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Stability Analysis and Control of Grids with High Renewable Energy Penetration

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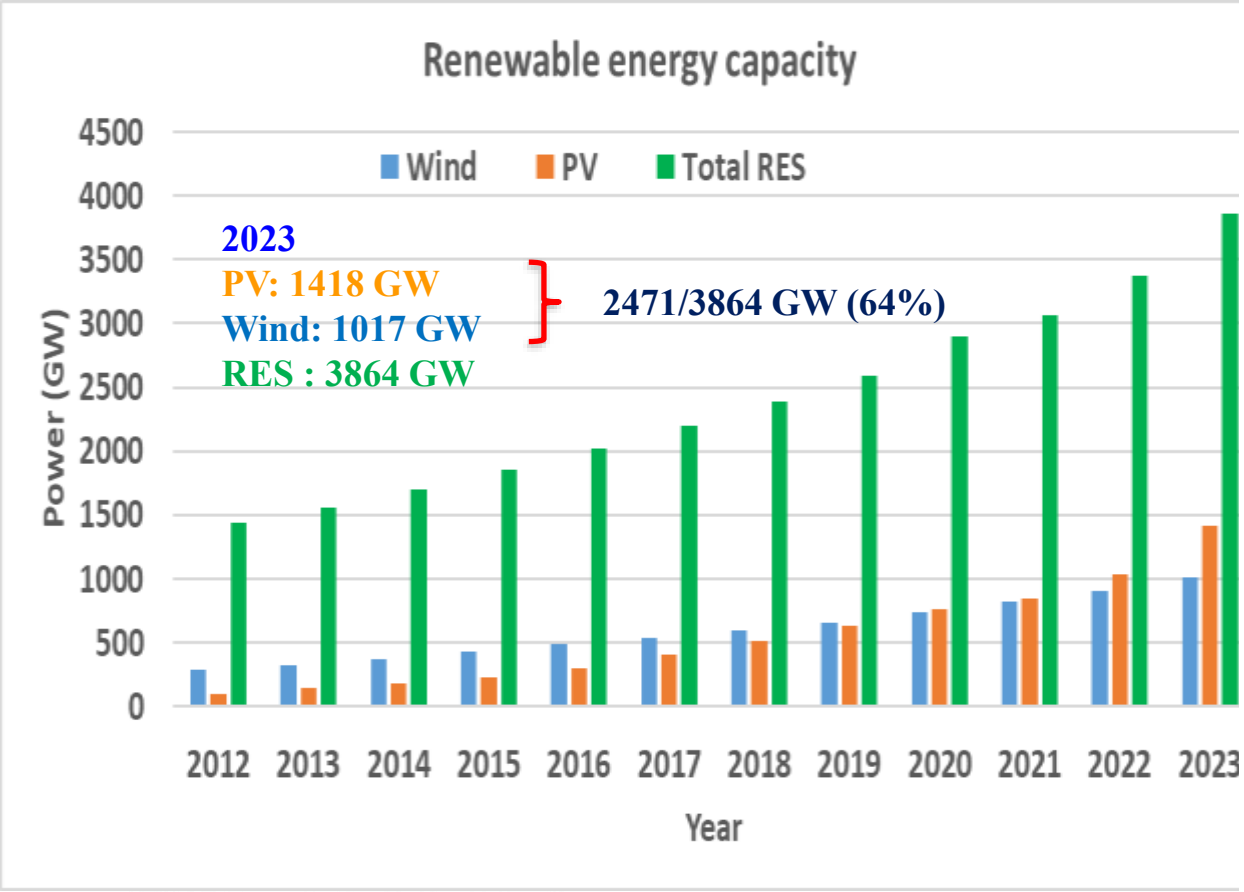
CEA Liten – INES

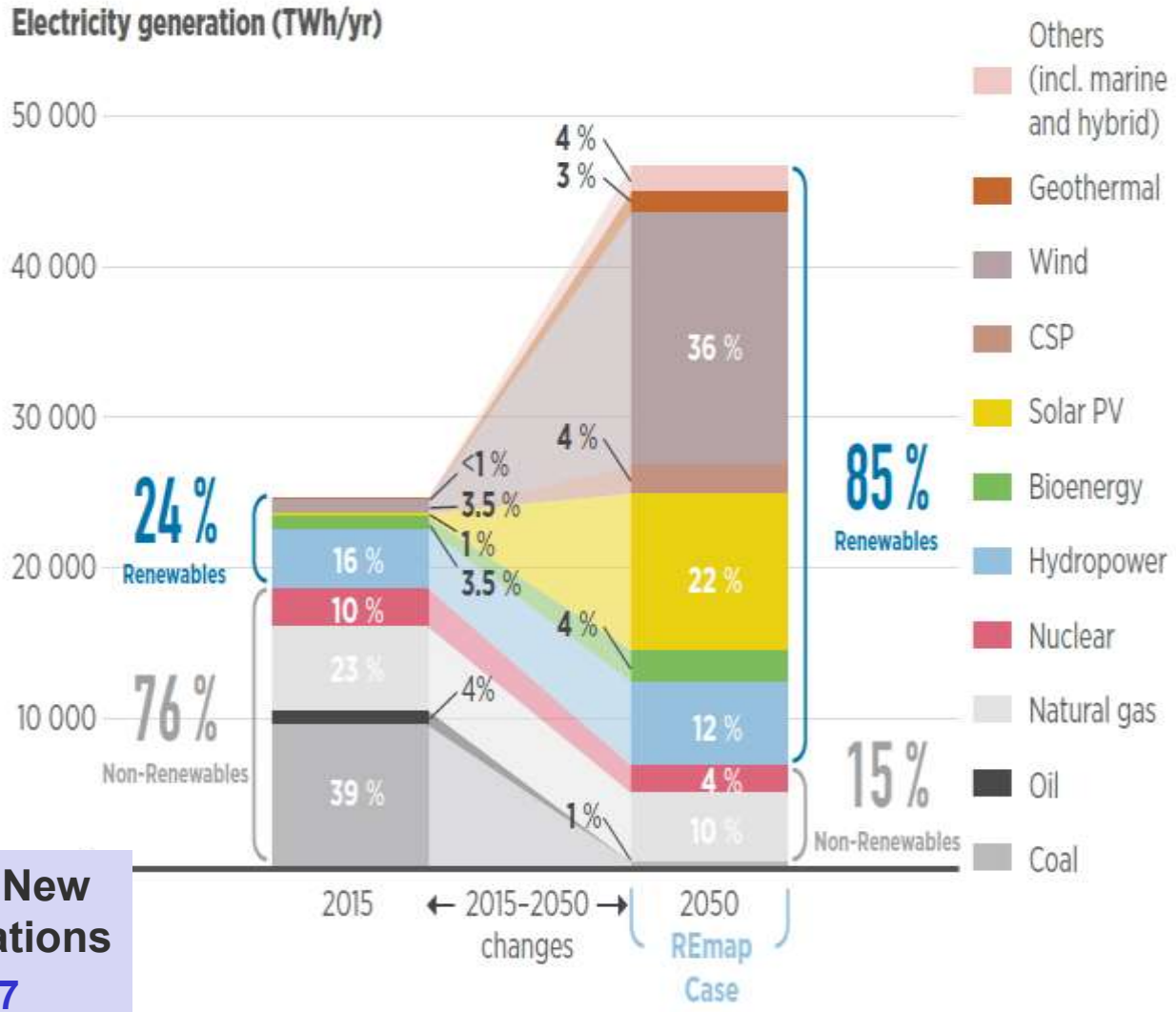
Workshop Digitalization, Stability and Protection
Grenoble, 11 -12 June 2025

Renewable Energy



https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Apr/IRENA_RE_Capacity_Statistics_2023.pdf

Forecast for renewable energies until 2050 (IRENA)



chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/viewer.html?pdfurl=https%3A%2F%2Fwww.irena.org%2F-%2Fmedia%2FFiles%2FIRENA%2FAgency%2FPublication%2F2018%2FApr%2FIRENA_Report_GET_2018.pdf&clen=4135242&chunk=true

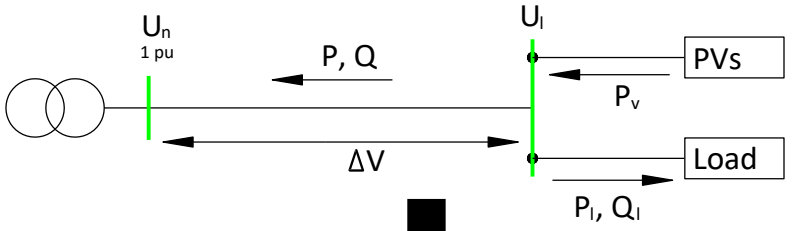
Worldwide	Wind Total Capacity	Wind New Installations	Solar Total Capacity	Solar New Installations
2024 (GW)est	1170	150	2200	597
2023 (GW)	1017	111	1418	365

Context

High penetration of RES

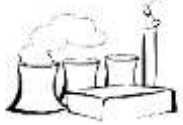
Low inertia

Intermittency → v, f, angle ↕

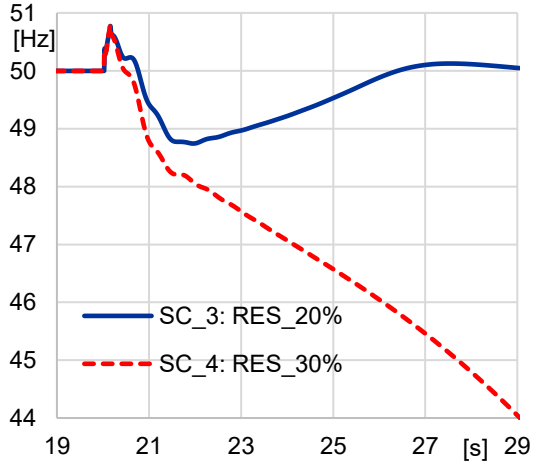


Complex issue in grids

- Low inertia, fast response
- Different types of productions.

