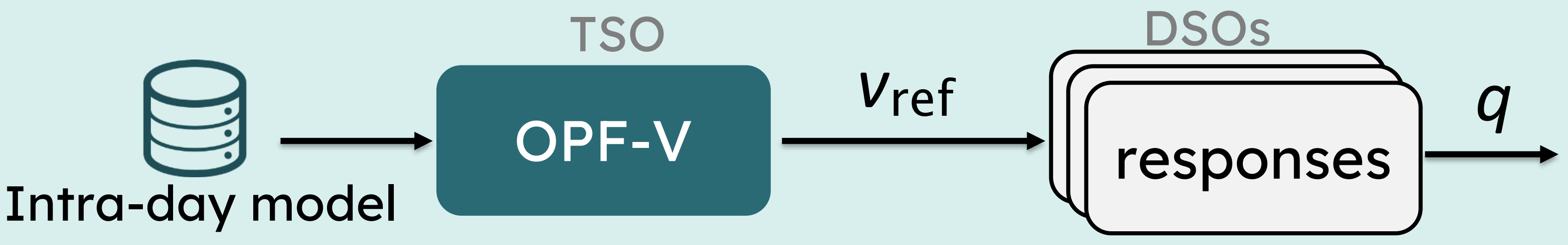
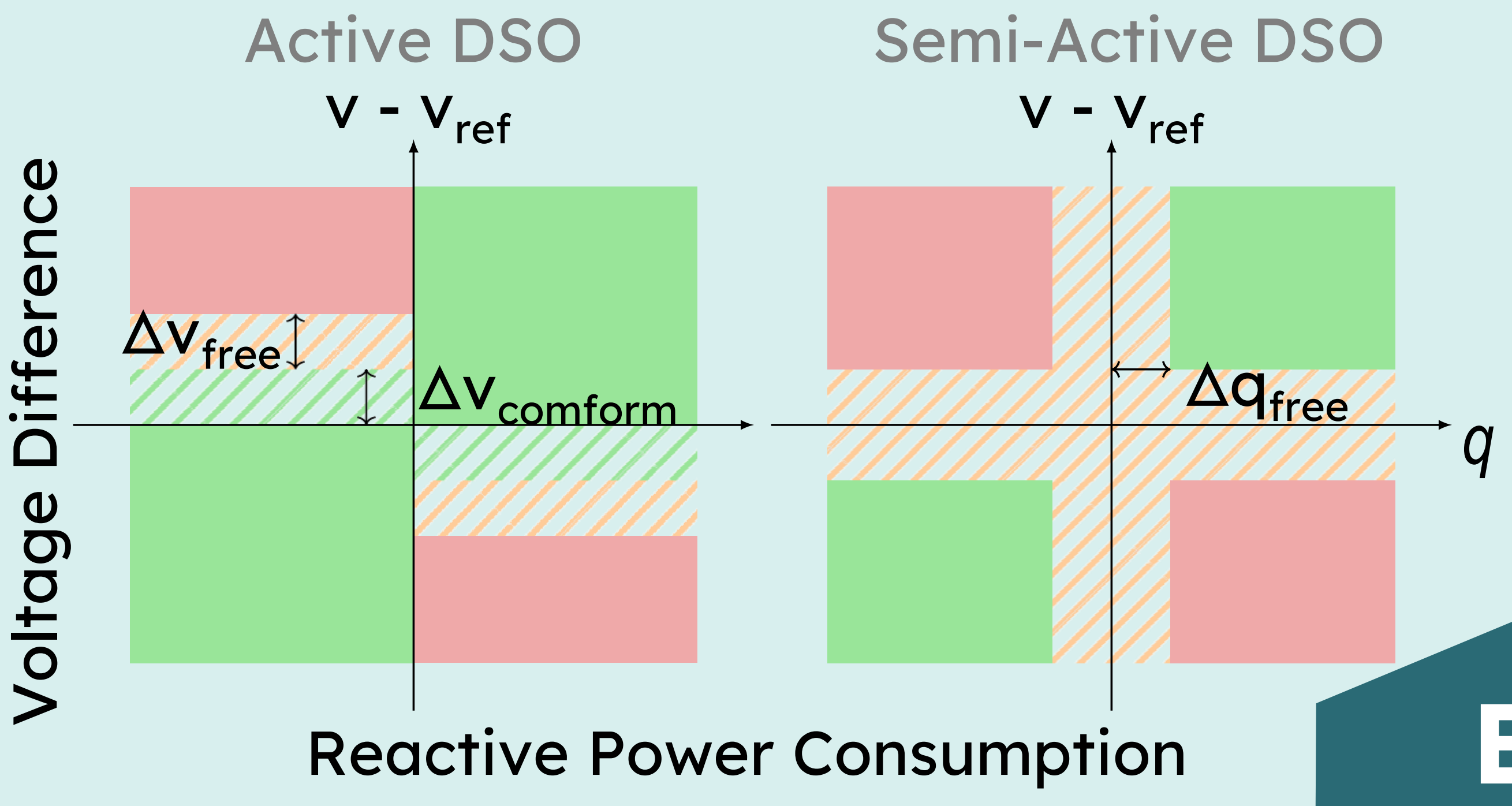
OPFV 2.0: Re-Engineering Voltage Procurement via Online Bilevel Games

