial network model (2.4 MW)-Average model

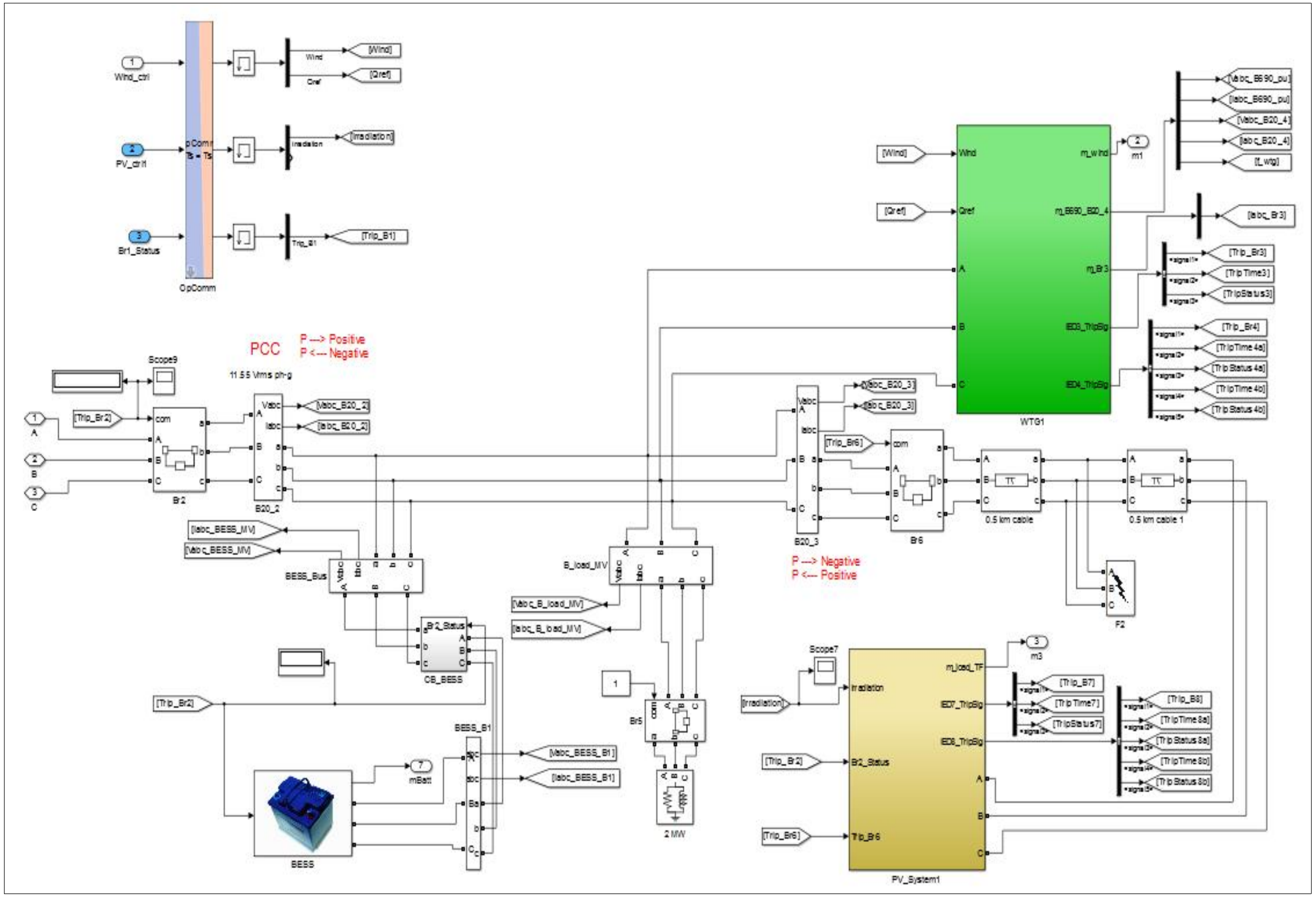
Top View: Three Subsystems (Two subsystems + Console)



Radial network model (2.4 MW)-Average model
SM_Grid1 subsystem

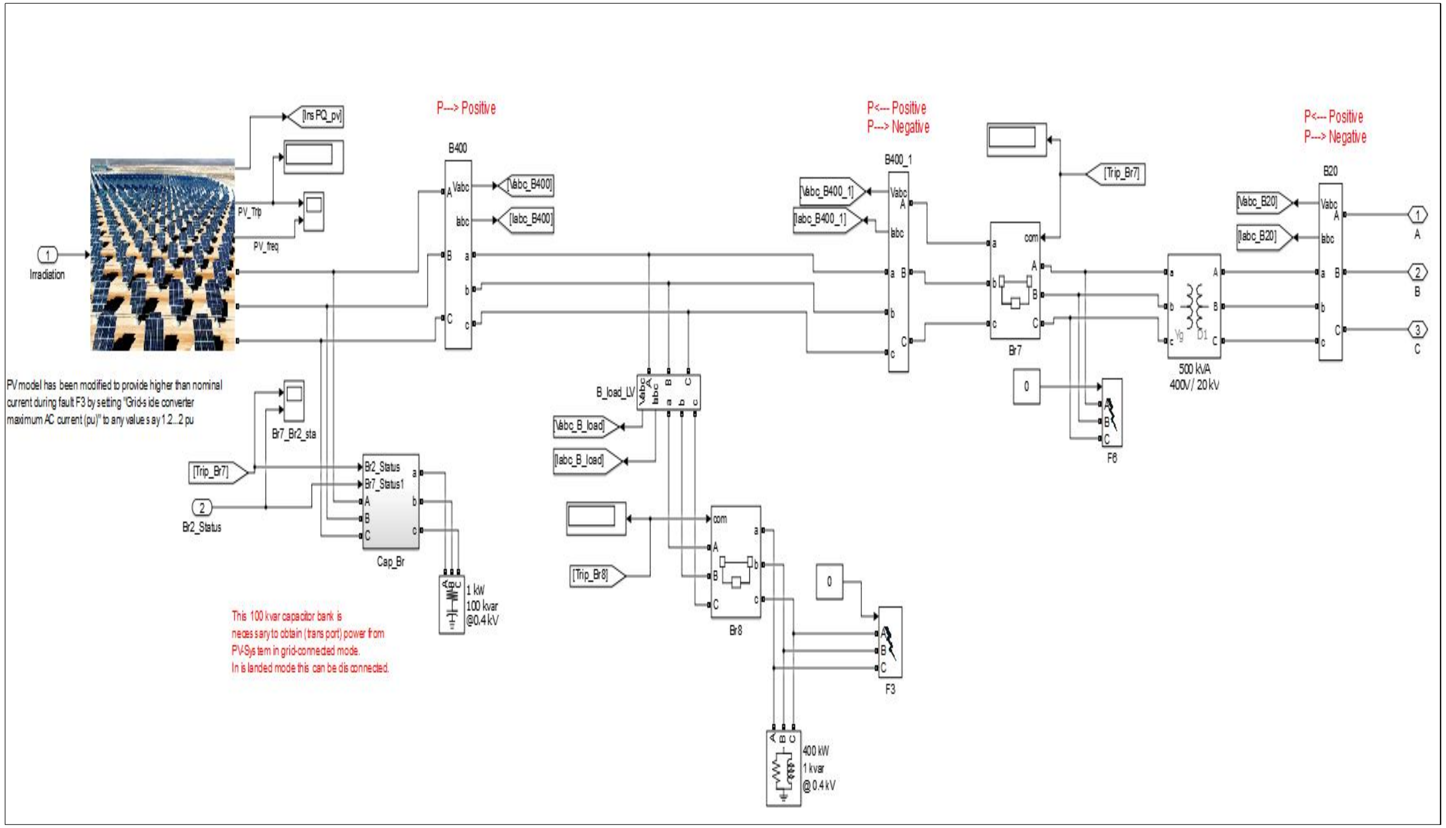


Radial network model (2.4 MW)-Average model
SS_WTG_PV1 subsystem



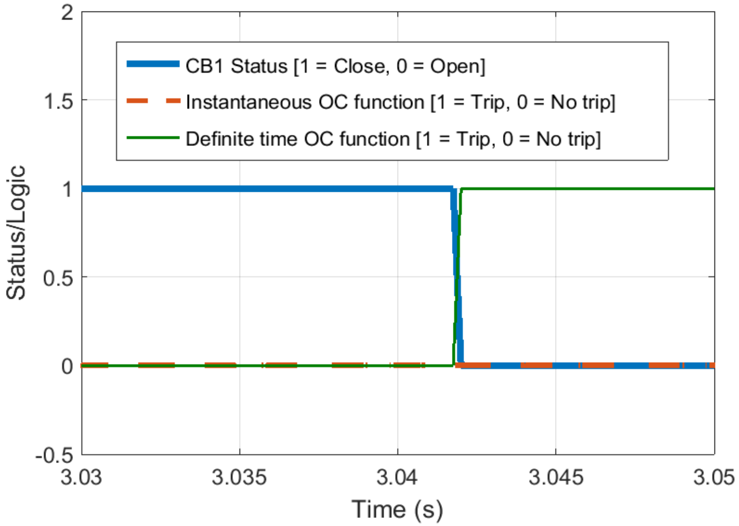
Radial network model (2.4 MW)-Average model

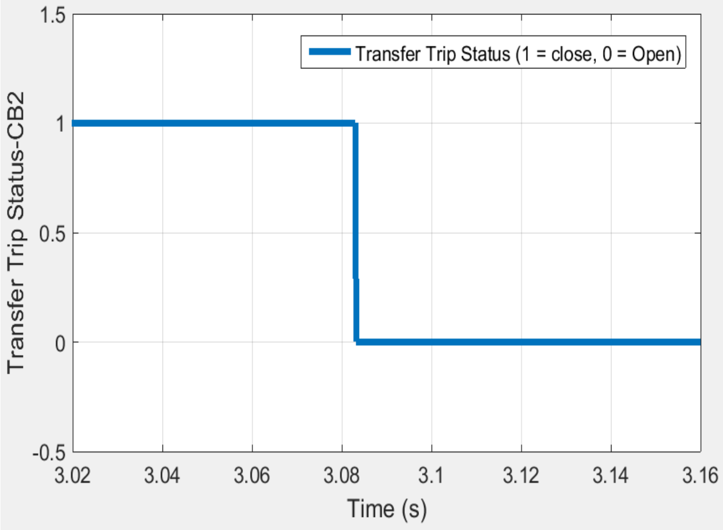
PV_System



Radial network model (2.4 MW)-Average model
Real-time simulation results: Trip signals

3-Ph fault F1 (3-4 s) in grid-connected mode
- CB1 trips at 3.04 s and CB2 transfer trips at 3.08 s





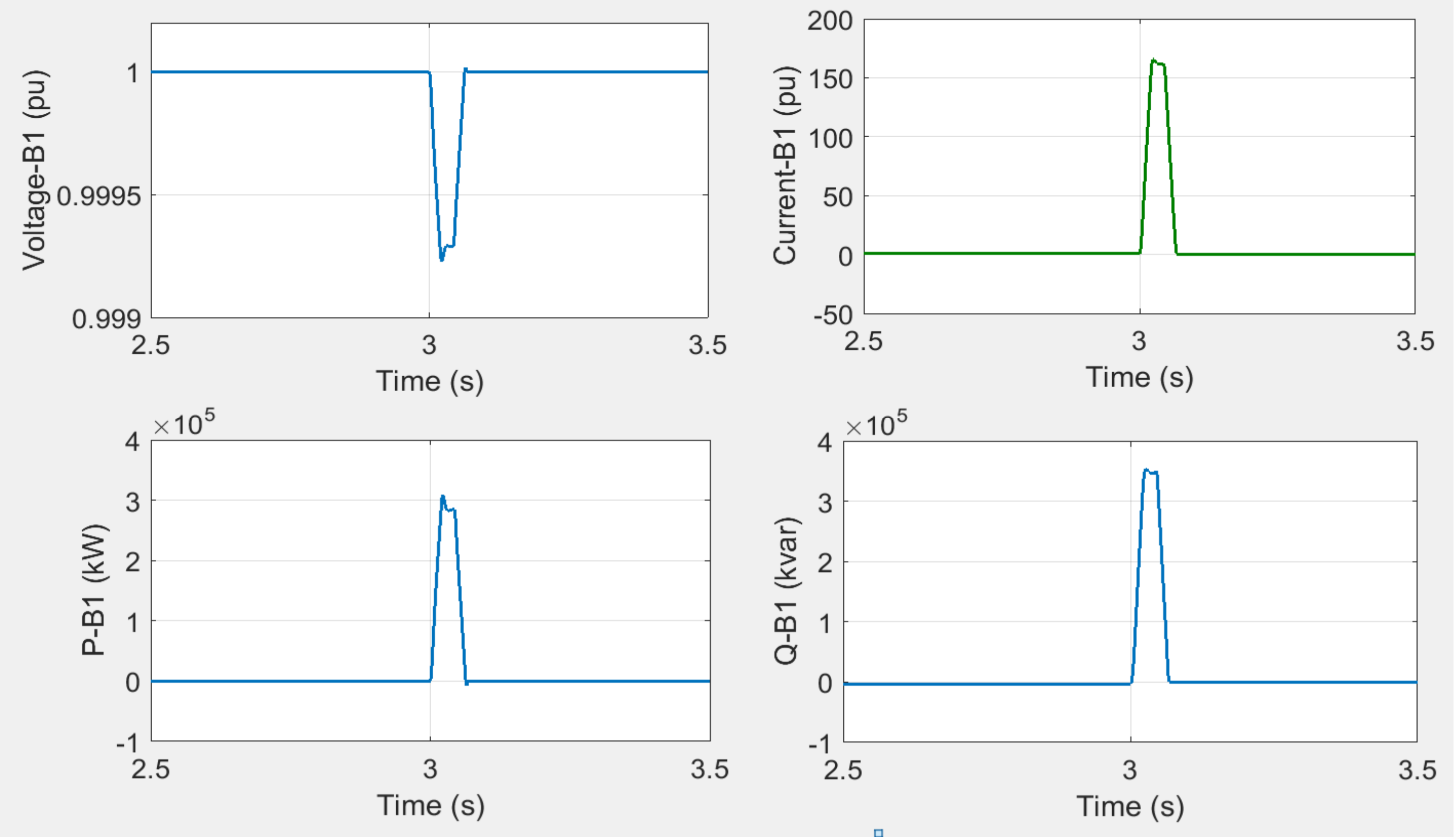
20 ms fault detection delay
20 ms CB1 trip delay

