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Hydro-Québec EMT Simulation of a Radial Network with a High Penetration of Wind Generation to Validate System Operating Limits

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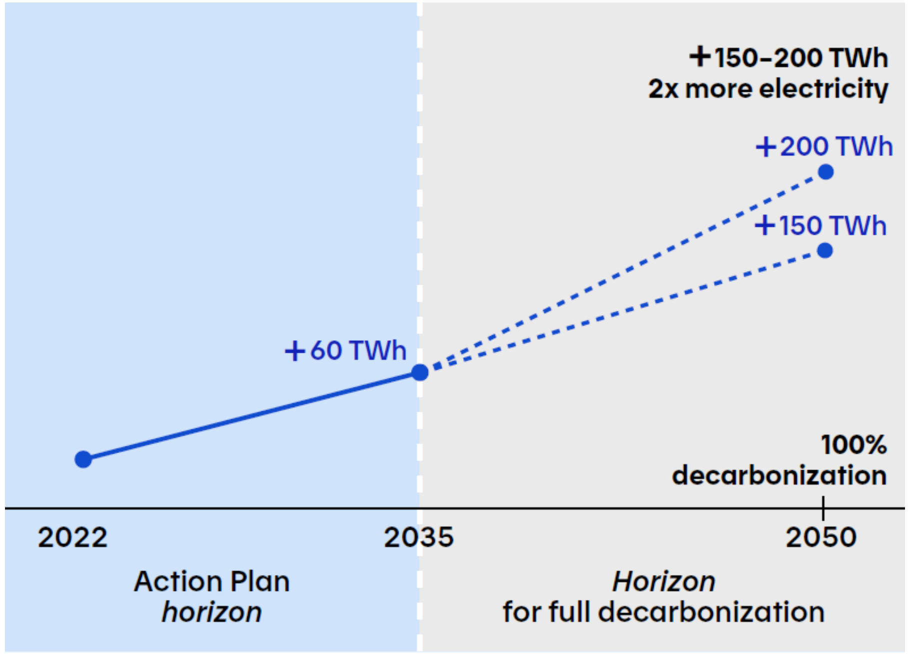
General context

General context

Electricity consumption in Québec could double by 2050

Projected trajectory of electricity demand by 2050



Why higher forecasts?

- Better understanding of technologies, and therefore of needs
- Stronger economic growth
- New green economy sectors (e.g., renewable fuels, green hydrogen)

By **2035**, we plan to add **60 TWh**,
or between **8,000 and 9,000 MW** of capacity.

That's equivalent to the installed capacity of three of our largest hydropower facilities:
Robert-Bourassa (LG-2), Manic-5 and the Romaine complex.

The goal of the study

Motivation

- Phasor domain transient (PDT, for example PSSE) simulations cannot accurately represent the fast control system dynamics of IBR
- Previous EMTP study revealed the severe transient overvoltage created by the separation of the transmission lines encircling the Gaspésie Peninsula
- Inverter based resources (IBR) performances are affected in weak grid conditions

Scope

- Evaluate the operational active power transfer limit of a main link of the Gaspésie network with EMTP simulations
- Compare the EMTP and PDT simulations

Goal: Validate the current operational active power transfer limit of a main link of the Gaspésie network with EMTP simulations to ensure reliable system operation

The Gaspésie power system

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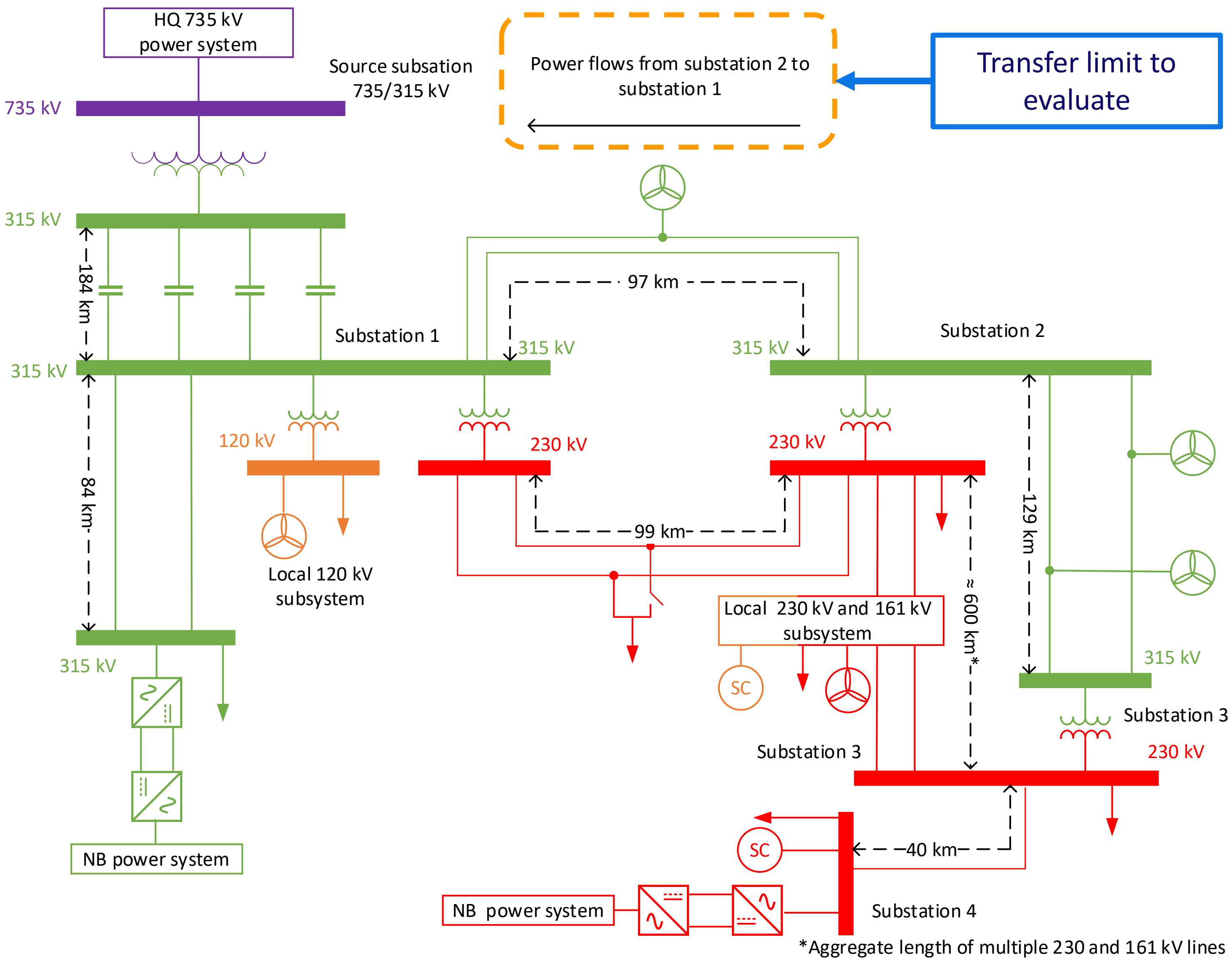
Power system description



