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Demand Response for Ancillary Services: Thermal Storage Control

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Abstract:

• In power grids, demand and supply must always be balanced. This balance is achieved by *ancillary services*. In Switzerland, these services are provided by generators, mainly hydro pumps.

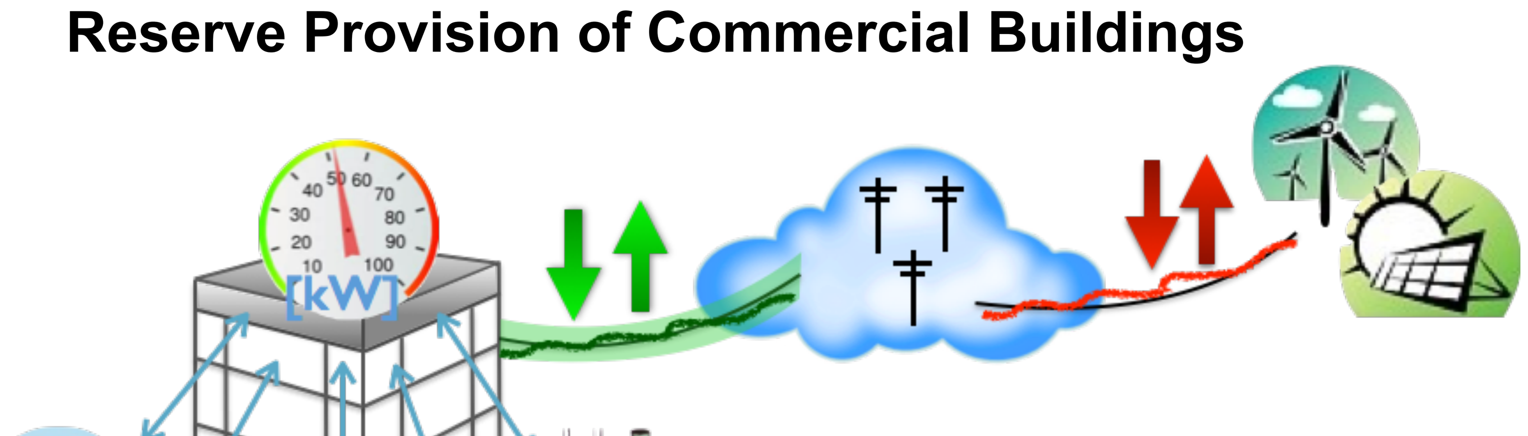
• The increase in renewable energy sources leads to an increase in uncertainty of supply power. Therefore, *additional ancillary services* are required to balance supply and demand.

Key Ideas:

➢ Control *demand side* to provide ancillary services through:
- Control of HVAC systems of commercial buildings.
- Control of appliances of thousands of households.

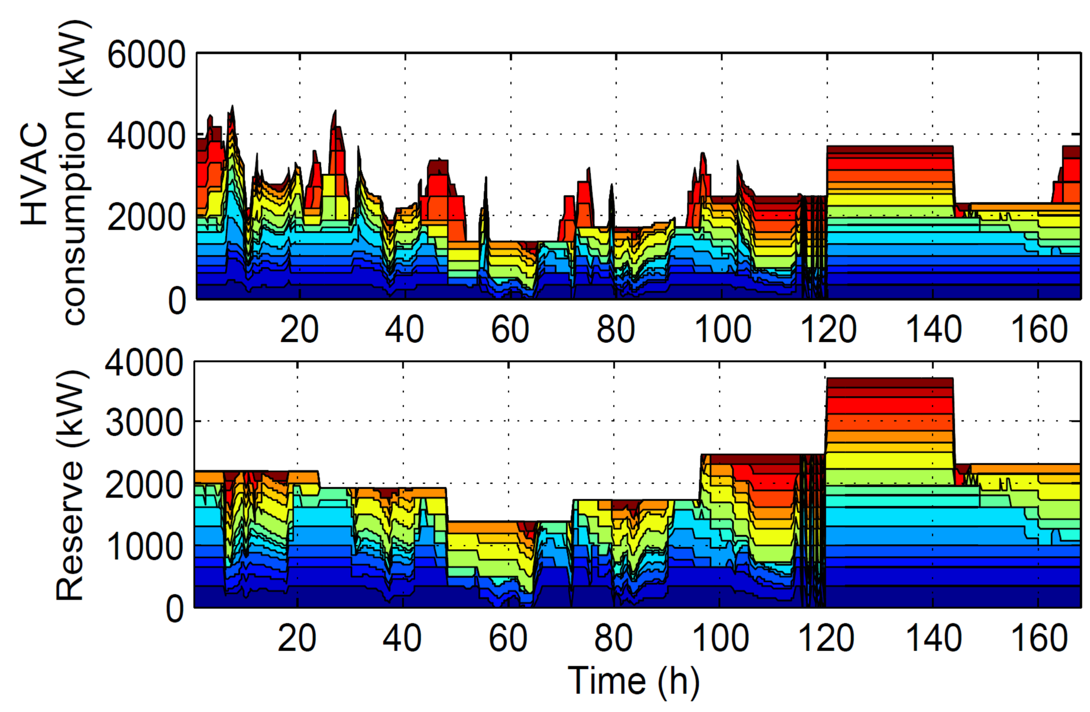
➢ Benefits of controlling the above thermal loads:
- Reduce transmission line loads.
- Improve ancillary service market.