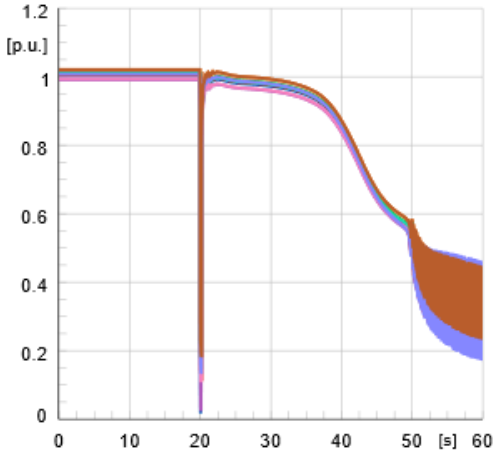



Frequency variation



$$\frac{df}{dt} = \frac{P_p - P_c}{2H_{tot}}$$

Voltage variation

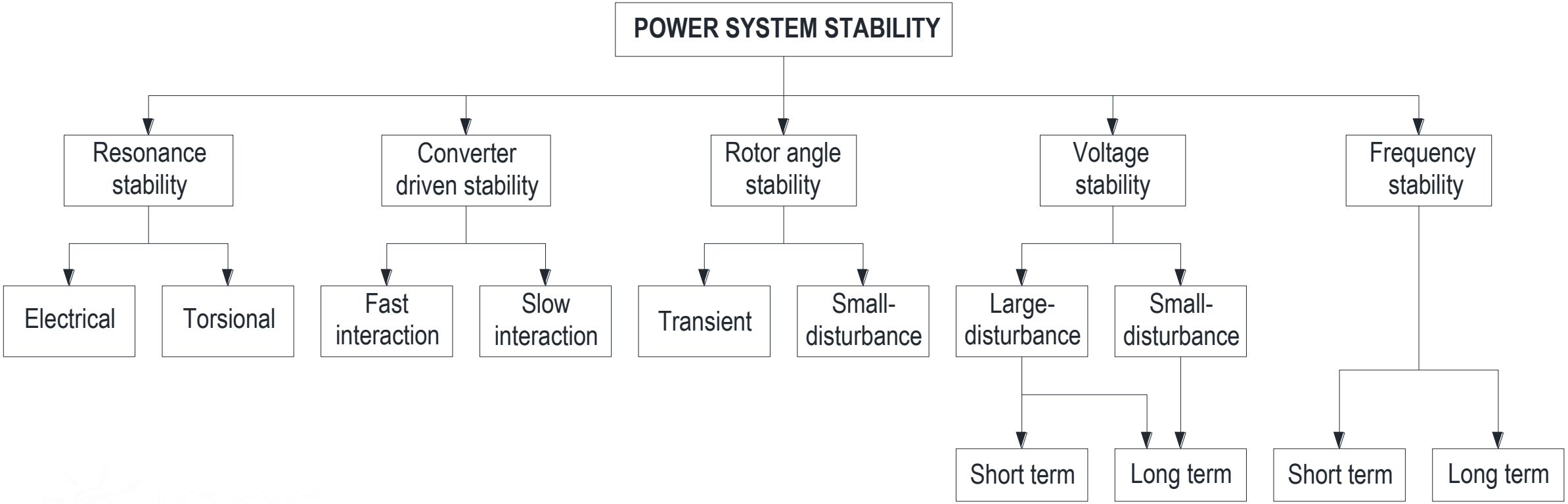


$$\Delta V = \frac{P.R + Q.X}{U_n}$$

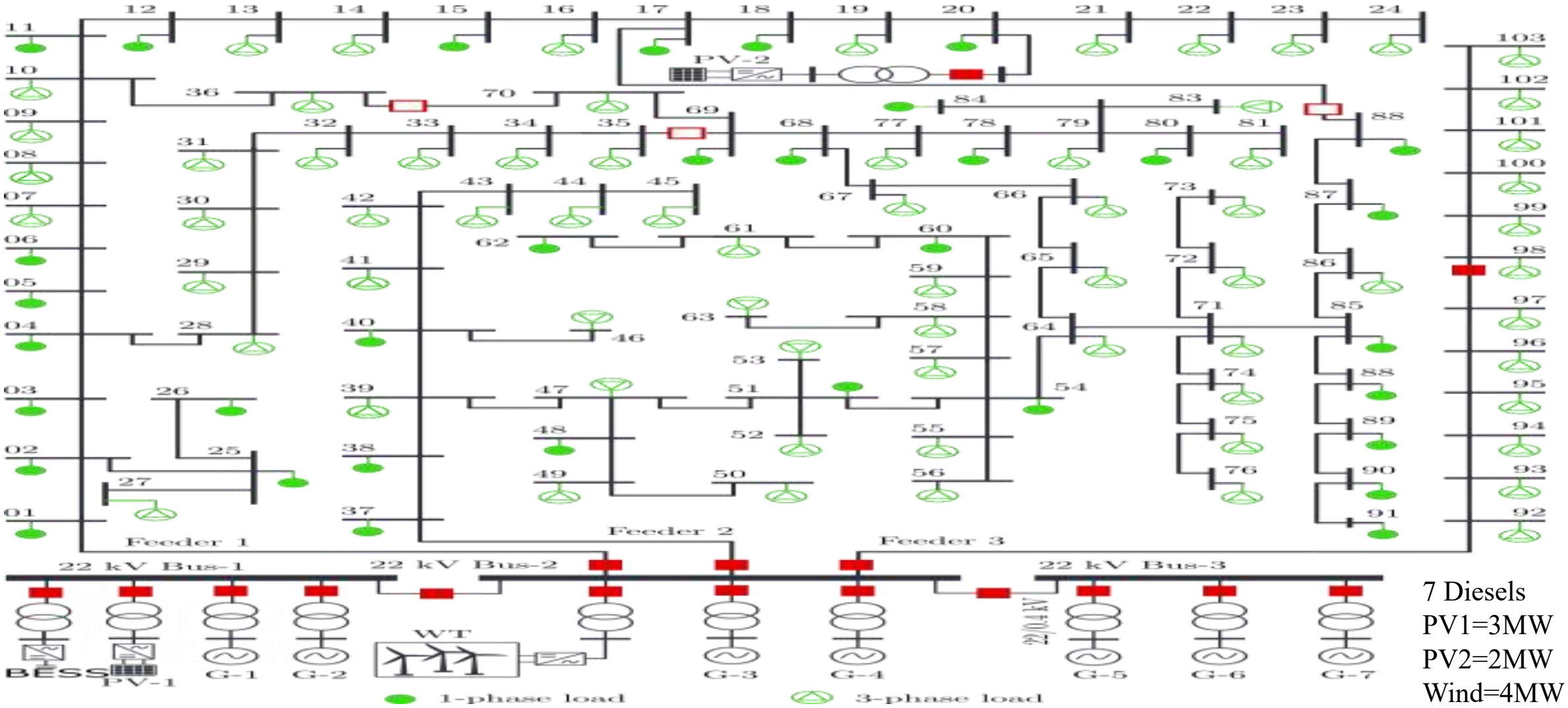
Motivations

- What impacts?
- What are the stability indicators (criteria)?
- What methodology to assess stability (Rotor angle + Voltage + **Frequency** …)?
- What solutions to improve stability?

Categories of Power system stability



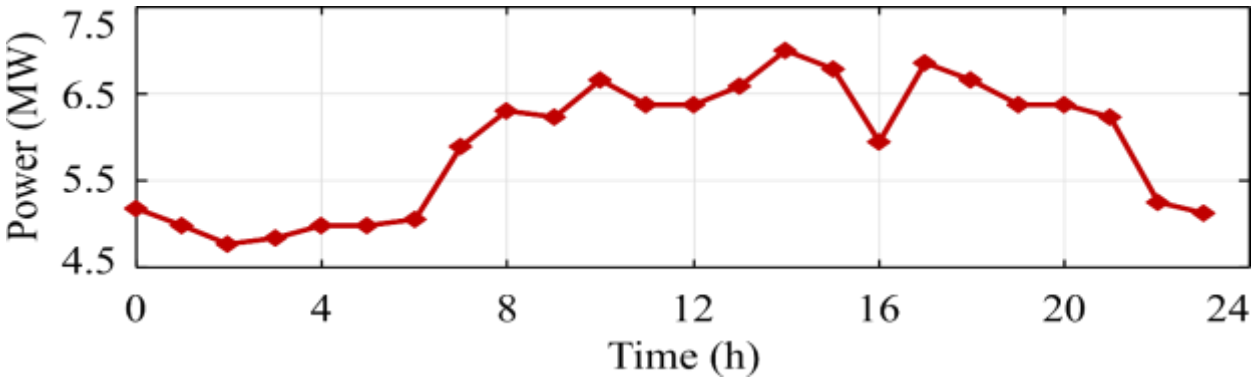
Stability for an island microgrid (Con Dao, Vietnam)



7 Diesels
PV1=3MW
PV2=2MW
Wind=4MW
Load=7MW
BESS=3 MW

Quoc Tuan Tran, Tran The Hoang et all; **"Stability Assessment of Con Dao Island Grid with High Penetration of Photovoltaic Systems";** IEEE PES, General Meeting 17-21 July, 2022, Denver, USA; **DOI:** 10.1109/PESGM48719.2022.9916978