- Regional network that is not part of the Bulk Power System as defined by the NERC and NPCC.
- Contains 1000 km of HV overhead-lines
- Radially connected to the main grid by 315-kV series compensated lines
- Integrates:
  - 2250 MW of wind generation
  - 775 MW of LCC HVDC
  - 1135 MW of additional projected wind generation in the short-term
  - 220 Mvar of Synchronous condensers
  - Winter peak load of 1200 MW and minimum summer load of 550 MW

Power system characteristics

Weak grid

Low short-circuit current

No local synchronous generation which means low local inertia

Local generation-load balance

Local wind productions exceeds peak and minimal loads

Local penetration of IBR > 100%

Wind parks in close proximity

Series compensations and HVDC

Region connected to main grid through series compensation

Integrates 2 converter stations with New-Brunswick (neighbor province)

NERC EMT study recommendations

Conditions requiring EMT simulations	Present in the Gaspésie power system
Areas of low (or decreasing) short-circuit strength	✓
Areas near series compensated transmission circuits, presenting a risk SSO, SSCI, and other resonance with high transient overvoltages	✓
High concentration of inverter-based resources with risks of control interactions	✓
Interconnections of inverter-based resources near HVDC and FACTS	✓

Reference : NERC IBR Interconnection Requirement Improvement Table 1.2 and Chapter 3

Operational stability criteria

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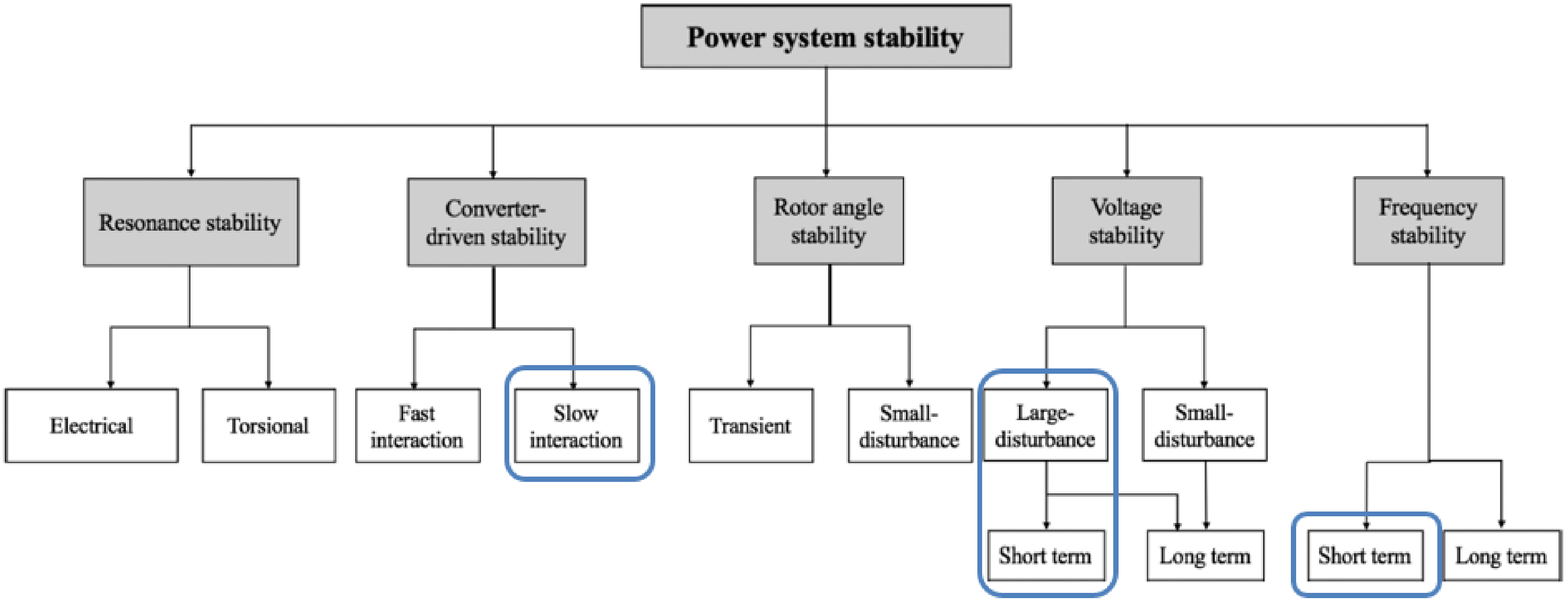
Stability criteria