20 ms communication delay
20 ms CB2 trip delay

Radial network model (2.4 MW)-Average model
Real-time simulation results: Voltages and currents

3-Ph fault F1 (3-4 s) in grid-connected mode

-Voltage, current, active and reactive power at the main grid bus B20-1

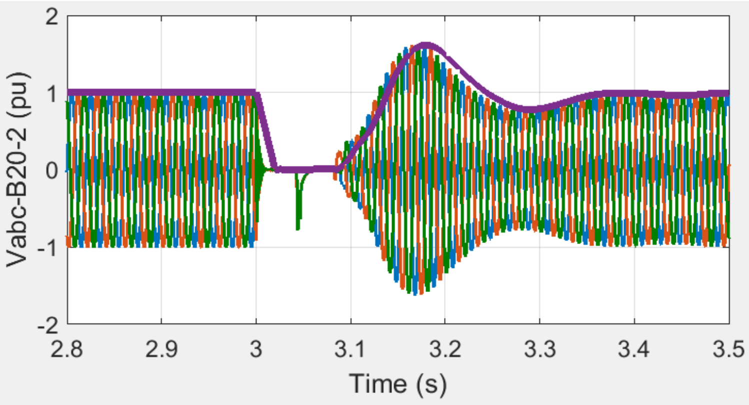


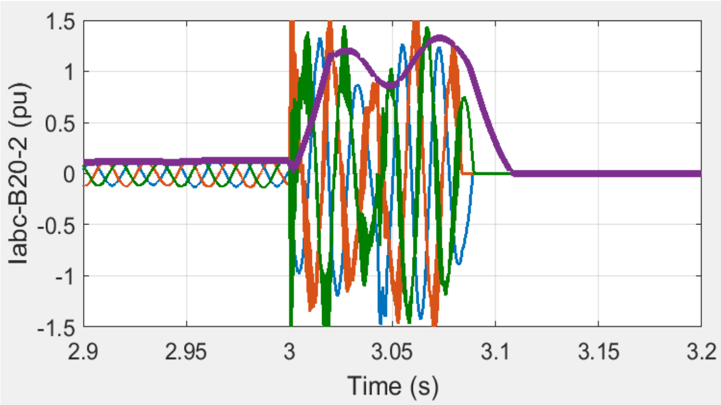
Radial network model (2.4 MW)-Average model
Real-time simulation results: Voltages and currents

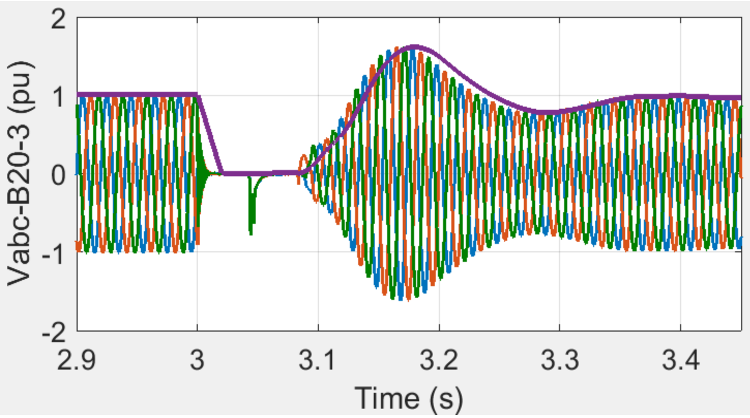
3-Ph fault F1 (3-4 s) in grid-connected mode

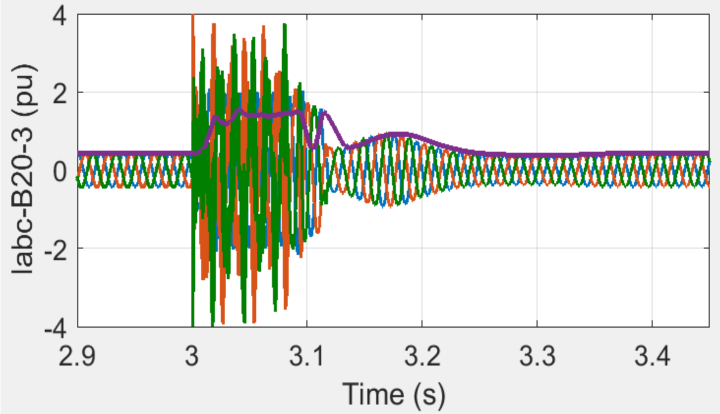
-AC Microgrid is islanded at 3.1 s, BESS between B20-2 and B20-3 immediately acts as grid forming source (provides balancing power and regulated voltage)

-Voltage and current at MV-buses B20-2 and B20-3





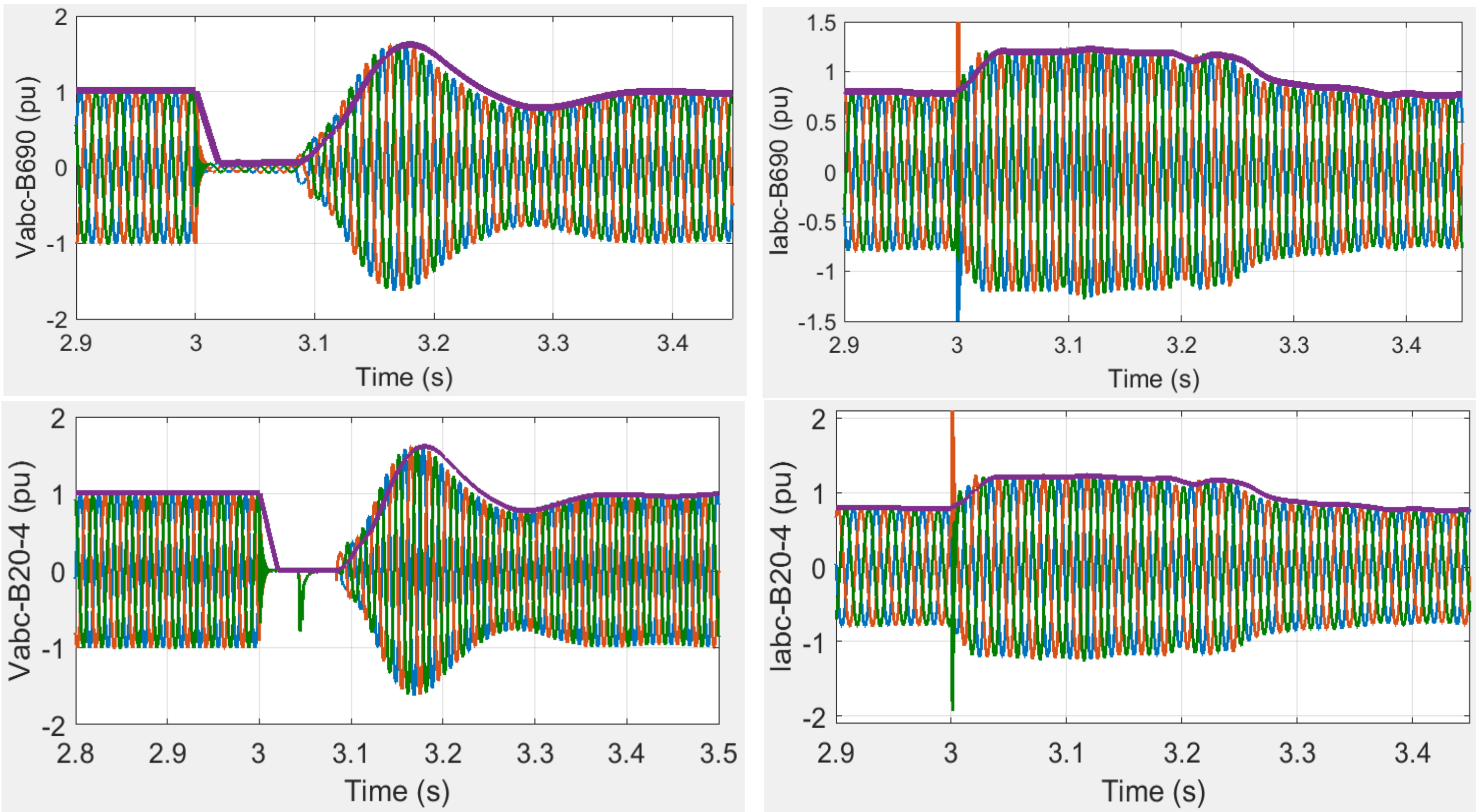




Radial network model (2.4 MW)-Average model
Real-time simulation results: Voltages and currents

3-Ph fault F1 (3-4 s) in grid-connected mode

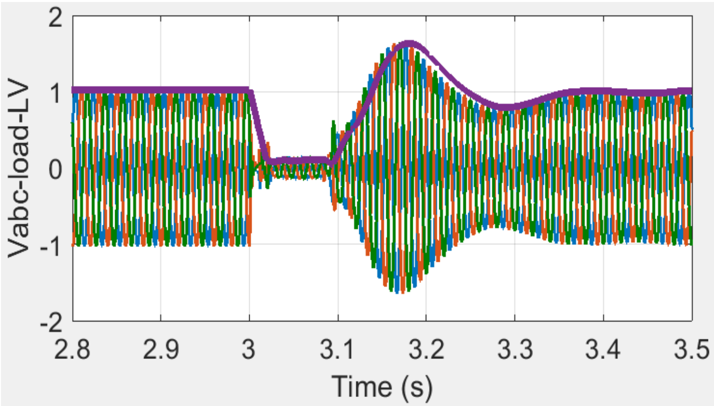
- *WTG set to provide 1.2 p.u. rated current during fault*
- *Voltage and current at LV-bus (B690) and MV-bus (B20-4) of WTG*

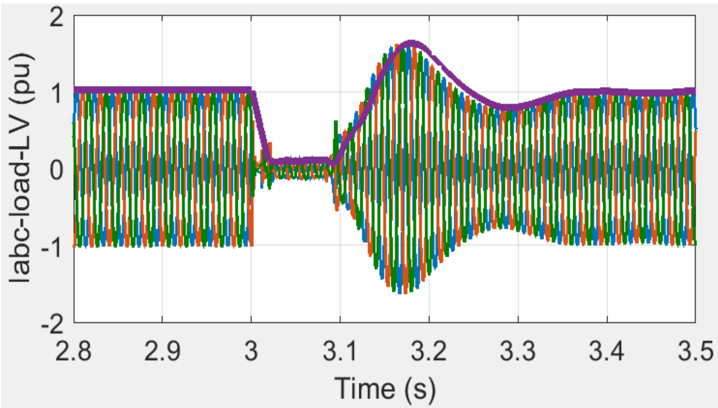


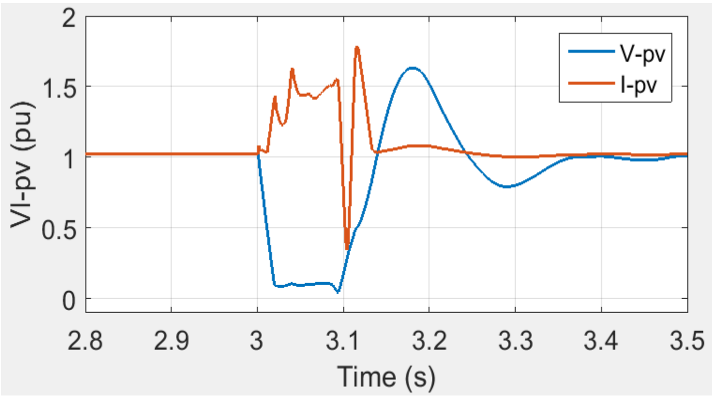
Radial network model (2.4 MW)-Average model
Real-time simulation results: Voltages and currents

3-Ph fault F1 (3-4 s) in grid-connected mode

-Voltage and current at LV load and PV





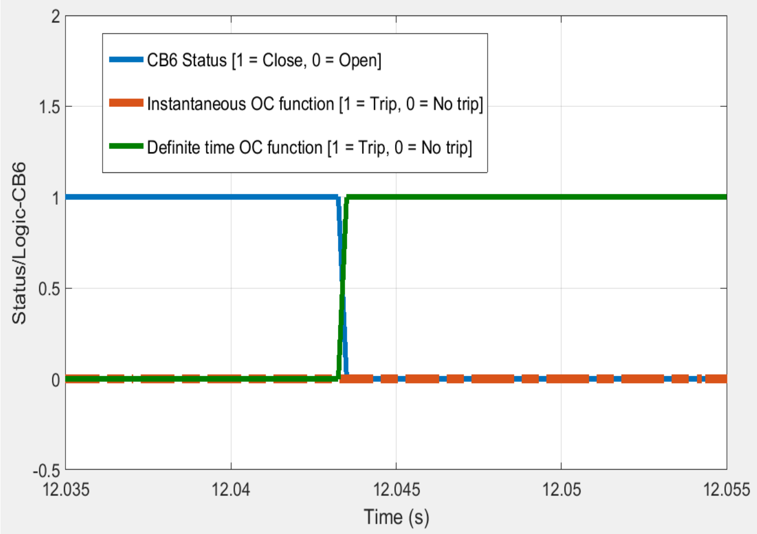


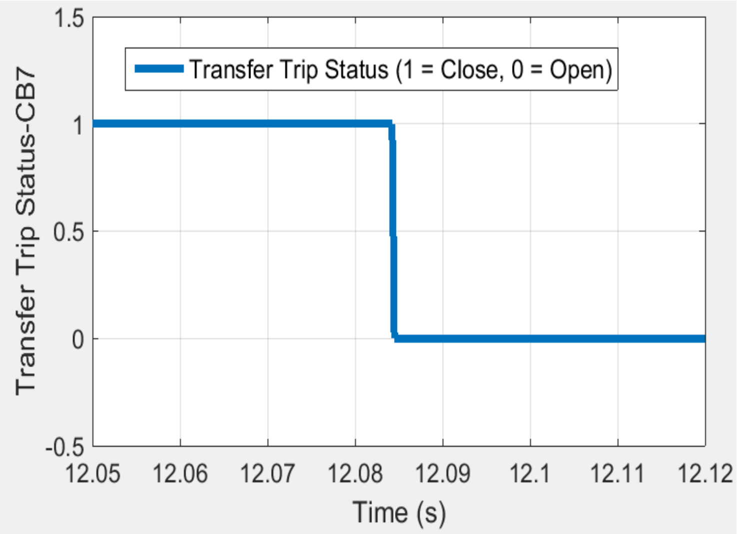
Voltage swells to 1.5 p.u. for a duration of 5 cycles (3.1-3.2 s) after islanding of Microgrid (Resonance or ferro-resonance phenomena due to WTG

