School of Electrical Engineering and Telecommunications &
Real-Time Digital Simulations Laboratory (RTS@UNSW)

Modelling and Simulation of Advanced Energy Conversion Systems for Large-Scale Integration Studies

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UNSW
Challenges
and Opportunities


UNSW
Need
of New Models


UNSW
Advanced Energy
Conversion Systems


UNSW
Case Study

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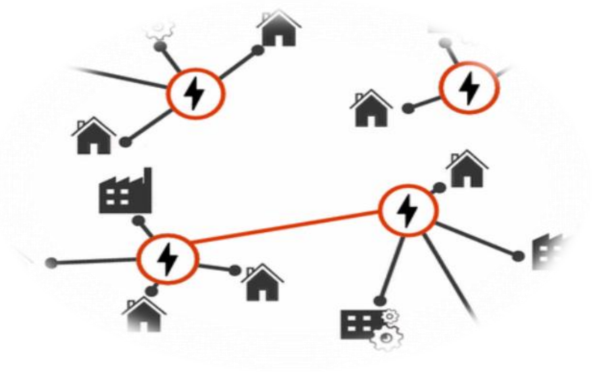
Challenges and Opportunities

Energy Sector Transformation

Decarbonisation

Decentralisation



Digitalisation

Energy Trilemma

New Challenges and Opportunities Arise

- Adopting and understanding new technologies:
  - Renewable and power electronics-based generation.
    - Low-inertia power systems (if no additional grid support is provided).
    - Weak grids (low system strength and short circuit capacities).
  - Big data-driven alignment of supply and demand.
- Optimise transmission/generation investments while maintaining reliability.
- New regulatory and market frameworks:
  - Ancillary services.
  - Distributed energy sources.
- Cyber security threats.

What can we do?

- **New technology**
  - New and more detailed models.
  - New tests.
  - New control schemes.
- **New problems**
  - New methods, algorithms, processes and tools.
- **New regulatory and market frameworks**
  - New policies and laws (and lawyers/economists with specialised insight).
- **New threats**
  - Joint/interdisciplinary efforts.

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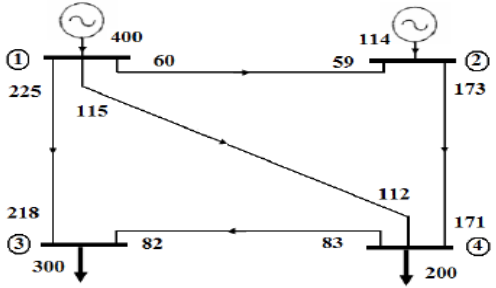
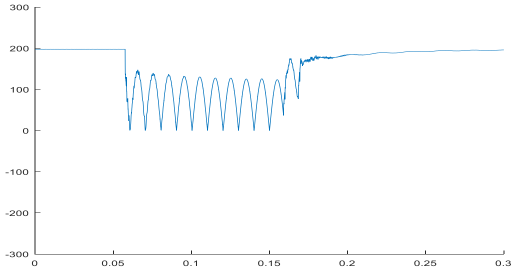
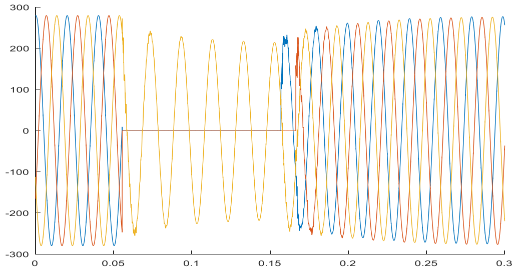
Need of New Models

New Technology → New Models

- Models will depend on the power system phenomena under study:
  - Steady-state: load flows, short circuits.
  - Phasor-based: electromechanical stability, quasi-steady state analysis.
  - EMT-type: detailed protection coordination, harmonics analysis.







Need for Real-Time Simulations?

- EMT-type models can run in real time.
- Protection and controller behaviour can be tested.
- Multi-vendor interoperability and testing is possible.
- A digital-twin implementation of a power system may allow the training of operators.

"A single scenario of the SA PSCAD case, run on a modern high performance machine, takes approximately 4-5 hours of real time to simulate 20 seconds of simulation time"[1]

[1] https://www.aemo.com.au/Media-Centre/South-Australia-System-Strength-Assessment

Advanced Energy Conversion Systems

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Advanced Energy Conversion Systems (AECS)

1. Adaptation of generic and widely used models:
   - Accessibility to information.
   - Better visualization and understanding when comparing to black boxes.
   - No confidential information is needed or released.
   - May require variations to fulfil specific requirements.
2. Expansion to include reactive power (Q), voltage (V_{PCC}) and power factor ($\cos(\theta)$) control at the PCC.
3. Response under steady state conditions.
4. Integration to an open-source and practical test system.