Power system stability classification according to IEEE Power System Dynamic Performance Committee and CIGRE Study Committee C4 – System Technical Performance



Legend :

Evaluated in the study

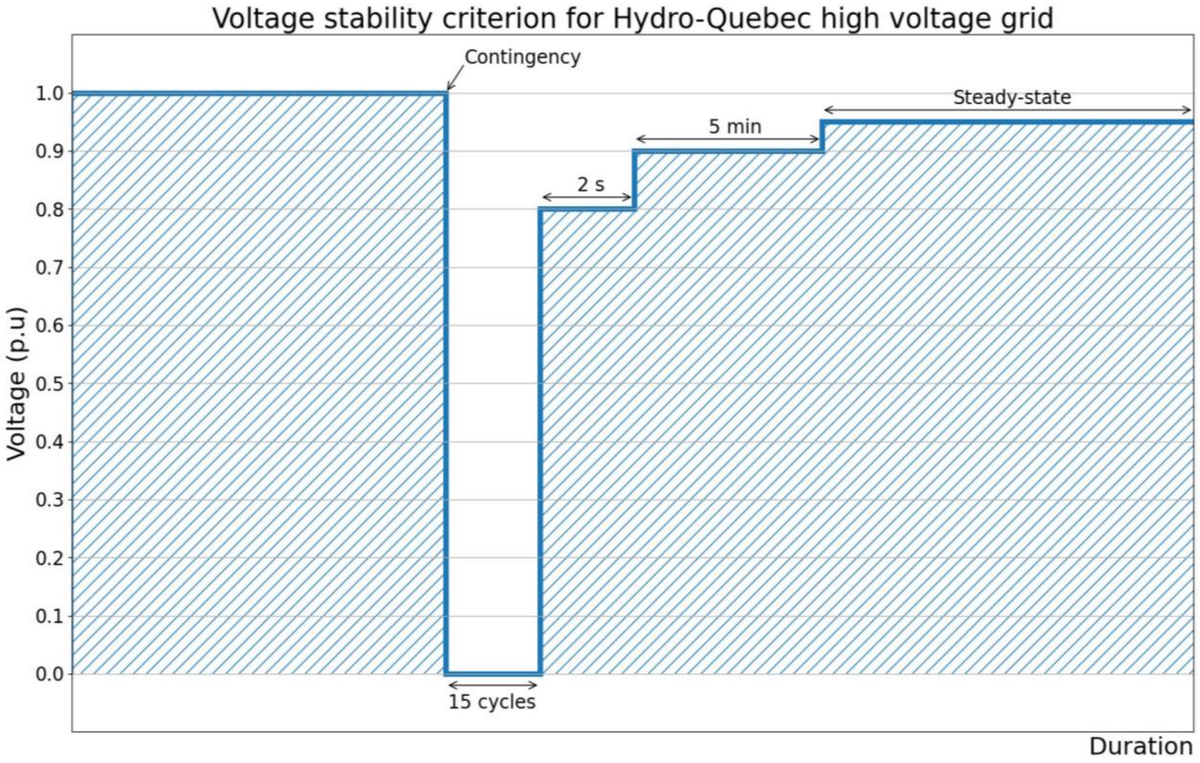
Operationnal stability criteria studied to limit power transfer

- **Loss of production as a proxy to short-term frequency stability**
- **Transient voltage recovery after a contingency**

Stability criteria in details

Short-term voltage stability

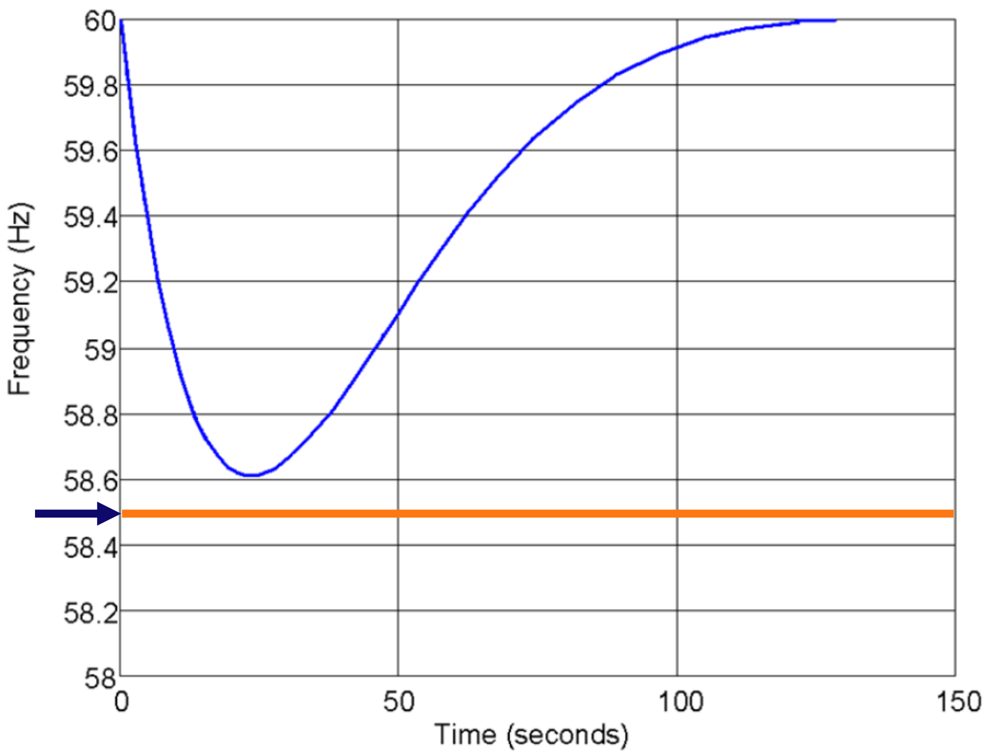
Voltage of all the bus in the power system have to remain in the white region of the Figure during the simulation.