The Current State: swissgrid OPF-V

Feed-forward Calculation + Ex-post Incentive



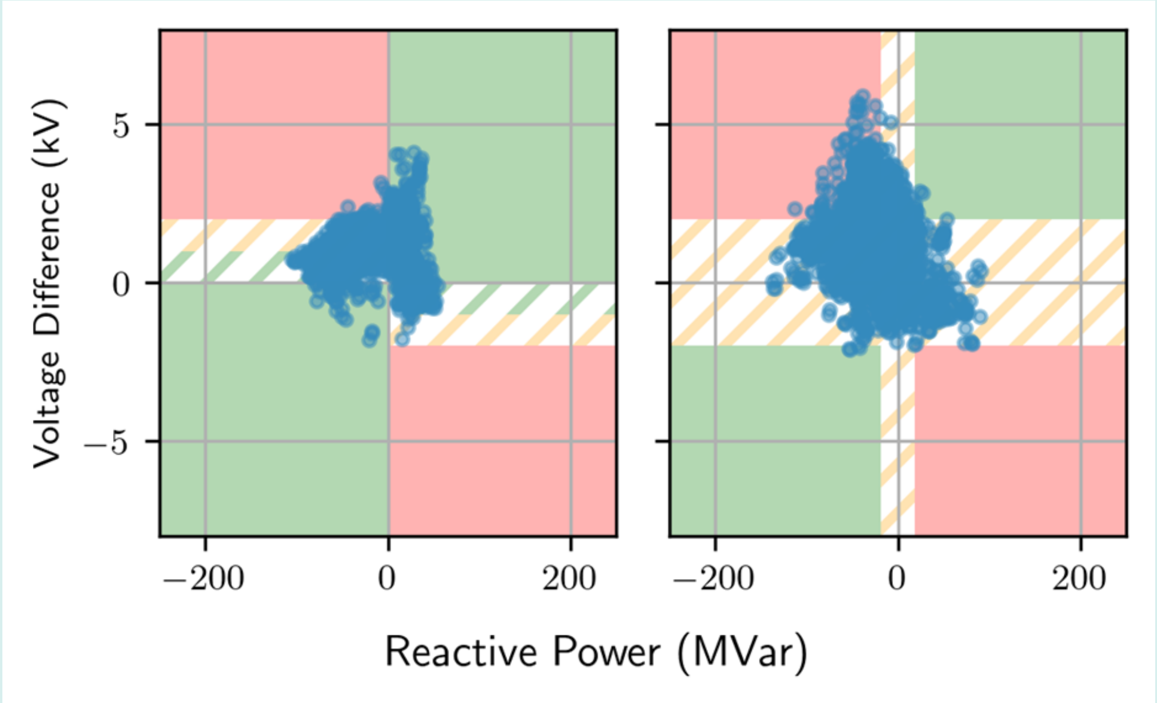
The Swiss Voltage-Reactive Power Incentive Schemes