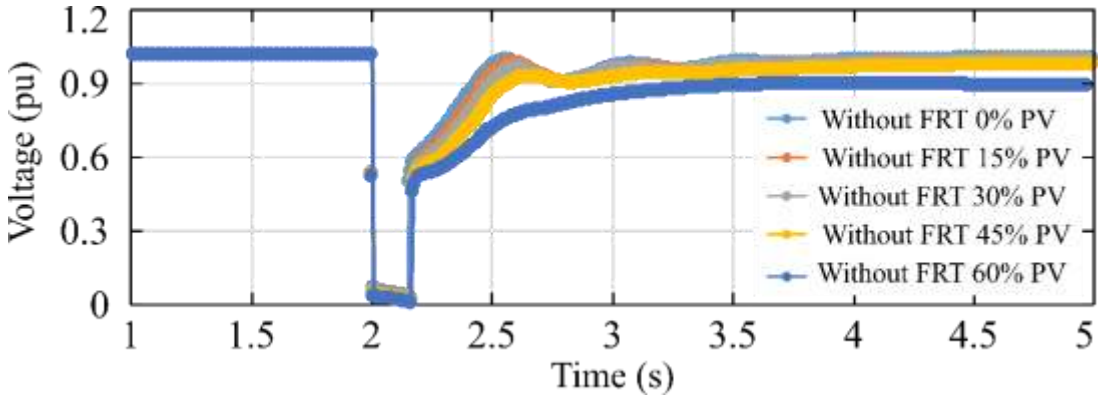
Con Dao – Vietnam : Island microgrid

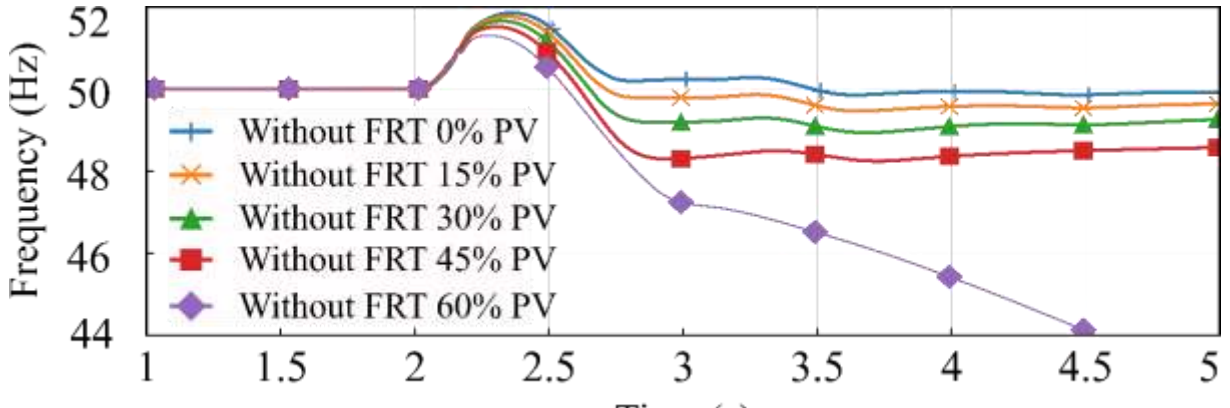


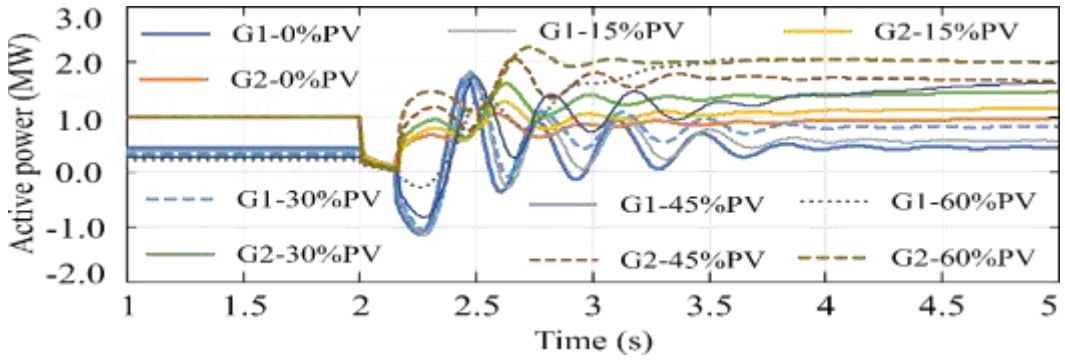
Case A: Diesel generator G1 as slack bus without BESS

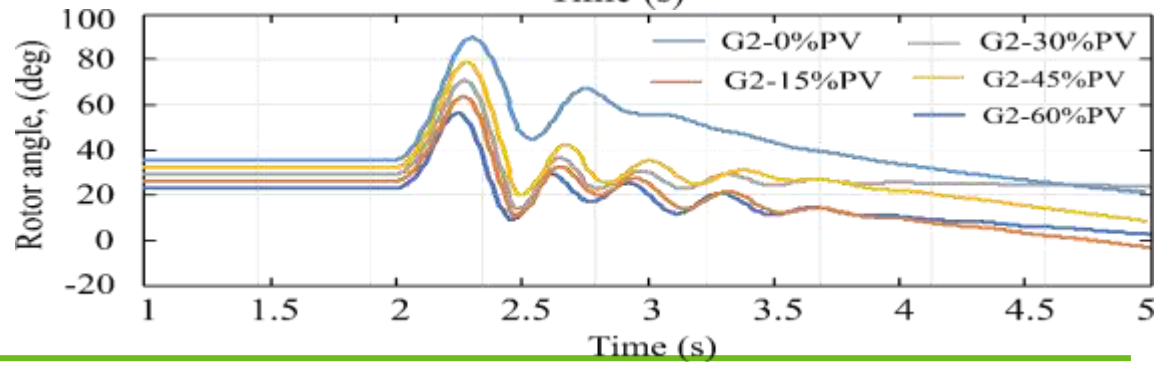
PV systems without FRT capability

PV level	Diesel	PV, (MW)	WT (MW)	PV + WTRES Rate (%)	H_{sys} (s)
PV0%	G1-G6	0	1.5	21.4	4.82
PV15%	G1-G5	1.05	1.5	32.1	4.02
PV30%	G1-G4	2.1	1.5	51.4	3.21
PV45%	G1-G3	3.15	1.5	66.4	2.41
PV60%	G1-G2	4.2	1.5	81.4	1.61