-PV set to provide 1.5 p.u. rated current during fault

Radial network model (2.4 MW)-Average model
Real-time simulation results: Trip signals

3-Ph fault F2 (12-13 s) in islanded mode
- CB6 trips at 12.04s and CB7 transfer trips at 12.08 s





20 ms fault detection delay
20 ms CB trip delay

20 ms communication delay
20 ms CB trip delay

Radial network model (2.4 MW)-Average model

Real-time simulation results: Voltages and currents

3-Ph fault F2 (12-13 s) in islanded mode *(B20-1 and B20-2 disconnected)*

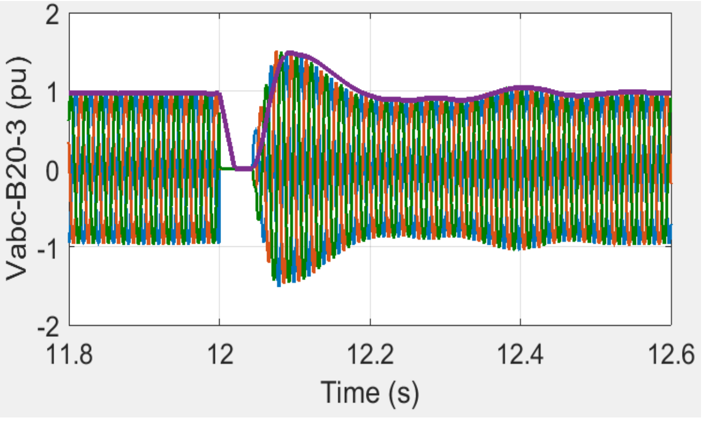
-B6 trips at 12.04s, B7 transfer trips at 12.08s (MV and LV systems isolated)

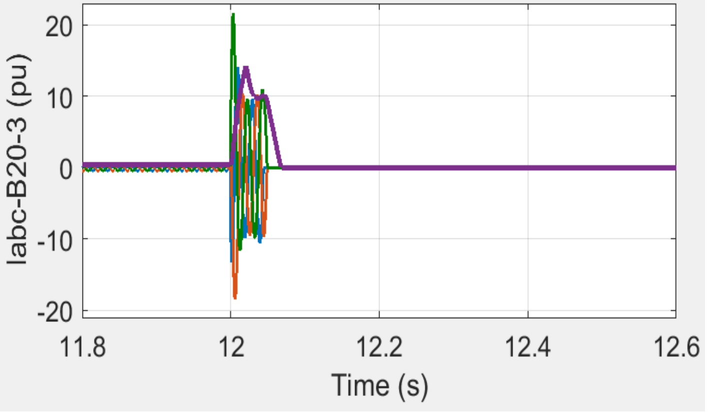
-Isolated MV system consists of BESS, WTG and 2 MW load

-Isolated LV system consists of PV system and LV load.

Þ *BESS provides 2.6 x In during fault in islanded-mode (I-B20-3)*

Þ *Voltage and current at MV-bus B20-3*

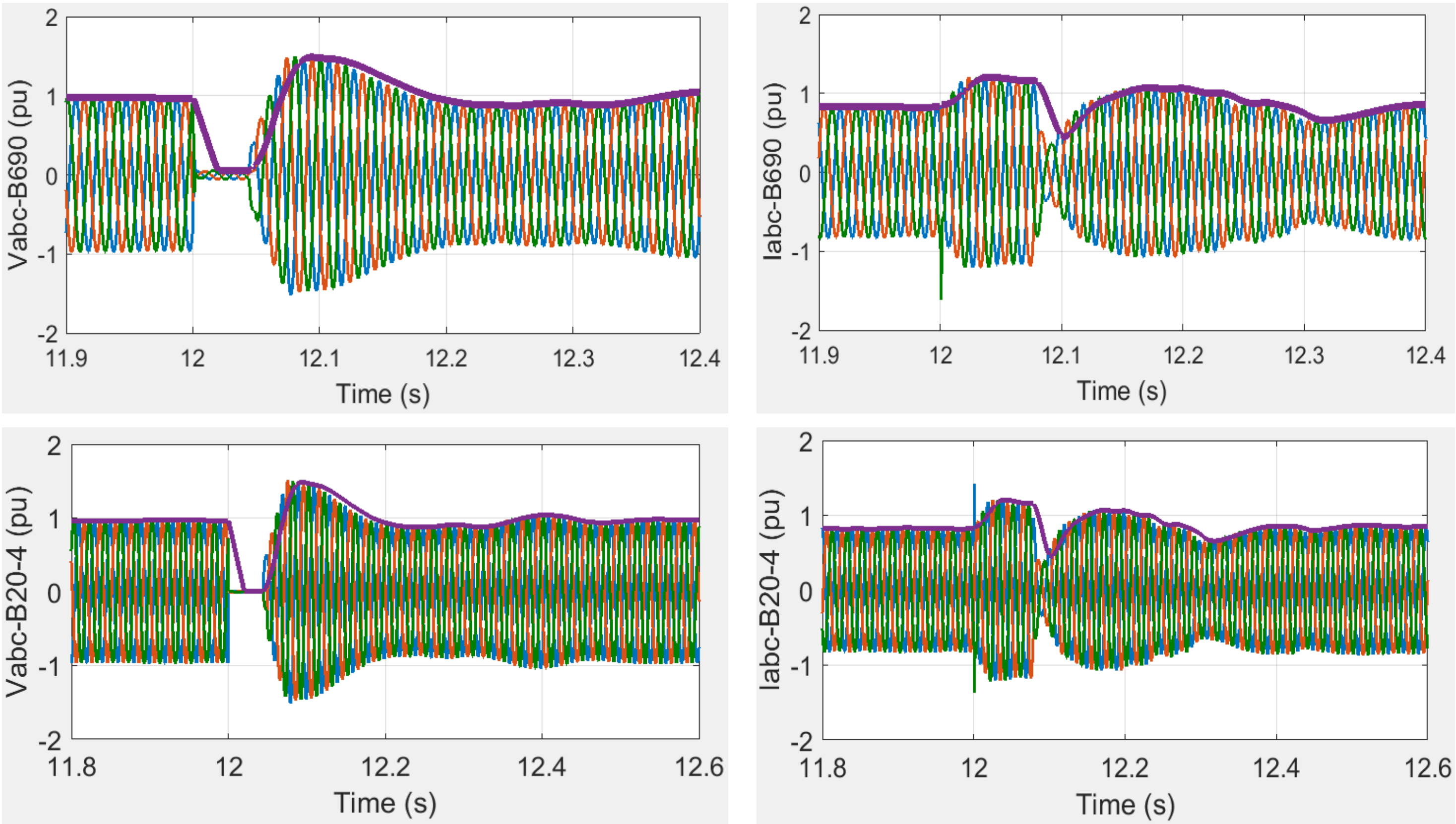




Radial network model (2.4 MW)-Average model
Real-time simulation results: Voltages and currents

3-Ph fault F2 (12-13 s) in islanded mode

- Voltage and current at LV-bus (B690) and MV-bus (B20-4) of WTG

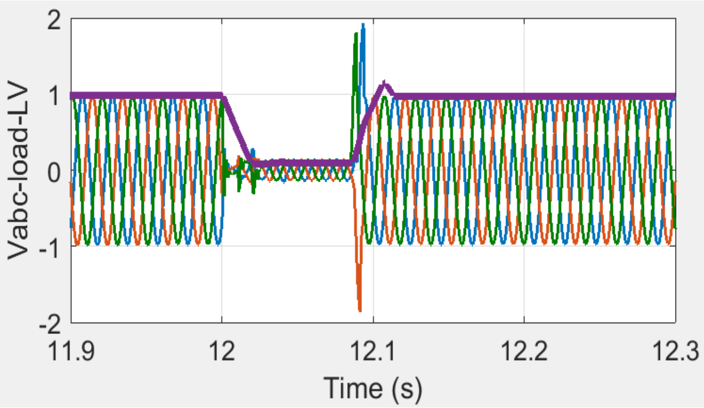


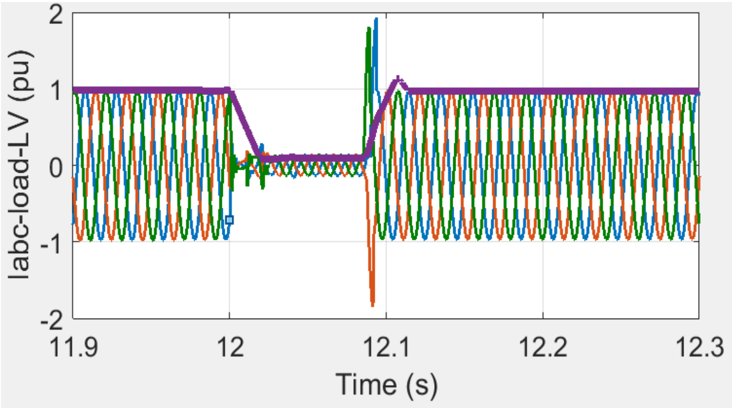
Radial network model (2.4 MW)-Average model

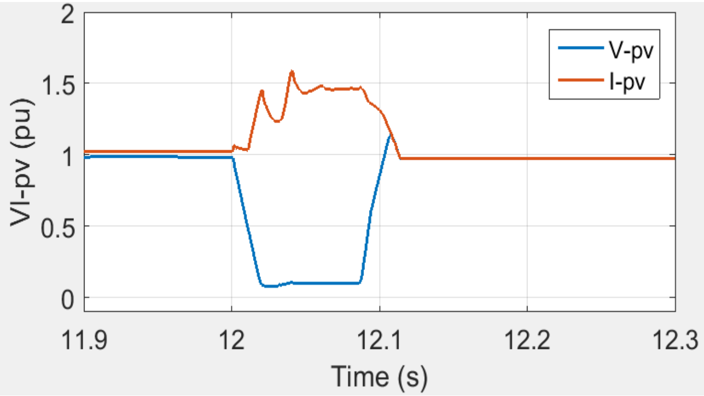
Real-time simulation results: Voltages and currents

3-Ph fault F2 (12-13 s) in islanded mode

- Voltage and current at LV load and PV







-PV system set to provide 1.5 pu current during fault.

-Although PV model works fine in "isolated LV system" after F2, it will require additional local BESS for frequency and power control due to intermittent insolation.

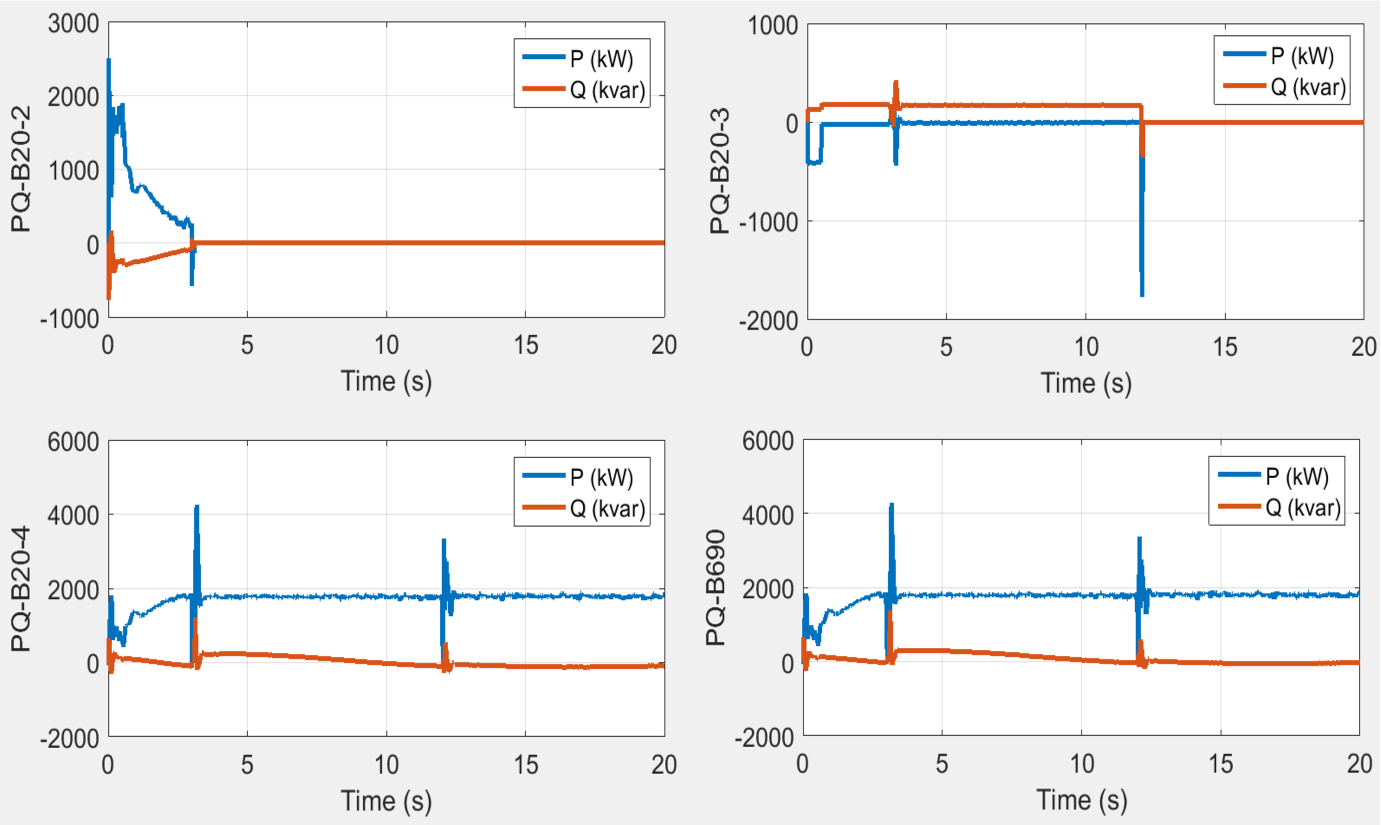
Radial network model (2.4 MW)-Average model

