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Towards a Cost-Effective Operation of Low-Inertia Power Systems

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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

Power System Dynamics

Economic Optimisation

Described by differential equations

Based on algebraic equations

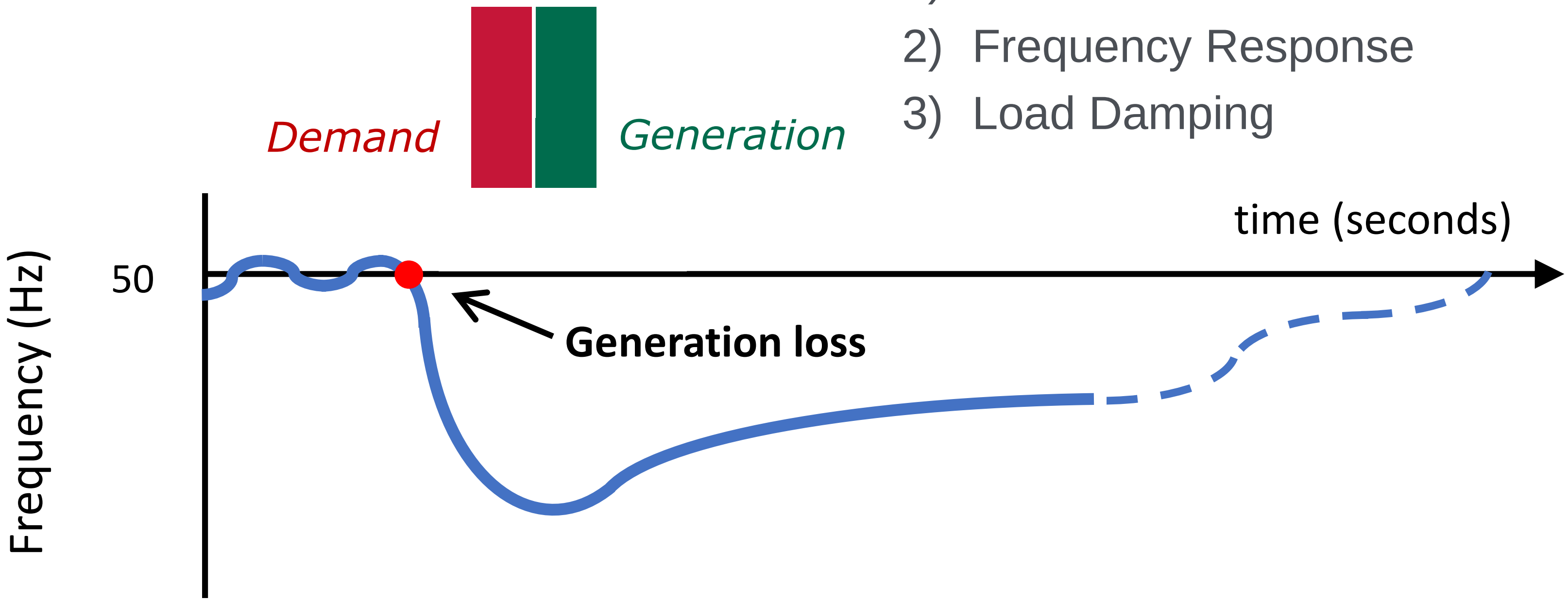
Goal: achieve minimum cost while keeping the system stable

