Converter-Interfaced CHP Plant for Improved Grid-Integration, Flexibility and Resiliency

DE-EE0008412
GE Research/GE Renewable
10/1/2018 – 5/31/2021

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Overview

Project Title: Converter-Interfaced CHP Plant for Improved Grid-Integration, Flexibility and Resiliency

Timeline:

Project Start Date: 10/01/2018

Budget Period End Date: 12/31/2020

Project End Date: 5/31/2021

Barriers and Challenges:

- Economic viability of converter-interface CHP
- Comprehensive modeling of reciprocating engines controls
- Complexity of integrating controls of engines, converter and plant controller
- Integration of evolving grid code requirements, energy markets dynamics and other economic factors

AMO MYPP Connection:

- Combined Heat and Power (CHP) systems

Project Budget and Costs:

Budget	DOE Share	Cost Share	Total	Cost Share %
Overall Budget	$1,499,533	$374,883	$1,874,416	20%
Approved Budget (BP-1)	$916,338	$229,084	$1,145,422	20%
Approved Budget (BP-2)	$583,174	$145,799	$728,973	20%
Costs as of 5/31/2021	$1,485,828	$373,957	$1,869,785	20%

Project Team and Roles:

- GE Research: project management, economic and technical feasibility analysis, development of the control platform, validation tests
- GE Renewable: cost share, steering committee, technical support with converter controls
- National Grid: advisory, support on user cases applications and grid code requirements

Project Objective

- Streamline the grid interconnection process of small-to medium sized CHP systems (1-20 MWe) while providing a higher ROI for CHP plants.
  - Grid code requirements are increasingly more stringent for DER
  - Limited flexibility of current CHP systems discourages their participation in ancillary services markets which limits their potential revenue streams
  - Potential impacts of current CHP solutions limit the grid hosting capacity

- **Specific objective**: Develop a grid-interface converter controls and microgrid controller algorithms for a seamless interconnection of small to medium sized CHP plants to the distribution grid
  - Technical Approach: Confirm both the technical and economic benefits with multiple user cases, Develop and size the interface converter; Develop, test and validate the control integration (engine, generator, converter and microgrid controller), Validate compliance with IEEE 1547-2018 and IEEE 2030.7, Build a power testbed for performance validation
  - Targets: ROI > 10%, meet IEEE 1547 requirements

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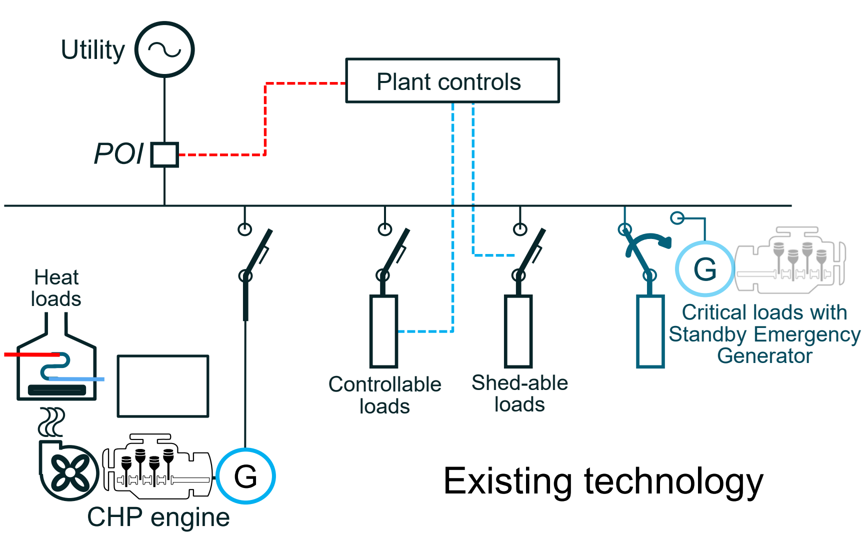
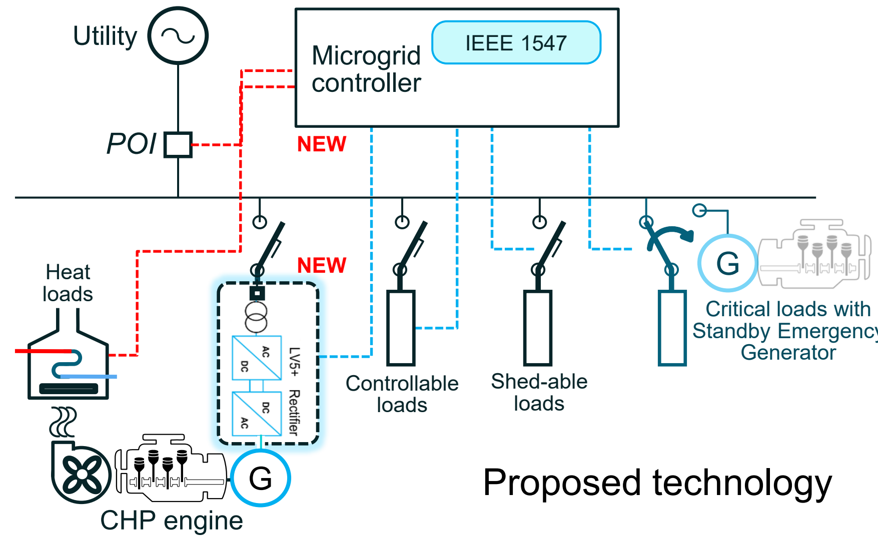
Technical Innovation





- **<u>Limitations with current practice</u>**:
  - lengthy interconnection process with comprehensive system studies to demonstrate compliance with utility requirements
  - high fault contribution that limits hosting capacity of the feeder
  - generator oversized for harmonics and reactive power
  - limited reactive power support
  - high interconnection costs limiting ROI and discouraging projects to go to commissioning
- **<u>Proposed technical approach</u>**:
  - interconnect CHP systems using a grid-ready inverter which already incorporates the key grid functions.
  - Use microgrid controller for operation flexibility
- Critical innovations
  - reduce required size of the generator by 25%
  - significantly limit the short-circuit fault contribution of CHP eliminating a key barrier to higher penetration
  - decouple the CHP frequency from the grid dynamics
  - streamline the interconnection process of CHP in the distribution grid with the grid-ready inverter

