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# 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


*Described by
differential equations*

*Based on algebraic
equations*

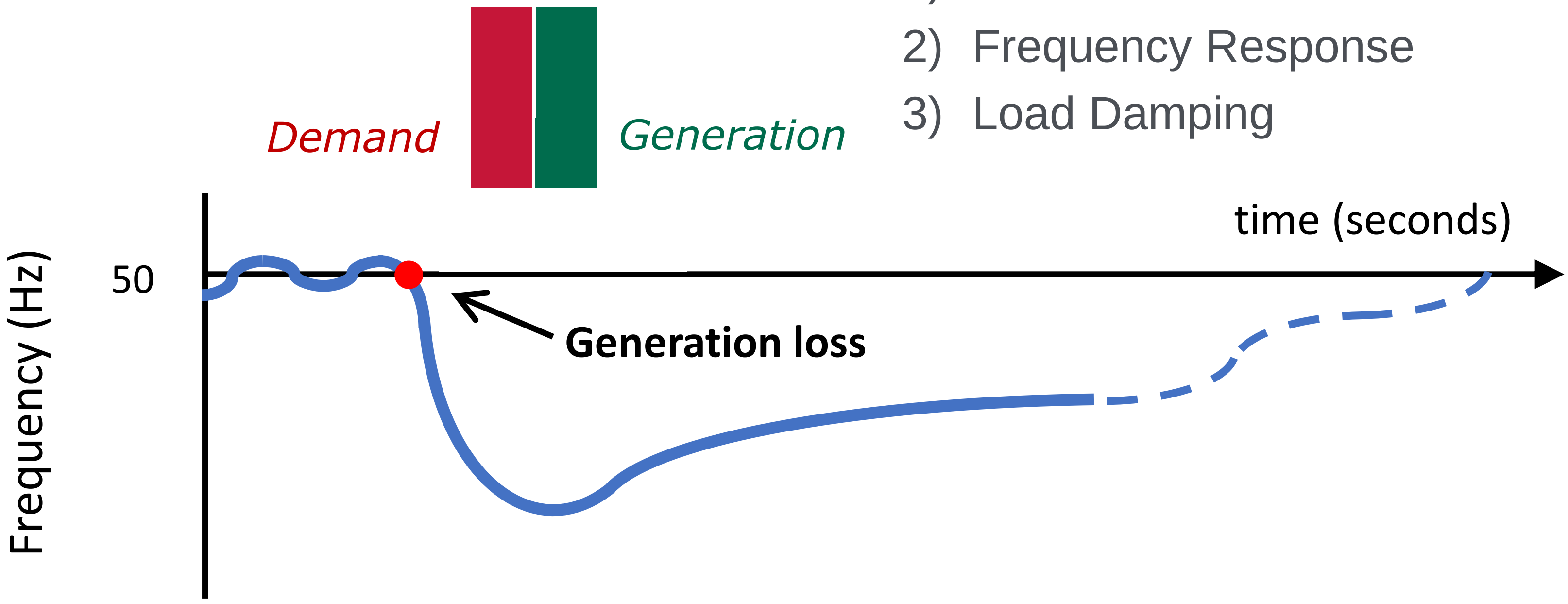
**Goal**: achieve minimum cost while keeping the system stable