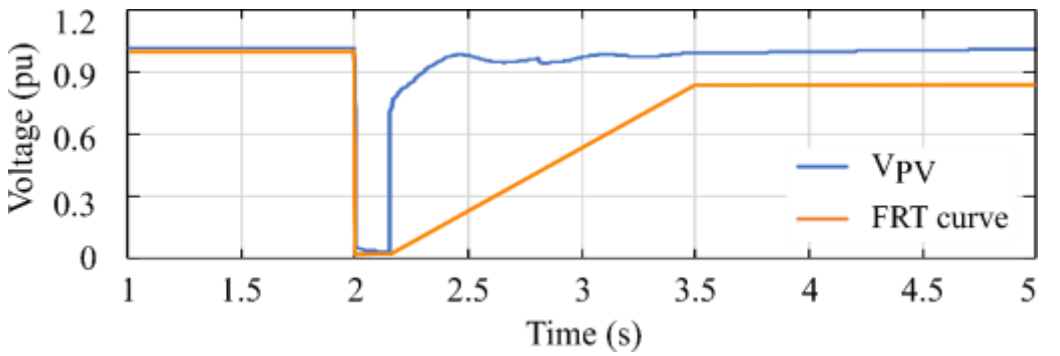


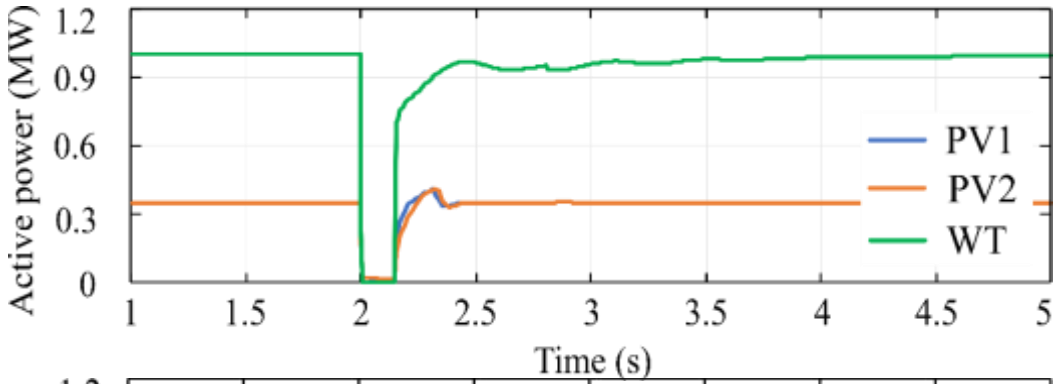


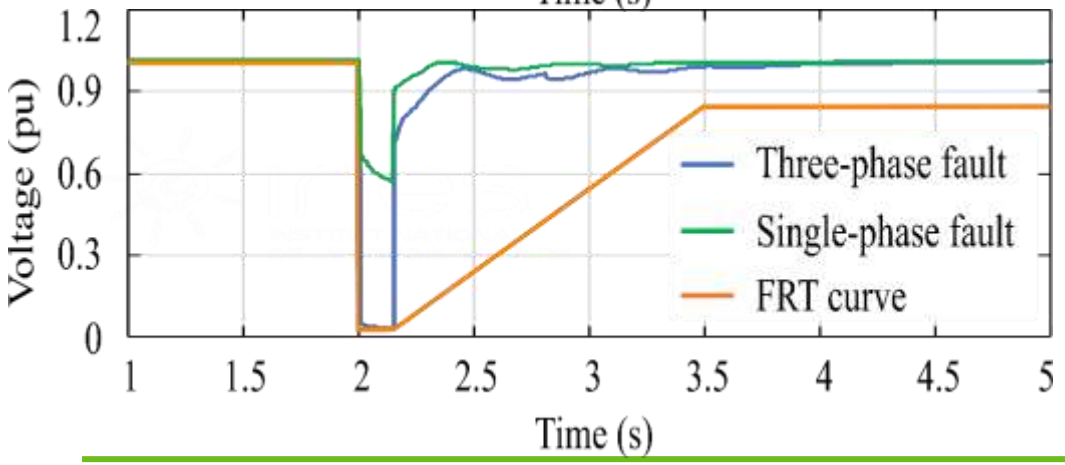




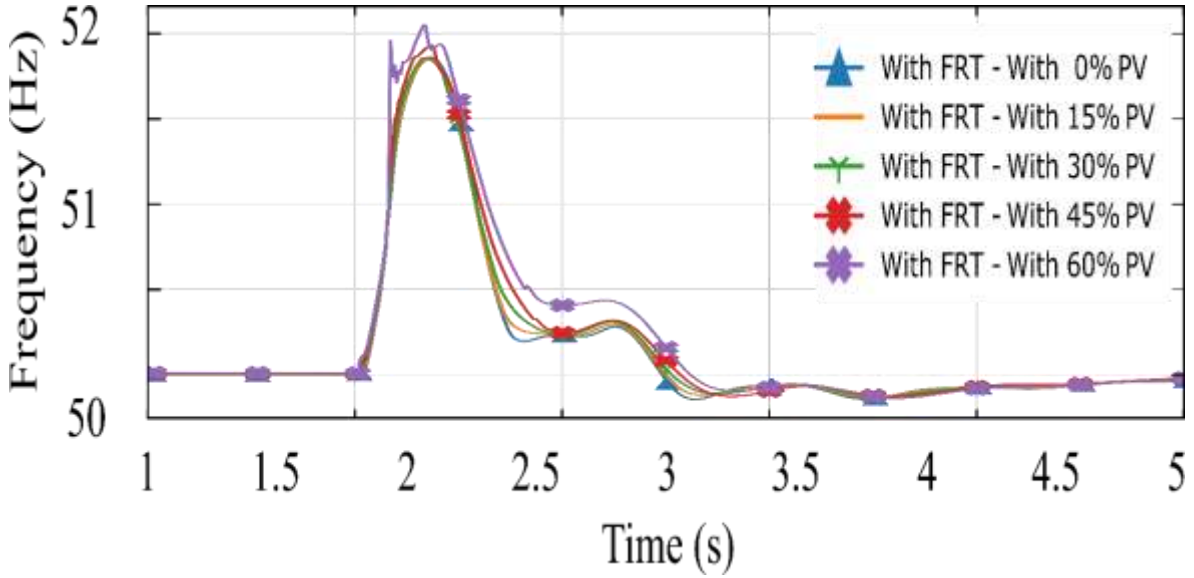
Con Dao – Vietnam : Island microgrid

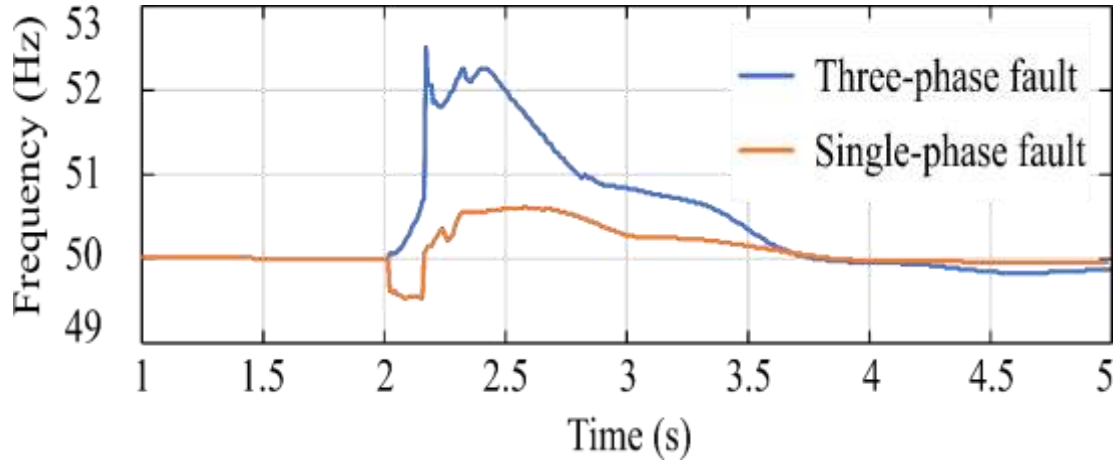






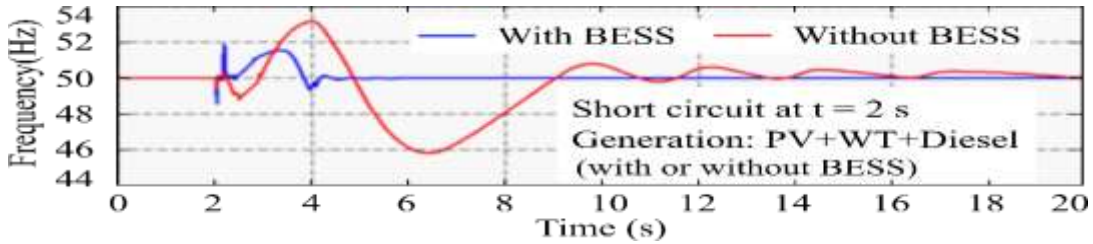
PV systems without FRT capability



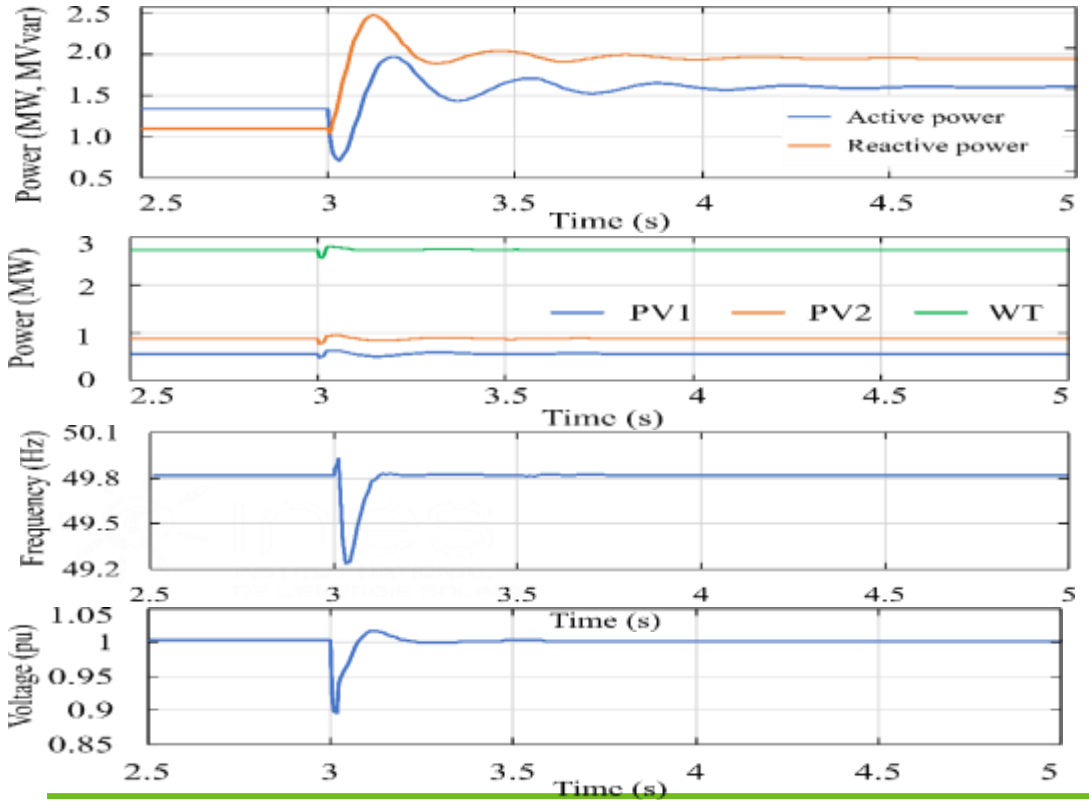


Con Dao – Vietnam : Island microgrid

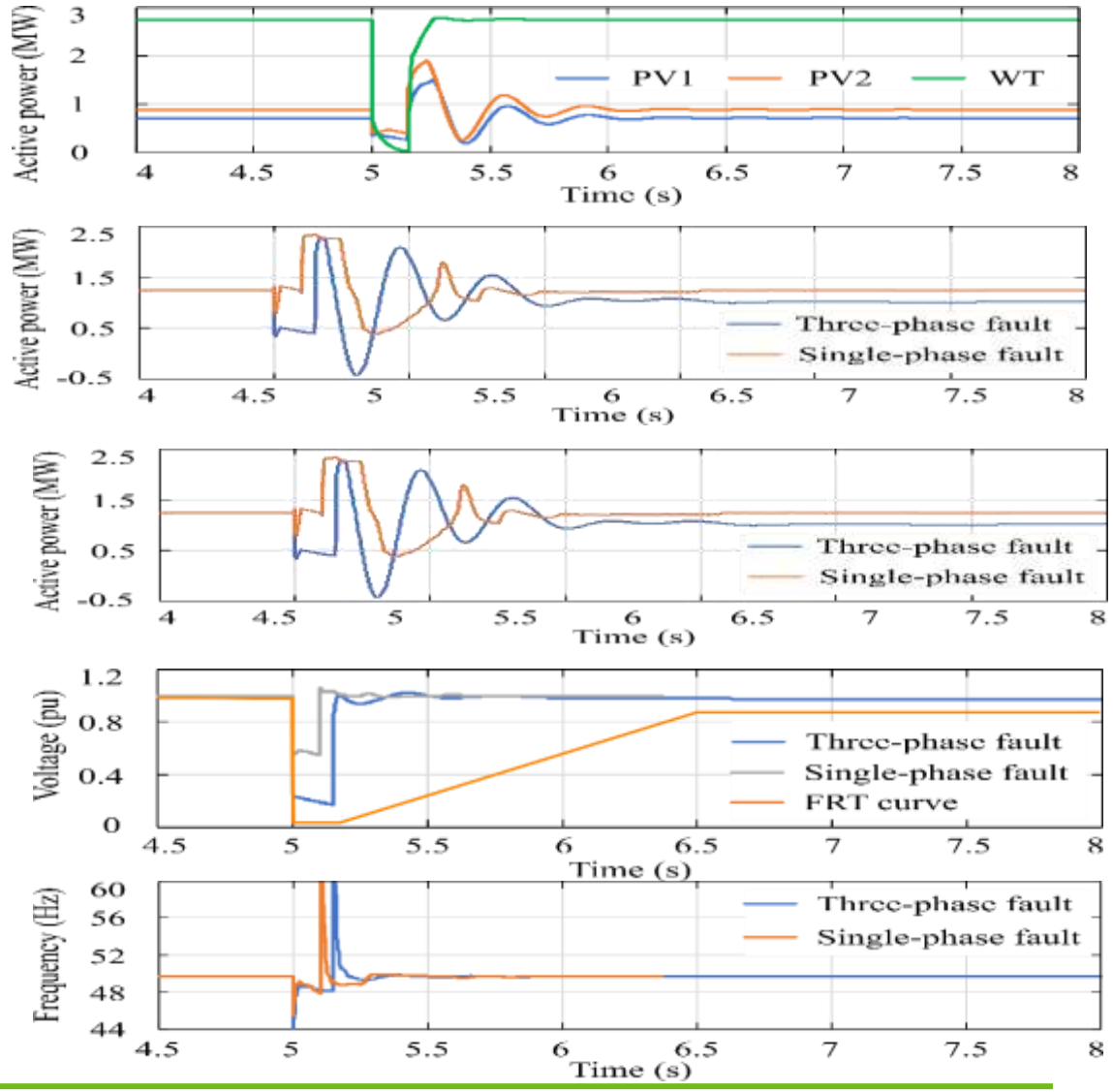
Case B: BESS as slack bus



Outage of diesel generator G1



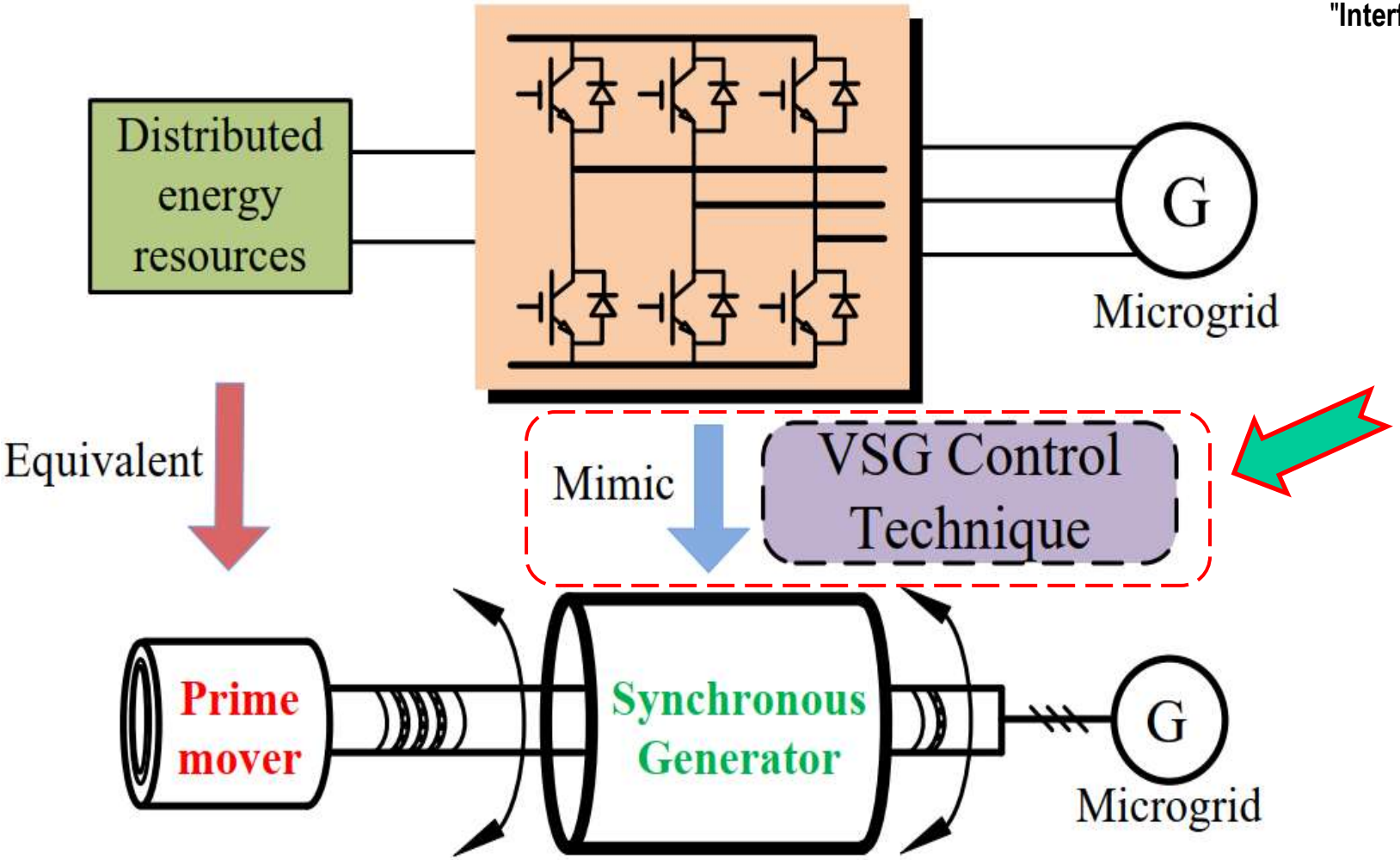
Short circuit without synchronous machines



Flexibility by VSG (Virtual Synchronous Generator)

PhD thesis: Minh Cong PHAM– 2021