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

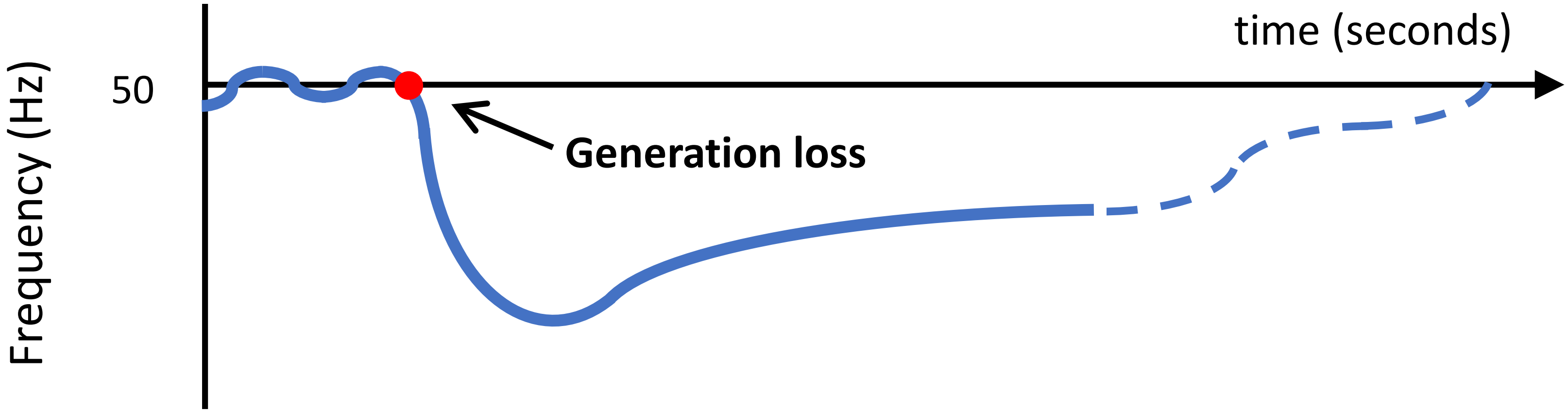


1. Frequency Stability

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:

Loss of largest power infeed (N-1 requirement)

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

Nomenclature

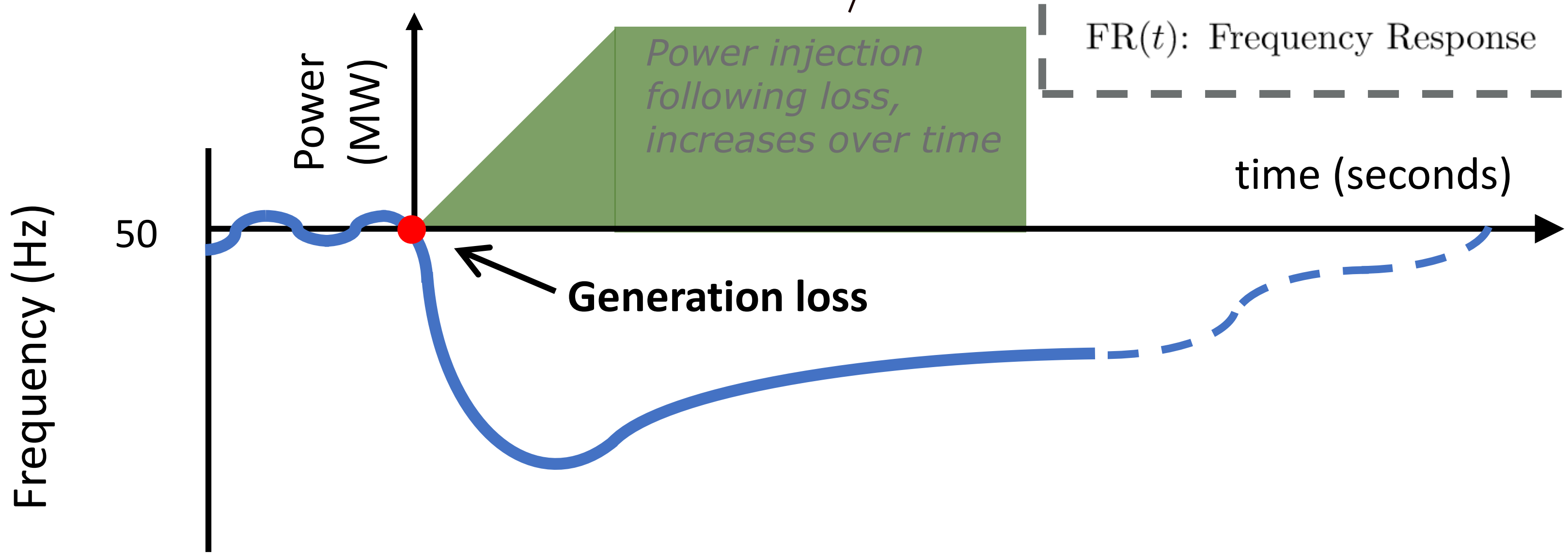
H: System's inertia

D: Load damping factor

$\mathrm{P_D}$: System's demand

$\mathrm{P}_{\mathrm{Loss}}^{\mathrm{max}}$: Largest possible power loss in the system

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



1. Frequency Stability

Loss of largest power infeed (N-1 requirement)

Swing equation:

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

Power injection following loss, increases over time

Nomenclature

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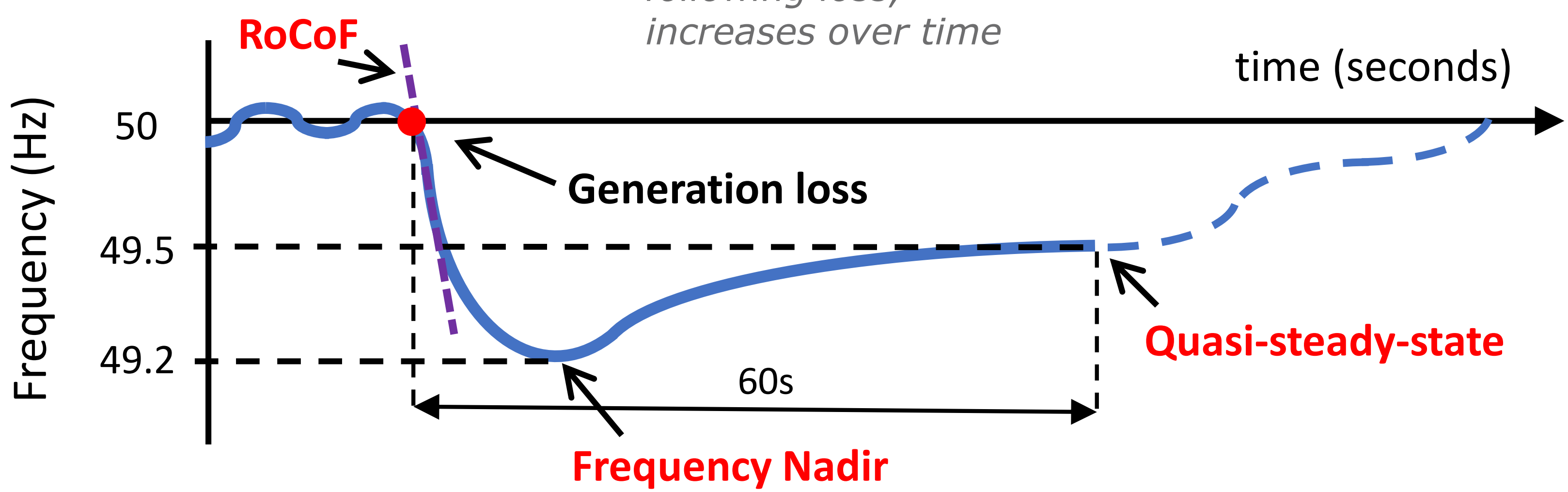


2. Frequency-Security Constraints

From the swing equation, deduce the 3 security conditions:

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

Nomenclature

H:	System's inertia
D:	Load damping factor
$\mathrm{P_D}$:	System's demand
$\mathrm{P_{Loss}^{max}}$:	Largest possible power loss in the system
$\mathrm{FR}(t)$:	Frequency Response

*These are the **frequency services**, system's variables that allow to comply with frequency-security conditions*

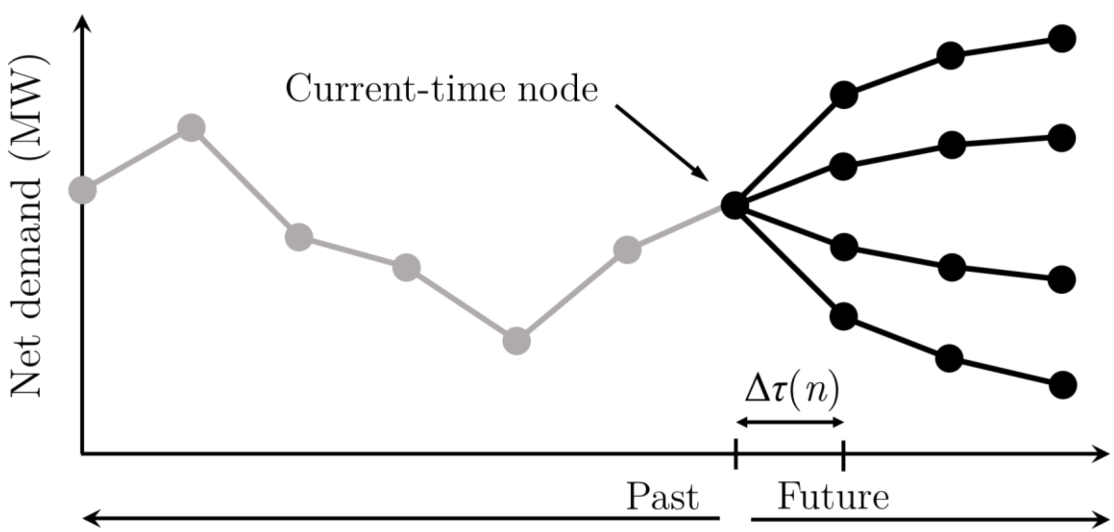
Still several problems:

- Sometimes impossible to obtain closed-form solutions for the frequency-security constraints
- Even if constraints can be obtained, they might be highly nonlinear and nonconvex

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



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

$$\begin{aligned} \text{subject to} \quad & \text{RoCoF constraint} \\ & \text{Nadir constraint} \\ & \text{SteadyState constraint} \end{aligned}$$

(and other typical constraints)

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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.)