- positive payment (reward) if 'conform'
- negative payment (penalty) if 'non-conform'
- no payment or penalty if in 'tolerance band'

Inefficiencies of Current Incentives

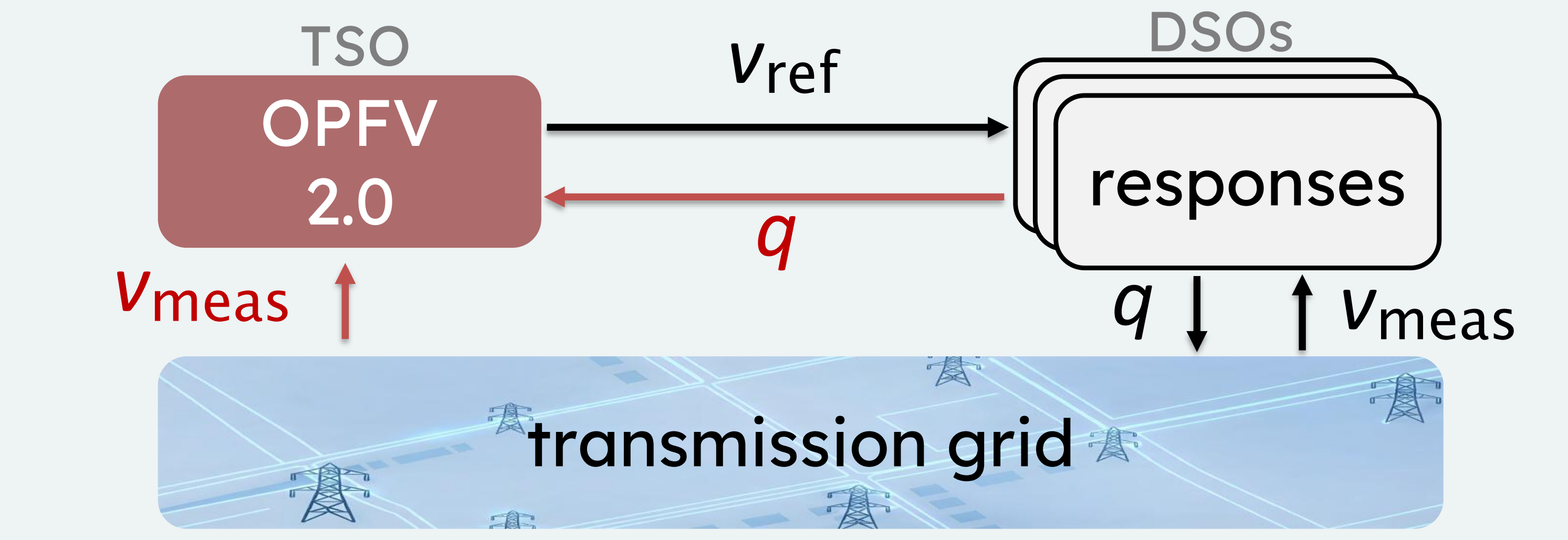
- Financial incentives have been designed **ex-post**
- DSOs strategically utilize 'free' bands or incur penalties



How should the TSO design and update incentives so that self-interested DSOs collectively regulate voltages?