Short-term frequency stability

The loss of generation has to be limited to 1000 MW to prevent under frequency load shedding (UFLS) after a single contingency

UFLS threshold at 58.5 Hz



EMTP modeling and contingency

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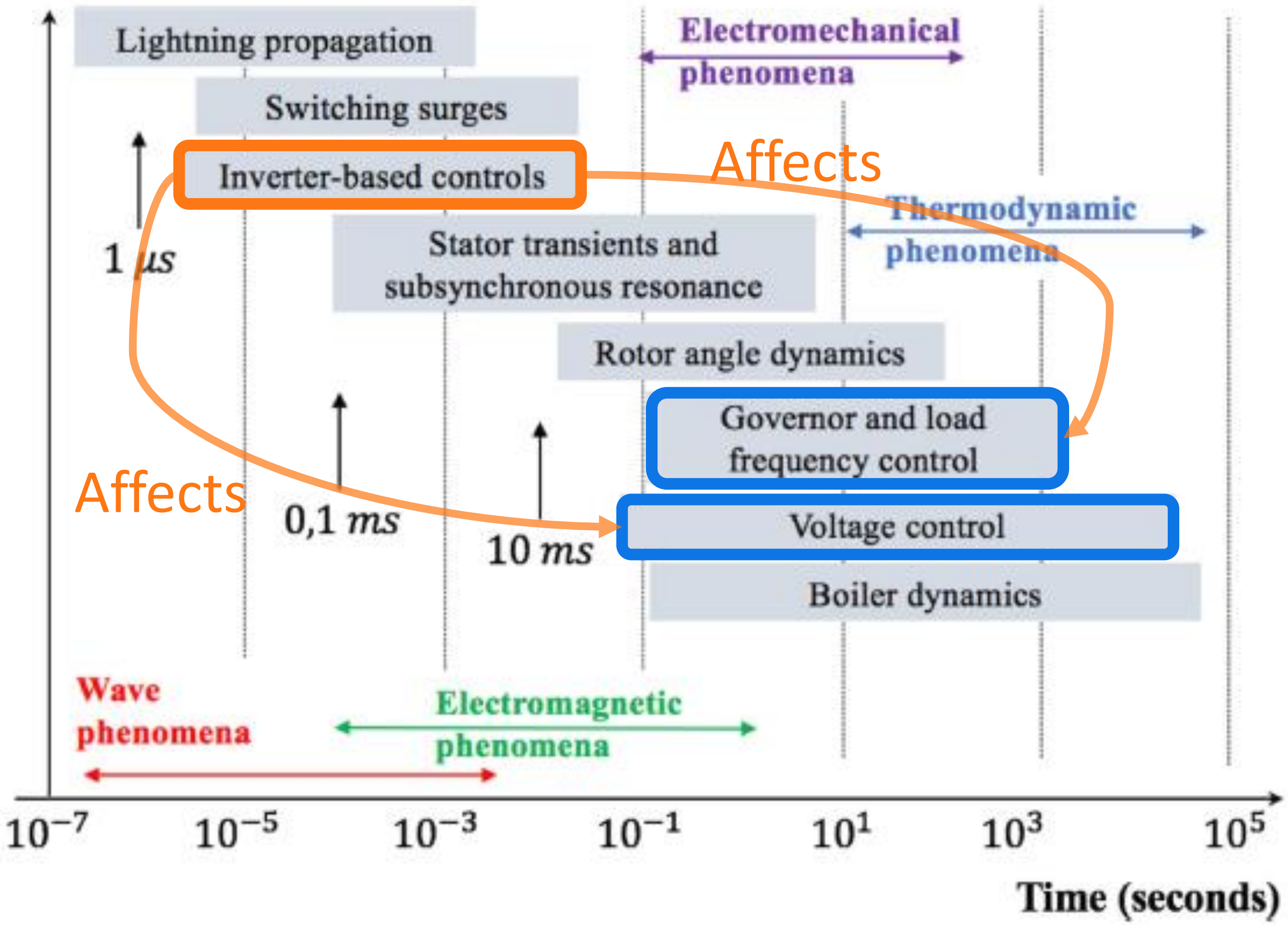
EMTP modeling

The EMTP modelling of the Gaspésie region:

- Follows the recommendations of section 3 of CIGRE TB-881
- Uses site-specific OEM black-box models for wind parks
- Contains the Gaspésie regional subsystem and a voltage source behind an impedance to emulate the 735 kV grid

EMTP modeling is required because PDT simulations cannot accurately represent fast control system (CIGRE TB-881).