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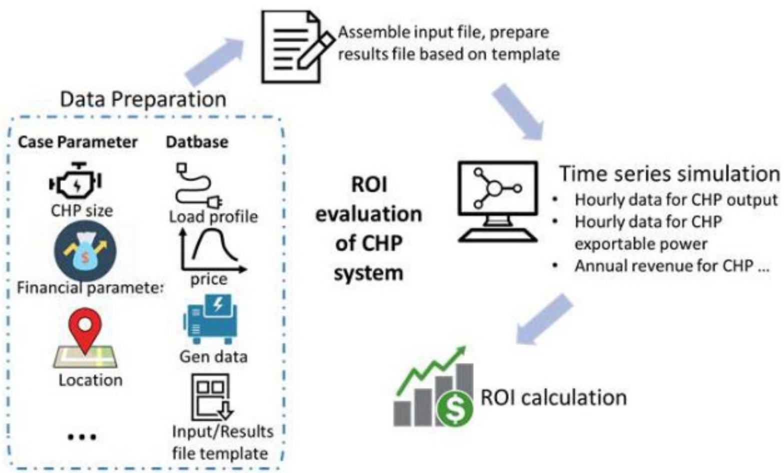
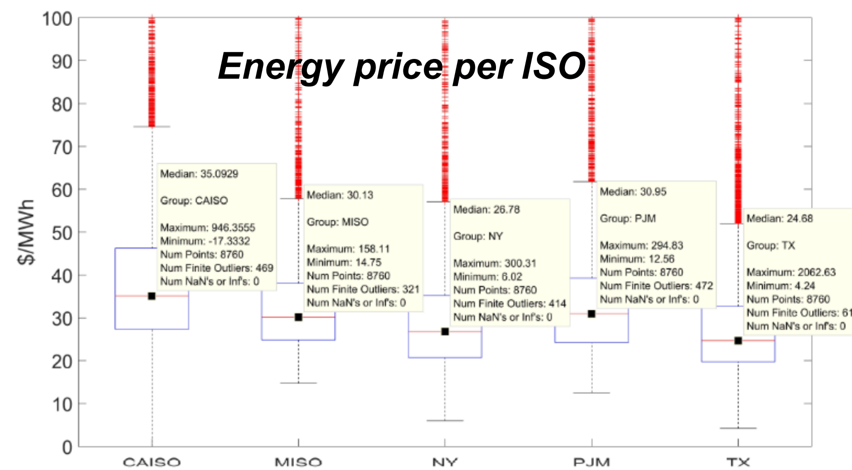
Results and Accomplishments

- ROI evaluation and sensitivity analysis:



Automatic toolkit for ROI evaluation

Application	ISO	CHP MW	Primary Mover
College/Univ.	CAISO	4.4 MW	Combustion
Water Reclamation	ERCOT	5.2 MW	Combustion
Hospital	NYISO	2.2 MW	Reciprocating
Commercial Building	PJM	1.48 MW	Reciprocating
Hotel	MISO	2.6 MW	Reciprocating



Economic feasibility analysis

- 25 user cases (5 applications in 5 ISO)
- 975 scenarios including sizing scenario (average thermal, average electric, peak electric), and sensitivity analysis
- In each case converter-interfaced CHP ROI is compared with directly-coupled

Critical Parameters	Varying Scenario	Critical Parameters	Varying Scenario
Energy price	Up 50%; Dn 50%	Generator cost	Up 25%; Dn 25%
Voltage support price	Up 50%; Dn 50%	Converter to engine size ratio	Up 25%; Dn 25%
Converter cost	4 cent/W; 8 cent/W	Interconnection delay	6 months; 18 months

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Results and Accomplishments

- ROI of converter-interfaced CHP

Application	CAISO	MISO	NYISO	PJM	ERCOT
Hospital	3.98% (18.73%)	3.51% (13.64%)	0.82% (10.26%)	1.25% (9.56%)	2.69% (10.08%)
Large office	9.15% (12.44%)	5.73% (12.87%)	1.94% (11.12%)	**-0.62%** (9.62%)	3.89% (10.08%)
Water Rec.	3.48% (12.95%)	2.51% (11.21%)	**-4.78%** (10.52%)	**-9.68%** (9.68%)	0.70% (10.60%)
College/Univ.	3.06% (14.78%)	1.30% (15.62%)	**-5.39%** (13.67%)	**-8.47%** (11.39%)	**-1.15%** (14.27%)
Hotel	4.67% (18.33%)	5.06% (15.63%)	1.12% (13.61%)	0.85% (13.49%)	2.23% (14.33%)

ROI of directly-coupled in bracket

Critical Parameter	Change in winning rate	Average change of ΔROI	Standard deviation of change in ΔROI
Energy price up 50%	24.00%	2.75%	-2.40%
Energy price dn 50%	-36.00%	-21.33%	57.33%
Converter cost at 8¢/W	-36.00%	-2.61%	0.41%
Converter cost at 4¢/W	8.00%	2.68%	-0.27%
Converter to engine size ratio up 25%	-36.00%	-3.10%	1.92%
Converter to engine size ratio dn 25%	8.00%	1.65%	0.08%
Intercnntn delay as 18 months	8.00%	2.34%	0.89%
Intercnntn delay as 6 months	-36.00%	-2.22%	-0.78%
Generator cost up 25%	0.00%	0.23%	-0.03%
Generator cost down 25%	0.00%	-0.23%	0.02%
Voltage support price up 50%	0.00%	0.17%	0.11%
Voltage support price dn 50%	0.00%	-0.17%	-0.08%

Summary results

- Converter-interfaced CHP can be more profitable than directly-coupled in a variety of user cases
- The profitability is more sensitive to energy price, converter cost and delay in operation
- Hospital and hotel are more favorable as well as CAISO, MISO and NYISO

