UNIVERSIDAD POLITÉCNICA DE MADRID
escuela técnica superior de ingeniería y diseño industrial

IMPERFECT COMPETITION IN MARKETS FOR SHORT-CIRCUIT CURRENT SERVICES

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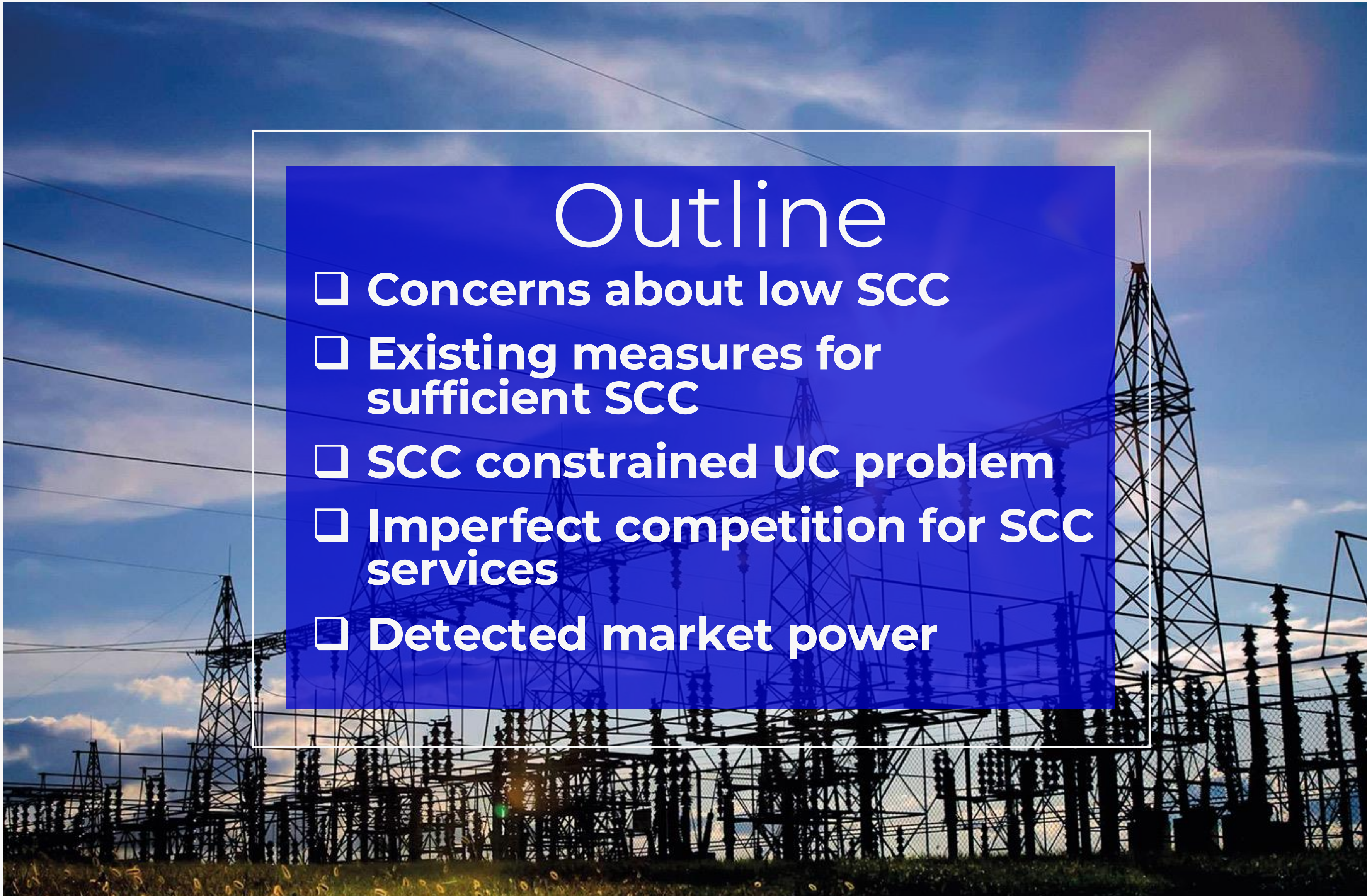

Outline
❑ Concerns about low SCC
❑ Existing measures for sufficient SCC
❑ SCC constrained UC problem
❑ Imperfect competition for SCC services
❑ Detected market power

Imperfect Competition for SCC

-- concerns about low SCC

SCC:

- Maximum **Short-Circuit Current** capability at the fault bus (three phase fault assumed).
- Determined by the **equivalent impedance** and **SCC contribution capability** of resources.