The Solution: OPFV 2.0 & Incentive Automation

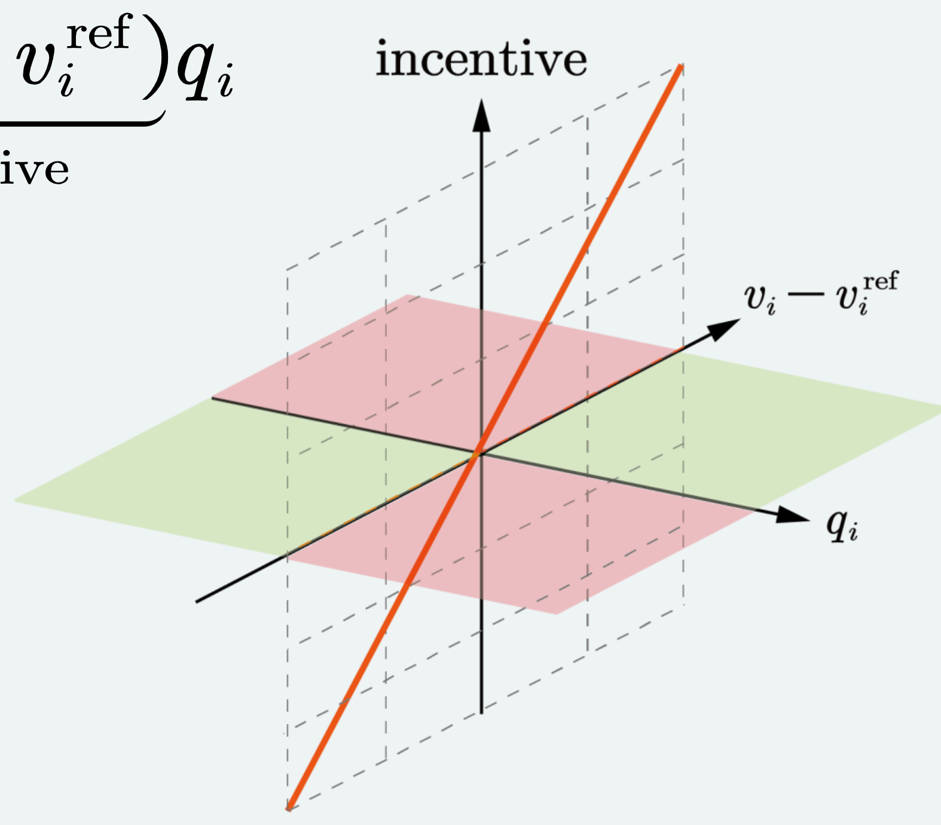
Feedback Optimization on Bilevel Structure



Two types of feedback:
- Voltages of power grids
- Reactive power responses from DSOs

Setpoint-Parametrized Incentive

$$\text{payment} = \underbrace{\gamma(v_i - v_i^{\text{ref}})}_{\text{incentive}} q_i$$