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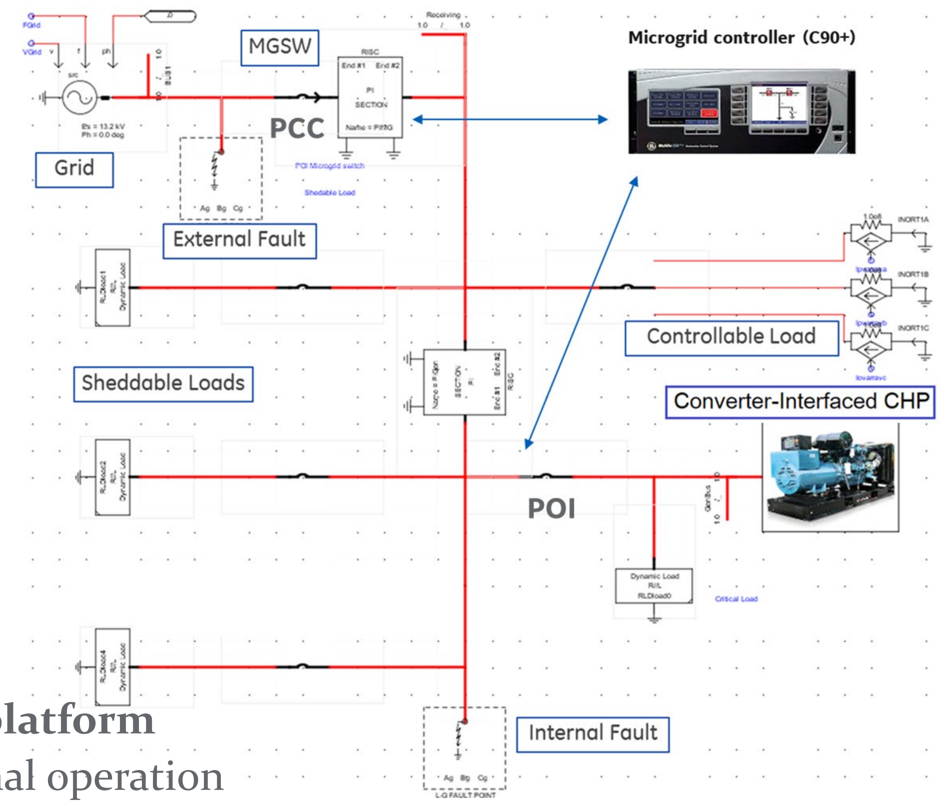
Results and Accomplishments

- HIL simulations:

System components	Max Pow [MW]	Min Pow [MW]	Voltage [kV]	Up Ramp [MW/s]	Dwn Ramp [MW/s]
CHP engine	1.06	0.15	0.48	0.070	0.070
Interface Converter	1.25	0.15	0.48	25	25
Grid model	n/a	n/a	0.48	n/a	n/a
Main Breaker (PCC)	n/a	n/a	0.48	n/a	n/a
Sheddable load #1	1.6	0.8	0.48	0.1	0.1
Sheddable load #2	0.8	0.4	0.48	0.1	0.1
Controllable load	0.4	0	0.48	0.1	0.1
Critical load	0.3	0.2	0.48	0.1	0.1



Test cases for the validation of the control platform

- Planned disconnection from the grid in normal operation
- Synchronization and reconnection to the grid
- Voltage and Frequency ride-through following faults
- Active power dispatch
- Power factor correction at PCC
- Internal and external faults

25 test cases successfully passed!

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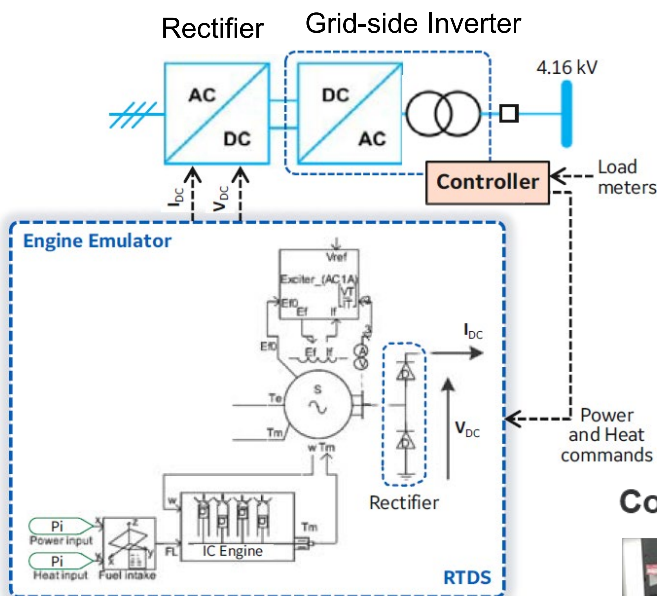
Results and Accomplishments

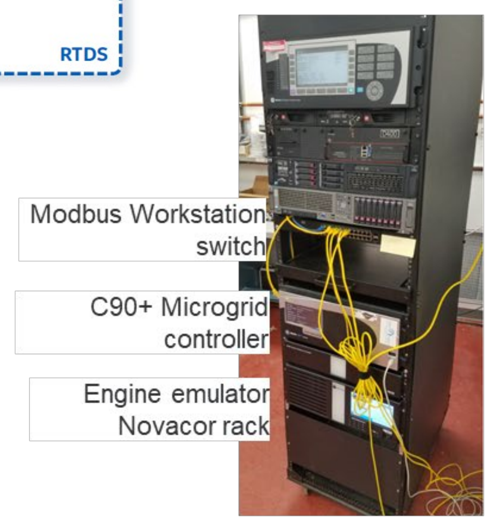
- PHIL testbed for performance validation



Performance Objective	Metric	Data Requirements	Success Criteria
C1. Disconnection	disconnection times	measurements of V, I, P at the POC and breaker opening timeline	IEEE 1547 compatible
C2. Reconnection	POC breaker status	measurements of V, I, and P at the POC and breaker closing timeline	No trip after reconnection
C3. Power Quality	Voltage, frequency, harmonics and power factor values	measurements of V, f, THD, and power factor at the POC	IEEE 1547 and IEEE 2030.7 and 2030.8 compatible
C4. Dispatch	generation outputs following heat and power commands	Loads meters P and H demand, measurement of P at POC and Heat from engine emulator	IEEE 2030.7 and 2030.8 compatible