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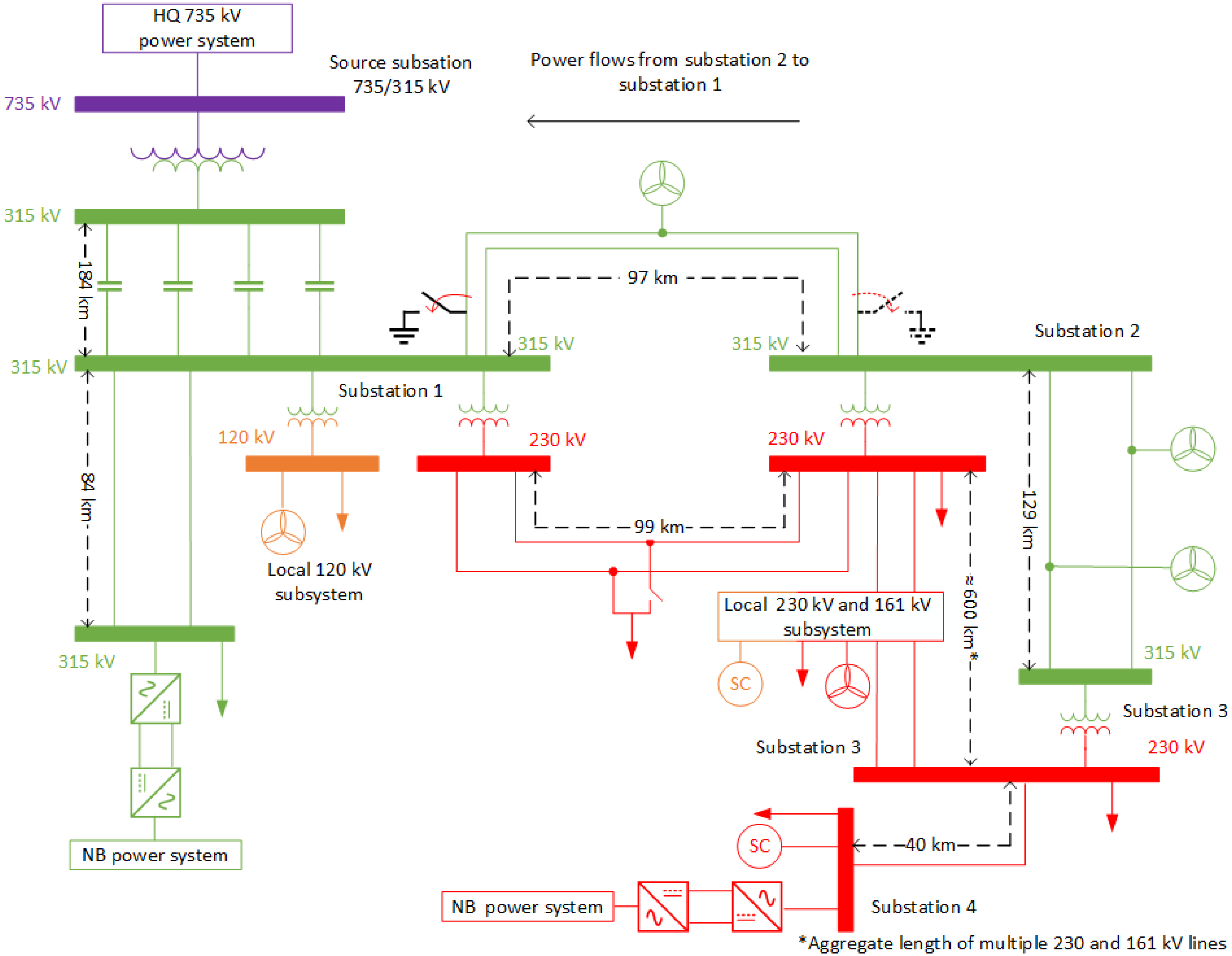
Contingency simulated