"Interface framework and energy management for microgrids"

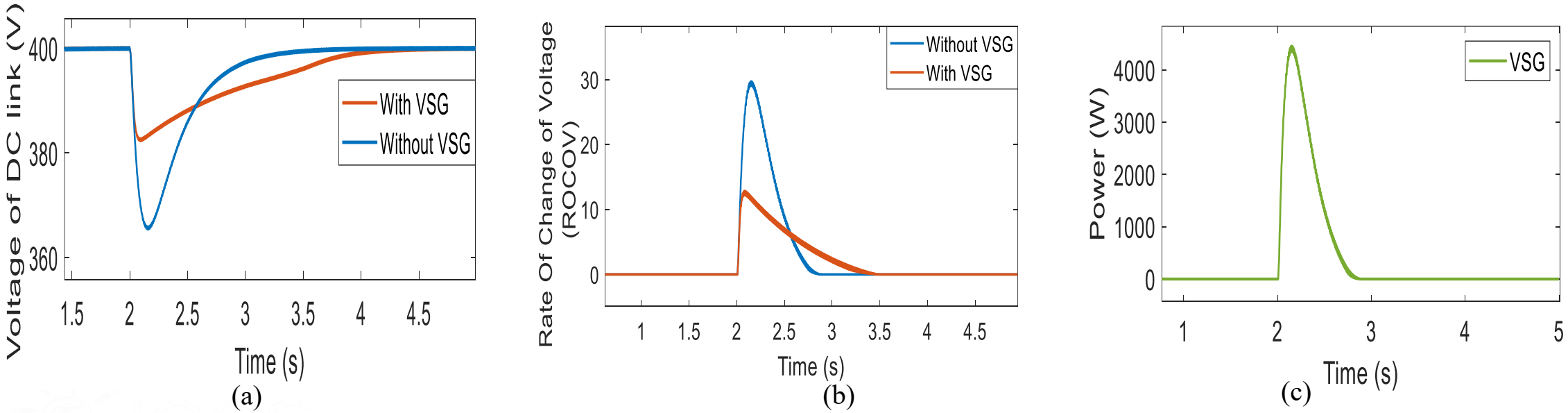


Purpose of VSG

Copy the dynamic properties of tradional synchrnous machines such as:

- Adjusting active and reactive power.
- Dependency of the grid frequency on the rotor speed.
- Highlighting the rotating mass and damping windings effect.

- **Interface in multi-microgrid (MMG) system**
  - Methodology for stability enhancement in MMG system
    - ✓ Inertia support: Virtual synchronous generator approach $P_{VSG} = K_D.\Delta V_{DC} + K_I.\frac{dV_{DC}}{dt}$



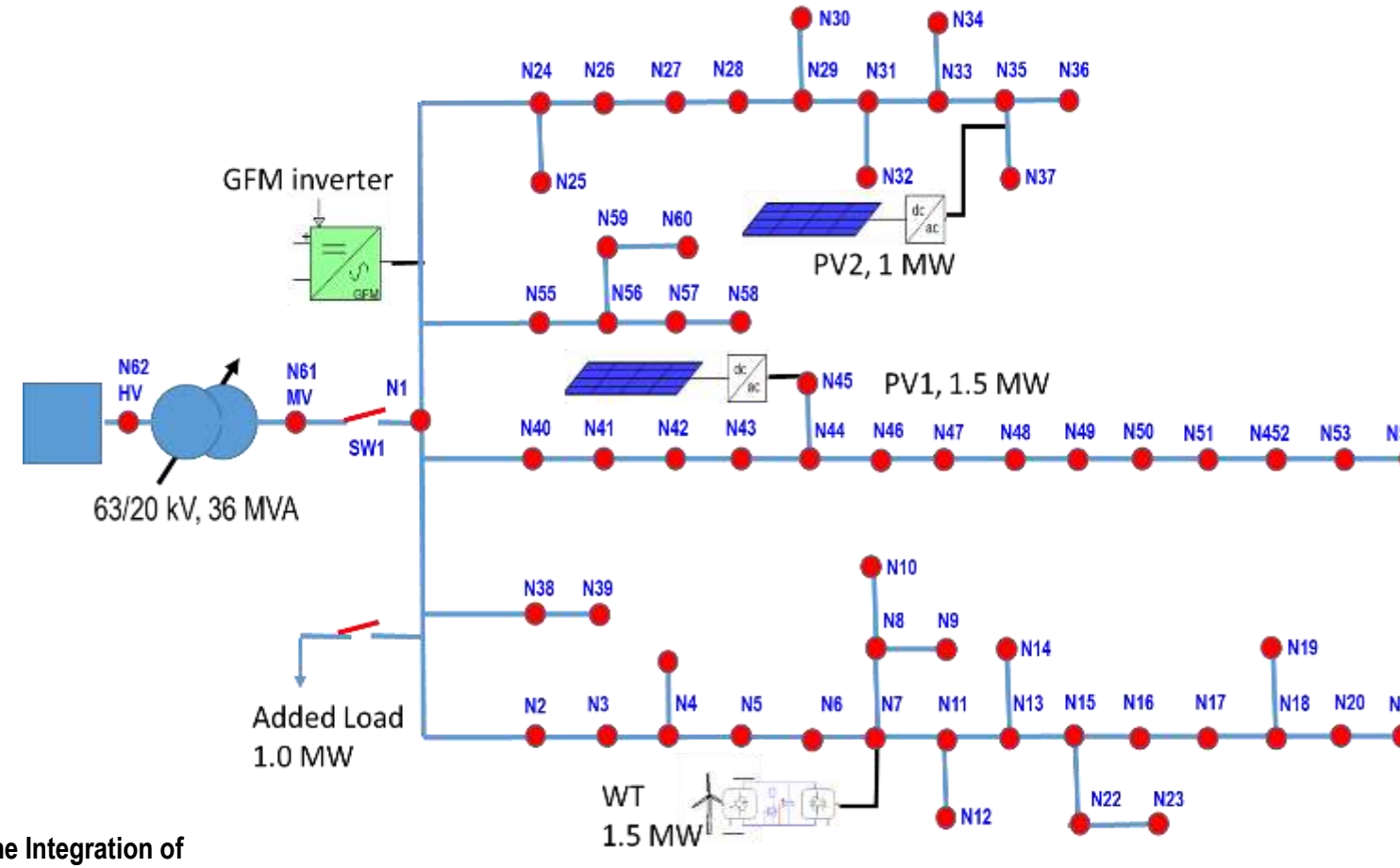
VSG approach: (a) Voltage response of DC-link, (b) ROCOV of DC-link, (c) Power from VSG