700kVA power capability

Controls cabinet



Back-to-back inverters

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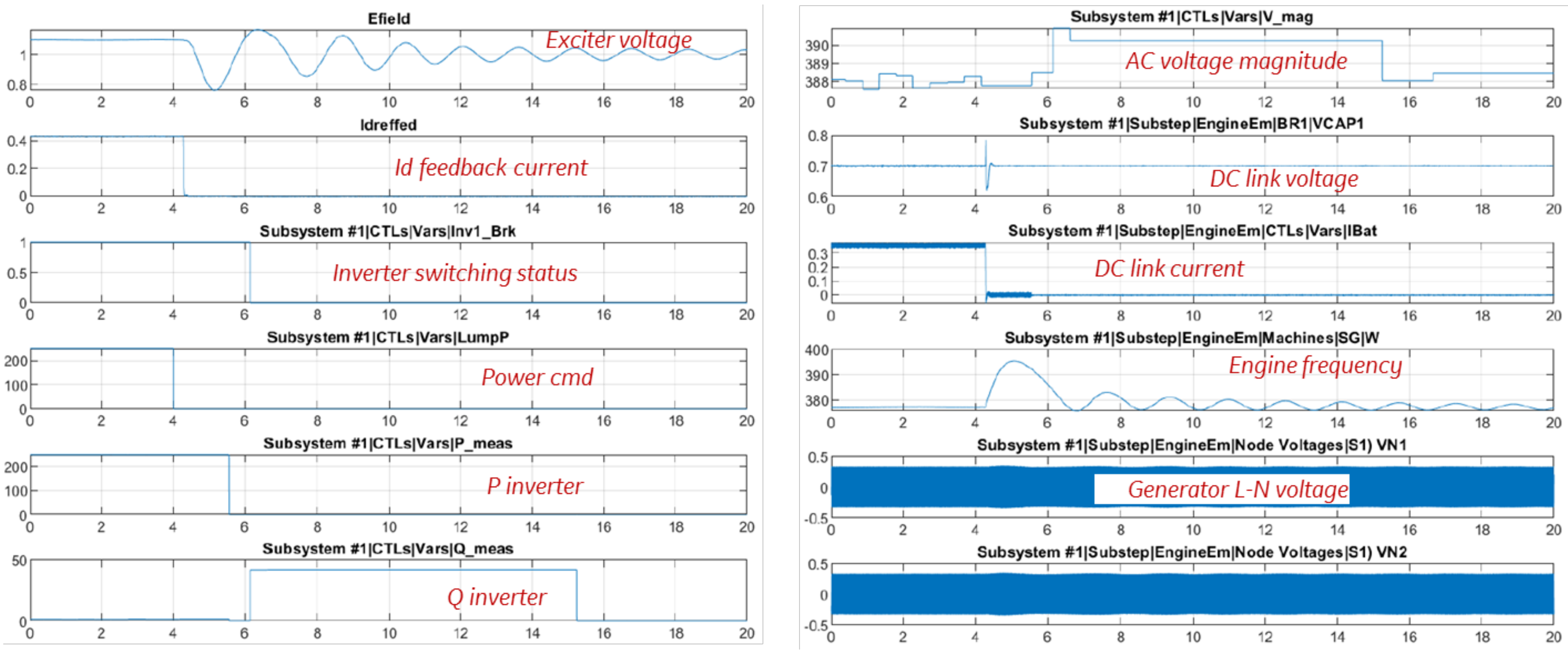
Results and Accomplishments

- Test results: Planned disconnection

Test case: Ramp down the power to 0, before opening the AC breaker (inverter). Monitor the transients at the engine emulator. Operation at ~250kW with pf = 1



No overstress of the converter or the engine

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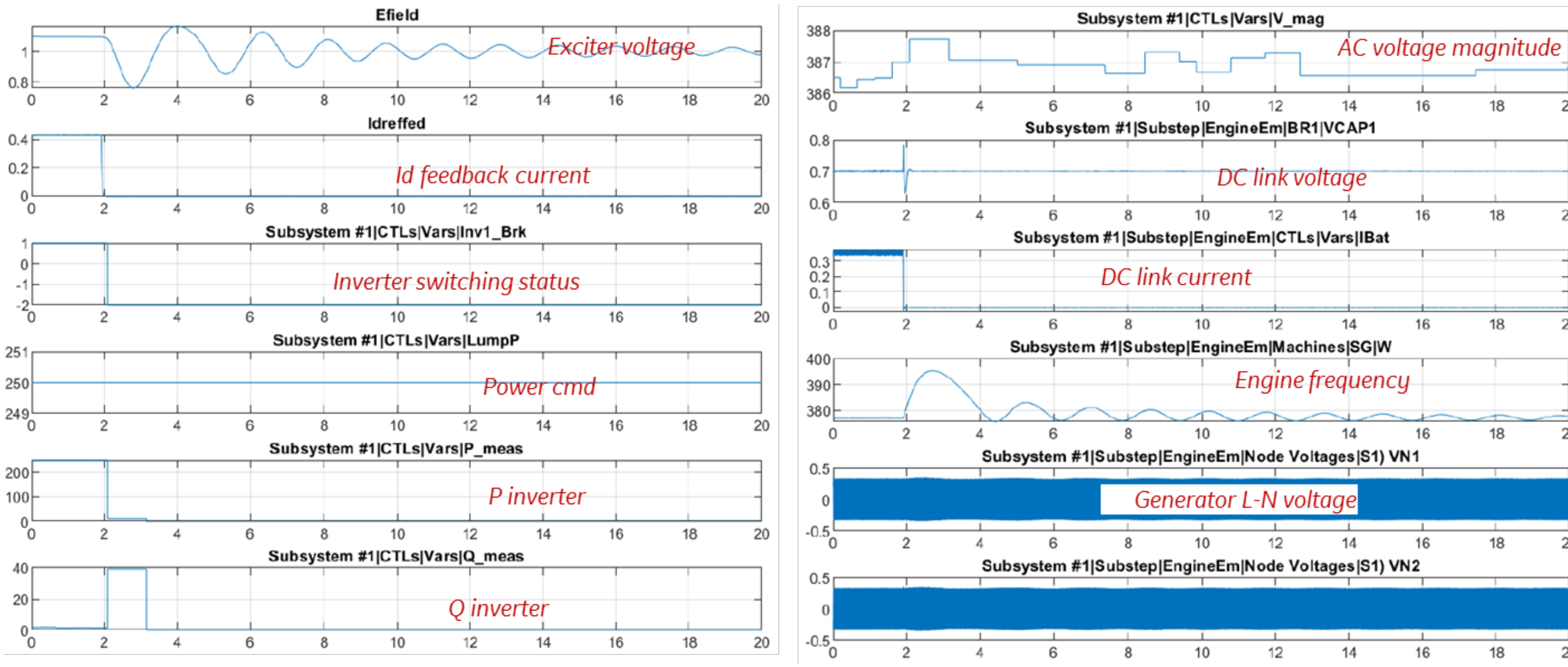
Results and Accomplishments

- Test results: Emergency disconnection

Test case: Trip the AC breaker (inverter) for emergency shutdown at ~250kW with pf = 1. Monitor the transients at the engine emulator.