Real-time simulation results: Active and reactive power

3-Ph fault F1 (3-4 s) in grid-connected mode

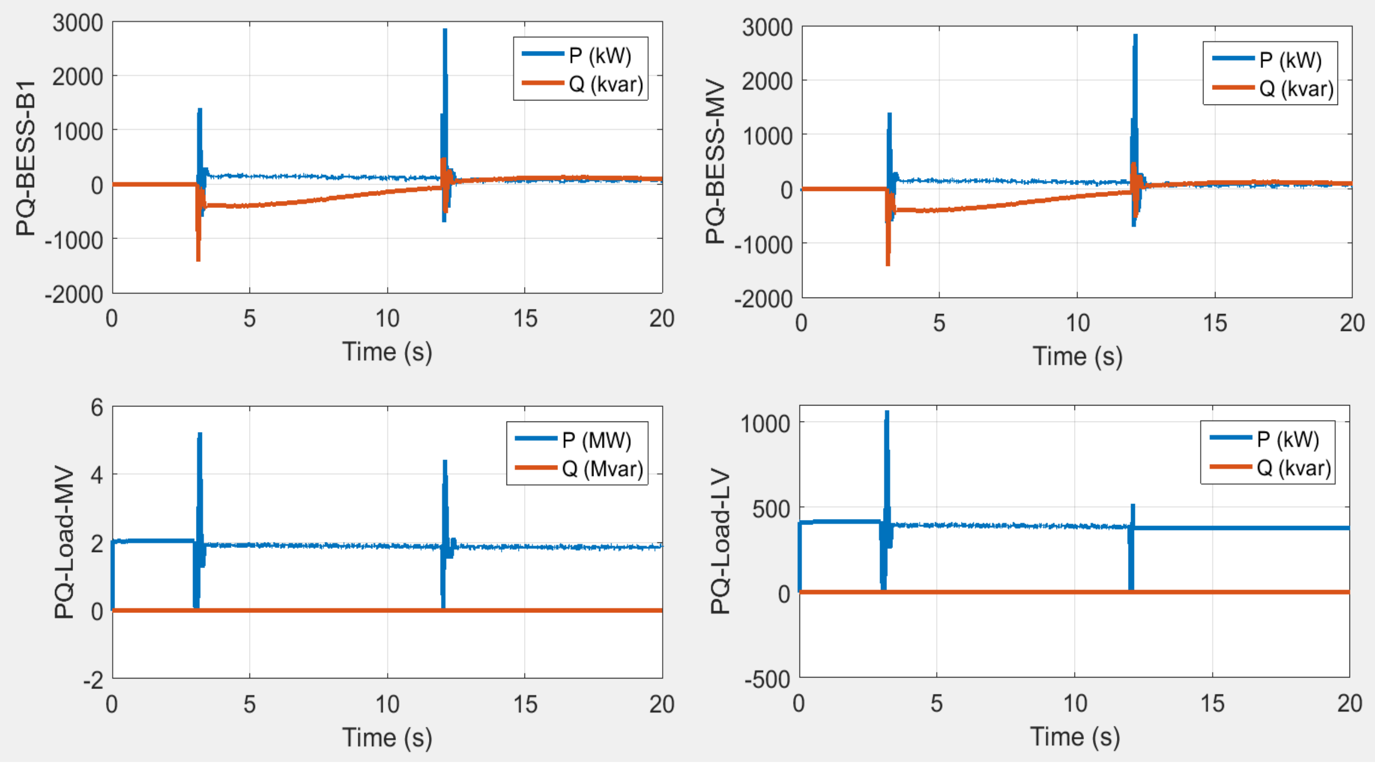
3-Ph fault F2 (12-13 s) in islanded mode

-Active and reactive power at MV buses B20_2...4 and LV bus (B690) of WTG



Radial network model (2.4 MW)-Average model
Real-time simulation results: Active and reactive power

3-Ph fault F1 (3-4 s) in grid-connected mode
3-Ph fault F2 (12-13 s) in islanded mode
-Active and reactive power at BESS connection point, MV-load and LV-load



AC Microgrid Protection Studies

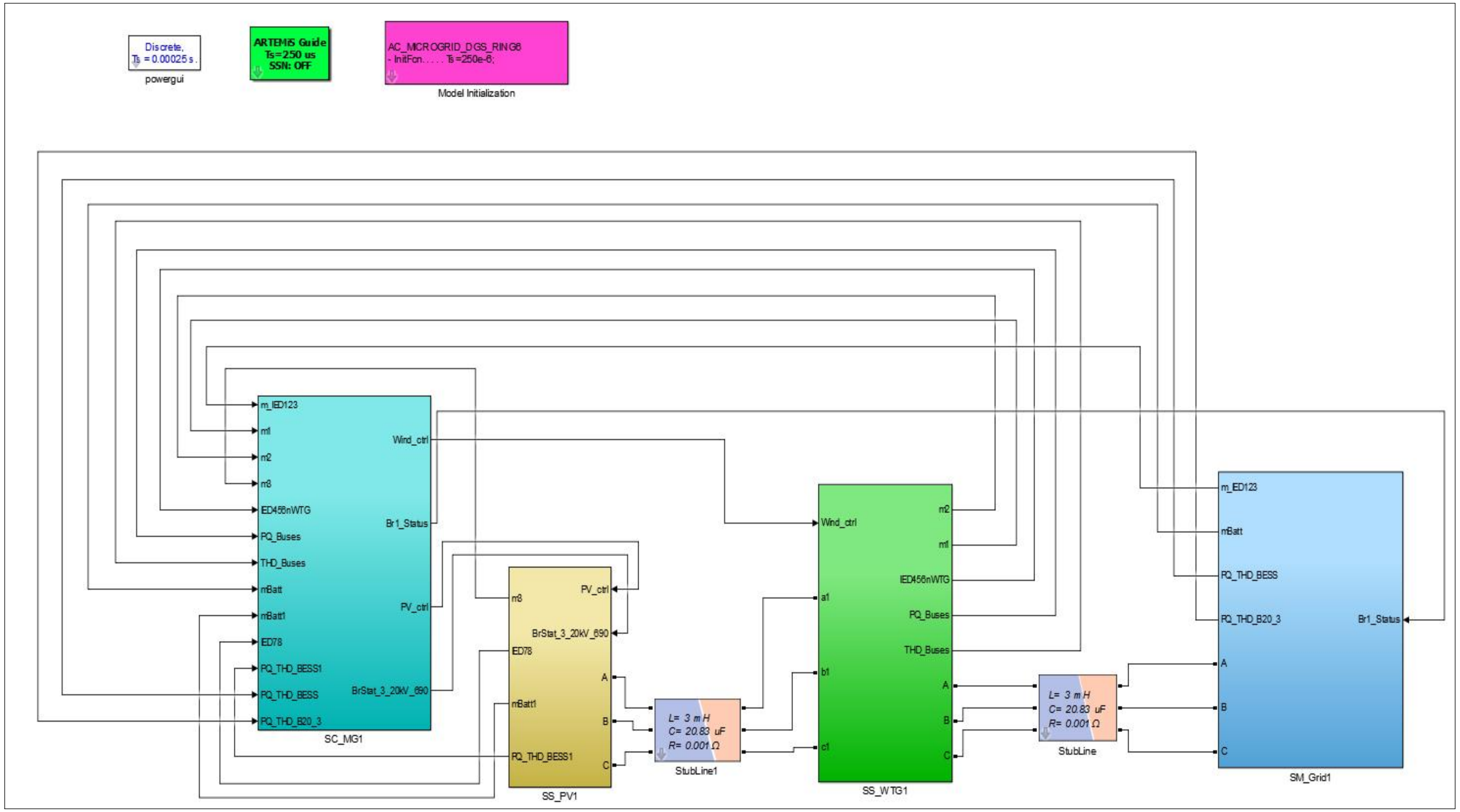
Radial and ring network model (10 MW load)

Real-time model and protection results

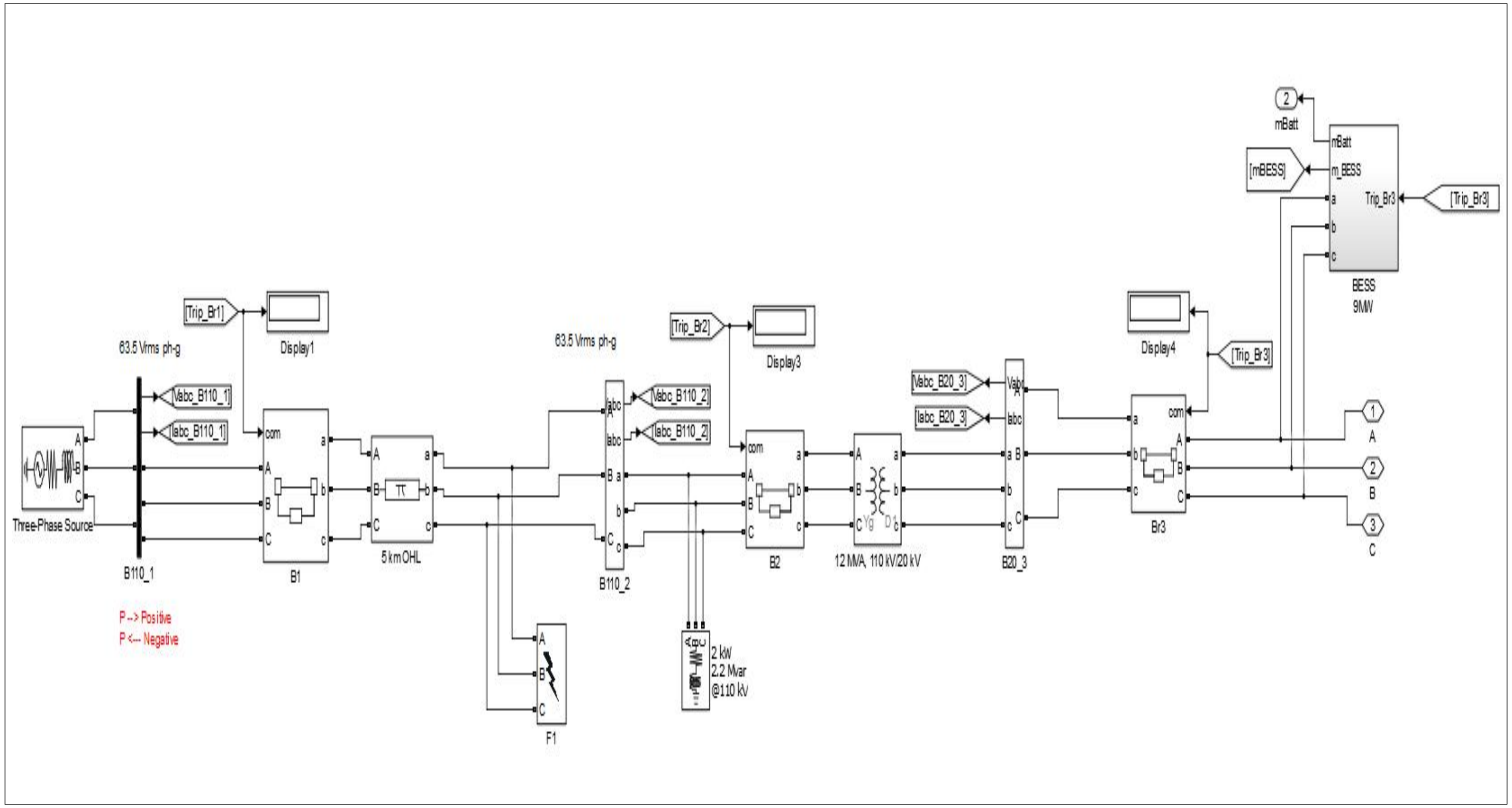
-Software-in-the-Loop (SIL) selected results

The results show that everything works fine within limits in both grid-connected and islanded mode

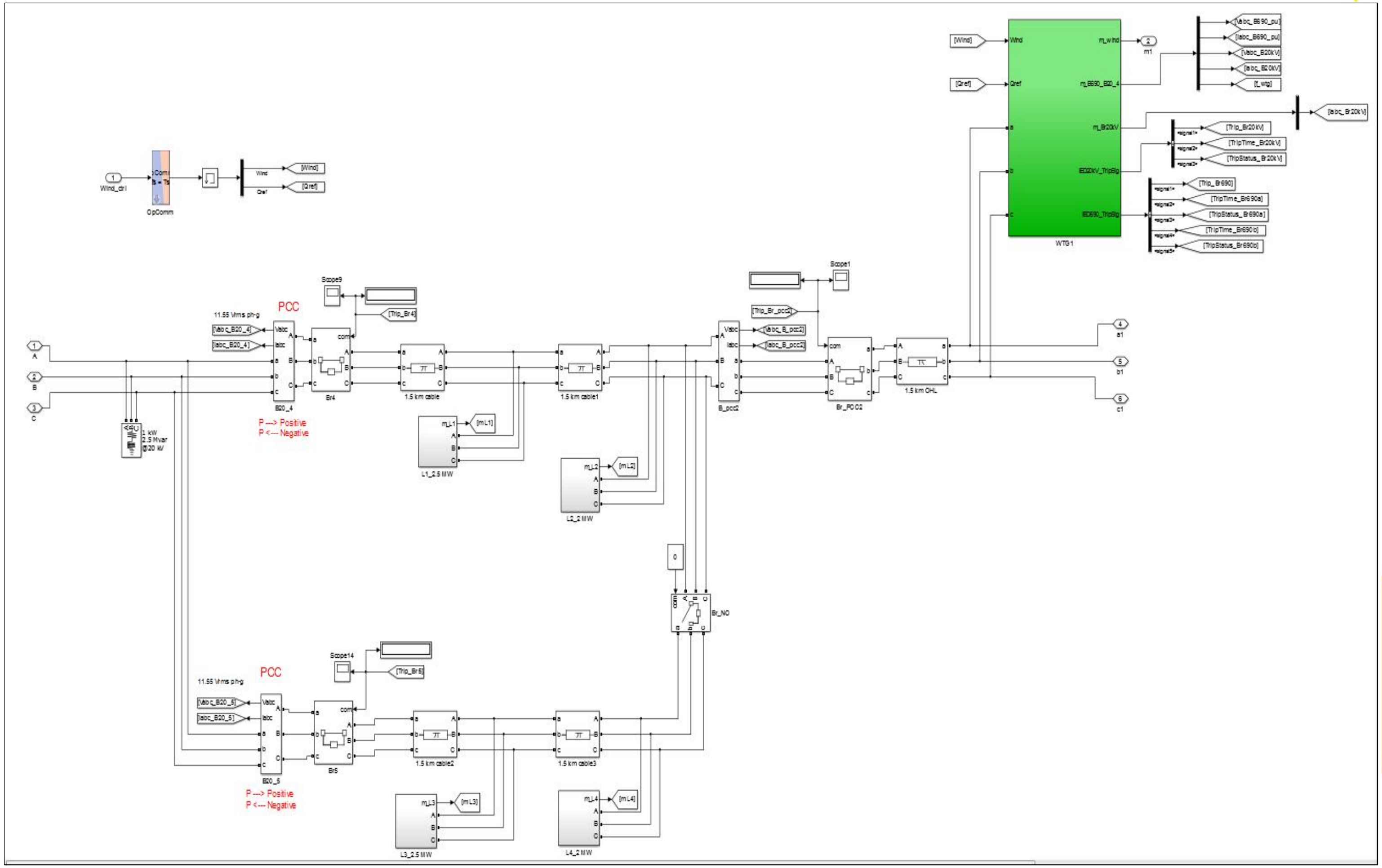
Radial and ring network model (10 MW)-Average model
Top View: Four subsystems (Three subsystems + Console)