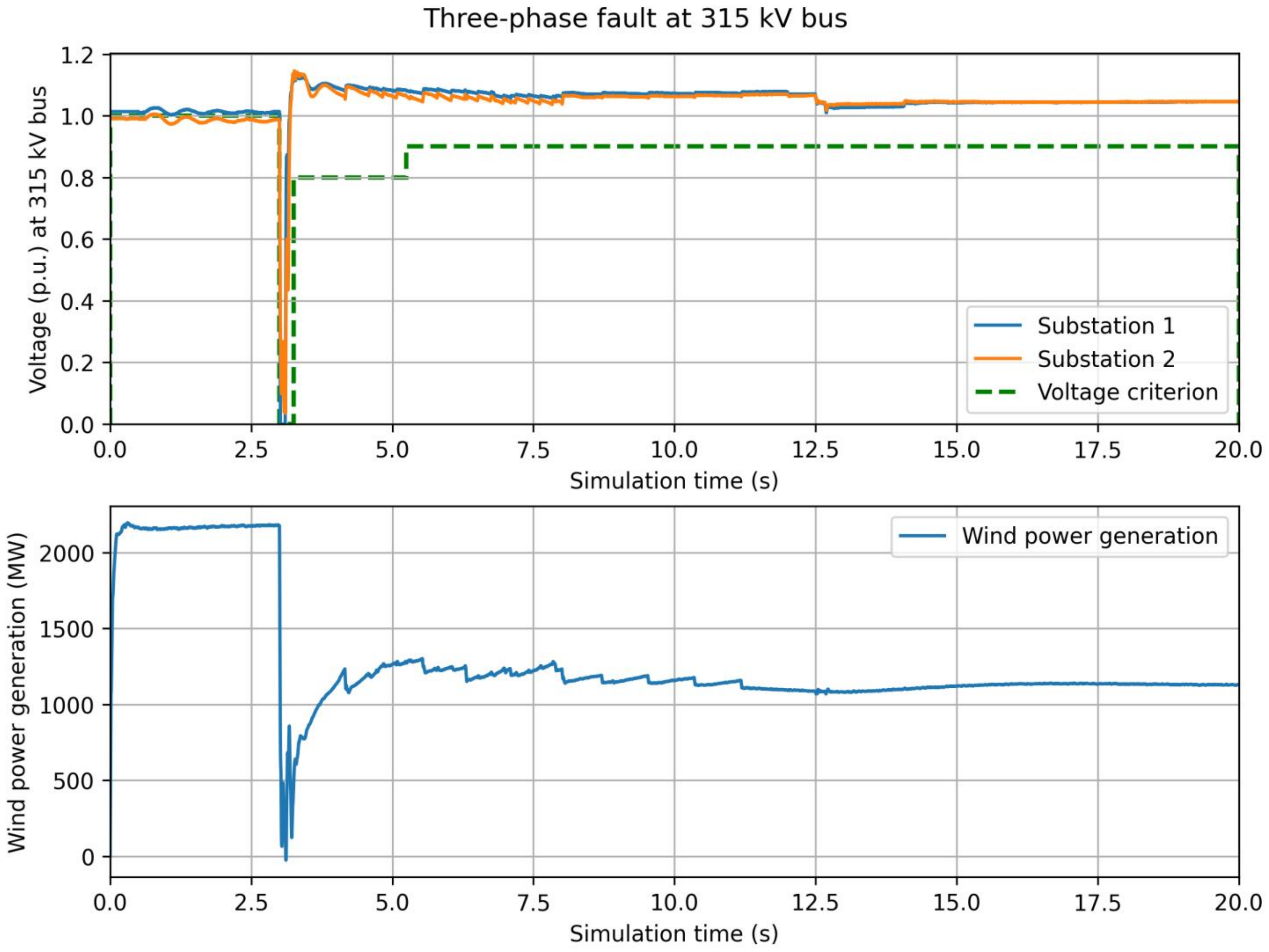


- Phase-to-ground and three-phase faults
- Faults at substations 1 and 2 on both transmission line between substations 1 and 2
- Faults cleared in 100ms
- Loss of the transmission line where the faults is located

EMTP simulations results

Three-phase fault at Substation 1

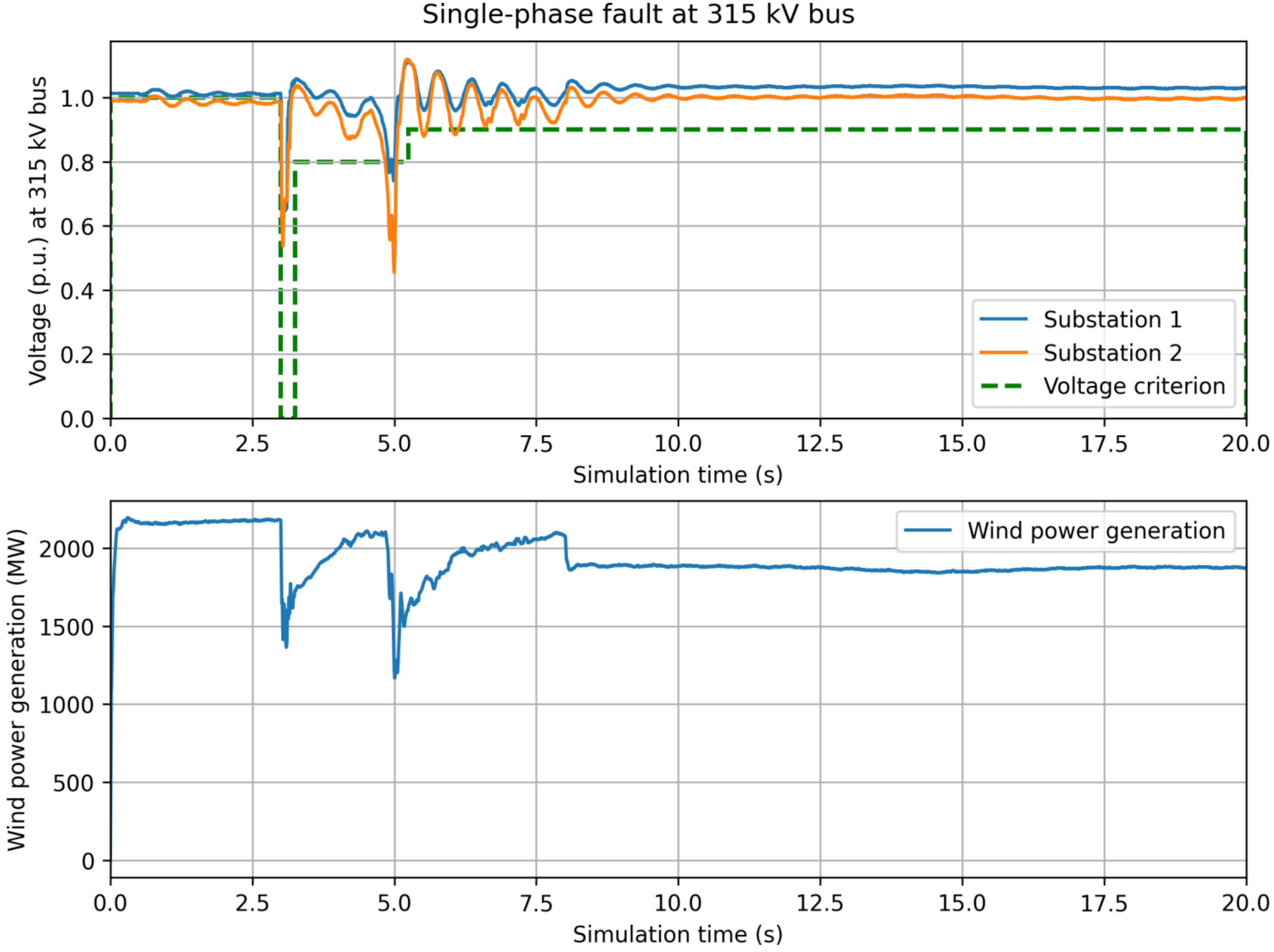
Voltages at subsations 1 and 2 and wind power generation



- A three-phase fault is applied at 3 seconds and is cleared at 3.1 seconds
- The wind generation drop during and after the fault
- The wind generation after the fault recovery is 1000 MW less than the initial value