No overstress of the converter or the engine

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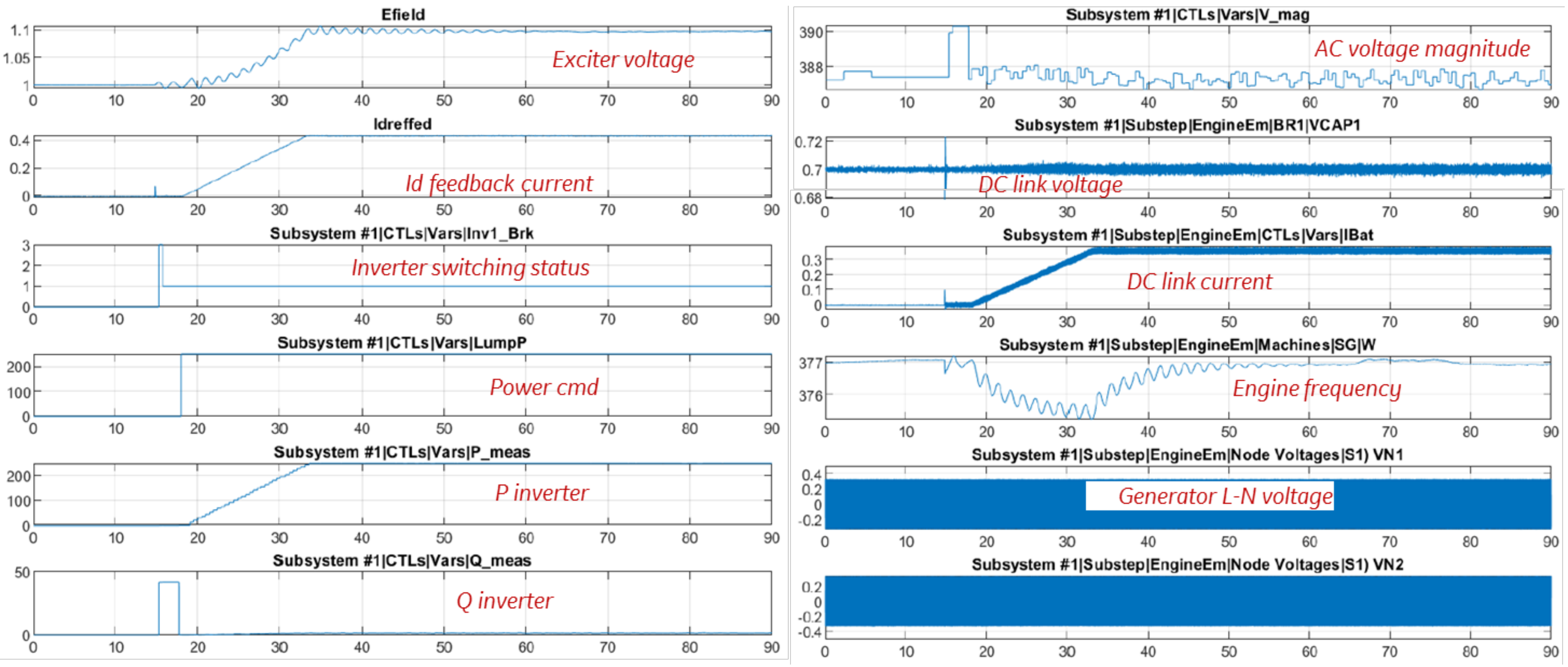
Results and Accomplishments

- Test results: Reconnection and ramp rate

Test case: Reconnect the system to the grid and test different ramp rates. Monitor the transients at the engine emulator. Operation with ramp rate of 1000kW/min



Engine can ramp up at 1MW/min without limitation from the converter

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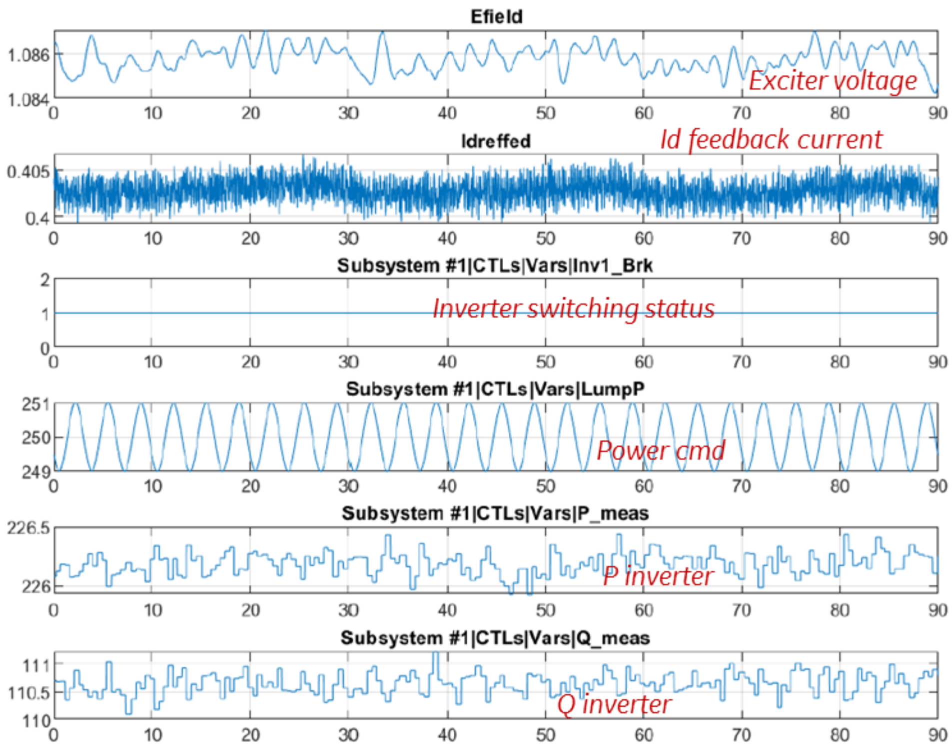
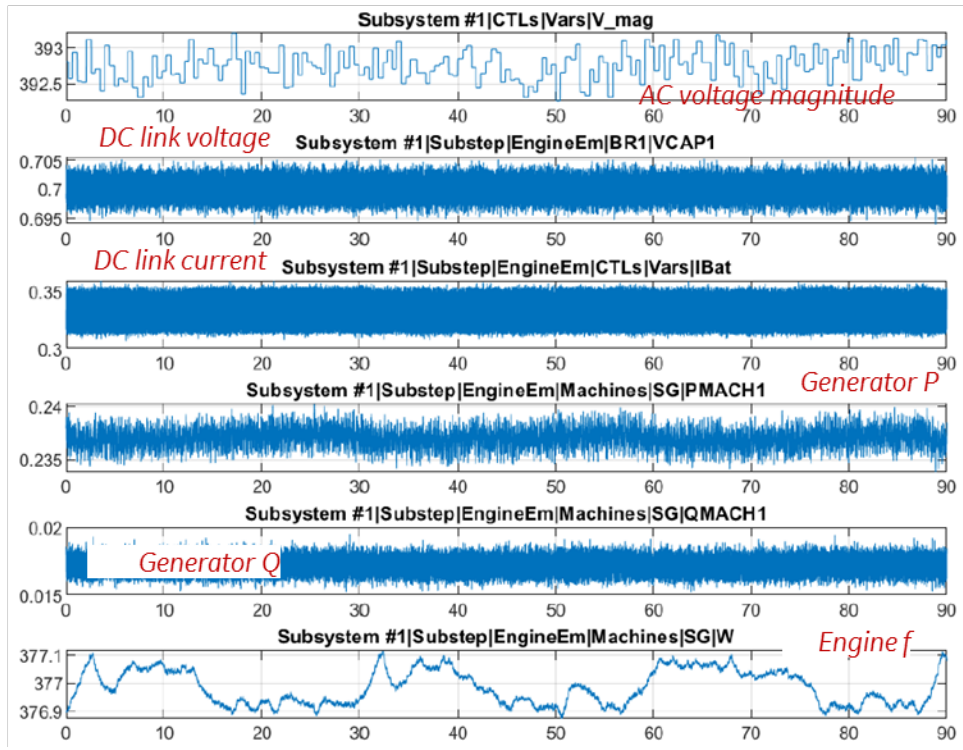
Results and Accomplishments