F. Arraño-Vargas & G. Konstantinou, "Real-Time Models of Advanced energy Conversion Systems for Large-Scale Integration Studies," in *IEEE 10th PEDG.* Xi'an, China, Jun. 2019, pp. 756-761.
~, "Development of Real-Time Benchmark Models for Integration Studies of Advanced Energy Conversion Systems," *IEEE Trans. Energy Convers., Sep. 2019.*

Power Electronics Modelling in RTDS

1. Switch representation: on\off

$$R_{on} = 2L/\Delta t$$
$$R_{off} = R + \Delta t/2C$$

2. Conductance remains unchanged

$$G_{on} = G_{off}$$

3. Energy balance

$$Li^2/2 = Cv^2$$

4. Resistance is selected using a heuristic approach

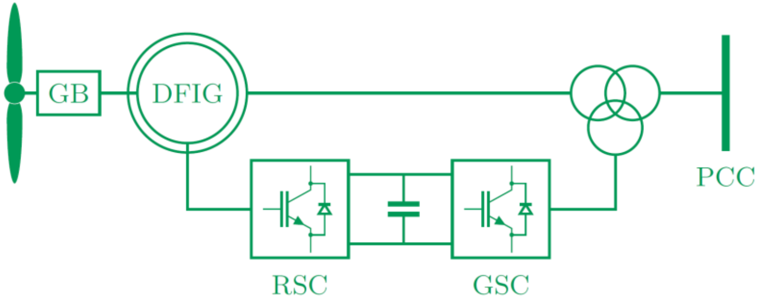
$$L = \sqrt{2}(\Delta t F)v/i$$
$$C = (\Delta t F)^2/L$$
$$R = 2L/\Delta t - \Delta t/2C$$
$$F = \frac{1}{2\left(\sqrt{\zeta^2 + 1} - \zeta\right)}$$

- ➢ Time-step of $\approx 2\mu$s

Wind Power Generation Systems (WPGS)

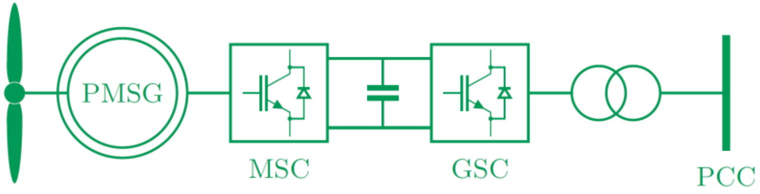
Type-III:

- Vestas V90 – 2 MW wind turbine
- 2-level VSCs
- RSC: T and Q_s $(Q^*, V_{PCC}^*, cos(\theta)^*)$
- GSC: V_{dc}



Type-IV:

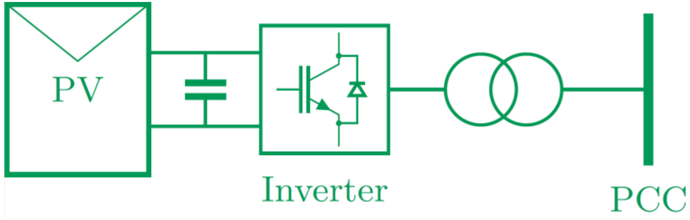
- Generic 2 MW wind turbine
- 3-level neutral-point clamped VSCs
- MSC: ω_r
- GSC: V_{dc} and Q_{PCC} $(Q^*, V_{PCC}^*, cos(\theta)^*)$



Photovoltaic Power Plant (PV-PP) and STATCOM

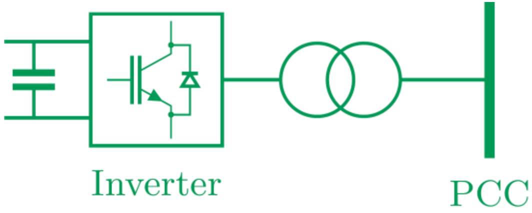
PV-PP:

- Generic 1.7 MW solar array
- Inv.: V_{dc} and Q_{PCC} $(Q^*, V_{PCC}^*, cos(\theta)^*)$



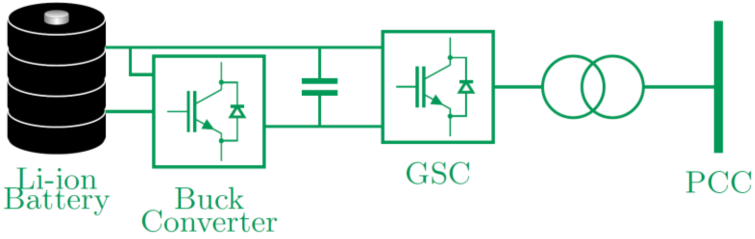
STATCOM:

- Generic 100 MVAr STATCOM
- Inv.: V_{dc} and V_{ac}

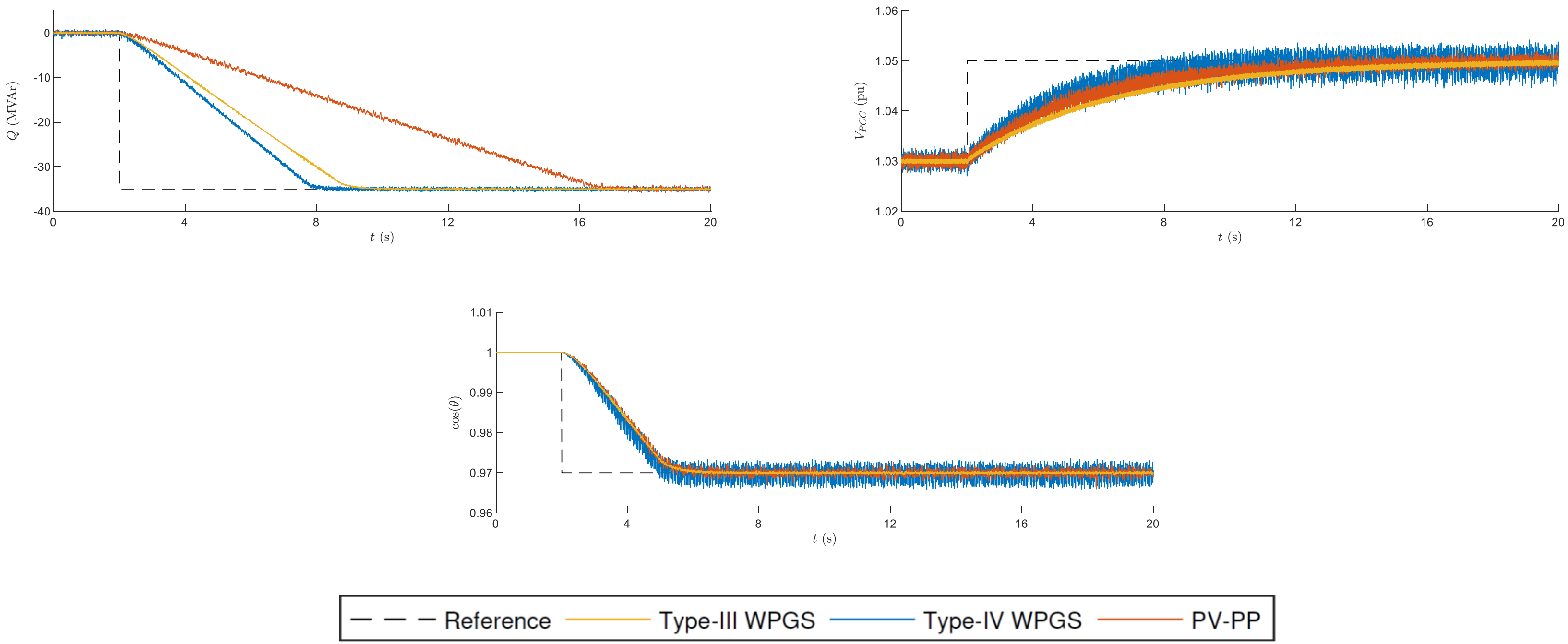


Battery Energy Storage System (BESS)

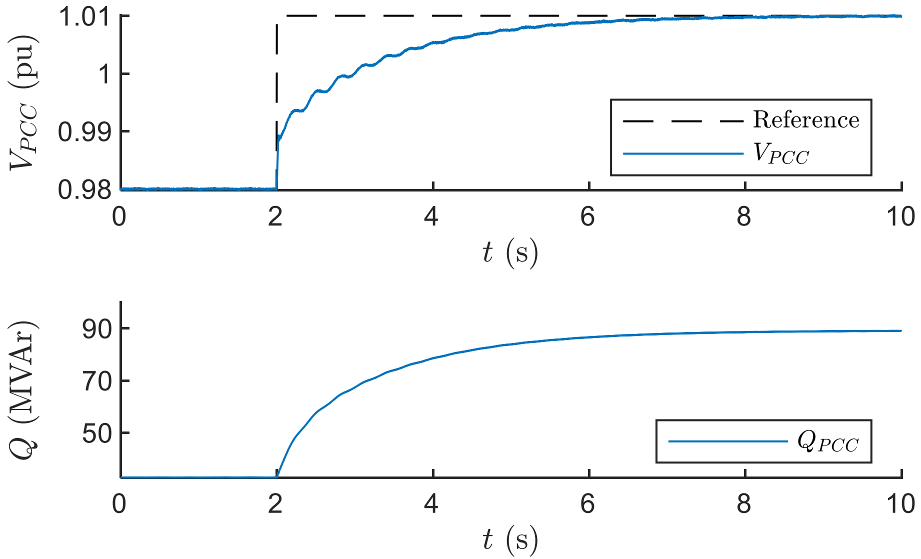
- Generic 0.6 MW Li-on battery pack
- Buck converter: V_{dc}
- GSC: P_{PCC}/f_{PCC} and Q_{PCC} (Q^*)
- Frequency support:
  - 1.75% droop
  - $\pm$0.15 Hz dead band



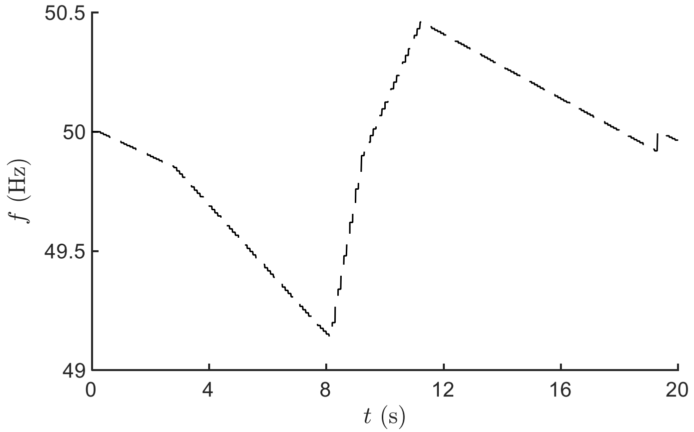
Step Responses: Q^*, V_{PCC}^* and $\cos(\theta)^*$