Game-theoretic Bilevel Problem Modeling

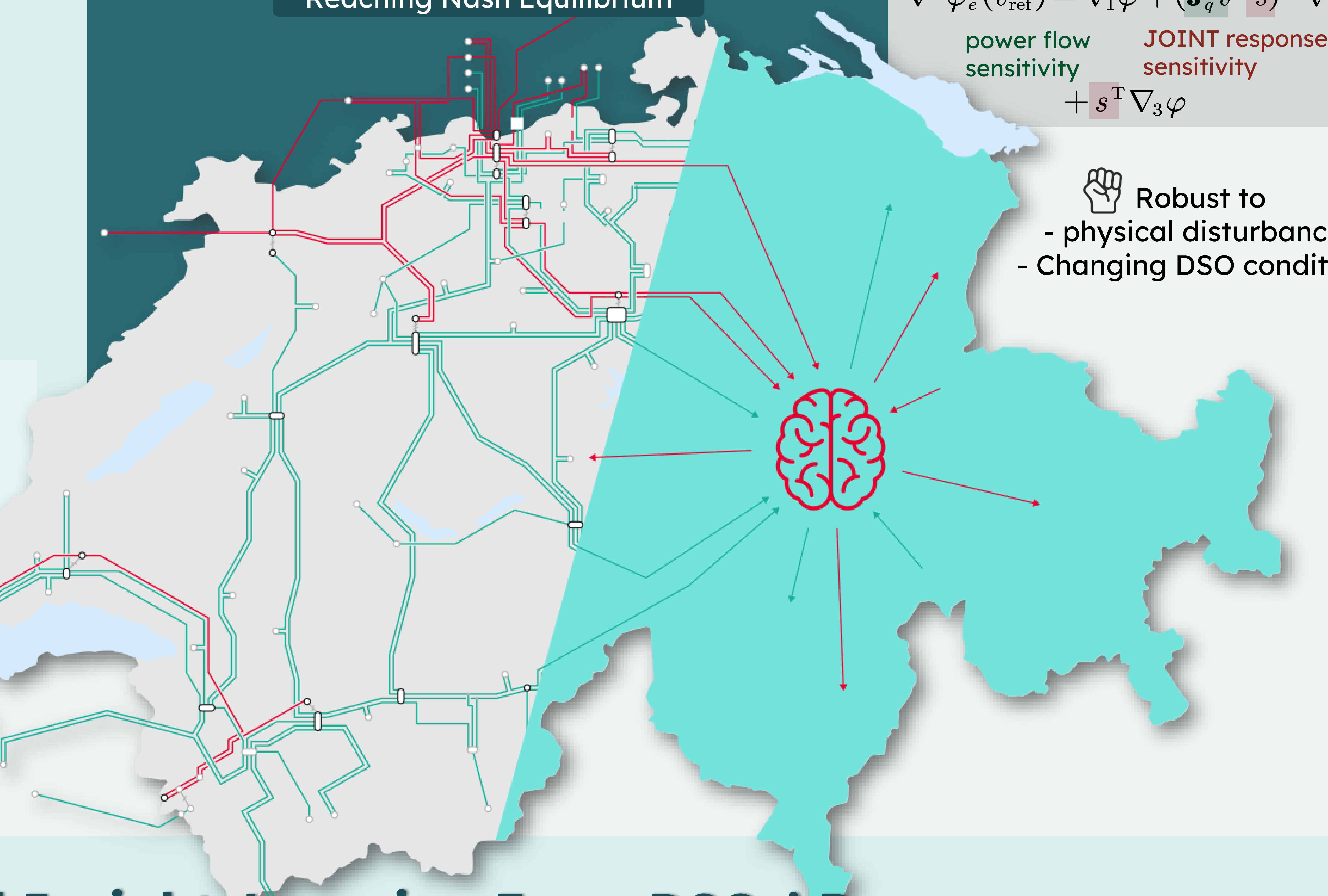
Leader (TSO) vs. Followers (DSOs)

Min $\varphi(v_{\text{ref}}, v, q)$ **TSO's cost**

s.t. $v^{\min} \le v(q,p) \le v^{\max}$

Min DSO's cost for reactive power
s.t. Local limits

Reaching Nash Equilibrium



Autonomous Incentive update

$$v_{\text{ref}}^{k+1} = v_{\text{ref}}^{k} - \eta \text{“}\nabla\text{”} \varphi_e(v_{\text{ref}}^{k})$$