In IBR-dominated grids:

Synchronous machines

Magnetic energy & rotor inertia

5–8 p.u. SCC

Grid-following IBR

Electronic converters

1–3 p.u. SCC, even lower

Ongoing trend:

- Increased equivalent impedance
- Limited SCC contributions from IBR
- Lack of rotational inertia
- ……

SCC is being decreasing

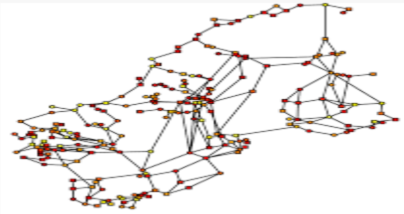
Potential risks:

- Protection failure: Fault currents are too low to reliably trigger protection.
- Severe voltage depression: Low SCC causes deep voltage dips and slow recovery.
- Higher risk of cascading events: Delayed or uncleared faults can propagate system disturbances.

Low SCC undermines **protection reliability**, **voltage stability**, and **overall system security** in IBR-dominated power systems.

Imperfect Competition for SCC

-- existing measures for sufficient SCC



Grid topology optimization:

Strengthen network connections or optimize transmission line configurations to alleviate low-SCC conditions.

Deployment of short-circuit current boosting devices:

Using dedicated equipment to enhance SCC contribution during fault conditions, such as STATCOMs.

……

Maintaining sufficient online synchronous generation: ★

Committing synchronous generators to provide inherent SCC support.

A further approach is to **design ancillary services that incentivize Synchronous Generators (SGs) to remain online and provide SCC**, thereby preventing critically low SCC levels.

However, this service is **highly local:**

Online SGs provide **little** SCC to **distant** buses, and **contribute more** SCC in their **surrounding** nodes.

➡ This nature may give certain generation companies some room to exert **market power** for increasing their own profits in the market.

Imperfect Competition for SCC

-- SCC constrained UC problem

$$I_{b_{SC}} = \frac{\sum_{g \in \mathcal{G}} Z_{b\Psi(g)} \mathrm{I}_g u_g + \sum_{c \in \mathcal{C}} Z_{b\Phi(c)} \mathrm{I}_c \alpha_c}{Z_{bb}}$$

Inverse operation between impedance matrix and admittance matrix

Data-driven method to approach the real SCC level

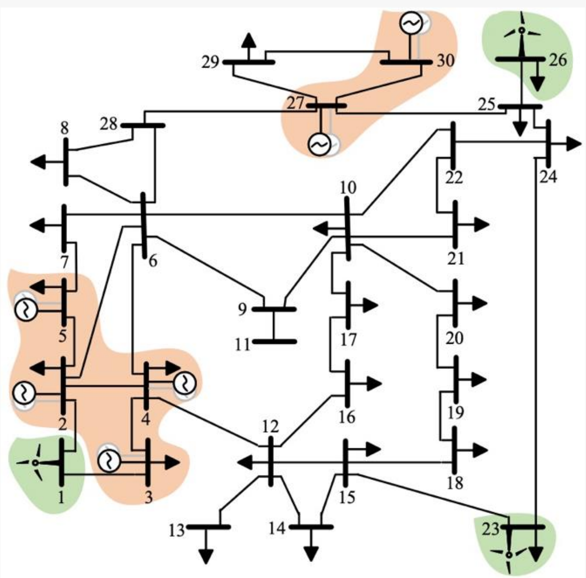
$$I_{b_L} = \sum_{g} k_{bg} u_g + \sum_{c} k_{bc} \alpha_c + \sum_{m} k_{bm} \eta_m$$