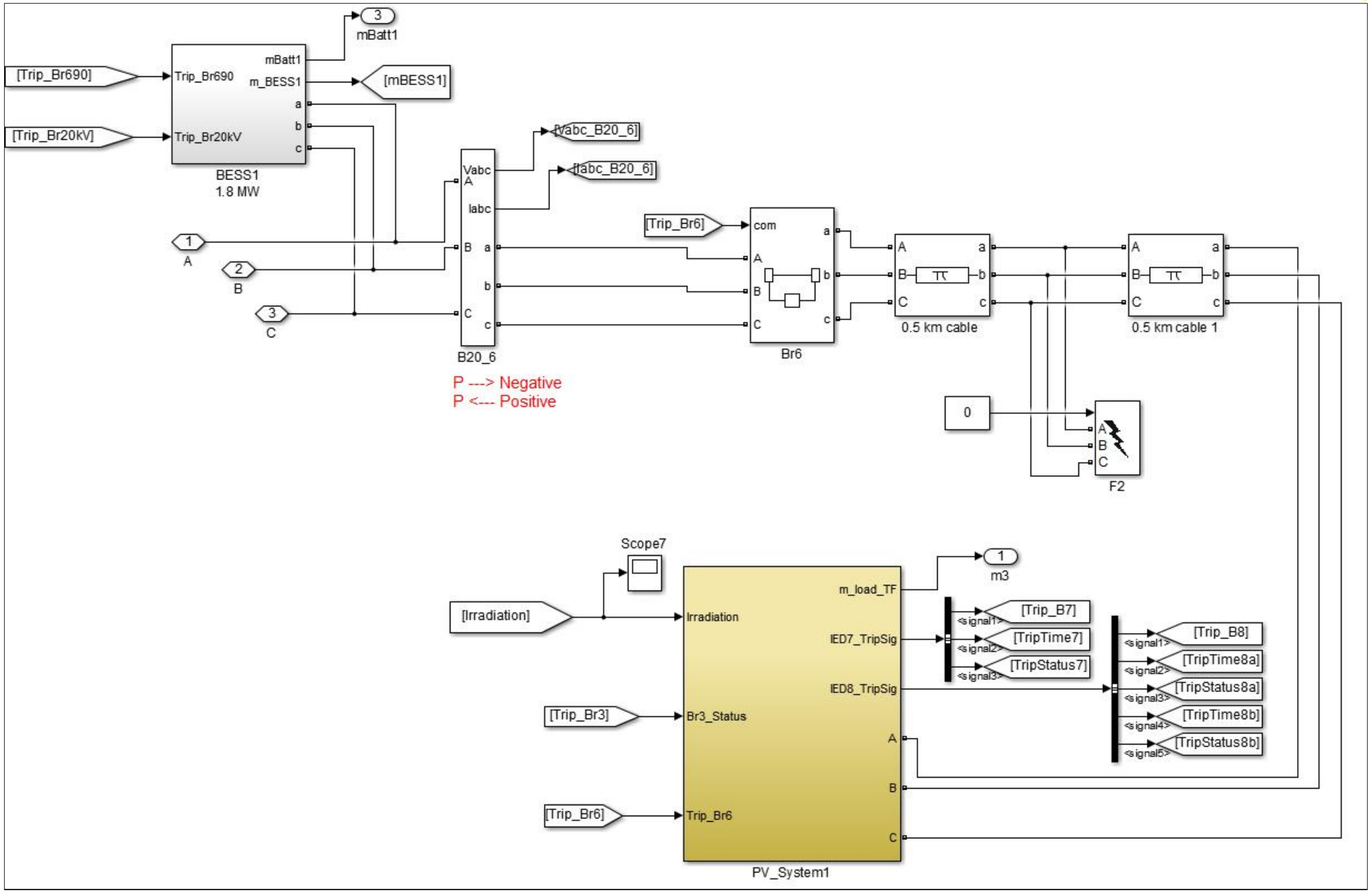
Radial and ring network model (10 MW)-Average model
SM_Grid1 subsystem



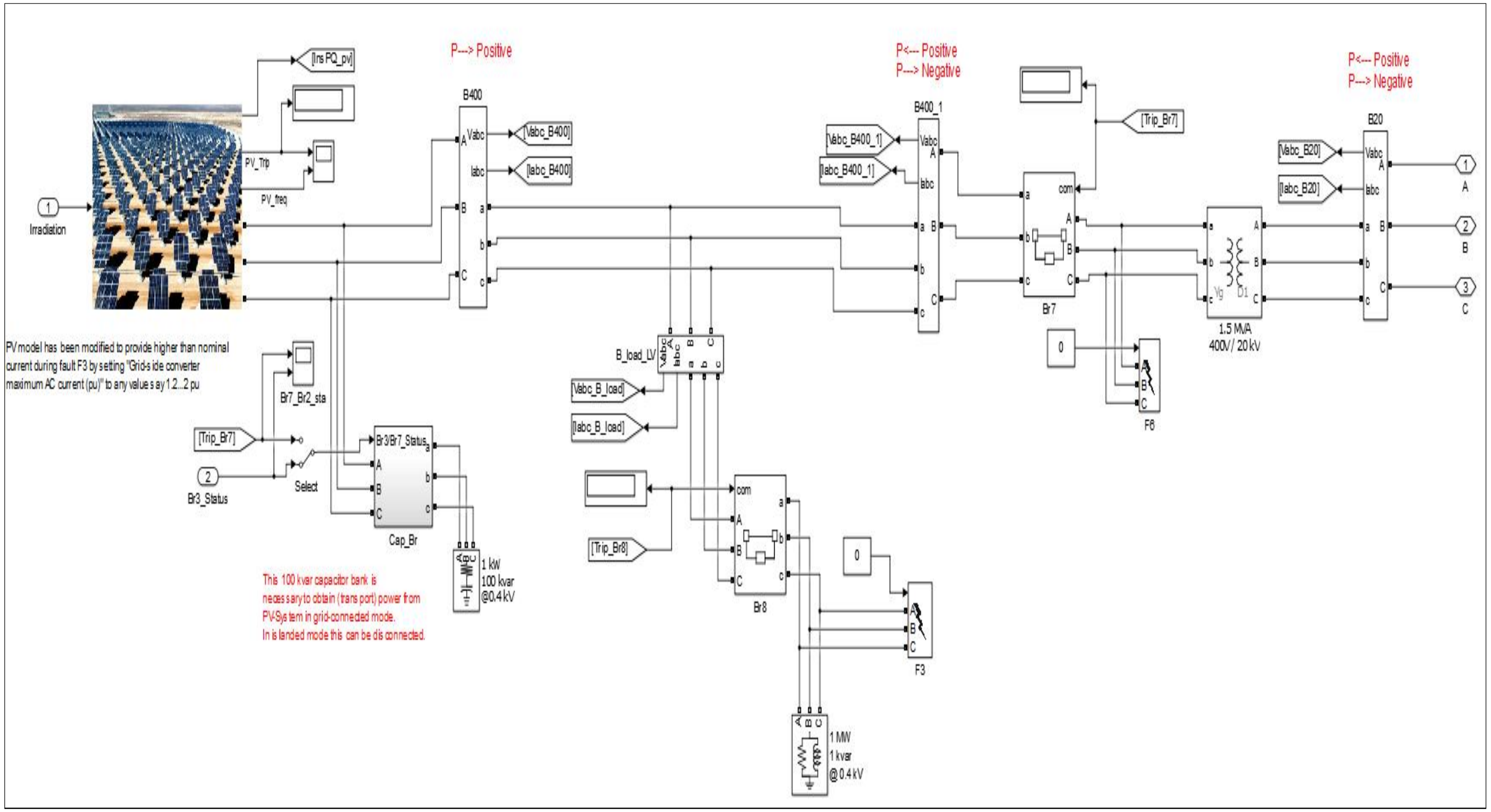
Radial and ring network model (10 MW)-Average model
SS_WTG1 subsystem



Radial and ring network model (10 MW)-Average model
SS_PV1 subsystem

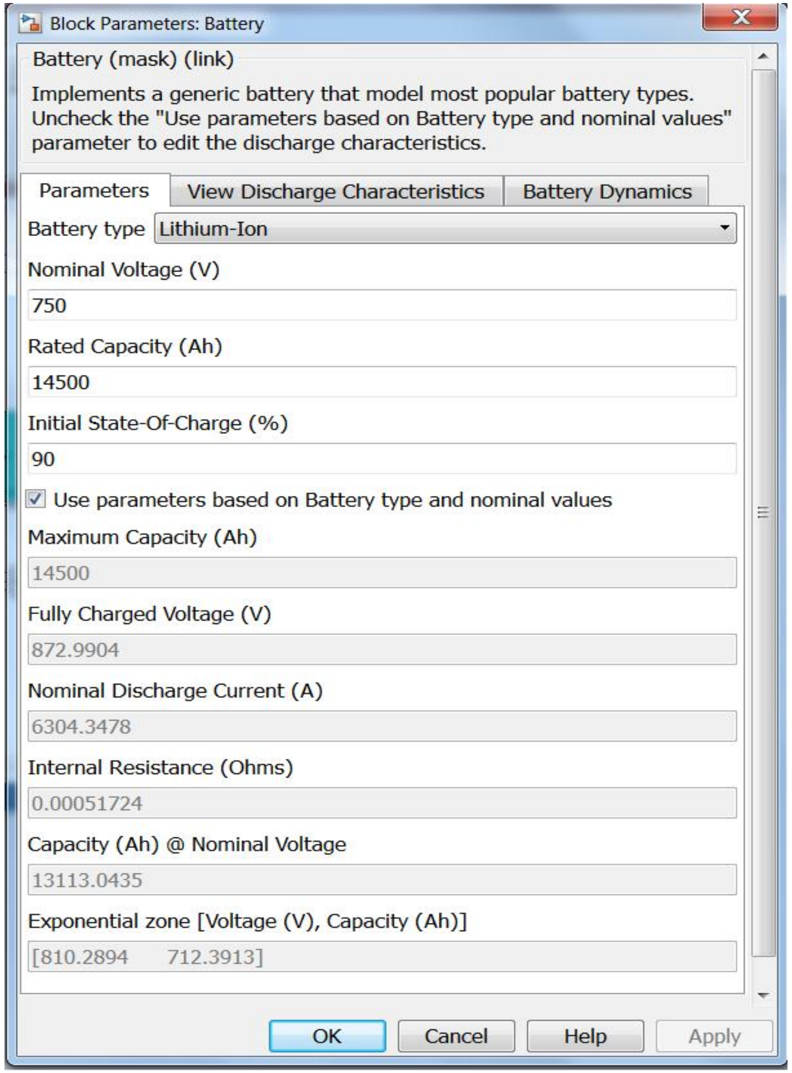


Radial and ring network model (10 MW)-Average model
PV_System1



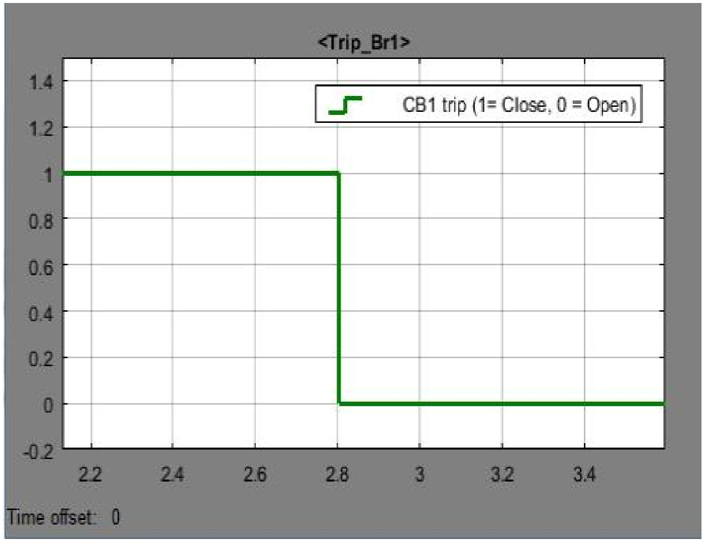
Radial and ring network model (10 MW)-Average model

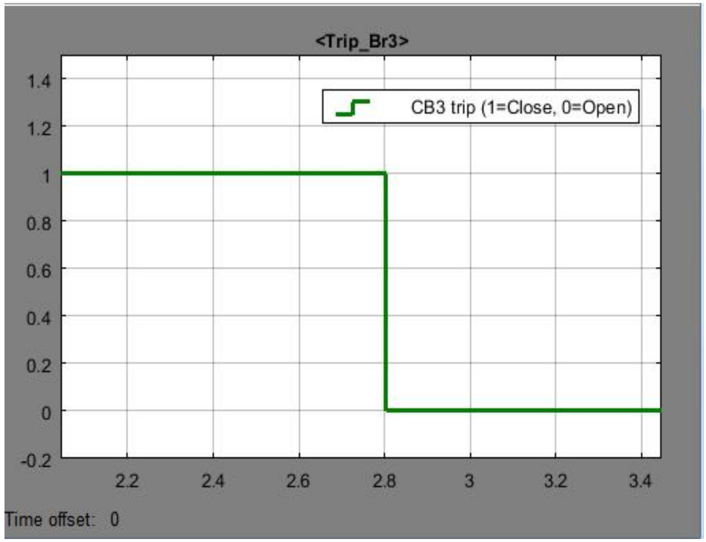
Parameters for central-BESS (9 MWh)