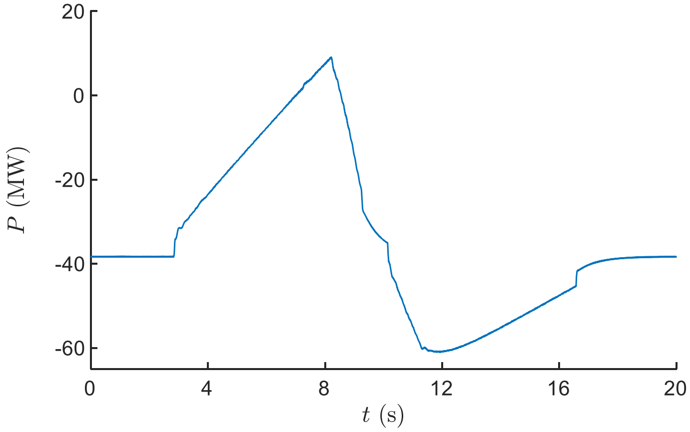


STATCOM: Step Response – Voltage Order



BESS: Frequency Variation Response



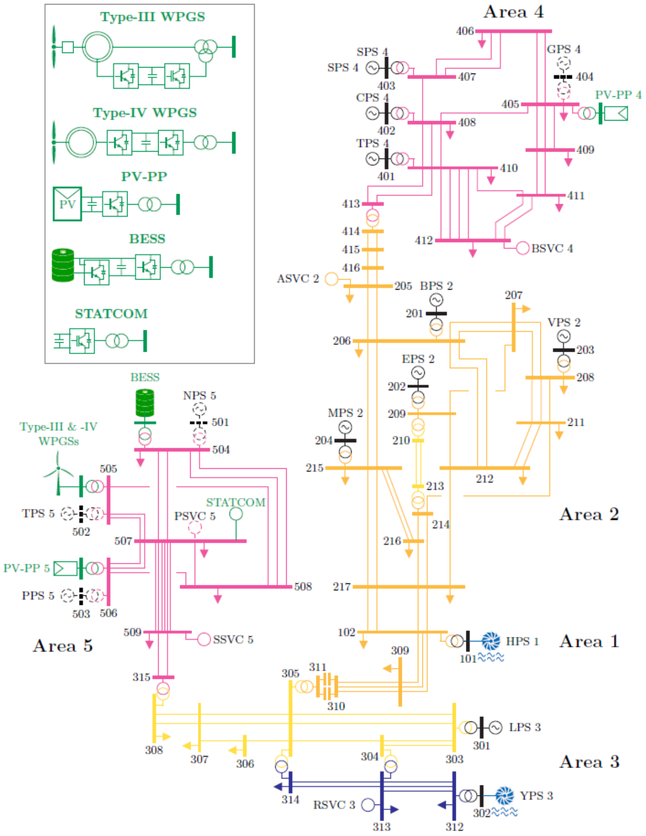


Case Study

Case Study

- **Simplified Australian power system:**
  - 14 generators: PSSs, exciters and governors.
  - 5 SVCs: TCR + TSC.
  - 59 buses.
  - 104 lines.
  - 6 operating conditions.
- **Simplified Australian power system + AECSs:**
  - Case 7: 1910 MW (89.6% A5 / 12.9% total)
  - Case 8: 4099 MW (27.8% total)

Case 7



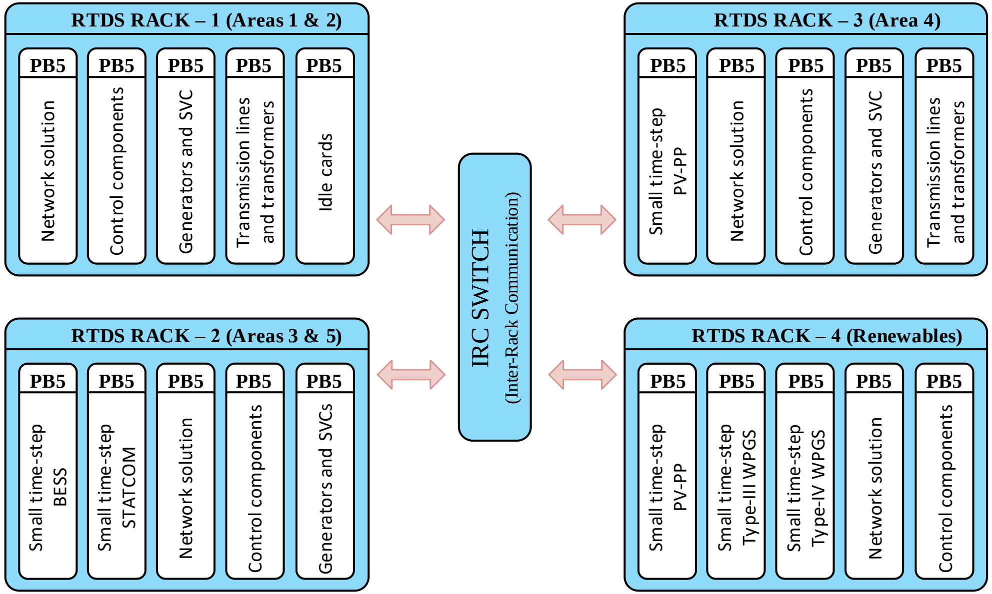
Simulation Requirements

RTDS simulator:

- Developed for “PB5” processor cards
  - Case 1 – 6: 12 cards
  - Case 7: 20 cards
  - Case 8: 22 cards

Time-steps:

- $50\mu s$
- $2.5\mu s$



Case 7: system layout

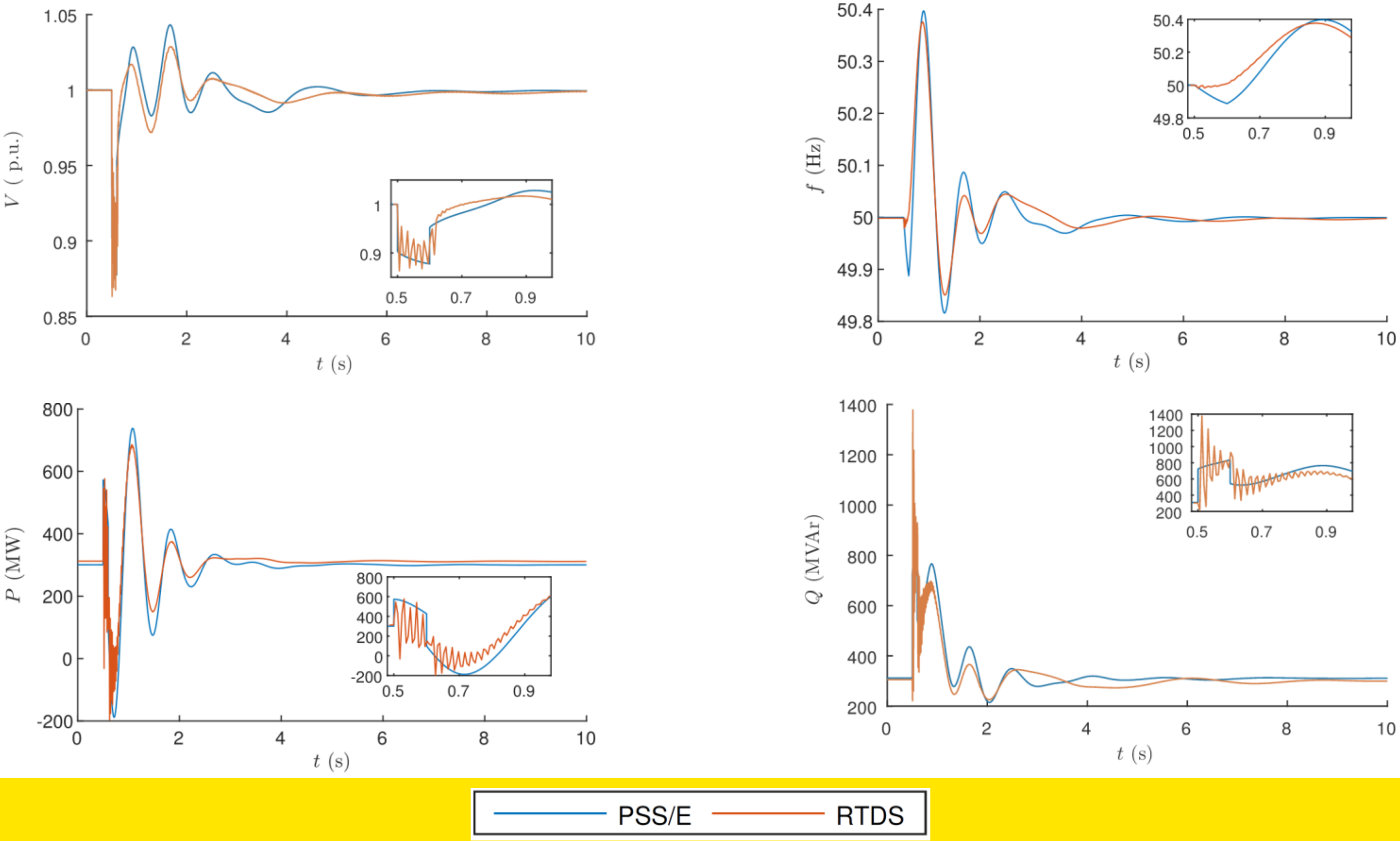
Validation of Original Cases

- RMSEs are calculated for V*, P and Q.
- Q_{gen} values vary mainly due to different dispatch in a generator (NPS 5) and an SVC (PSVC 5).

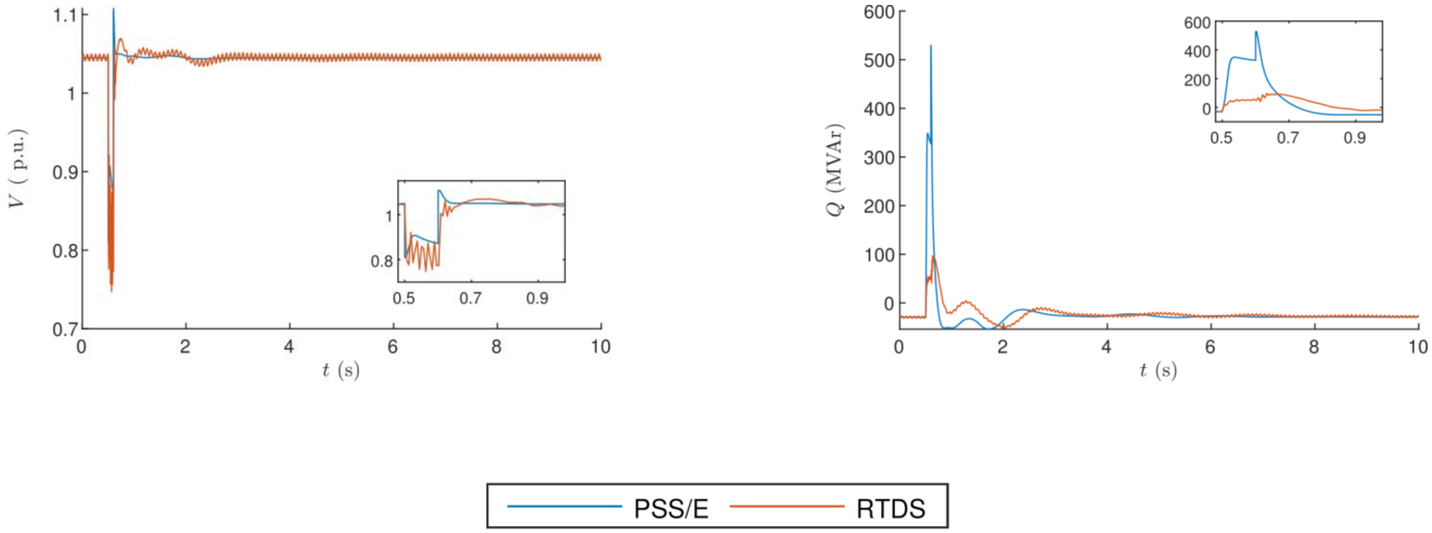
	$\|V\|$ (mV)	$\angle V$ (°)	P_{gen}(MW)	Q_{gen} (MVAr)	P_{load} (MW)	Q_{load} (MVAr)
Average	1.11	0.67	1.37	8.75	0.47	0.16