Minh-Cong Pham, Reza Razi, Ahmad Hably, Seddik Bacha, Quoc-Tuan Tran, et al.. , **"Robust hybrid control of parallel inverters for accurate power-sharing in microgrid".;** ICIT 2020, Feb 2020, Buenos Aires, Argentina.; **DOI:** 10.1109/ICIT45562.2020.9067116

Grid forming control: Grid model and Scenarios

This part presents a real 20kV MV network supplied by a 36-MVA, 63/20-kV OLTC transformer with 62 buses and the following characteristics:

- PV1 connected to bus 35: $P_{PV1} = 1.5\ MW$.
- PV2 connected to bus 45: $P_{PV2} = 1\ MW$.
- WT connected to bus 7: $P_{WT} = 1.5\ MW$.
- GFI connected to bus N1: $P_{GFI} = 5.0\ MW$
- An added load connected to bus N1: $P_{L\_Add} = 1.0\ MW$
- Total active consumption: $P_{load} = 4.85\ MW$.
- Total reactive consumption: $Q_{load} = 0.97\ MVAR$.



Studied MV distribution network.

Quoc Tuan Tran, Minh Cong Pham; "**Grid-Forming Inverters for Facilitating the Integration of Renewable Energy Sources and Enhancing the Stability of Grids**"; IEEE Conference – IHTC, November 2024, Bari, Italy; DOI: 10.1109/IHTC61819.2024.10855136

Simulation and Analysis: Scenario without GFI

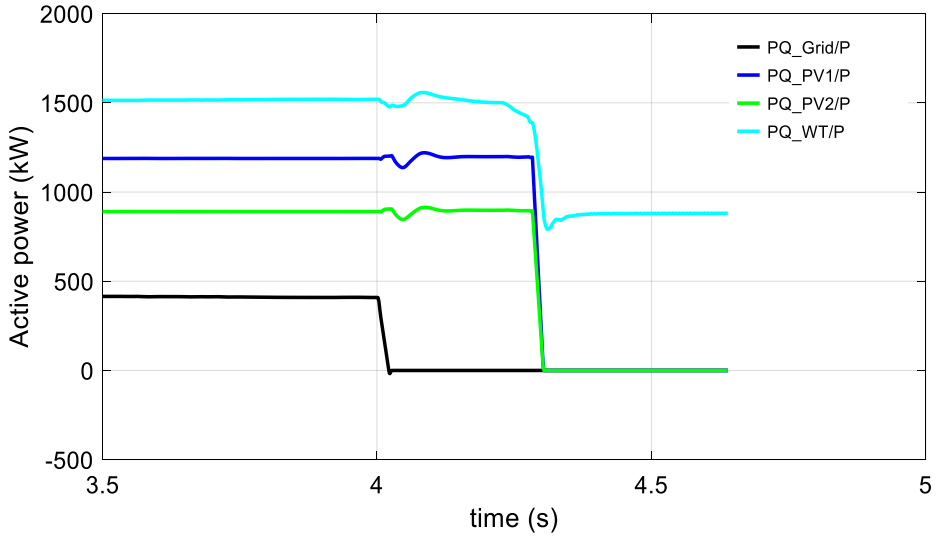


Fig. 1. Active power variation (without GFI).

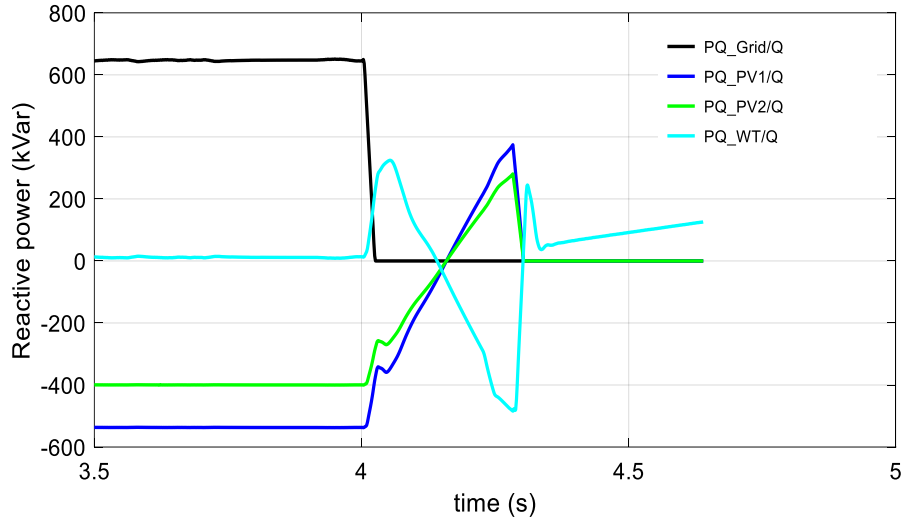


Fig. 2. Reactive power variation (without GFI).

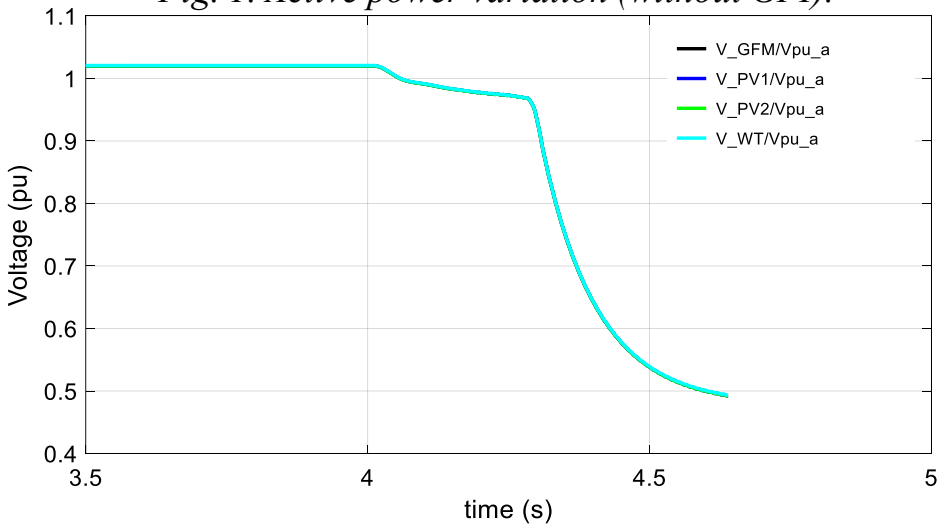


Fig. 3. Voltage variation (without GFI).

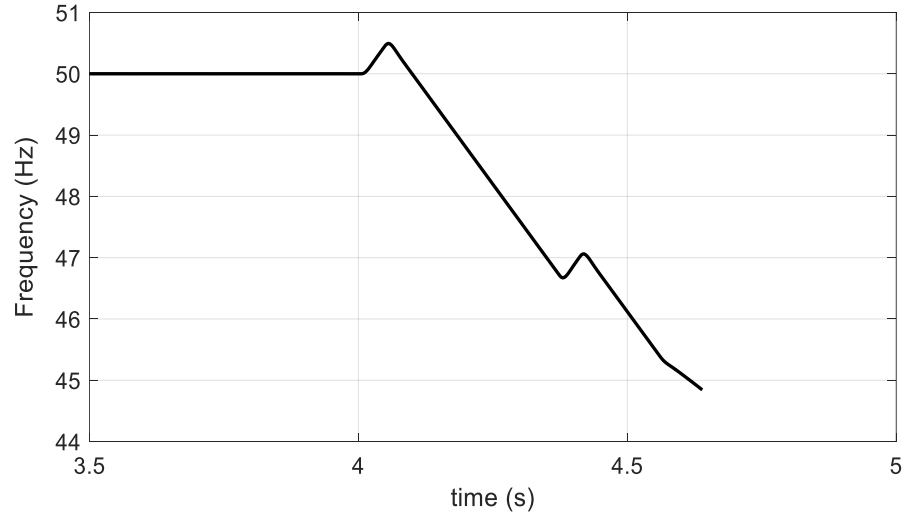


Fig. 4. Frequency variation (without GFI).