- Test results: Power factor control

Test case: Control the power factor at inverter output. Monitor the voltage, P, Q and harmonics at the at the engine emulator. Operation at 250kW at pf = 0.9





Generator outputs ~0kVAR while inverter outputs 110kVAR

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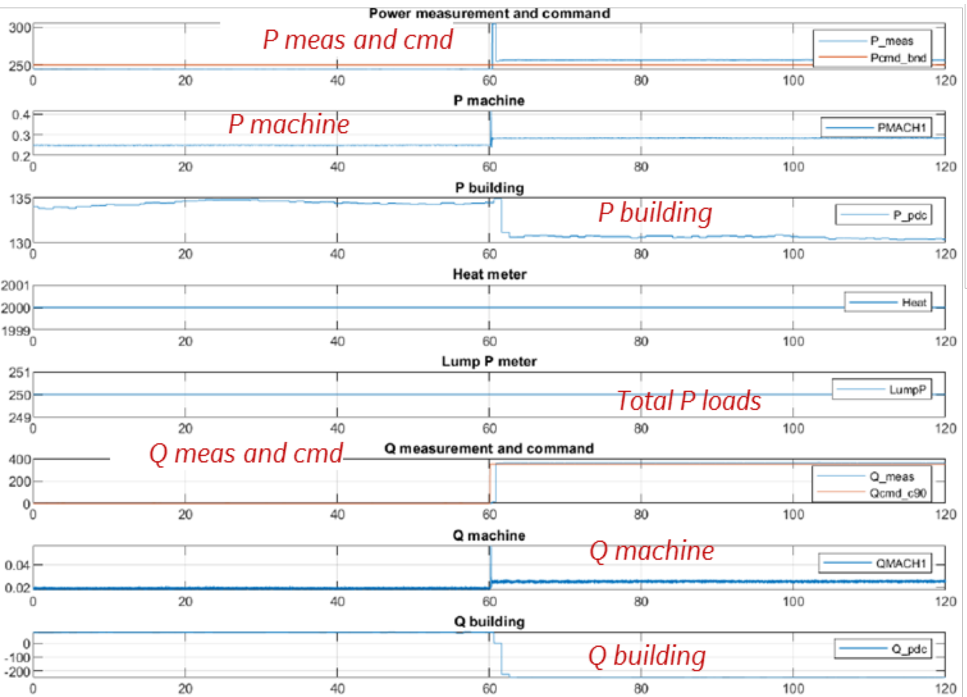
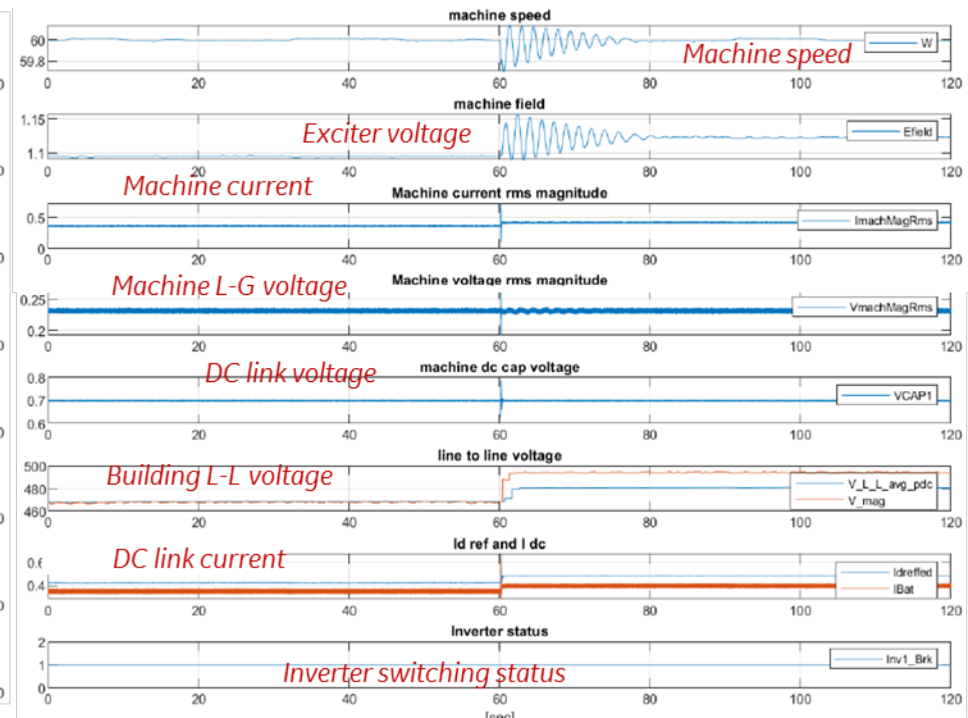
Results and Accomplishments

- Test results: Voltage regulation

Test case: Regulate the building voltage at POI by injecting/absorbing reactive power from the inverter output while the system is running at 250kW. Monitor the voltage, P, Q and harmonics measurements at the at the engine emulator.