*Angles at bus voltages are compensated by $30°$ ($Y - \Delta$ step-up transformers in RSCAD/RTDS).

Case 1: Fault at Bus 209 – HPS 1

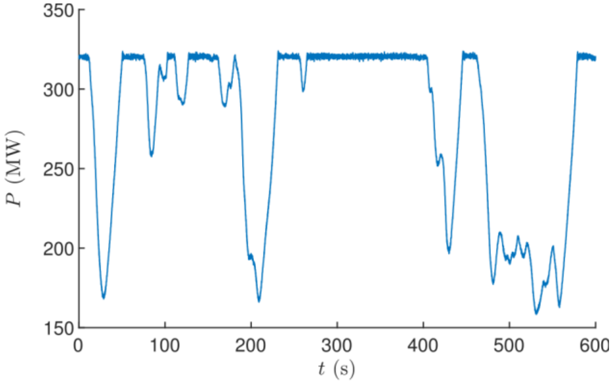


Case 6: Fault at Bus 209 – ASVC 2

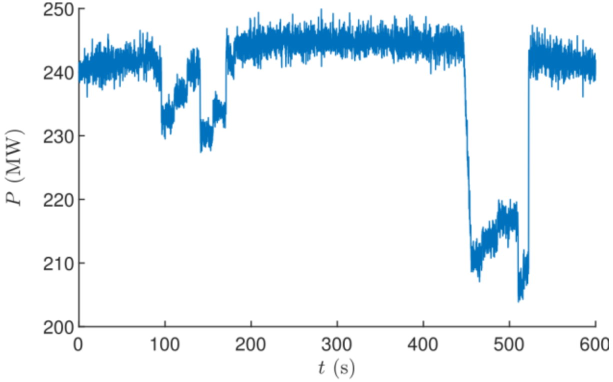


Case 7: Asynchronous Generation

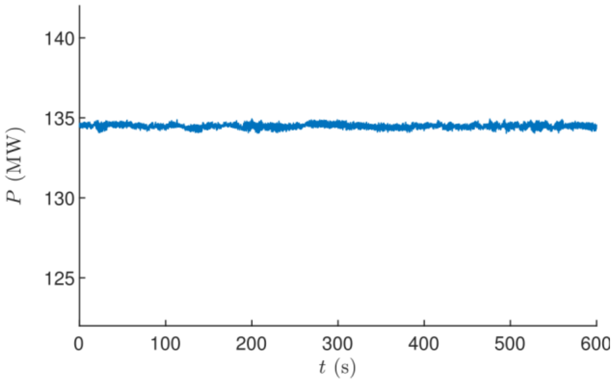
a)



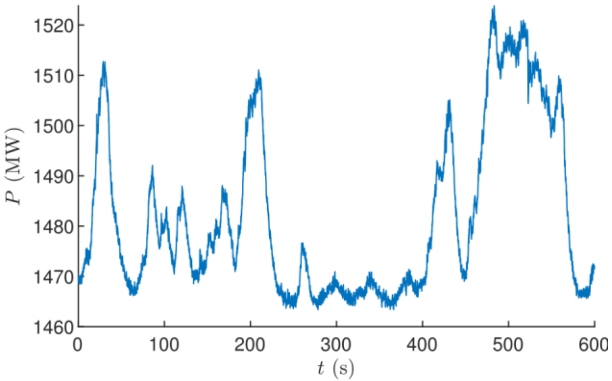
b)



c)