Phase to ground fault at Substation 1

Voltages at subsations 1 and 2 and wind power generation

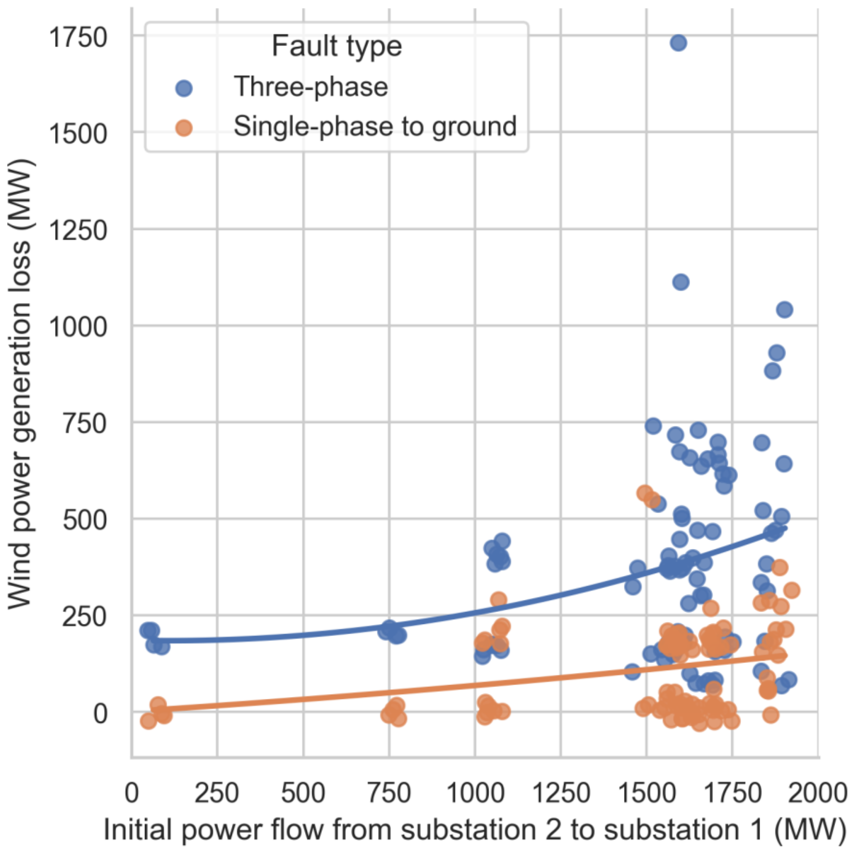


- A phase-to-ground fault is applied at 3 seconds and is cleared at 3.1 seconds
- Control-mode cycling after the fault until a few wind parks trip at 8 seconds
- Voltage criteria violation at 5 seconds

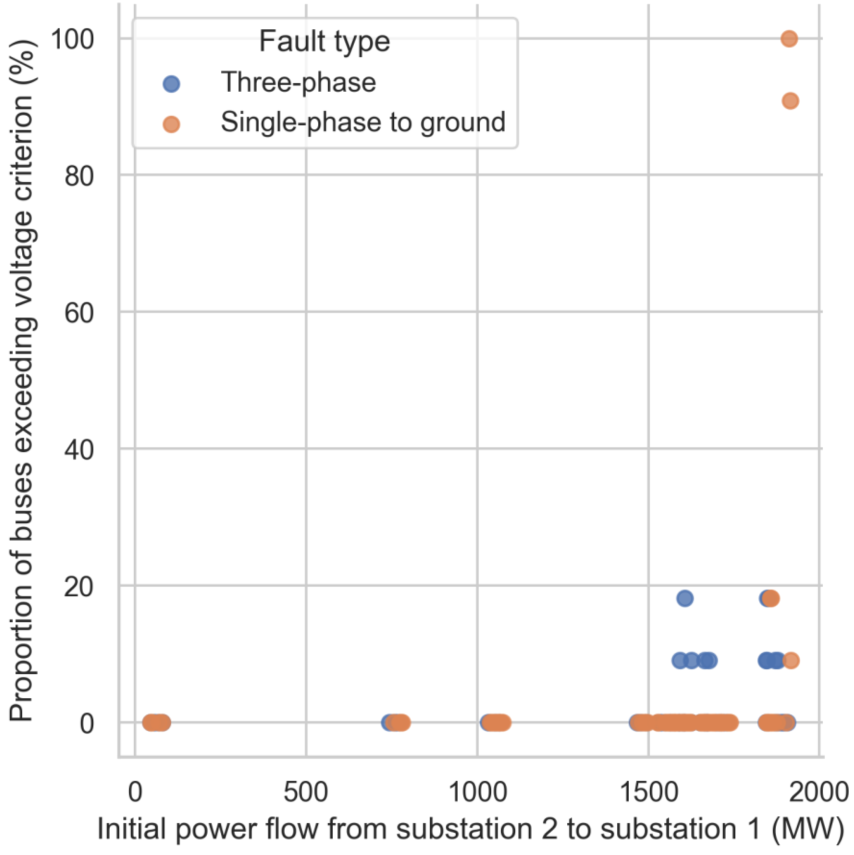
Overall trends in simulations

For multiple generation and load levels, where each dot represent the analysis of a simulation

