

# **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 rules** to  
implement them in an optimisation routine



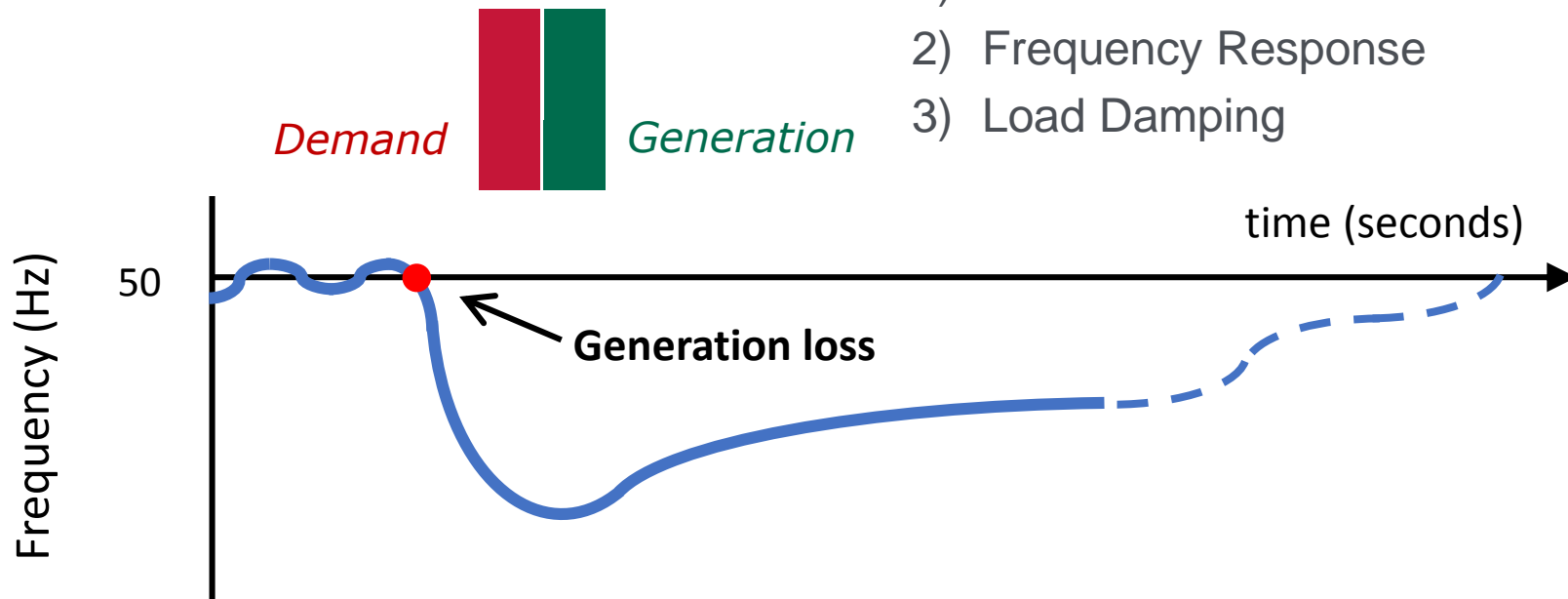
**Goal:** achieve minimum cost while keeping the system stable

