

Optimal Provision of Frequency Services in Low-Carbon Grids

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Presentation structure

Introduction

- 1. Frequency Stability**
- 2. Frequency-Security Constraints**
- 3. Optimisation of Power System's Operation**
- 4. Relevance of this work**

Intro: from Dynamics to Optimisation

Deduce **dynamic-security conditions** to implement them in an optimisation routine



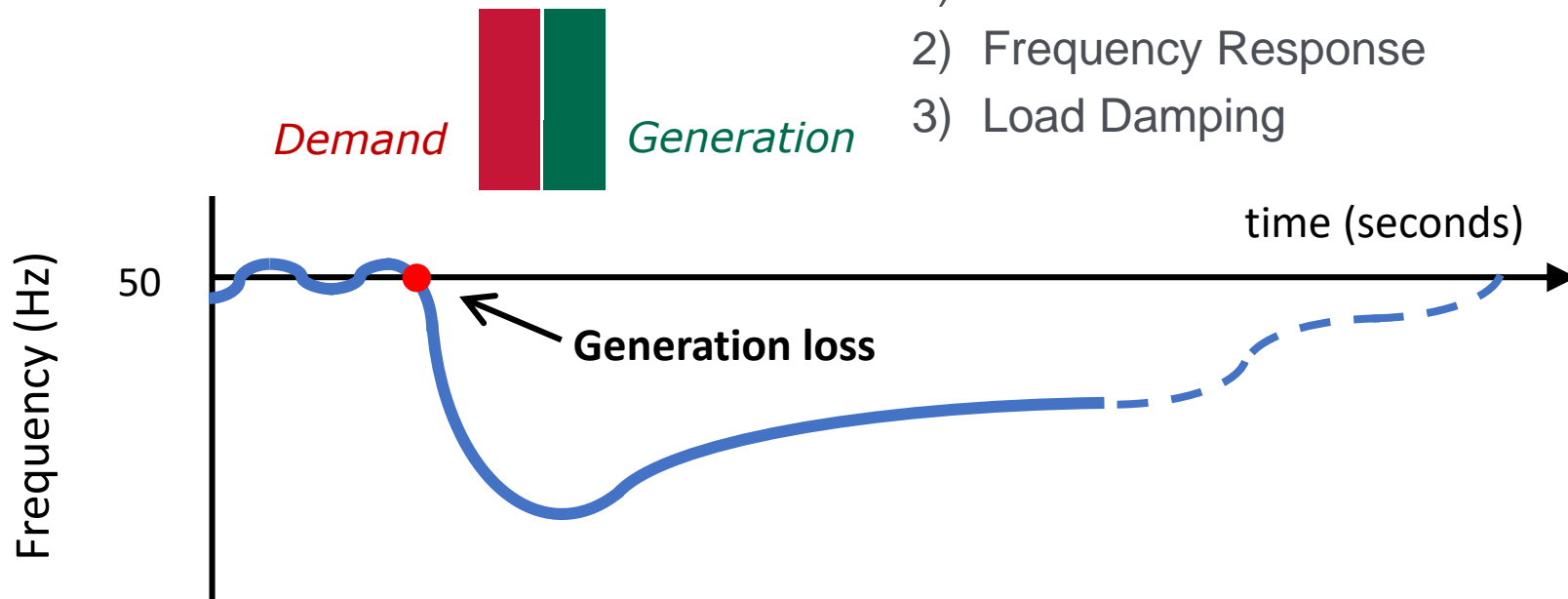
Goal: achieve minimum cost while keeping the system stable

1. Frequency Stability

My work focuses on **frequency dynamics**

- Why is it important? **Low inertia** in decarbonised electricity grids.
Risk of frequency instability has increased