Simulation and Analysis: Scenario with GFI

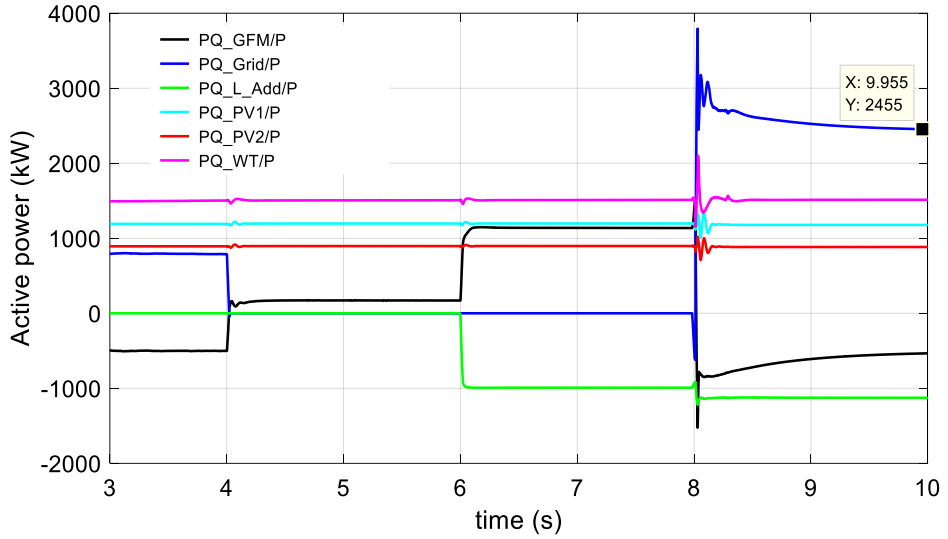


Fig. 1. Active power variation (with GFI).

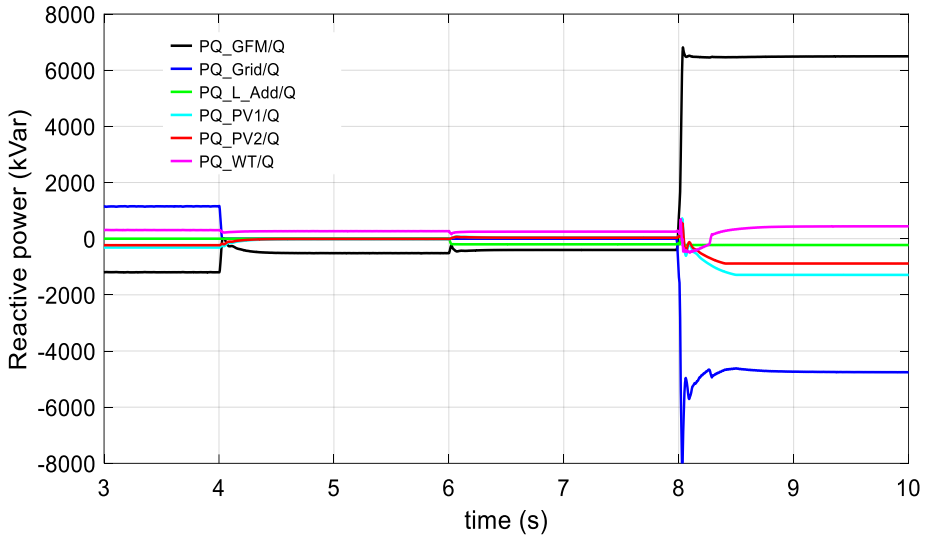


Fig. 2. Reactive power variation (with GFI).

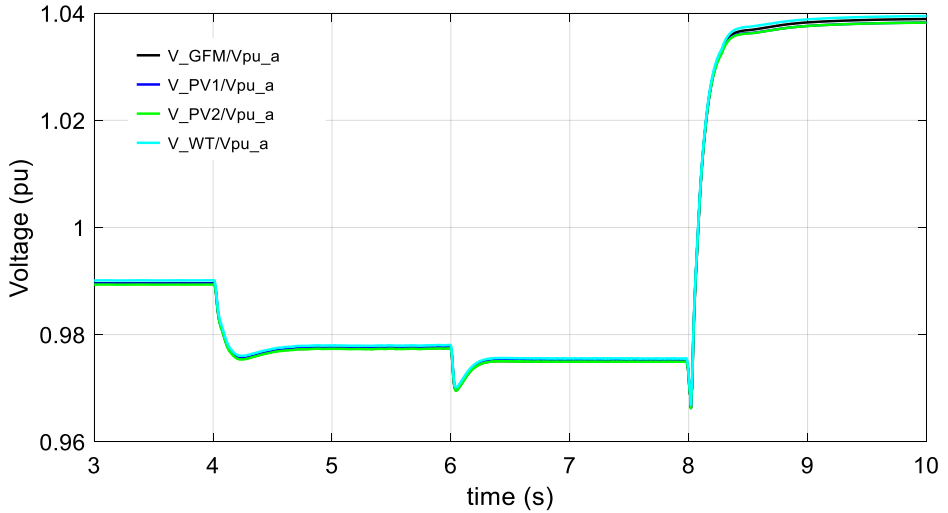


Fig. 3. Voltage variation (with GFI).

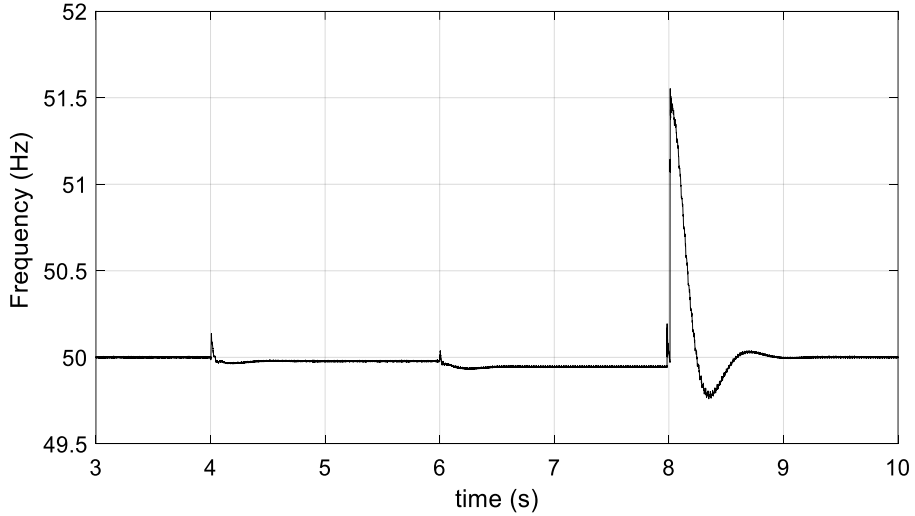
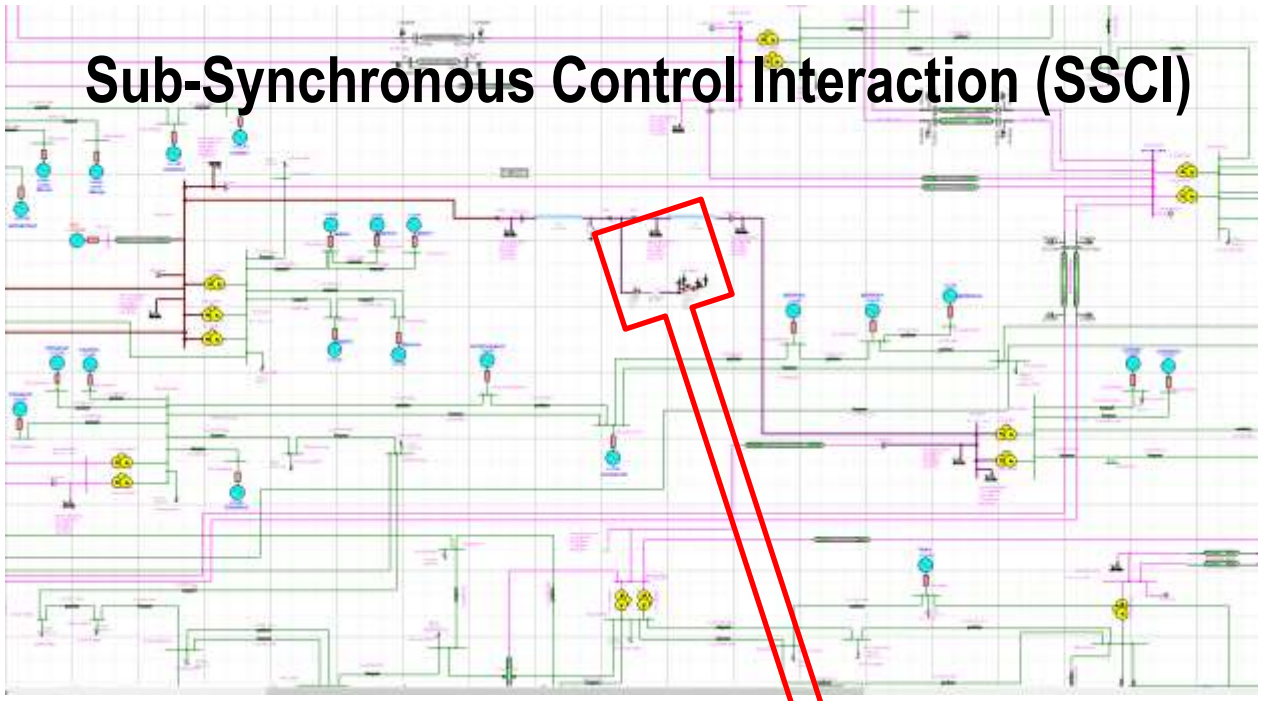
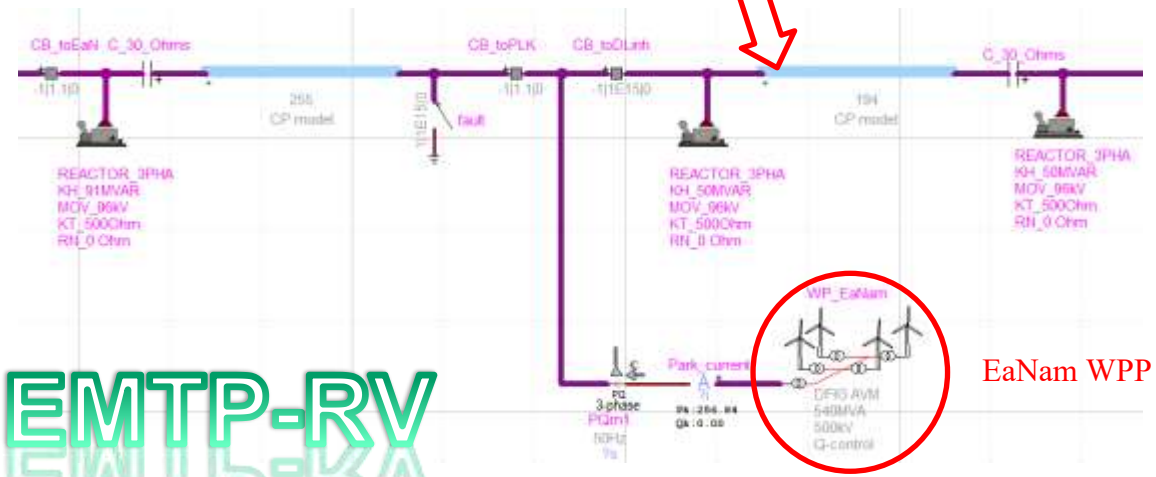


Fig. 4. Frequency variation (with GFI).