Radial and ring network model (10 MW)-Average model
Real-time simulation results: Trip signals

3-Ph fault F1 (2-3 s) in grid-connected mode
- CB1 trips at 2.8 s and CB3 transfer trips at 2.8 s





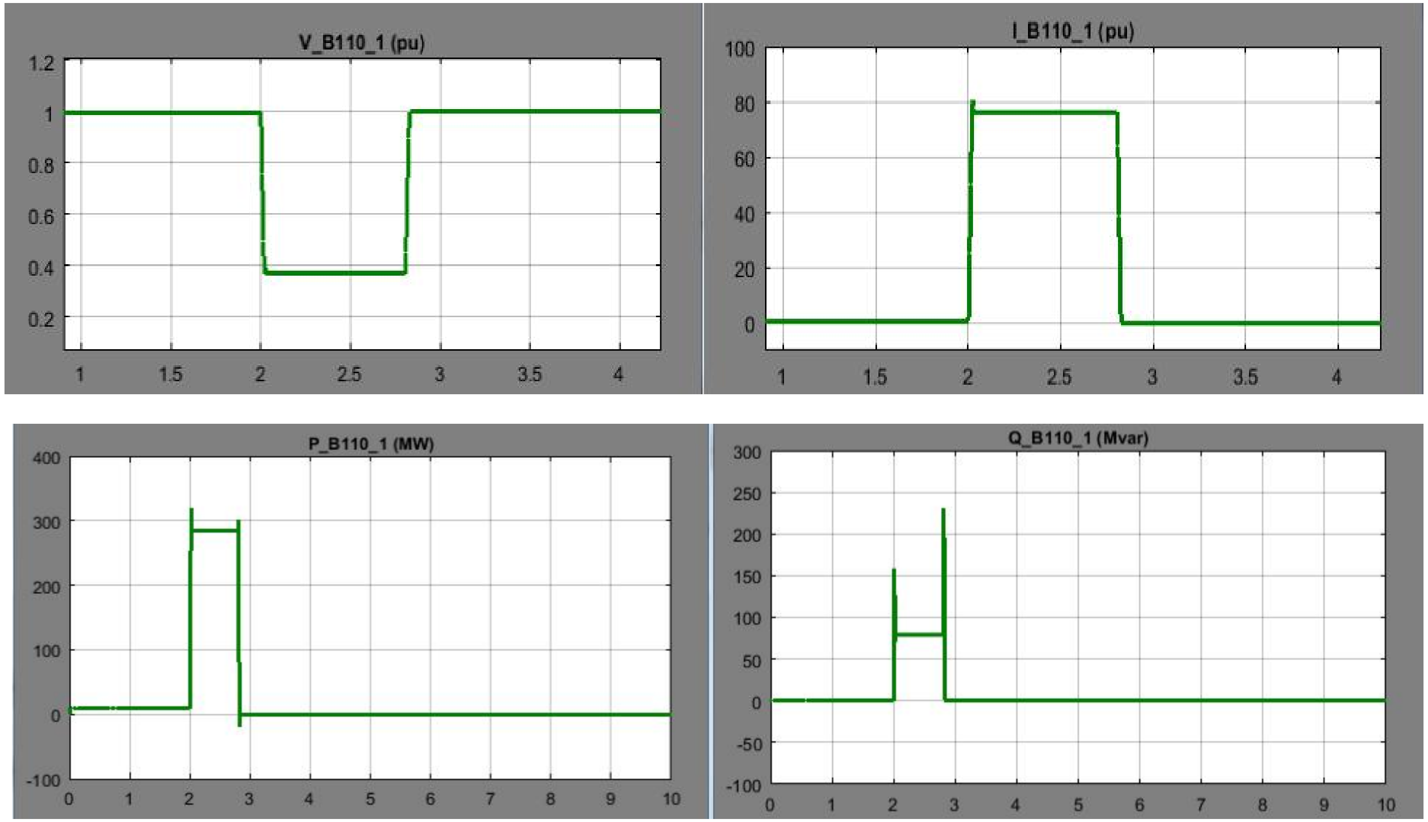
0.8 s is the normal OC coordination delay with downstream relays

No delay in transfer trip is assumed for this model

Radial and ring network model (10 MW)-Average model
Real-time simulation results: Voltages and currents

3-Ph fault F1 (2-3 s) in grid-connected mode

-Voltage, current, active and reactive power at the main grid bus B110-1

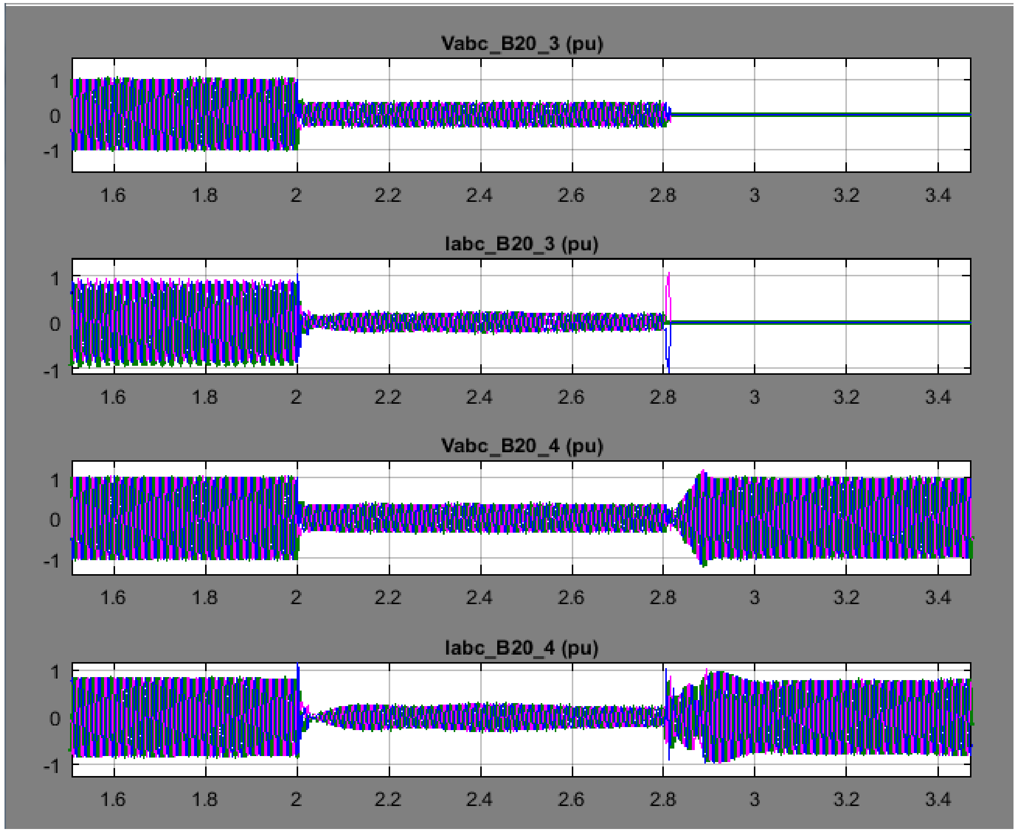


Radial and ring network model (10 MW)-Average model
Real-time simulation results: Voltages and currents

3-Ph fault F1 (2-3 s) in grid-connected mode

-AC Microgrid is islanded at 2.8 s, BESS between B20-3 and B20-4 immediately acts as grid forming source (provides balancing power and regulated voltage)

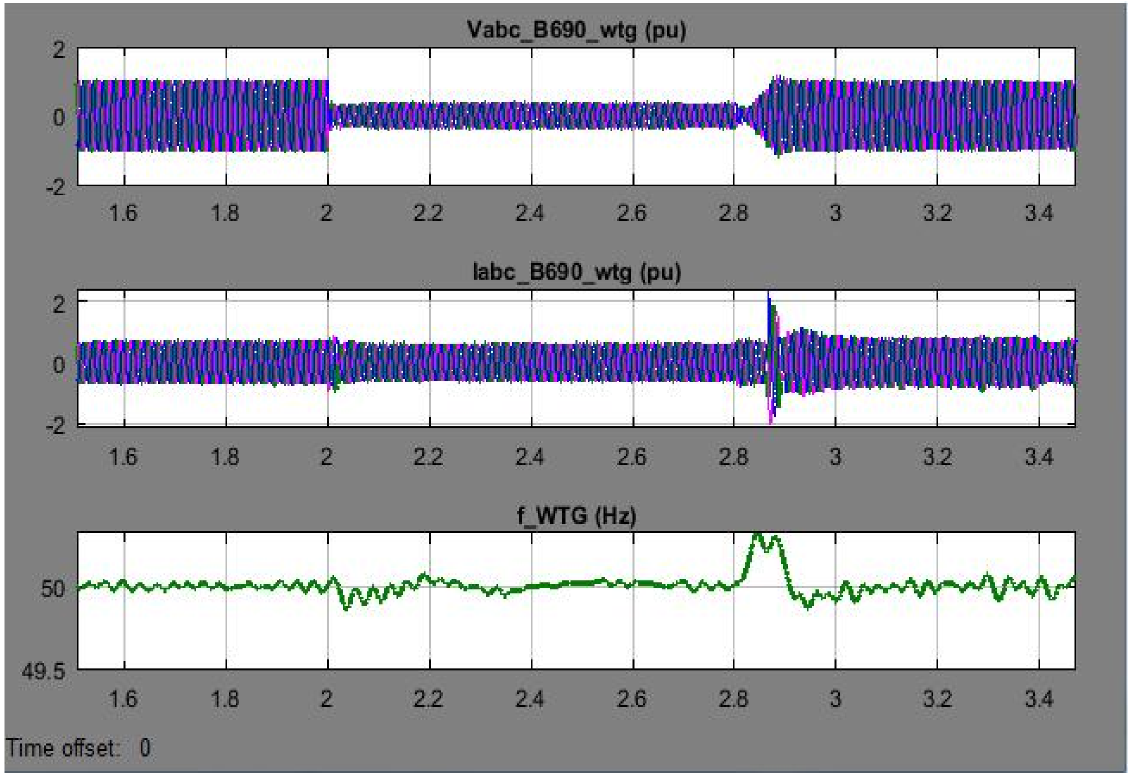
-Voltage and current at MV-buses B20-3 and B20-4 before and after islanding.



Radial and ring network model (10 MW)-Average model
Real-time simulation results: Voltages and currents

3-Ph fault F1 (2-3 s) in grid-connected mode

- *WTG set to provide 1.2 p.u. rated current during fault*
- *Voltage, current and frequency at LV-bus (B690) of WTG*
- *Connecting a resistor of few hundred milli-Ohms in series with RL-choke of WTG during fault removes the ferroresonance phenomena previously observed in "Radial network model (2.4 MW)", however it reduces the fault contribution from WTG during fault. This also decreases the overvoltage at C_dc-link during fault.*

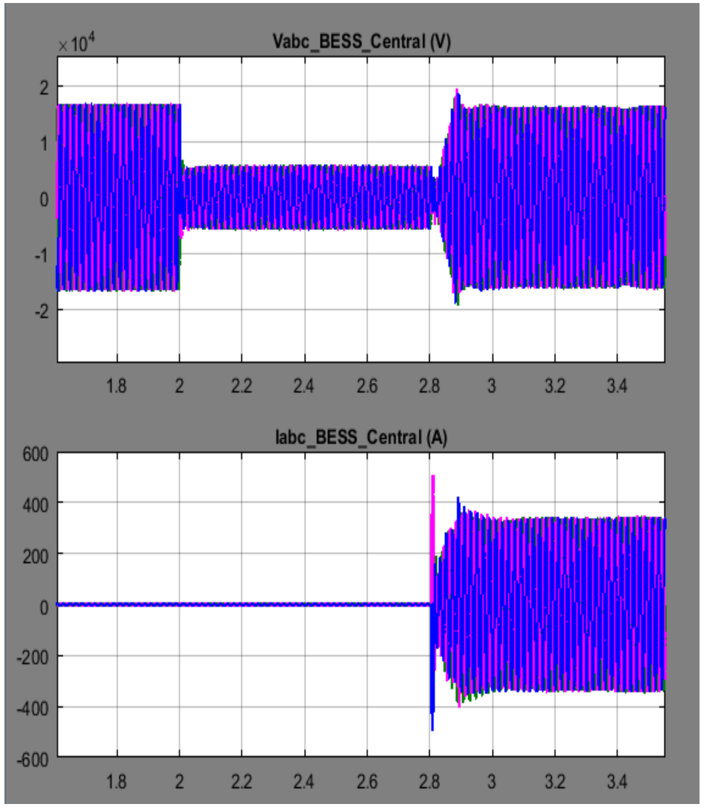


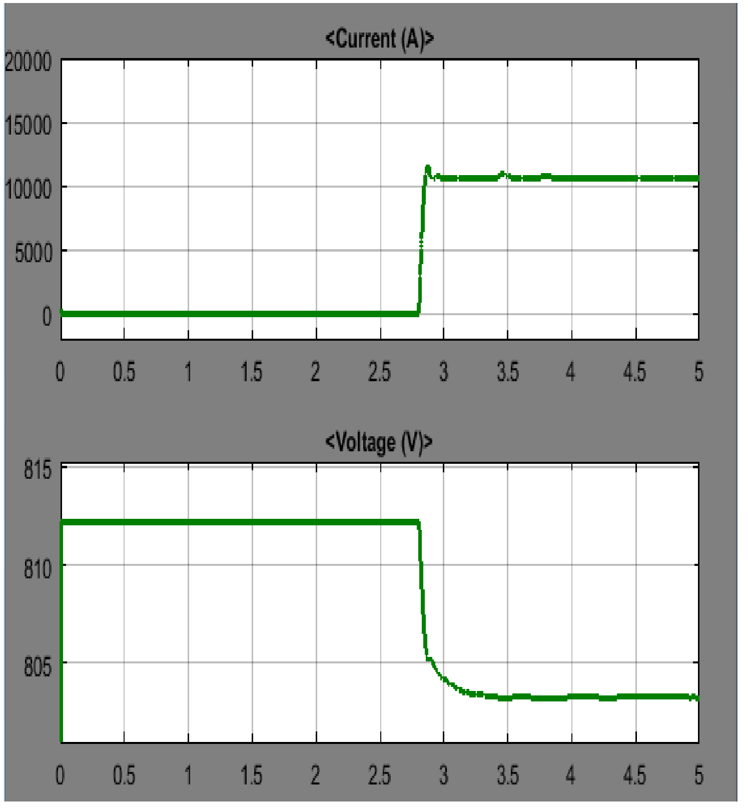
Radial and ring network model (10 MW)-Average model
Real-time simulation results: Voltages and currents

3-Ph fault F1 (2-3 s) in grid-connected mode

-Central-BESS is activated with trip signal of CB3

-Voltage (V) and current (A) at MV-bus (left) and LV terminal (right) of central-BESS before and after islanding due to fault F1.

