Secondary control may prevent Braess' paradox in AC power grids

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For a stable operation in electric networks, supply and demand have to match at all times since the grid itself cannot store any energy. To guarantee this match, different mechanisms, like day-ahead and intra-day markets are used. For unexpected mismatches, e.g., random fluctuations [1, 2], disturbances or extreme weather, fast control mechanisms are required. The control in power system is thus realized on different time scales to cope with short-term fluctuations and long-term power imbalance alike. Assuming a sudden shortage of energy or any failure in the system, the first second of the disturbance is mainly uncontrolled, i.e., energy is drawn from the spinning reserve of the generators. Within the next seconds, the primary control sets in to stabilize the frequency and prevents a large drop. To restore the frequency back to its nominal value of 50 Hz or 60 Hz, secondary control is necessary [1].

Due to the continuous increase in demand and the high penetration of renewable energy sources, the future grid topology and control mechanisms have to adapt to cope with this increase and with spatially distributed and fluctuating renewable generation. Grid adaptation includes additional transmission lines and increasing capacity of existing lines. Contrary to expectations, not all added lines are beneficial to the stability of a grid. Indeed, adding some lines may cause the grid to lose its operating state via Braess' paradox [3] (Fig. 1).

Many studies investigate the effect of the fast primary control on frequency quality and power grid stability. However, secondary control is rarely considered. In this work, we propose a simple implementation of secondary control and demonstrate its effectiveness in stabilizing the power grid.

We model each node by the well-known *swing equation* including primary and secondary control [1]. In the limit of instananeous response of the primary control the dynamics of a node can be written as

$$\dot{\theta}_i = \omega_i, \tag{1a}$$

$$\dot{\omega}_i = -\alpha_i\omega_i - \gamma_i\theta_i + P_i - \sum_{j=1}^{n} K_{ij}\sin(\theta_i - \theta_j), \tag{1b}$$

where θ_i and ω_i represent the voltage phase angle and the angular velocity deviation, respectively, α_i is the damping constant, γ_i is the gain of the secondary control, P_i is the effective power fed into the grid or consumed at node i, and K_{ij} determines the capacity of the line (i, j).

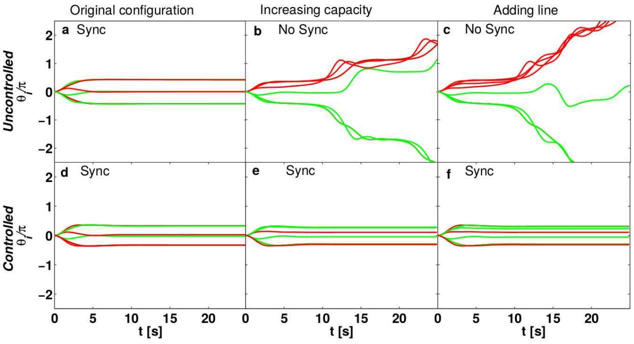

Fig. 1. Secondary control stabilizes a network. Braess' paradox in power grids observed when increasing the capacity of a line or adding an additional line in [3] is prevented.

We find that including secondary control in all nodes prevents Braess paradox in that, increasing the capacity of a line or including a new one carries always a positive effect on the stability of the network. However we have also found that when control is avalable to generator nodes only, as it is typically the case in present power grid configurations, the stability depends strongly on which line capacity is increased, indicating a non trivial interaction between control and topology.

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