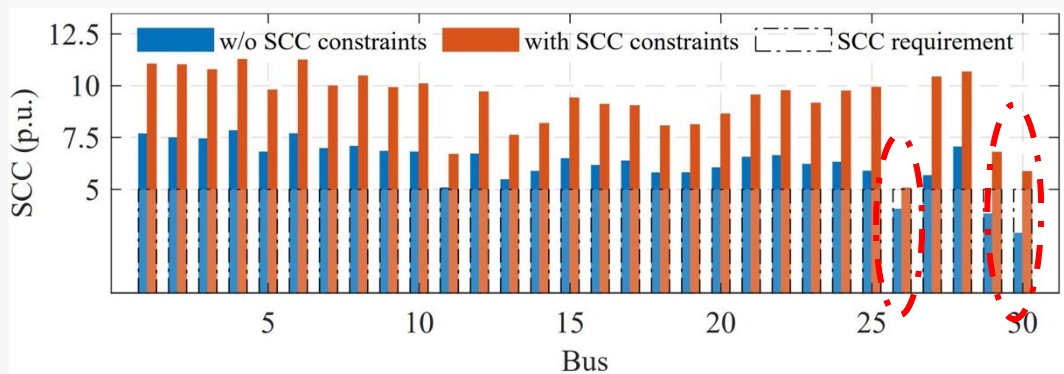
u_g: commitment variable

α_c: IBR's capacity factor

η_m: product of generators' operating states

For a cost minimization UC problem:





Bus 26: only IBR

Bus 29: distant from the main grid and no local SCC support machine

Bus 30: too expensive to be dispatched

Buses with insufficient SCC are constrained to stay in a safe range

Imperfect Competition for SCC

-- imperfect competition for SCC services

Bilevel model, an effective tool to model imperfect competition and potential **market power**.

Upper level:
(strategic SGs maximize profit)

$$\max_{V_{\mathrm{UL}}} \sum_t \Bigg[\sum_{\hat{g}} \Bigg(\lambda^{\mathrm{E}}_t P_{\hat{g},t} + \sum_b \lambda^{\mathrm{SCC}}_{b,t} \mathrm{k}_{b\hat{g}} u_{\hat{g},t} - \mathrm{O}^{\mathrm{nl}}_{\hat{g}} u_{\hat{g},t} - \mathrm{O}^{\mathrm{m}}_{\hat{g}} P_{\hat{g},t} - C^{\mathrm{st}}_{\hat{g},t} - C^{\mathrm{sh}}_{\hat{g},t} \Bigg) \Bigg]$$

Revenue from SCC services

Revenue from energy

Lower level:
(system operator minimize costs)

$$\min_{V_{\mathrm{LL}}} \sum_t \Bigg[\sum_{\hat{g}} \Bigg(\mathrm{O}^{\mathrm{nl}}_{\hat{g}} u_{\hat{g},t} + \sum_b \mathrm{O}^{\mathrm{SCC}}_{\hat{g},b,t} \beta^{\mathrm{SCC}}_{\hat{g},b,t} u_{\hat{g},t} + \mathrm{O}^{\mathrm{m}}_{\hat{g}} \beta^{\mathrm{m}}_{\hat{g},t} P_{\hat{g},t} + C^{\mathrm{st}}_{\hat{g},t} + C^{\mathrm{sh}}_{\hat{g},t} \Bigg) + \sum_{\breve{g}} \Bigg(\mathrm{O}^{\mathrm{nl}}_{\breve{g}} u_{\breve{g},t} + \sum_b \mathrm{O}^{\mathrm{SCC}}_{\breve{g},b,t} u_{\breve{g},t} + \mathrm{O}^{\mathrm{m}}_{\breve{g}} P_{\breve{g},t} + C^{\mathrm{st}}_{\breve{g},t} + C^{\mathrm{sh}}_{\breve{g},t} \Bigg) + \sum_c \mathrm{O}^{\mathrm{l}}_c P_{c,t} \Bigg]$$

Cost for energy

Cost for SCC services

Commitment binary variable

How to solve:

Traditional approach to solve the bilevel model is to **convert the lower level into its dual** problem, thus requiring it to be **continuous**.

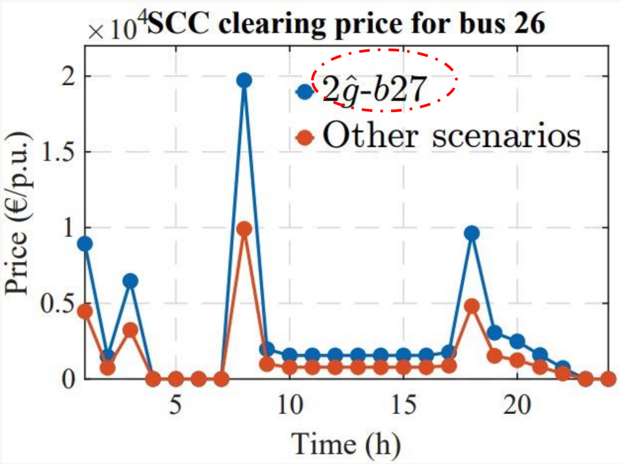
Specialized solving method is needed !