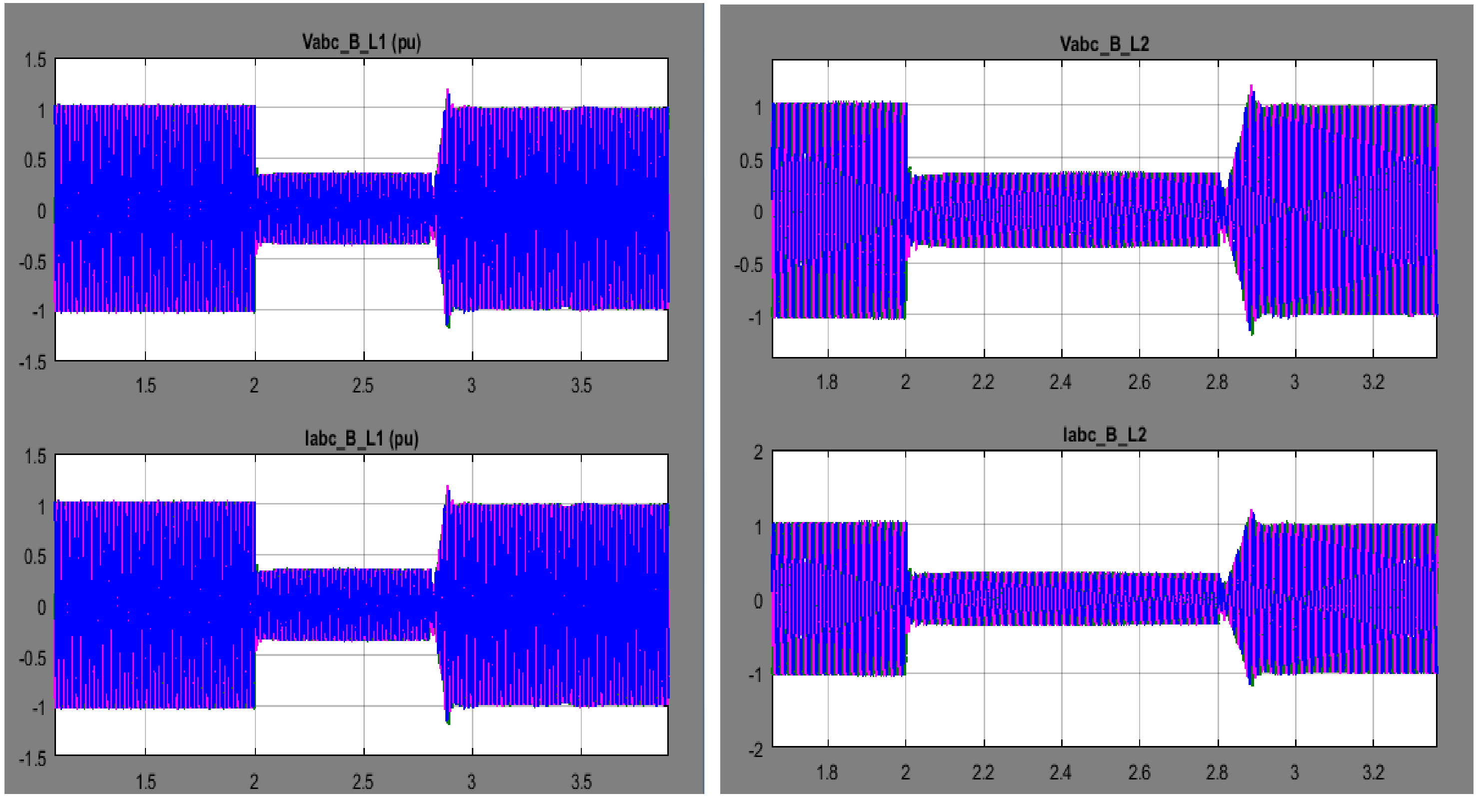




Radial and ring network model (10 MW)-Average model
Real-time simulation results: Voltages and currents

3-Ph fault F1 (2-3 s) in grid-connected mode

-Voltage and current in p.u. at MV loads L1 and L2 before and after islanding due to fault F1.



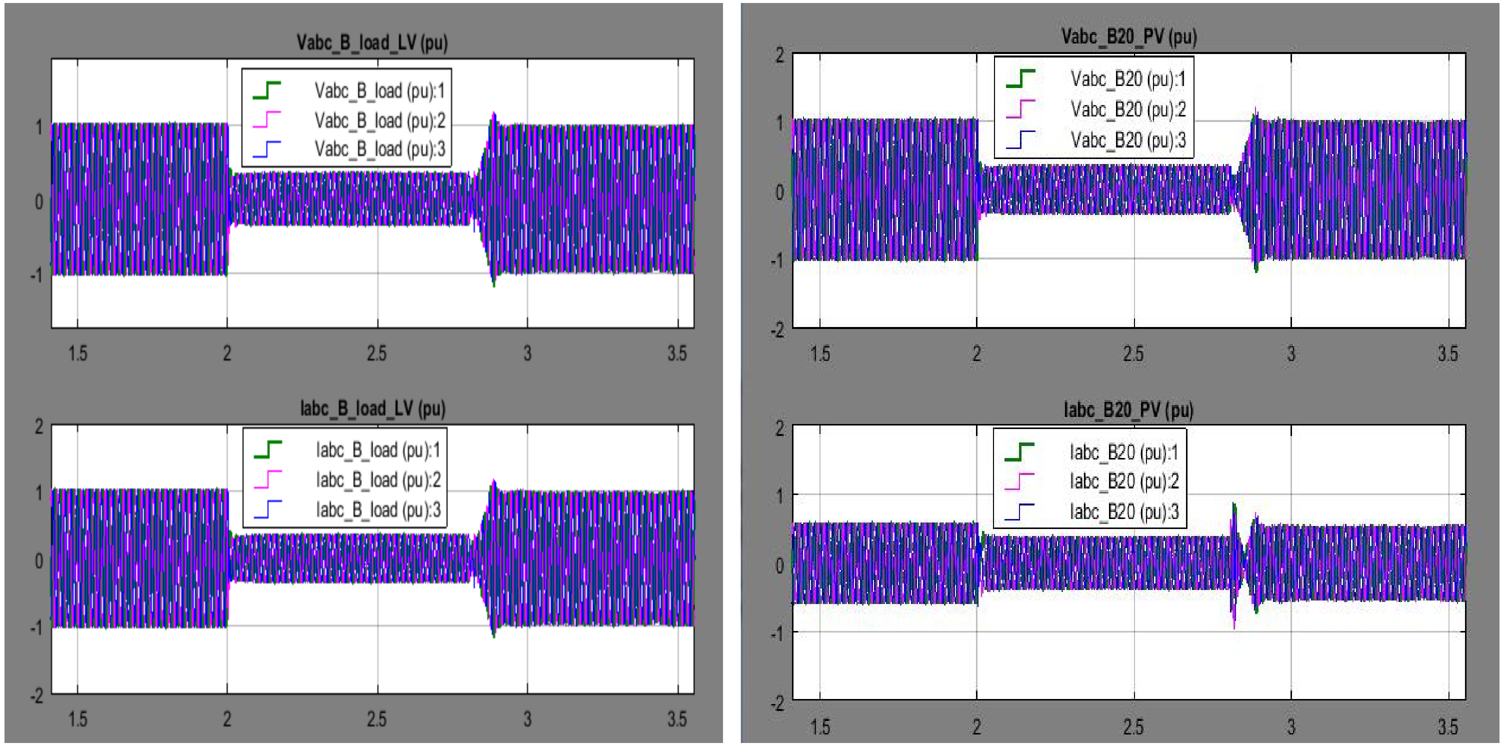
Radial and ring network model (10 MW)-Average model

Real-time simulation results: Voltages and currents

3-Ph fault F1 (2-3 s) in grid-connected mode

-PV set to provide 2 p.u. rated current during fault

-Voltage and current at LV load and MV bus of PV_System1 before and after islanding due to fault F1

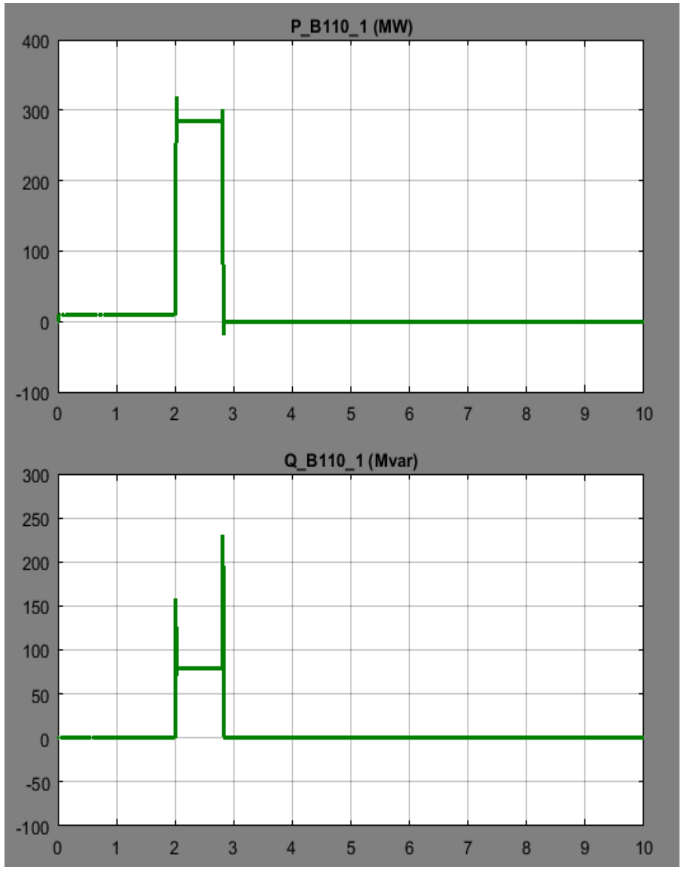


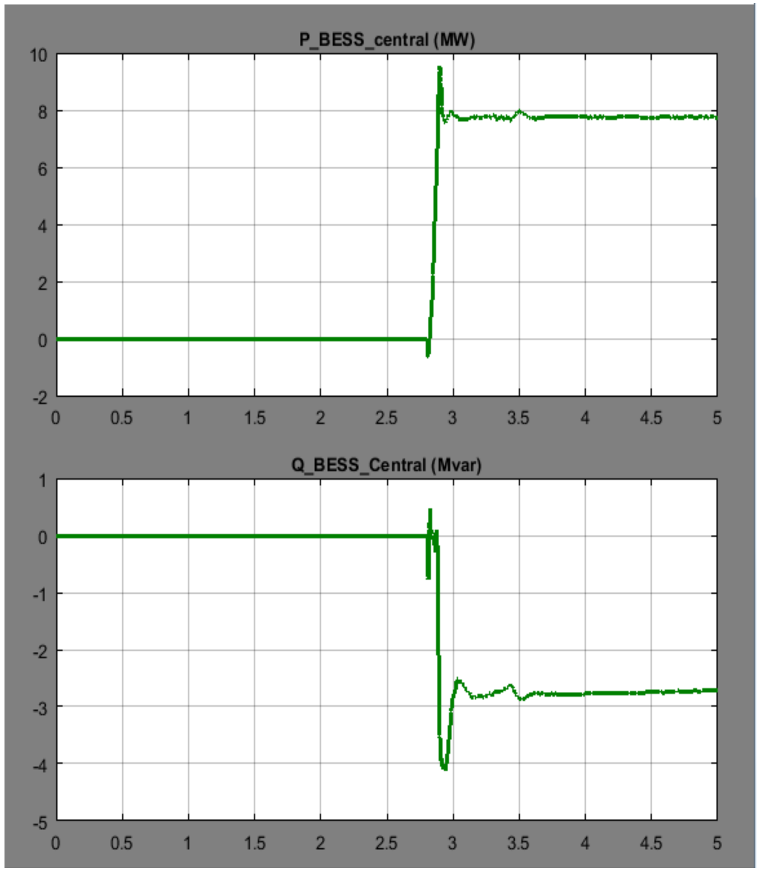
Radial and ring network model (10 MW)-Average model

Real-time simulation results: Active and reactive power

3-Ph fault F1 (2-3 s) in grid-connected mode

-Active power (MW) and reactive power (Mvar) at HV bus B110_1 and MV bus of Central-BESS before and after islanding due to fault F1