Generator operation fully decoupled from VAR support

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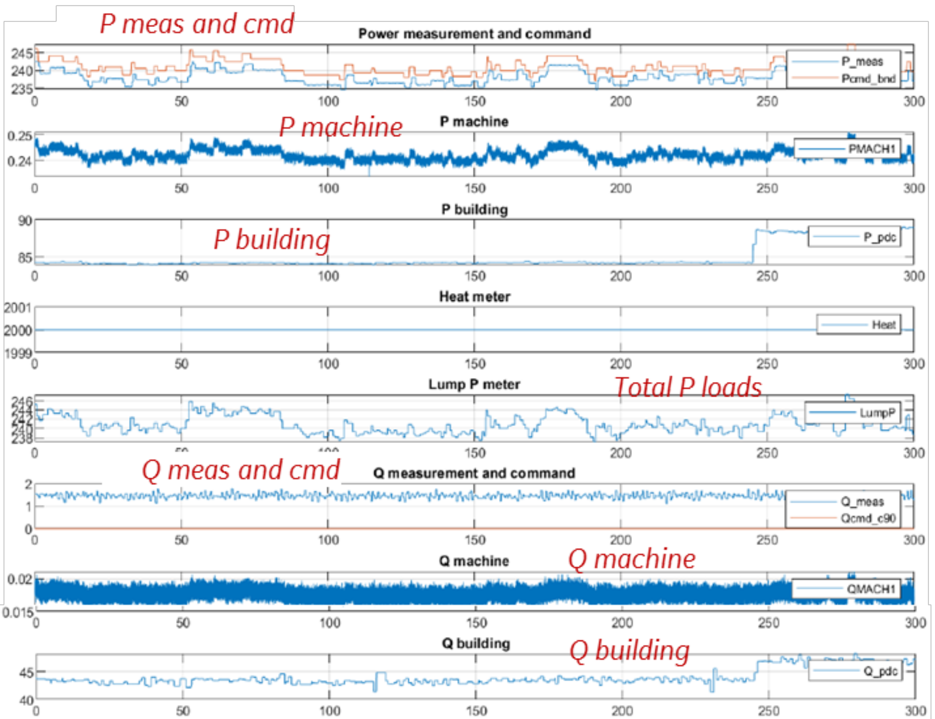
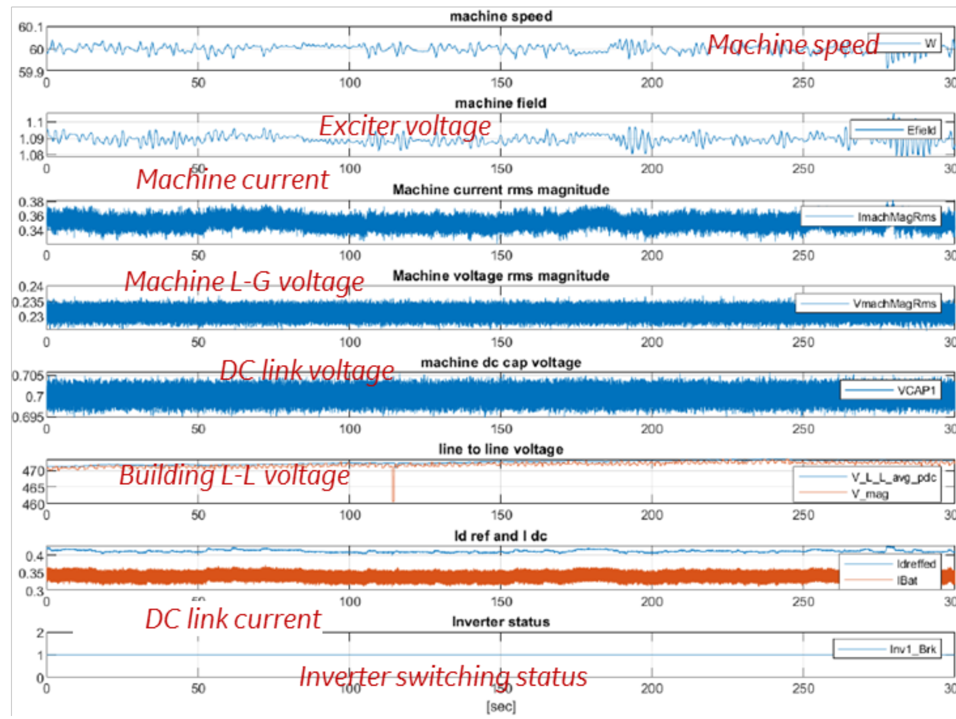
Results and Accomplishments

- Test results: Power following dispatch

Test case: Set the CHP emulator to follow the **electric load** while the converter is maintaining a **pf = 1** at POC. Monitor the voltage, P, Q and harmonics at the at the engine emulator.