- 1) Inertia
- 2) Frequency Response
- 3) Load Damping

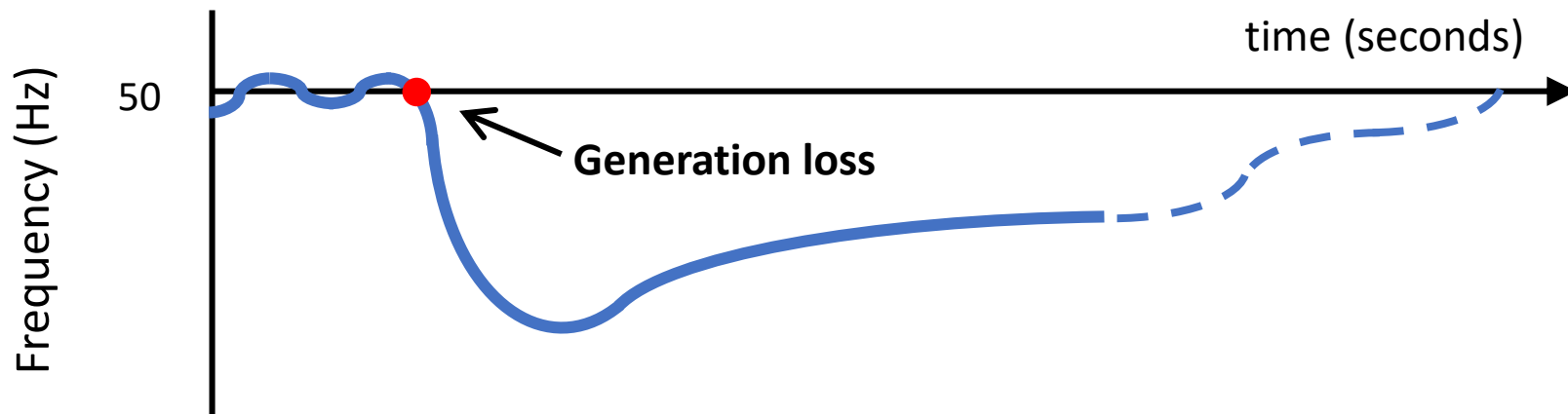


1. Frequency Stability

How to study frequency-stability conditions?

Options:

- Dynamic simulations of the system
 - Advantage: represents well the system dynamics
 - Disadvantage: computationally slow
- Analytical methods (swing equation)
 - Disadvantage: difficult to obtain closed-form solutions
 - Advantage: computationally fast and transparent information



1. Frequency Stability

Swing equation:

$$2H \frac{d\Delta f(t)}{dt} + D \cdot P_D \cdot \Delta f(t) = -P_{\text{Loss}}^{\text{max}} + \sum \text{FR}(t)$$

