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Operating Power Grids with Few Flow Control Buses

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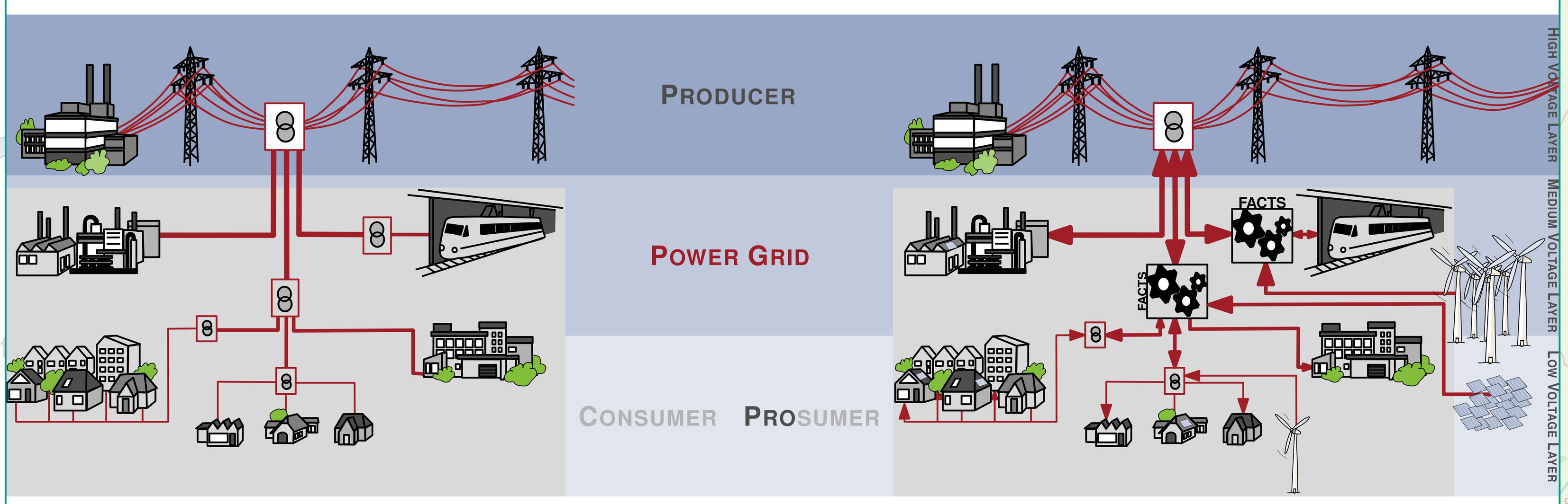
Operation of Power Grids [2]



Challenges

- Shift towards renewable distributed energy production
  → Changing energy flow patterns
- Independent power producers
- Volatile power flows and flow directions

⇒ Operation of the power grid becomes more demanding

Strategies to cope with the challenges

1. Extend the grid with additional transmission lines
2. Install control units like flexible AC transmission systems (FACTS) to enhance grid utilization (our approach)

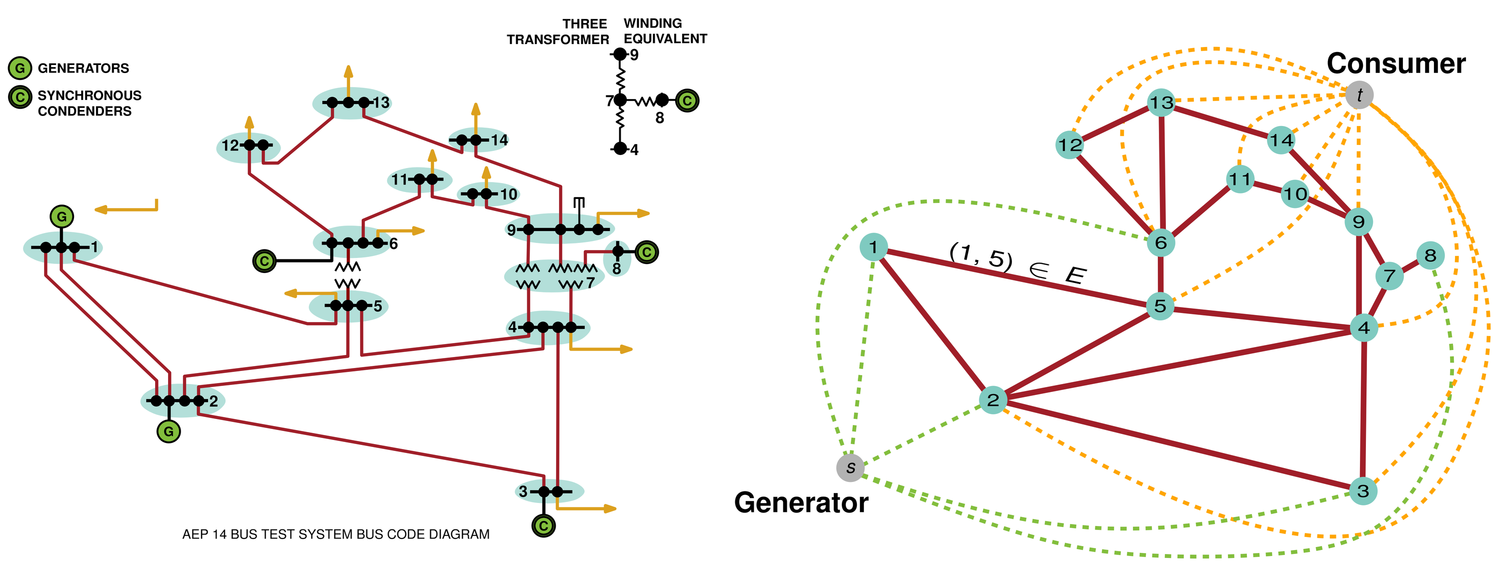
DC-based Flow Models [2, 3]