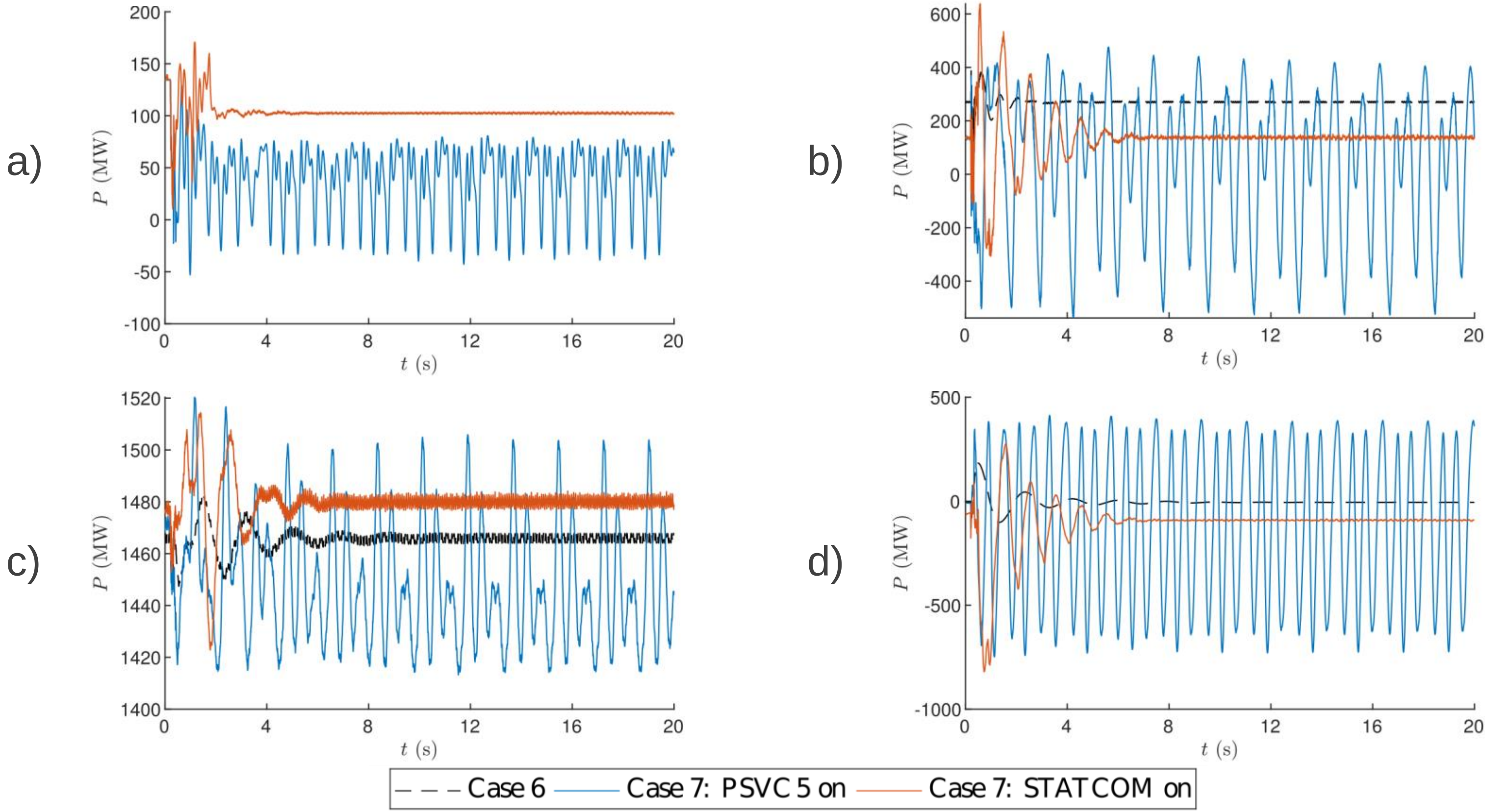


d)



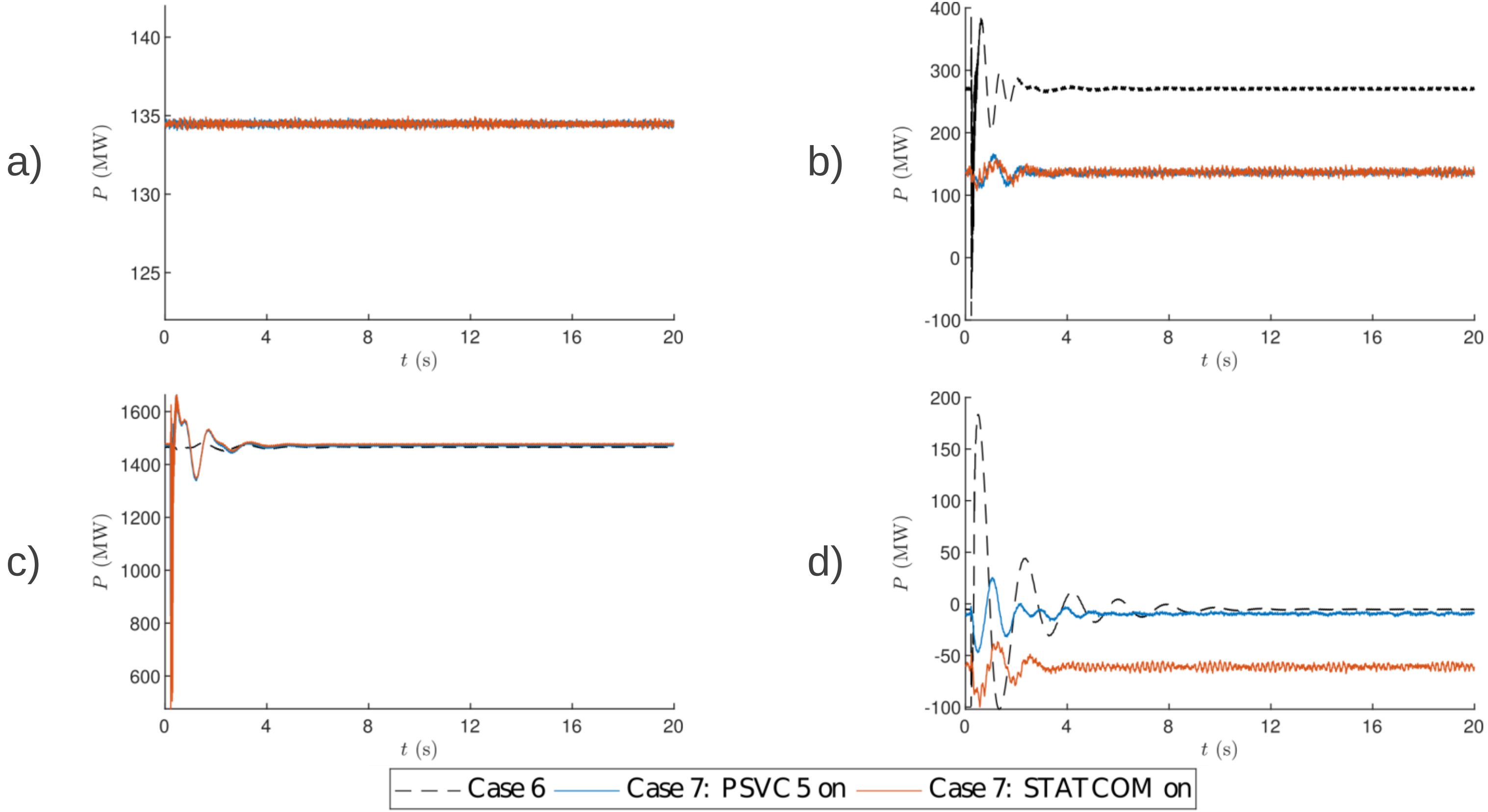
a) Type-III WPGS. b) PV-PP 4. c) BESS. d) MPS 2