# 1. Frequency Stability

My work focuses on **frequency dynamics**

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

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

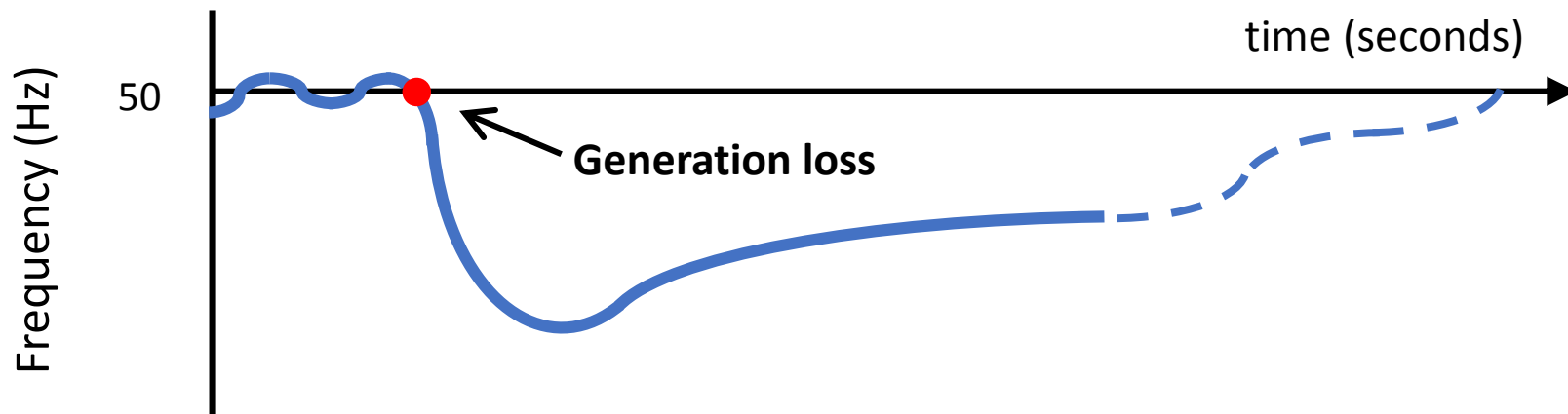


# 1. Frequency Stability

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

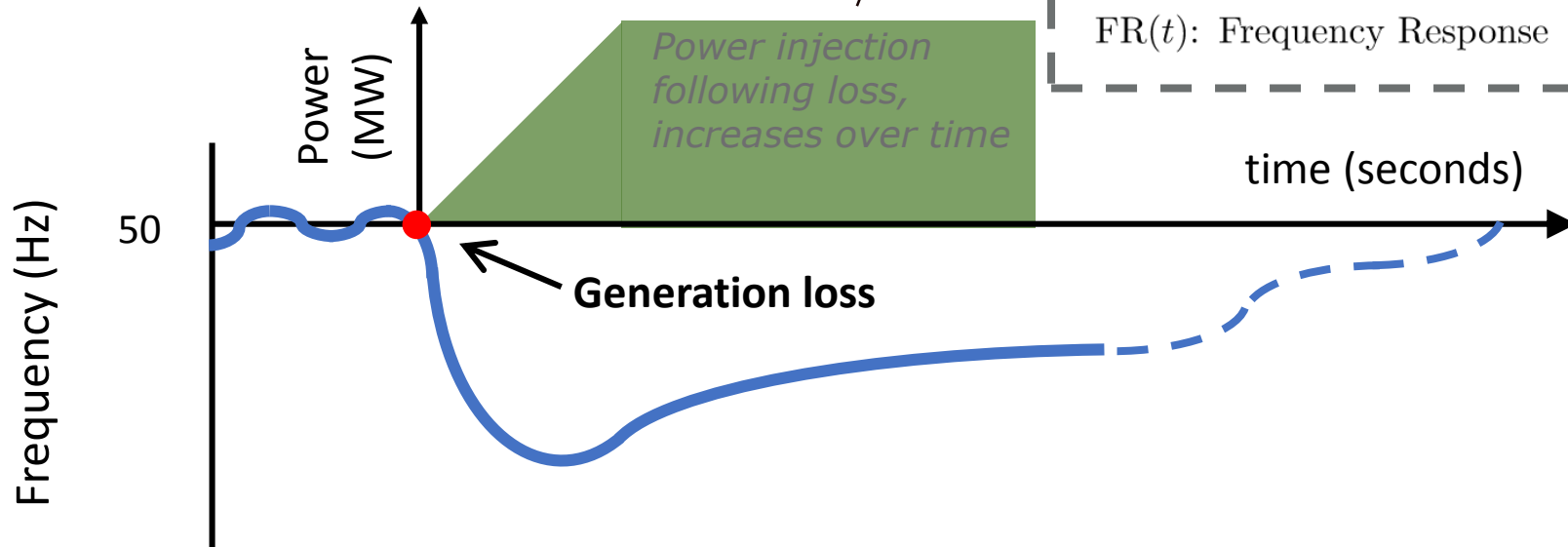
$H$ : System's inertia

$D$ : 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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*Power injection  
following loss,  
increases over time*