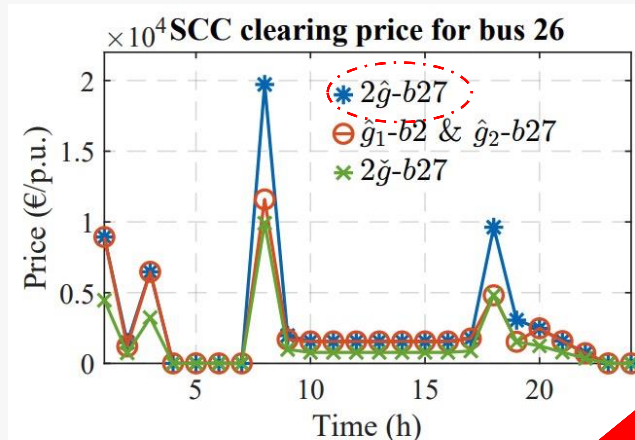
Primal-dual formulation is adopted. It preserves the binary variables and tries to clear the market with a minimum duality gap.

Imperfect Competition for SCC

-- detected market power

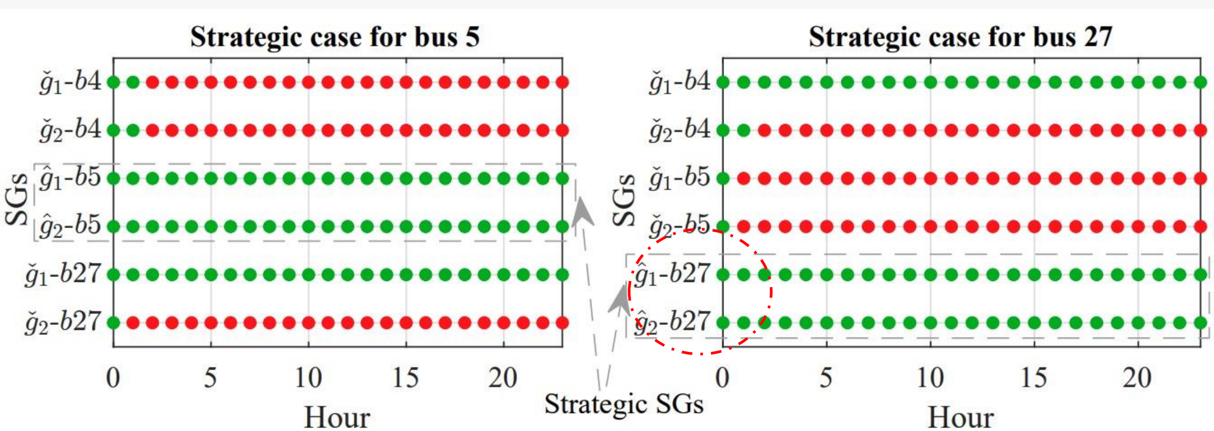
Higher service prices when certain 'critical-location' SGs are strategic bidding

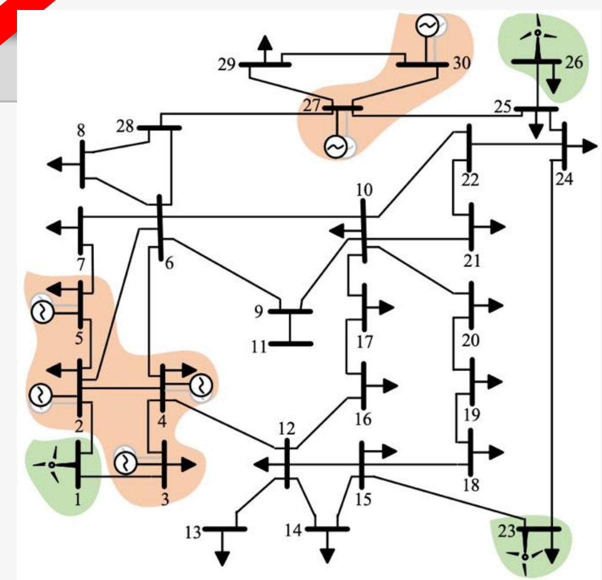




Result in more SCC revenues: from **44.38 k€** to **147.86 k€**

Longer operation periods of 'critical-location' strategic SGs





Thank you !

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