Case 7: Fault at Bus 508



a) BESS. b) NPS 5. c) MPS 2. d) Interconnector (A5-A3)

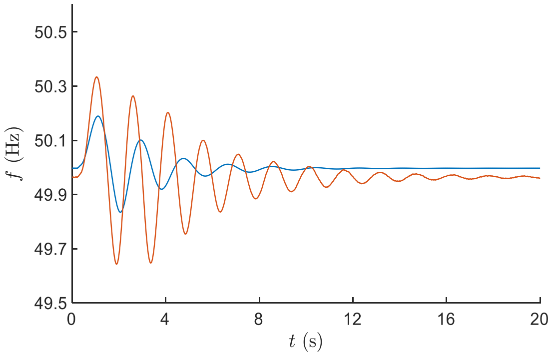
Case 7: Fault at Bus 212



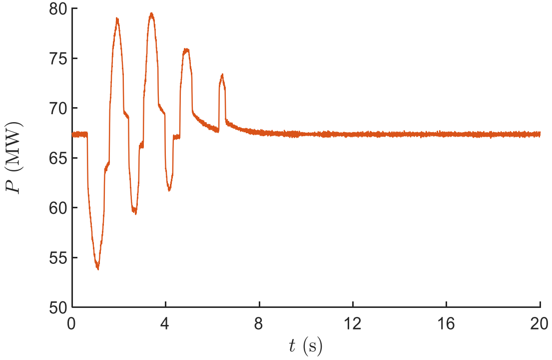
a) BESS. b) NPS 5. c) MPS 2. d) Interconnector (A5-A3)

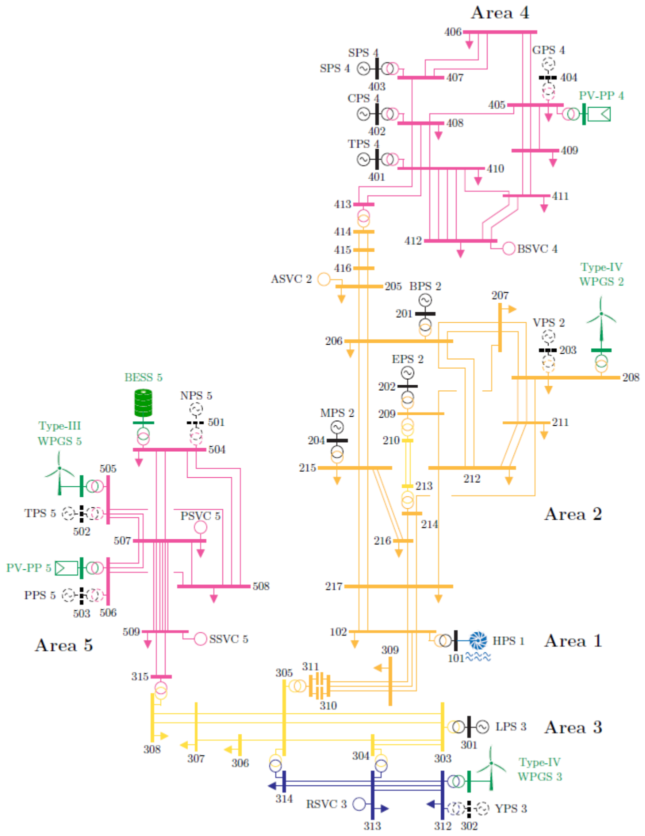
Case 8: Fault at Bus 209

- NPS 5



- BESS





Without AECSs With AECSs

Summary

- Benchmark models with reasonable balance between detail and simplifications are required.
- Real-time EMT models for Type-III and -IV WPGSs, PV-PP, BESS, and STATCOM have been proposed.
  - Models tested under both steady and transient operating conditions.
  - Models can be easily modified to analyse large penetration of renewables.
- The real-time EMT model of the *simplified Australian 14-Generator test system* has been made openly available.[1]
  - It can be further adapted and extended to consider HVDC and MTDC systems.

[1] http://bit.ly/RTBenchmark_14-Gen