# 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

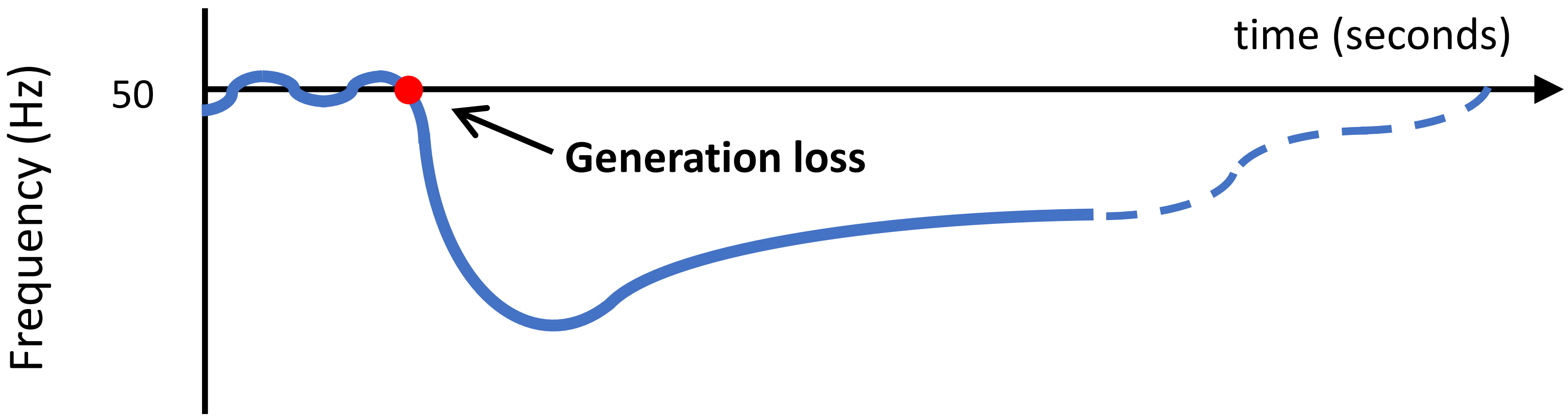


# 1. Frequency Stability

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

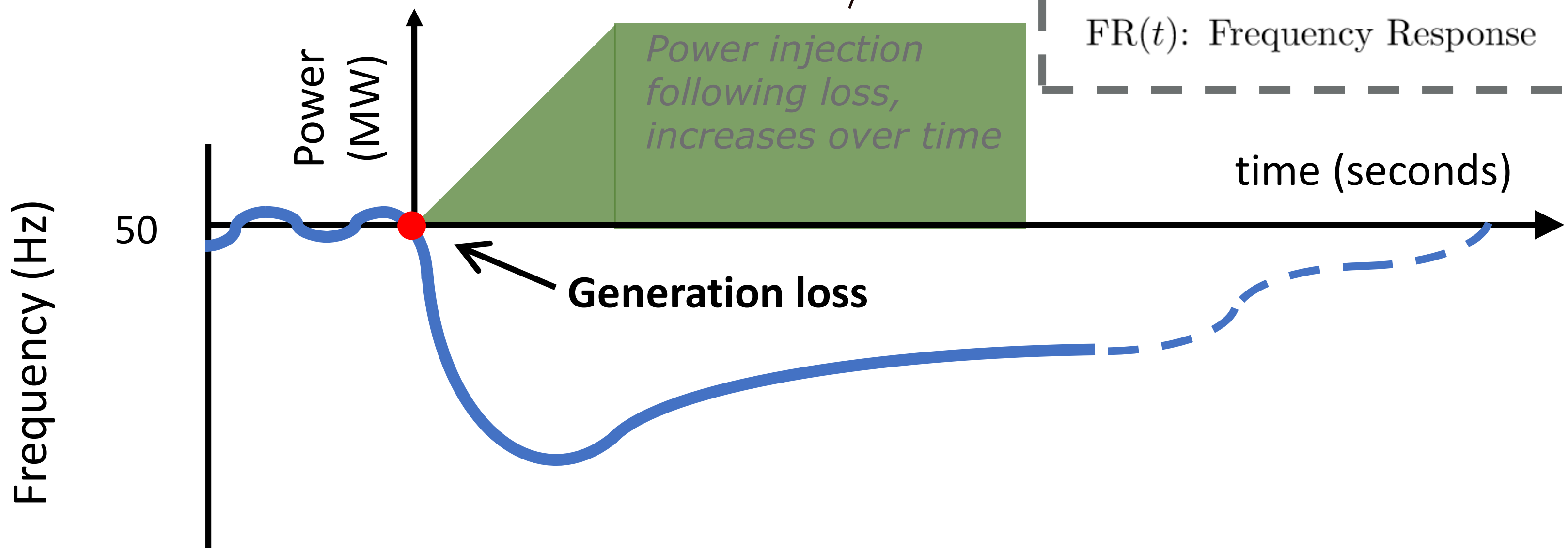
*Loss of largest power infeed (N-1 requirement)*