Sub-Synchronous Control Interaction (SSCI)

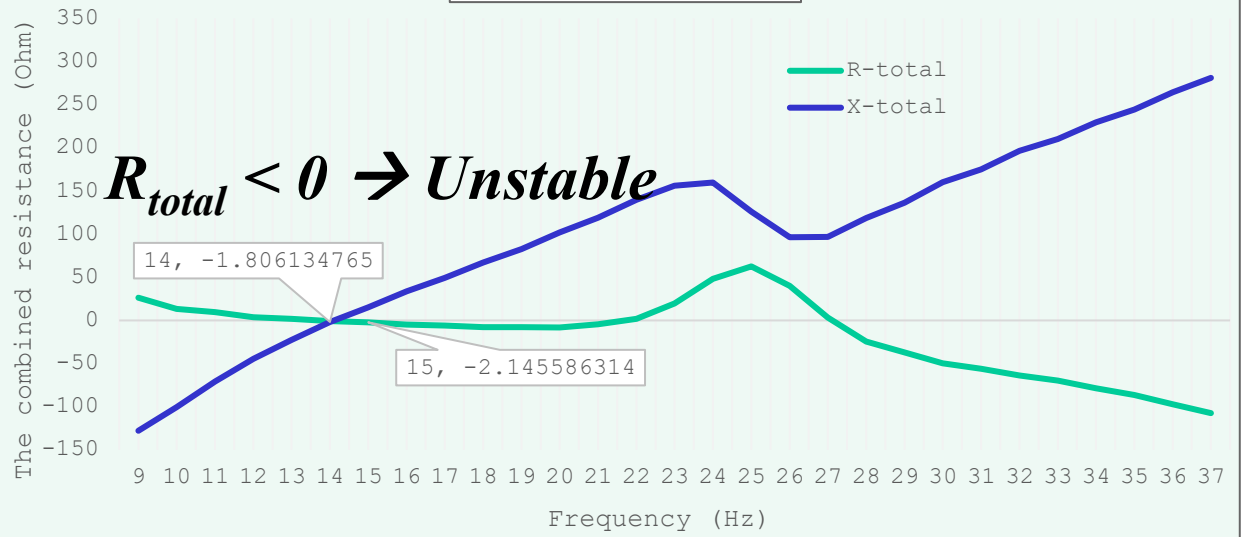




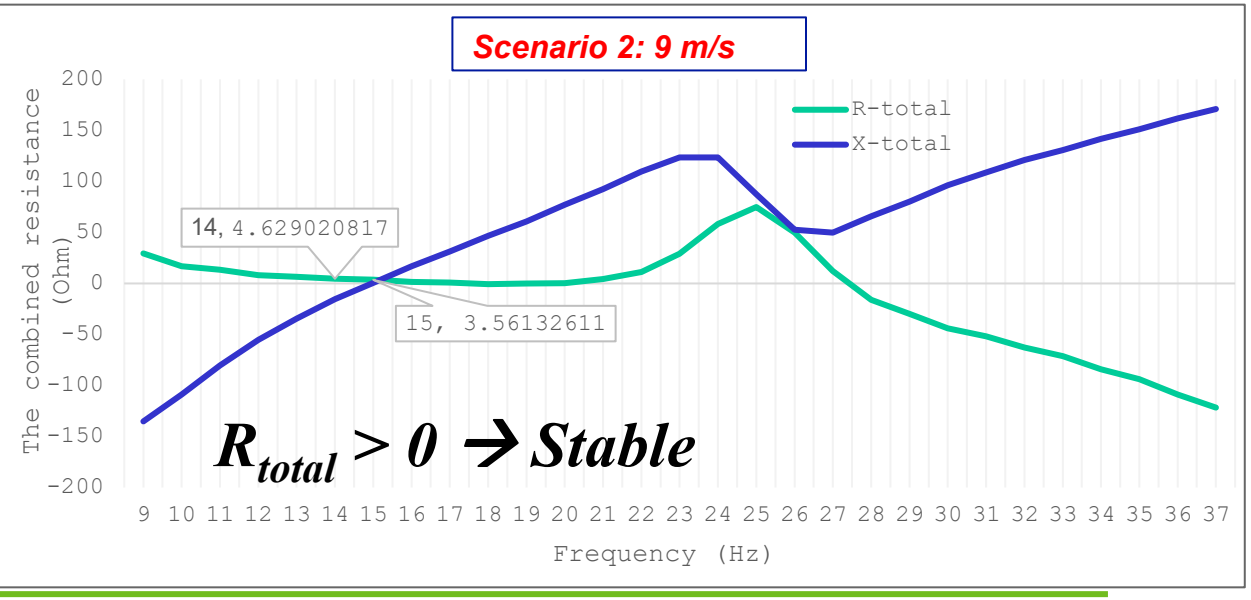
EMTP-RV

EaNam WPP

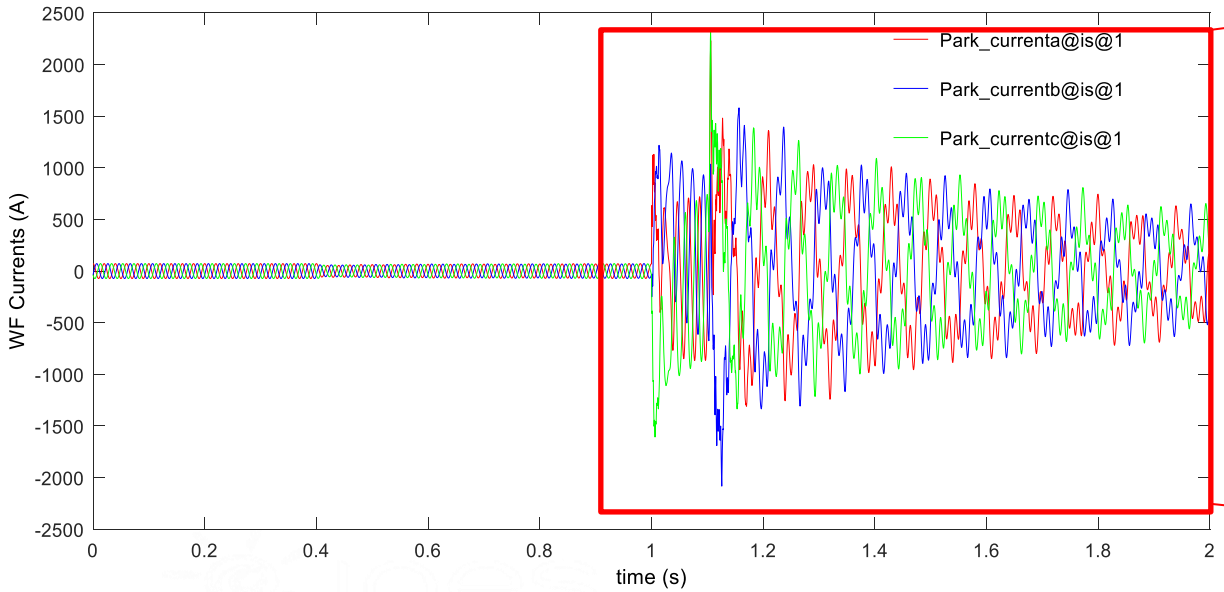
Scenario 1: 5 m/s

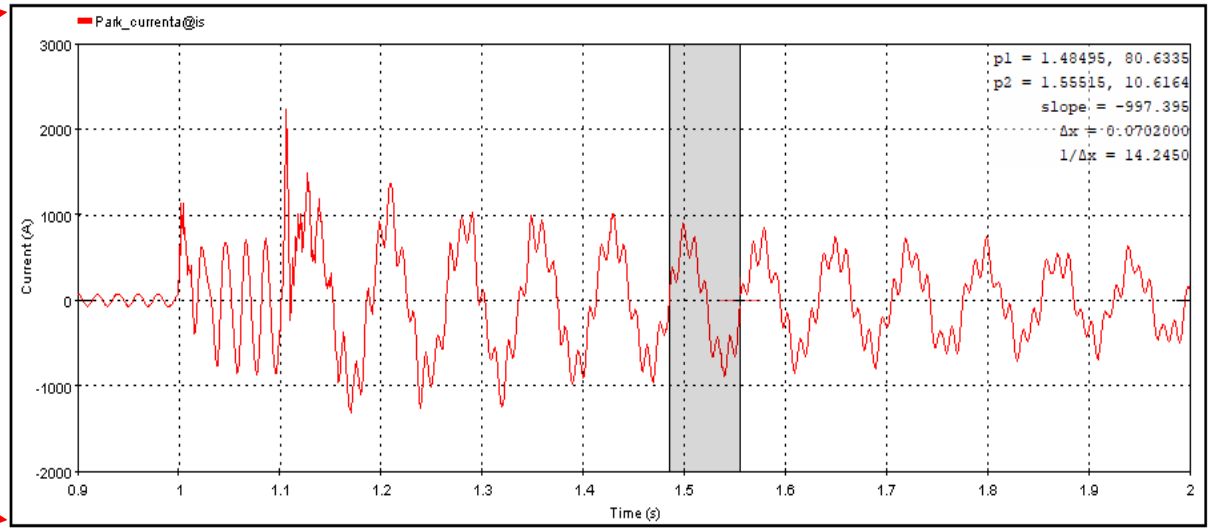


Scenario 2: 9 m/s



EMTP-RV
The reference for power systems transients





Risk of SSCI: causing high wind park current and can be resulting in damage to the wind turbine crowbar circuits.

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THANK YOU FOR YOUR ATTENTION

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