The machine successfully follows the electric load

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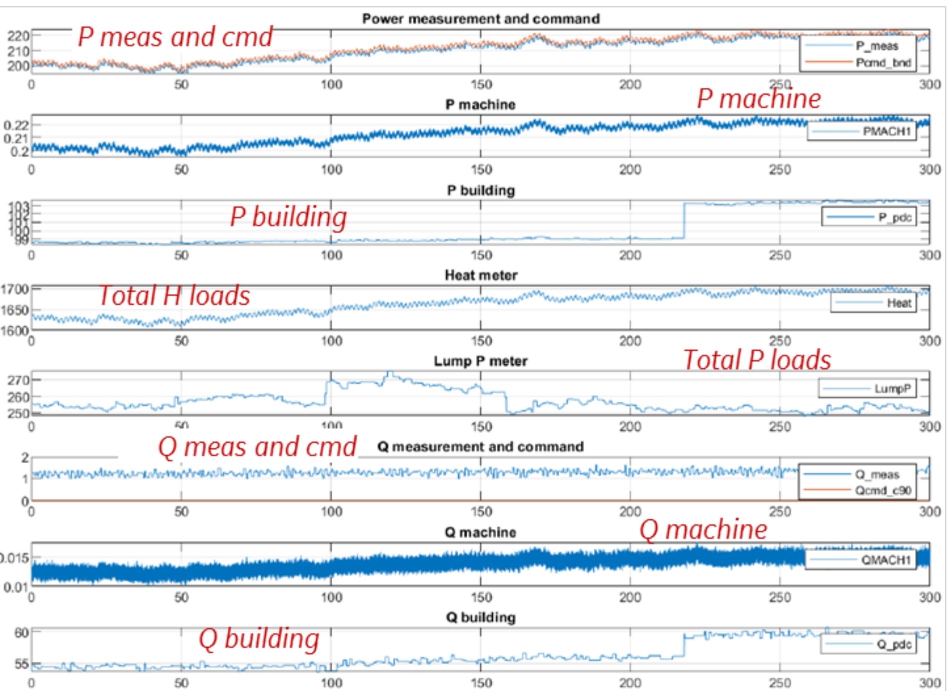
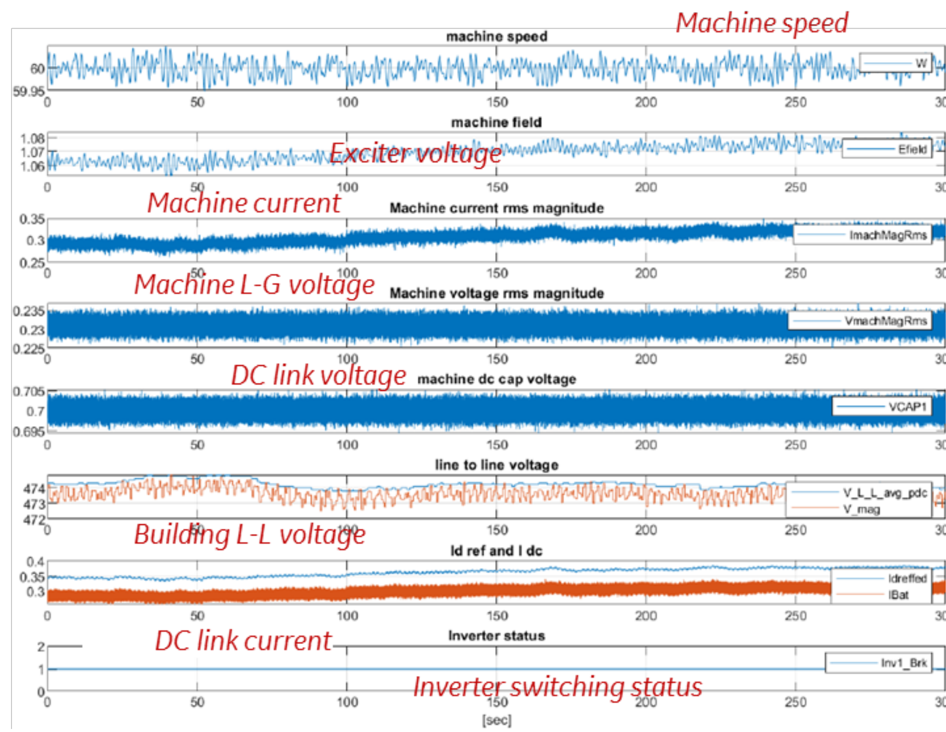
Results and Accomplishments

- Test results: Heat following dispatch

Test case: Set the CHP emulator to follow the **heat load** while the converter is maintaining a **pf = 1** at POC. Monitor the voltage, P, Q and harmonics at the at the engine emulator.





The machine successfully follows the heat load while the converter decouples P and Q

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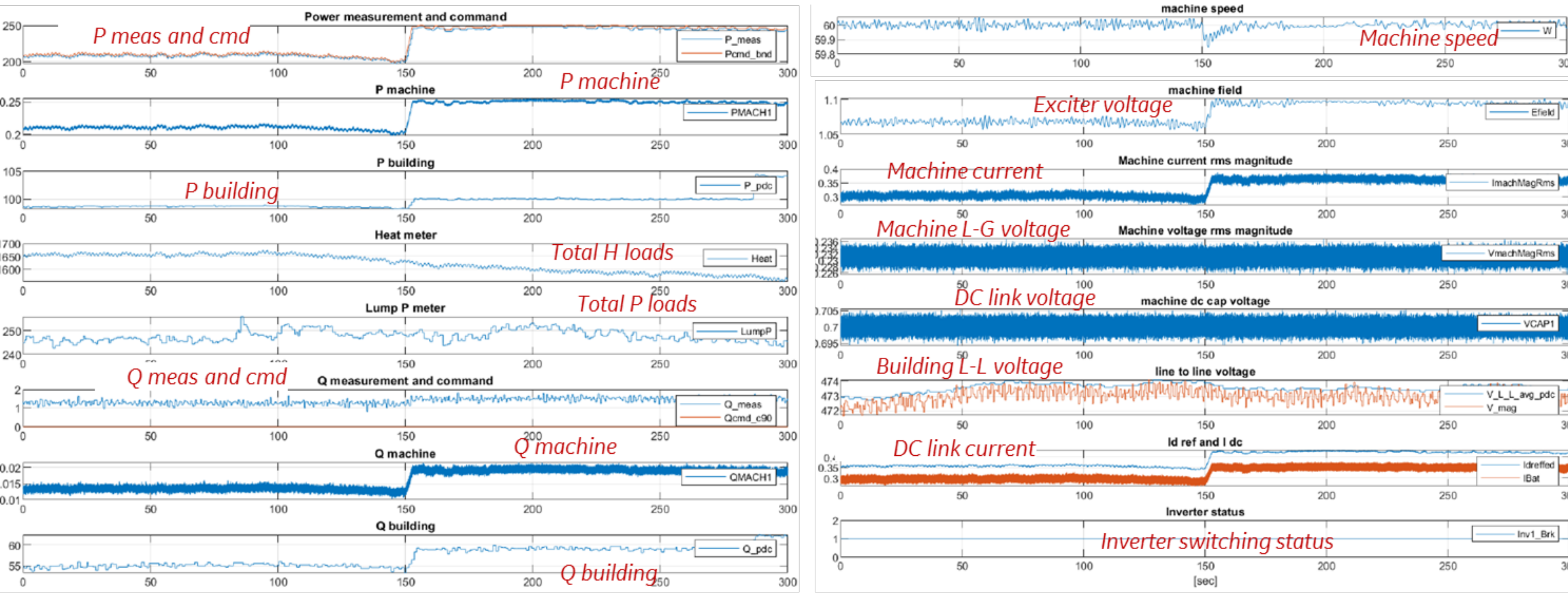
Results and Accomplishments

- Test results: Switch between heat and power following dispatch

Test case: Set the CHP emulator to follow the electric or heat load while the converter is maintaining a **pf = 1** at POC. Monitor the voltage, P, Q and harmonics at the at the engine emulator.



The machine successfully follows the load command while the converter decouples P and Q

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Conclusion

- Demonstrated higher ROI when compared with directly coupled CHP in numerous user case scenarios
- Validated compliance with IEEE standard 1547 and IEEE 2030.7 using a commercial microgrid controller
- Built a 700kW Power Hardware in the Loop (PHIL) testbed and validated performance

Impact:

- Increase flexibility of CHP plants for higher resiliency and grid support services
- Potential for lowering the installation costs and delays for greater penetration of CHP

Future research:

- Optimize CHP engine leveraging asynchronous operation with the grid to further reduce system costs
- Develop converter for coupling CHP with PV, BESS to streamline integration of renewable DER and optimize revenue streams

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Questions?

Contact:

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