## Nomenclature

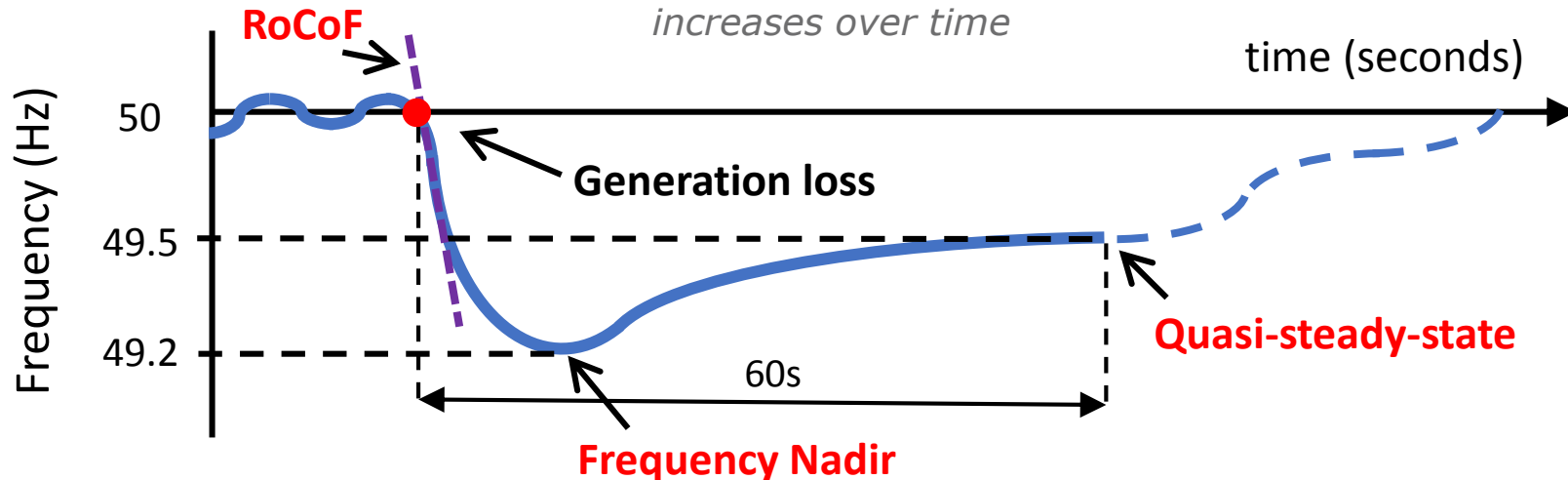
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## 2. Frequency-Security Constraints

From the swing equation, deduce the  
3 security rules:

- **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

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

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

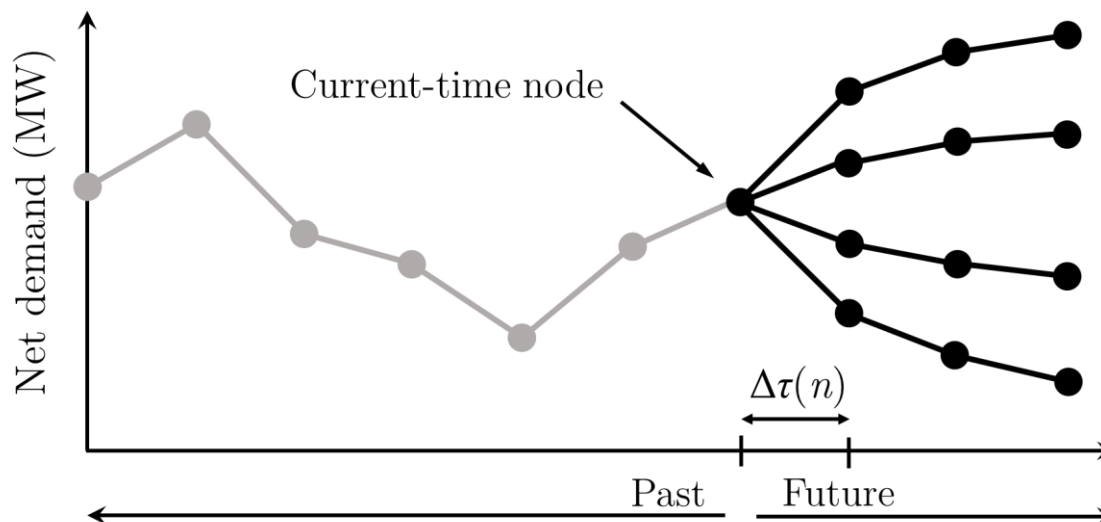


# 3. Optimisation of Power System's Operation

These security rules 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.)