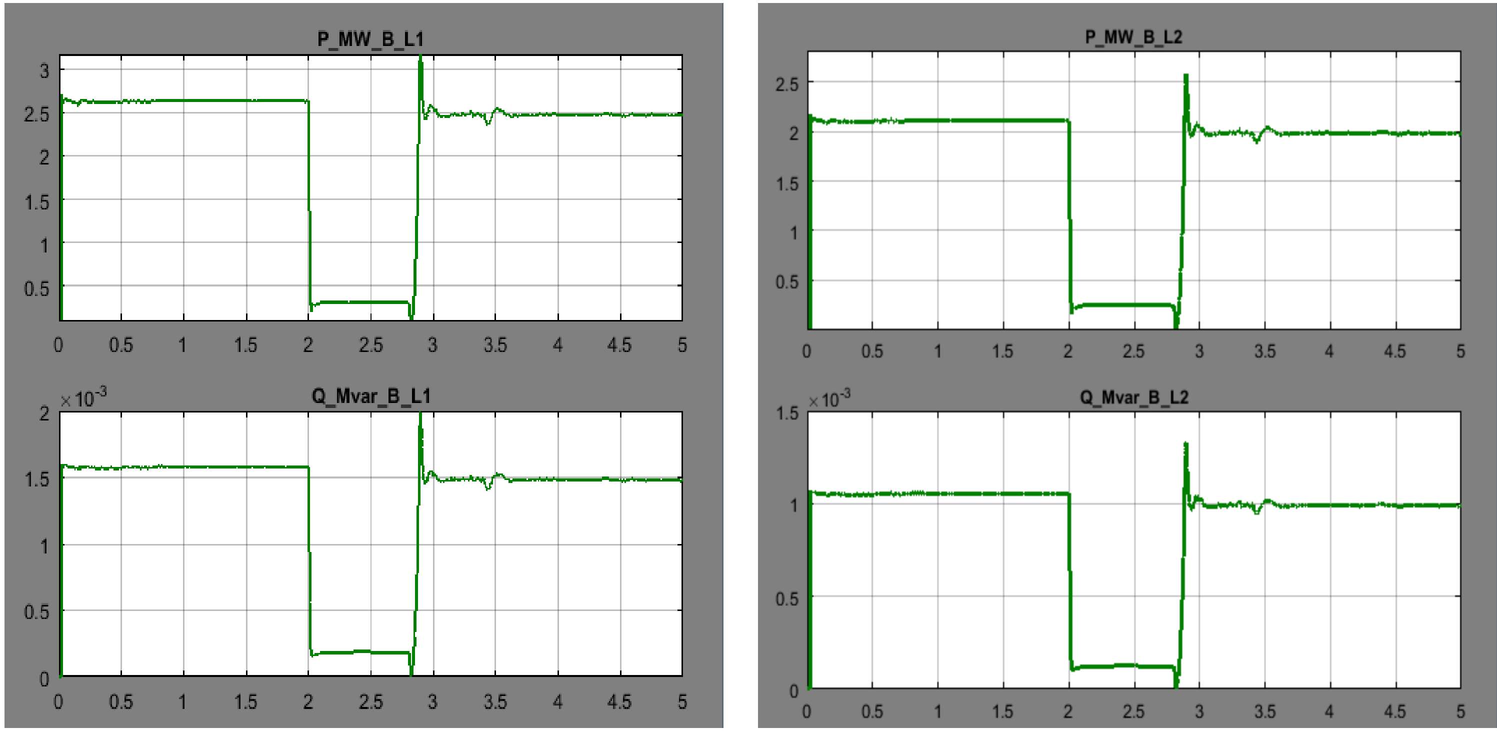


Radial and ring network model (10 MW)-Average model

Real-time simulation results: Active and reactive power

3-Ph fault F1 (2-3 s) in grid-connected mode

-Active power (MW) and reactive power (Mvar) at MV loads L1 and L2 before and after islanding due to fault F1

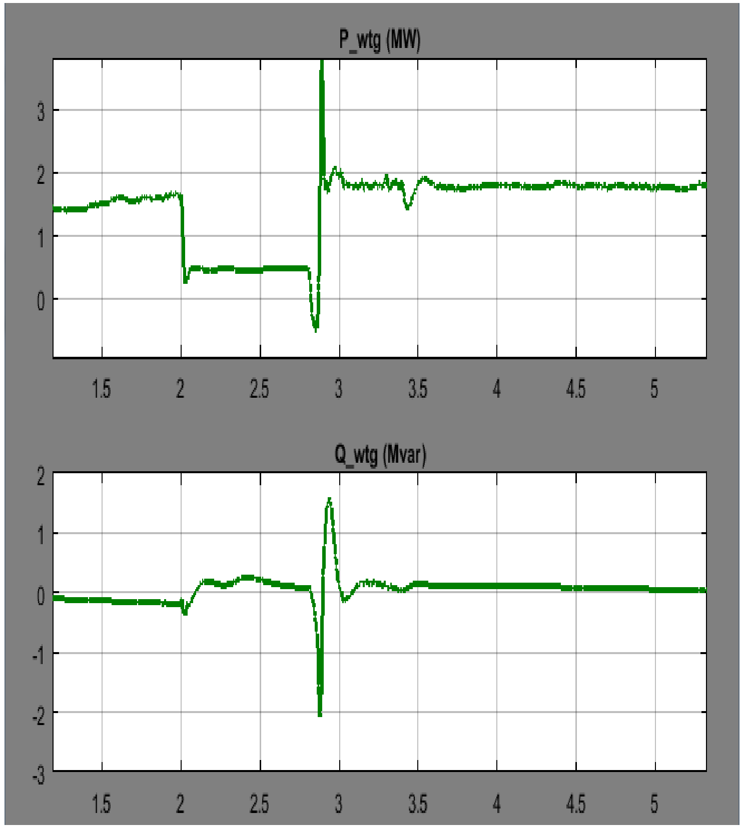


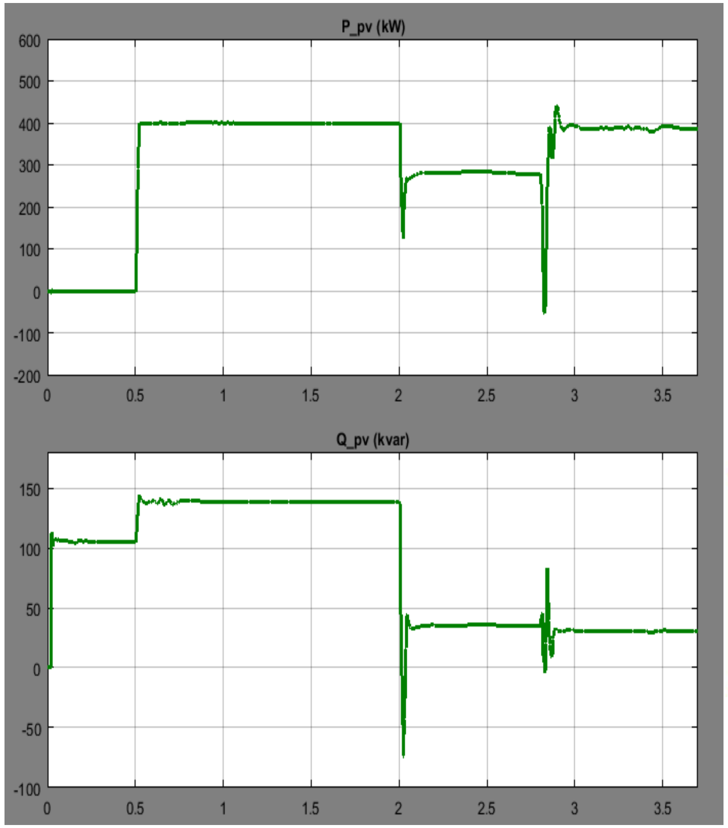
Radial and ring network model (10 MW)-Average model

Real-time simulation results: Active and reactive power

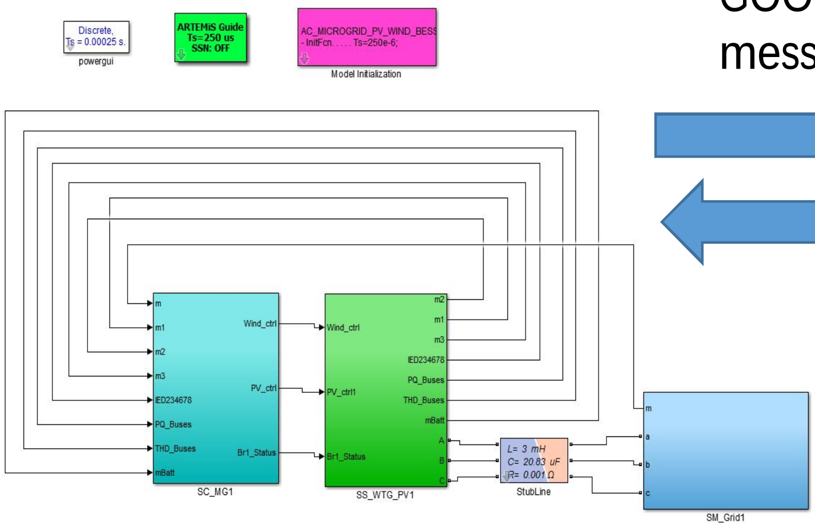
3-Ph fault F1 (2-3 s) in grid-connected mode

-Active power (MW) and reactive power (Mvar) at LV terminals of WTG and PV before and after islanding due to fault F1



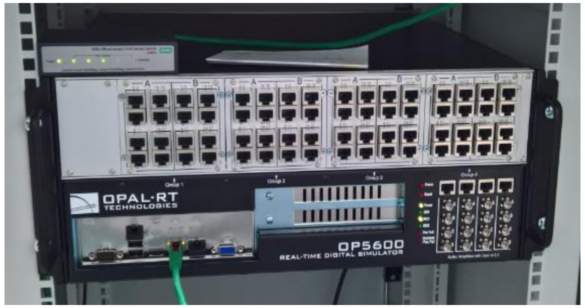


IEC 61850 Goose communication testing using real-time simulation



RT-LAB Model (Host PC)

GOOSE message



Real-time simulator (RTS)

GOOSE message

VAMP Relay

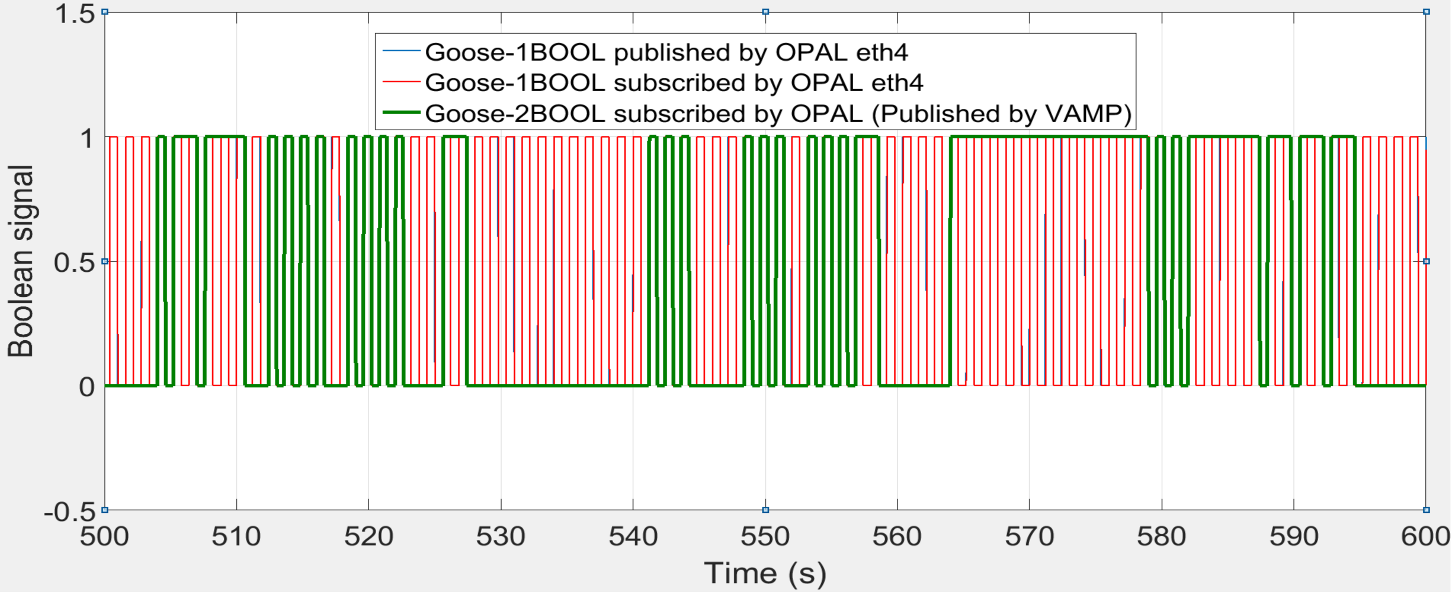
- -Hardware-in-loop (HIL) testing
- -IEC 61850 Standard
- -GOOSE message (Publisher/Subscriber)
- -Ethernet network

IEC 61850 Goose communication testing using real-time simulation

- VAMP relay to OPAL-RT => ”Goose-2BOOL” as Boolean pulse (Green)
- Goose pulse is recorded using OpWriteFile inside OPAL-RT model
- Goose message published and subscribed from eth4
- Mike modified the icd file of VAMP relay => used inside the Goose

subscriber block of Goose-2BOOL: RT simulation (500...600 s)

- Green signal shows OPAL-RT does not subscribe to every status change from VAMP relay



Conclusions

-Couple of AC Microgrid models have been developed and RT-simulation performed
-WTG and PV-System models behave with LVRT capability
Þ provide fault contribution of 1.1-2 pu of nominal current at their connection points depending on grid-side converter settings
-Central BESS also integrated for islanded mode operation
-BESS behavior during faults in islanded mode is also done
Þ Fault contribution from central BESS storage is 2.6xIn during 3-phase faults, this should be limited to maximum 2xIn using some kind of fault current limiters in grid-forming mode of converter.
-Protection IED models are also implemented in RT-models
Þ Protection IEDs include IEEE devices 50, 51, 27 and 59
Þ Only IEEE 50 and 51 protection functions tested
-Real-time SIL-testing of IED models done for few SC faults.
-IEC 61850 GOOSE HIL-testing with VAMP relays done
Þ IEC 61850 Goose communication from OPAL to VAMP relay works fine but VAMP to OPAL communication has some problems of missing data (OPAL does not subscribe to every status change)
Þ More comprehensive case studies and HIL testing will be presented in the continuation project (VINPOWER). The requirement of adaptive protection with respect to limitation of fault current contribution from both the grid-forming converter and grid-following converters will be analyzed further.

Future work

-Evaluation of protection algorithm based on IEC 61850 standard

Þ Additional BESS at DG locations for black-start capability

Þ Directional OC evaluation

Þ Directional selectivity requirements for networks with DG at both ends

Þ Review of new IEEE Std. 1547 requirements

Þ Negative sequence current provision by DGs

Þ New standards for BESS and islanding operation of AC Microgrids

Thank you!