Goal

- Minimize line losses and production costs

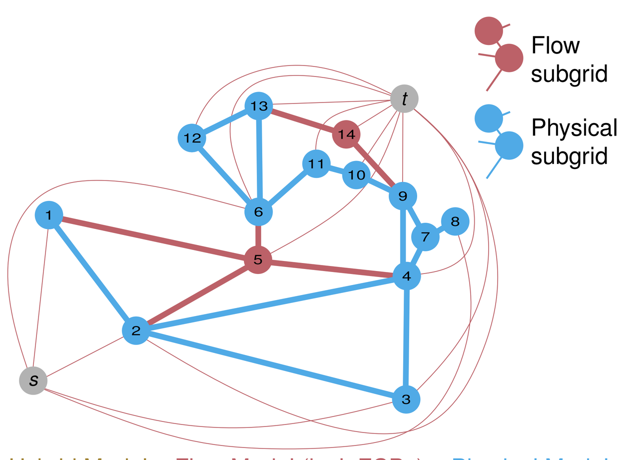
Input

- Graph $G = (V, E)$ representing power grid (e.g., IEEE instances)
- Set $F \subseteq V$ of flow control buses (FCBs)



Models

- Physical model assumes $F = \emptyset$ and requires the conservation of flow, feasible line limits and voltage laws [2]
- Flow model assumes $F = V$ and requires the conservation of flow, feasible line limits, but no voltage laws.
- Hybrid model assumes $F \subseteq V$ and combines both models. Requires flow conservation and feasible line limits on G, and voltage laws on $G - F$.



Hybrid Model = Flow Model (incl. FCBs) + Physical Model

Find

- Valid operation point for the hybrid model (Generator production and line loads)

Key Questions

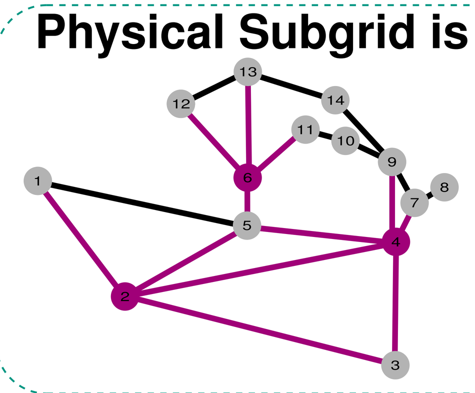
Q1. How many flow control buses are necessary to obtain globally optimal power flows and which buses need to be controlled?

Q2. If the number of available flow control buses is given, do we still see a positive effect on the flow costs and on the operability of the grid when approaching its capacity limits?

Matching the Flow Model (Q1) [1, 4]

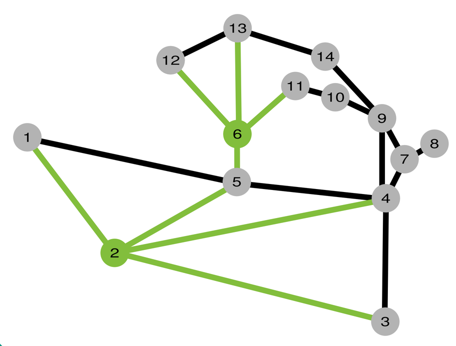
Number of FCBs necessary to match the operation cost lower bound of the flow model depends on structural situation.