**Swing equation**:

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

**Nomenclature**

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



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# 1. Frequency Stability

**Swing equation**:

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

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

*Power injection following loss, increases over time*

**Nomenclature**

$H$: System's inertia

D: Load damping factor

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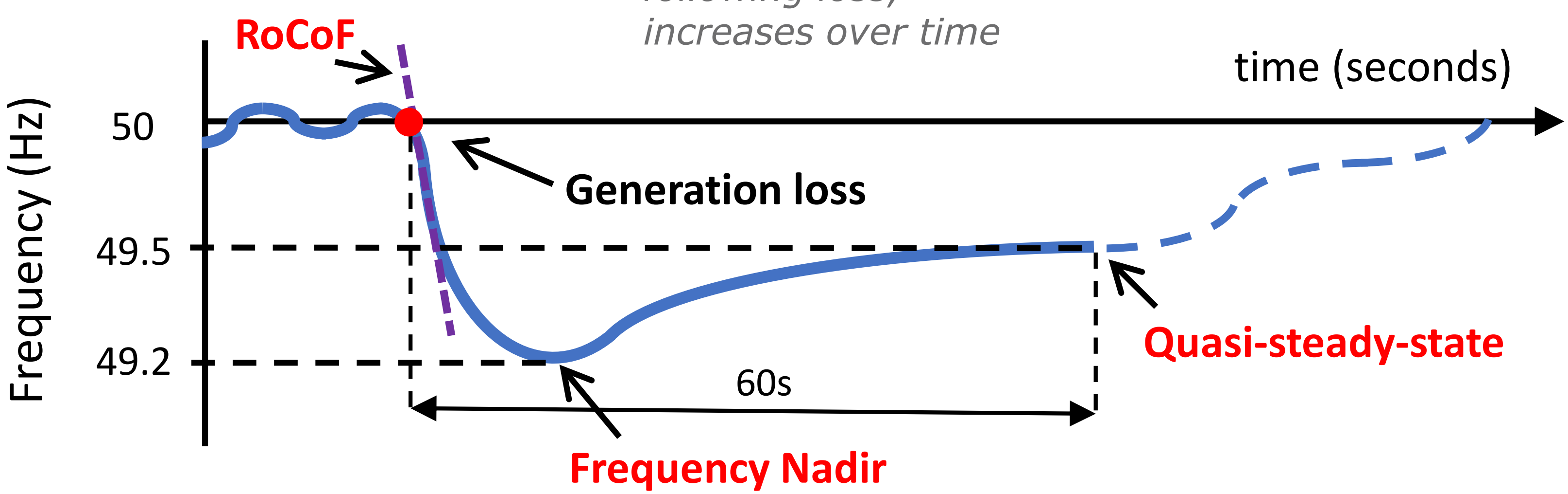

# 2. Frequency-Security Constraints

From the swing equation, deduce the 3 security conditions:

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

**Nomenclature**

$H$: System's inertia
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*These are the **frequency services**, system's variables that allow to comply with frequency-security conditions*

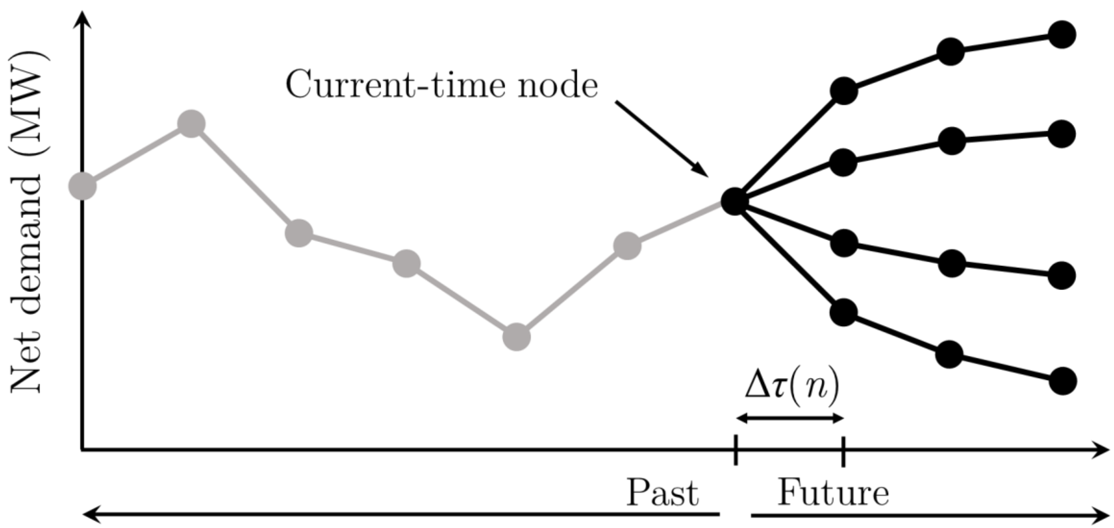
Still several problems:

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




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

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

*(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.)