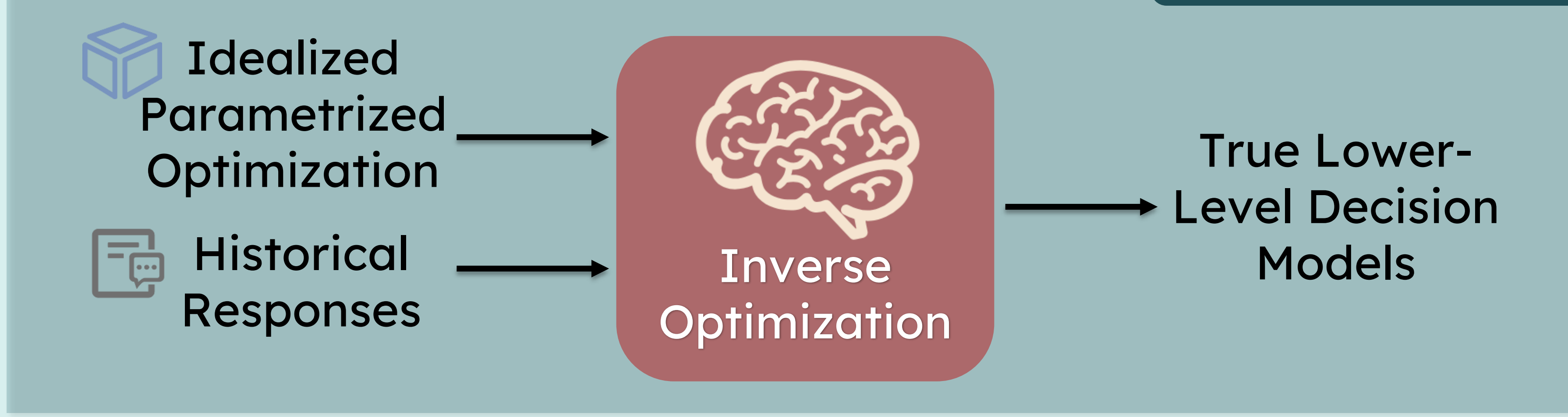
$$\text{“}\nabla\text{”} \varphi_e(v_{\text{ref}}) = \nabla_1 \varphi + (\mathbf{J}_q v \cdot s)^{\mathrm{T}} \nabla_2 \varphi + s^{\mathrm{T}} \nabla_3 \varphi$$

power flow sensitivity
JOINT response sensitivity

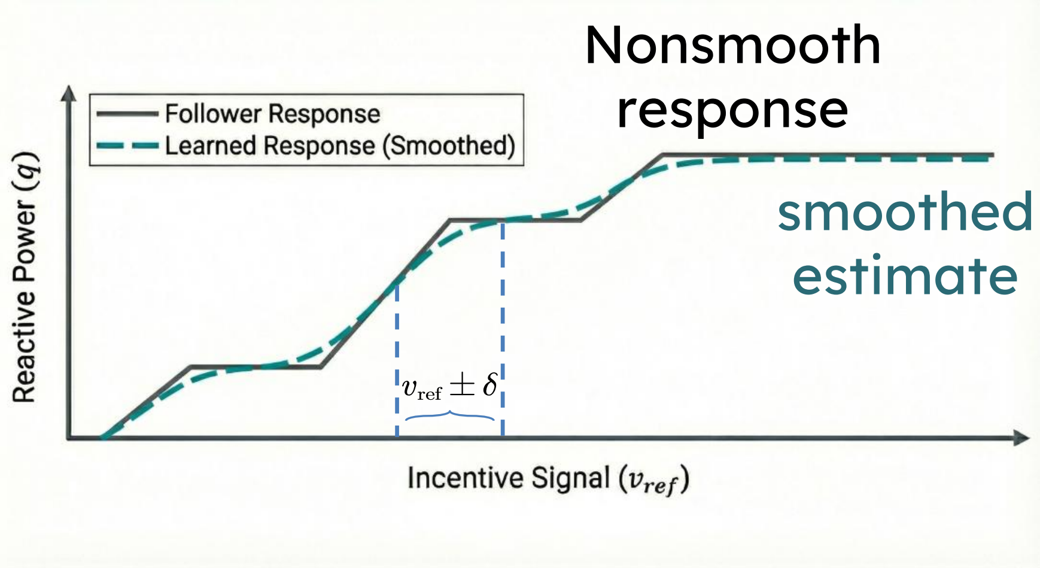
Robust to
- physical disturbances
- Changing DSO conditions

Advanced Insight: Learning From DSOs' Responses

Bridging the Model-Data Gap



Instead of reconstructing the full DSO model: directly **estimate the response sensitivity** (s), enabling **model-free** incentive updates.



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