Frequency stability



Voltage stability



Frequency stability

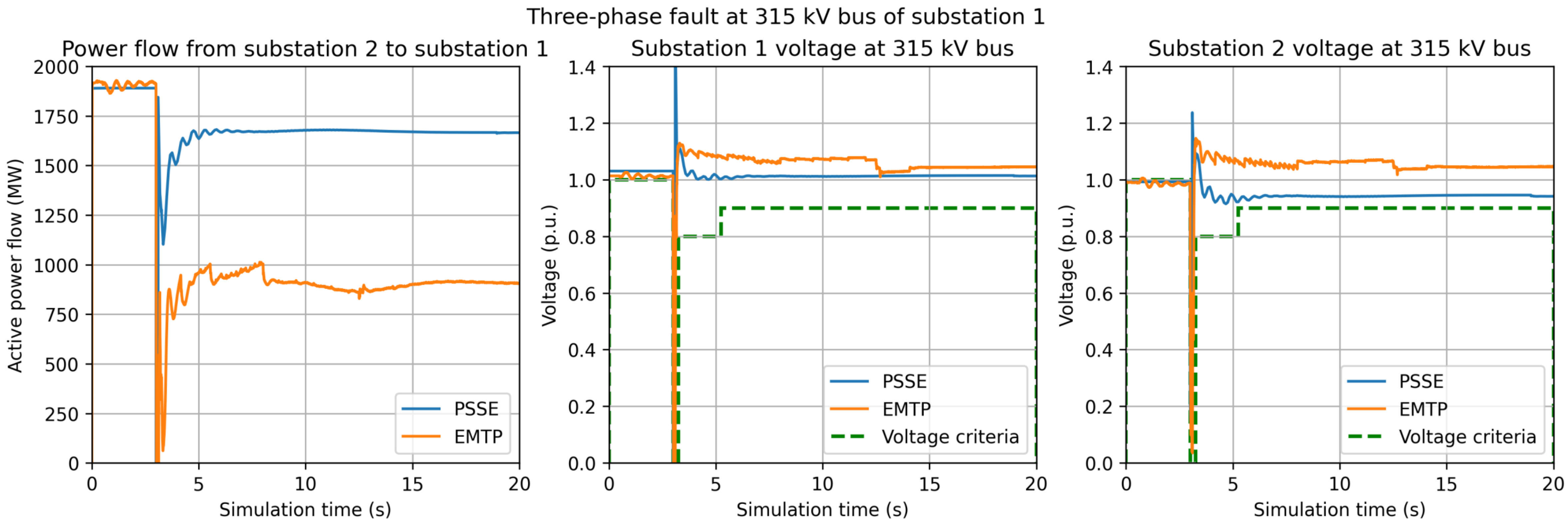
- Wind generation losses are greater as the power flow increases
- Wind generations losses are greater for three-phase faults

Voltage Stability

- Voltage instability increases as power flow increases
- Voltage instability are greater for phase-to-ground faults

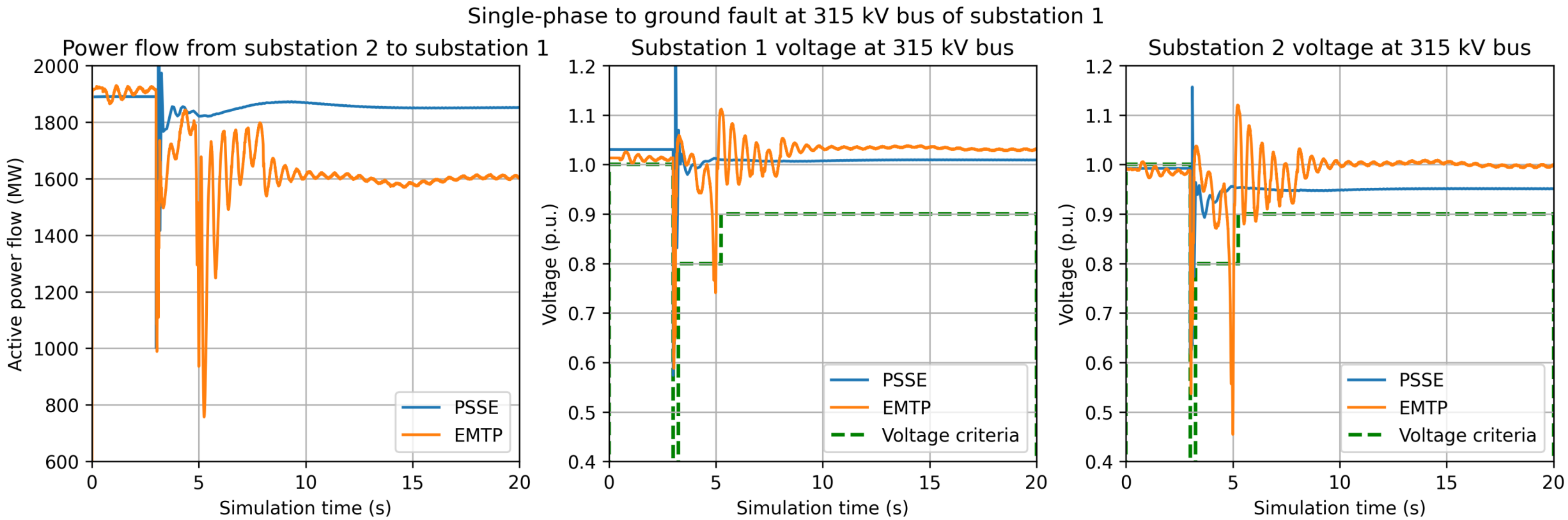
Comparison with PDT simulations

Three-phase fault



Simulation software	Wind generation loss	Voltage stability	Post-fault voltage
EMTP	Over 1000 MW	Within limits	> Initial voltage
PSSE	~ 200 MW	Within limits	< Initial voltage

Phase-to-ground fault



Simulation software	Wind generation loss	Voltage stability	Transient dynamics
EMTP	~ 300 MW	Exceed limits	Important low-frequency oscillations
PSSE	Less than 100 MW	Within limits	No oscillations

Conclusions

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Conclusions

- In EMTP simulations, operational transfer limits where limited by:
  - Loss of wind generation after a three-phase fault
  - Voltage instability after a phase-to-ground fault
- Compared to PDT simulations:
  - Loss of wind generation was greater in EMTP simulations
  - Important voltage oscillations in EMTP simulations, compared to the absence of voltage oscillations in PDT simulations

EMTP simulations were an essential tool to evaluate operational transfer limits in a weak grid with high-penetration of IBR.

Questions?

Or comments, suggestions, corrections, criticisms, praises, anxieties?

Thank you !

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– June 8 2025