Physical Subgrid is a Forest

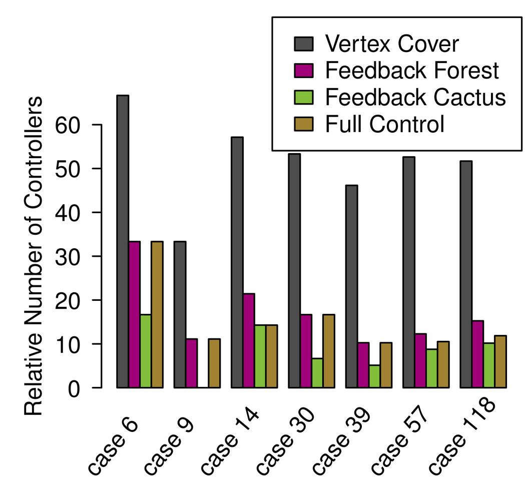


Theorem 1
Physical subgrid forest.
⇒
All flows obey voltage laws.

Physical Subgrid is a Cactus



Theorem 2
Physical subgrid cactus, line limits on cactus suitably bounded [4].
⇒
For every flow there is a cost-equivalent flow obeying voltage laws.



Findings
Often a small number of FCBs suffices for matching cost of the flow model.

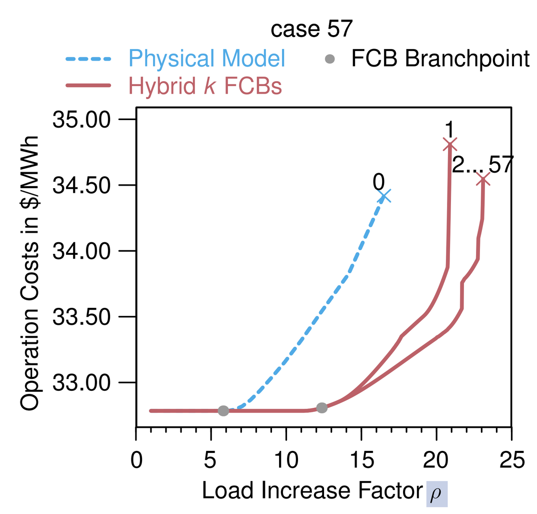
Effect of Few FCBs (Q2)

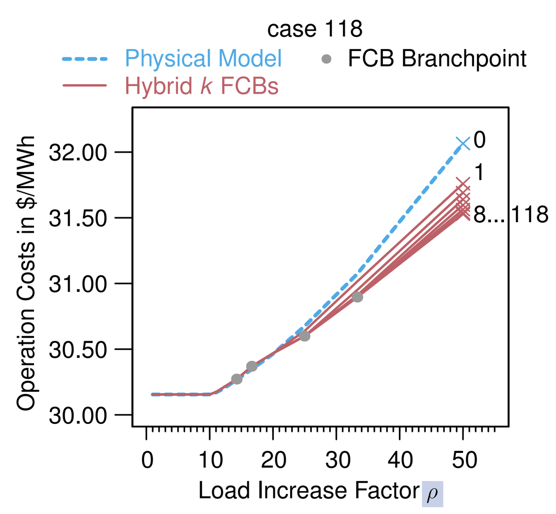
For a given number of available control buses, is there a positive effect on flow costs and operability when approaching grid capacity limits?

- Simulate load increase by a load increase factor ρ
- Simulations with different numbers k of FCBs

⇒ Physical model requires higher operation costs

⇒ Even a small number of FCBs has a significant effect





Findings
FCBs extend the operation point, while having lower operation cost.

Future Work

More realistic power grid models:

- Control units on transmission lines rather than buses [5],
- AC power grid model.

Volatility in power grids

Literature

[1] M. Farivar and S. Low. *Branch flow model: Relaxations and convexification – part II.* IEEE Transactions on Power Systems, 28(3):2565–2572, 2013.
[2] S. Frank, I. Steponavice, and S. Rebennack. *Optimal power flow: a bibliographic survey I.* Energy Systems, 3(3):221–258, 2012.
[3] A. V. Goldberg. *An efficient implementation of a scaling minimum-cost flow algorithm.* Journal of Algorithms, 22(1):1–29, 1997.
[4] T. Leibfried, T. Mchedlidze, N. Meyer-Hübner, M. Nöllenburg, I. Rutter, P. Sanders, D. Wagner, and F. Wegner. *Operating power grids with few flow control buses.* In Proceedings of the ACM Sixth International Conference on Future Energy Systems, e-Energy, pages 289–294, ACM, 2015.
[5] T. Mchedlidze, M. Nöllenburg, I. Rutter, D. Wagner, and F. Wegner. *Towards Realistic Flow Control in Power Grid Operation*, pages 192–199. Springer International Publishing, 2015.