*Loss of largest
power infeed
(N-1 requirement)*

Nomenclature

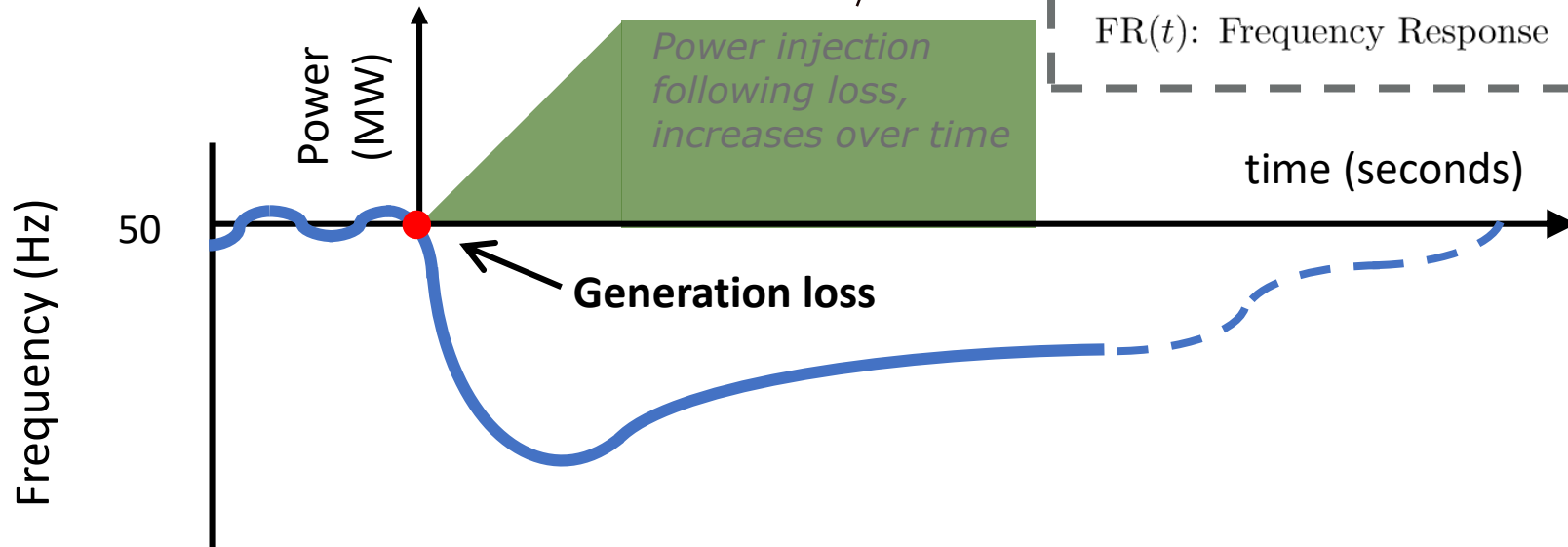
H : System's inertia

D : Load damping factor

P_D : System's demand

$P_{\text{Loss}}^{\text{max}}$: Largest possible power loss
in the system

$\text{FR}(t)$: Frequency Response



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Swing equation:

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*Loss of largest
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*Power injection
following loss,
increases over time*

Nomenclature

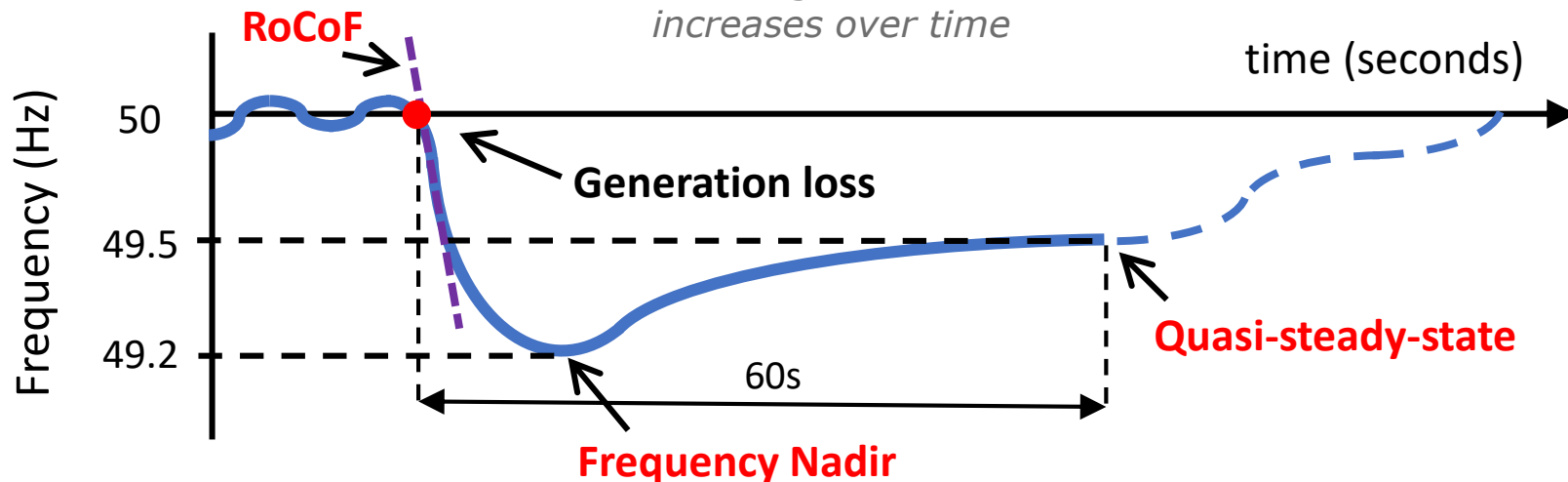
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2. Frequency-Security Constraints

From the swing equation, deduce the
3 security conditions:

- **RoCoF** $\rightarrow f(H, P_{loss}^{max})$
- Frequency **nadir** $\rightarrow f(H, P_{Loss}^{max}, D, FR)$
- Frequency **quasi-steady-state**
 $\rightarrow f(P_{Loss}^{max}, D, FR)$

Nomenclature

H : System's inertia

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P_{Loss}^{max} : Largest possible power loss
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*These are the **frequency services**, system's variables
that allow to comply with frequency-security conditions*

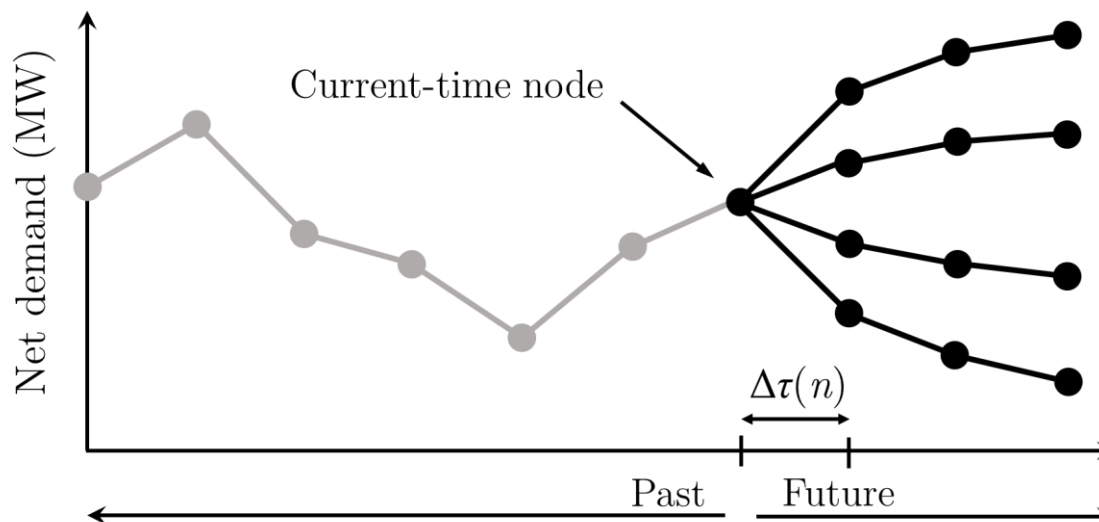
Still one big problem: **nadir is a nonlinear constraint** (even nonconvex in
some cases)

3. Optimisation of Power System's Operation

These security constraints can be applied to:

1. Optimal Power Flow and **Unit Commitment**

- We use Stochastic Unit Commitment, to model uncertainty from renewables



$$\min \sum_{n \in \mathcal{N}} \pi(n) \sum_{g \in \mathcal{G}} C_g(n)$$

subject to RoCoF constraint
 Nadir constraint
 SteadyState constraint
 (and other typical constraints)

4. Relevance of this work

Applied to a **current power system**:

- Allows to **optimally operate the system**, for example dynamically reducing the largest power infeed. Particularly valuable for systems with high renewable penetration

Applied to **potential future scenarios** of generation mix or market structure:

- Allows to **study the value of different technologies** (fast power injections from battery storage, flexibility from thermal units, etc.)