Reserve Provision of Commercial Buildings



- To provide reserves, the buildings' flexibility is used, incurring higher operating costs
- However, provision of the reserves is financially compensated

➢ Find the optimal trade-off



HVAC energy consumption and reserve capacity profile for 16 Swiss buildings during a winter week [2]

➢ Formulation as a tractable Convex Program [1]

minimize nominal operating cost of HVAC systems — maximize reward for offering frequency reserve capacity $\mathbb{W}_j$

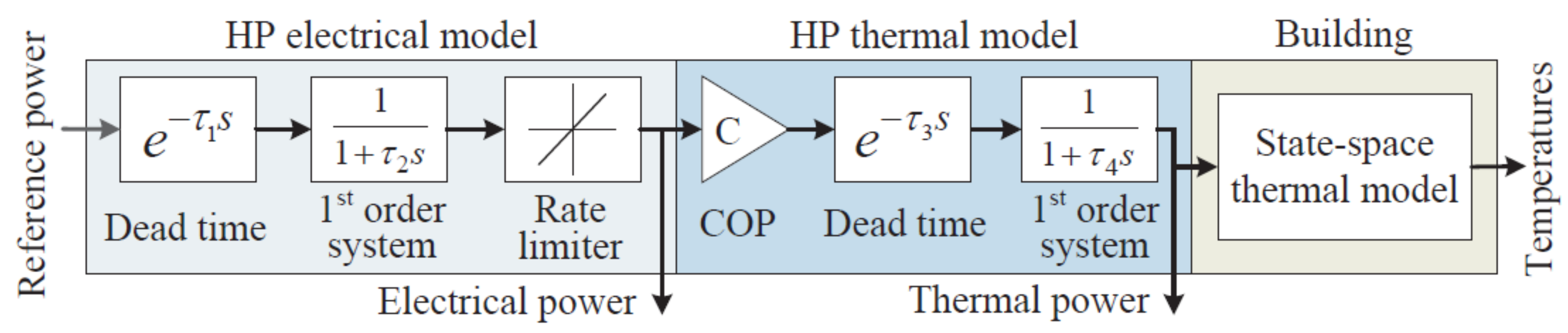
$$\min_{\pi,\mathcal{W}} \mathbb{E}\left[\sum_{k=0}^{N-1} \ell(\phi_k(\mathbf{w}_k), \pi_k(\mathbf{w}_k))\right] - \lambda \sum_{k=0}^{N-1} \varrho(\mathbb{W}_k)$$

$$\text{s.t.} \quad \pi_k(\mathbf{w}_k) \in \mathbb{U} \qquad \forall \mathbf{w}_k \in \times_{j=0}^{k} \mathbb{W}_j$$

$$\phi_k(\mathbf{w}_k) \in \mathbb{X} \qquad \forall \mathbf{w}_k \in \times_{j=0}^{k} \mathbb{W}_j$$

To increase reserve capacity and improve modeling:

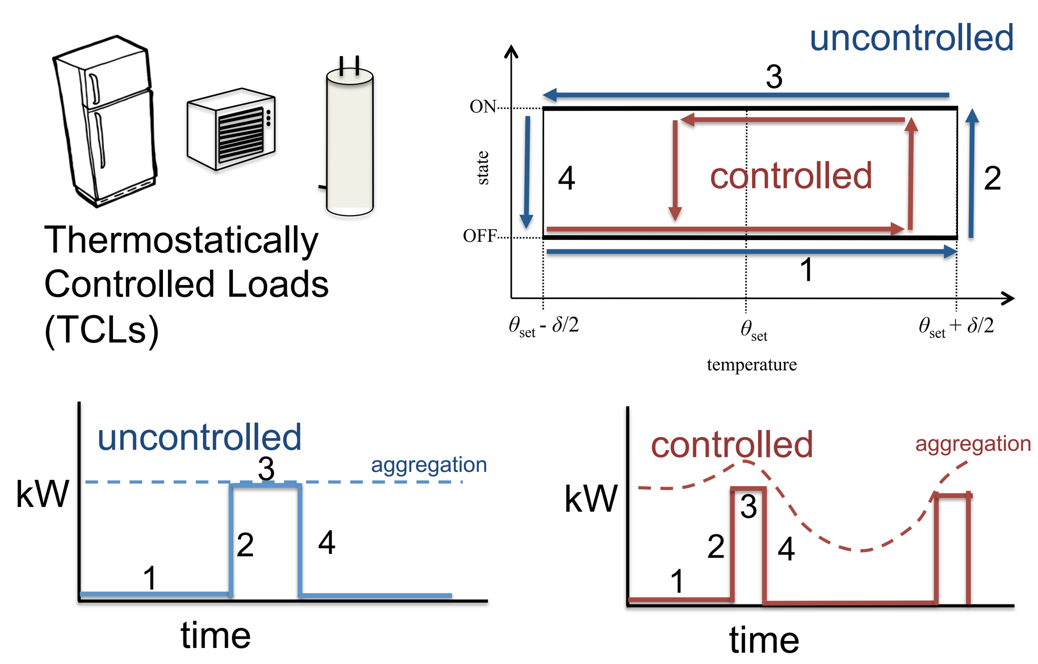
- Treat frequency reserves as random variables and formulate chance constraints -> increases capacity by up to 12% [3]
- Include energy-constrained frequency reserves -> increases capacity by up to 10% [4]



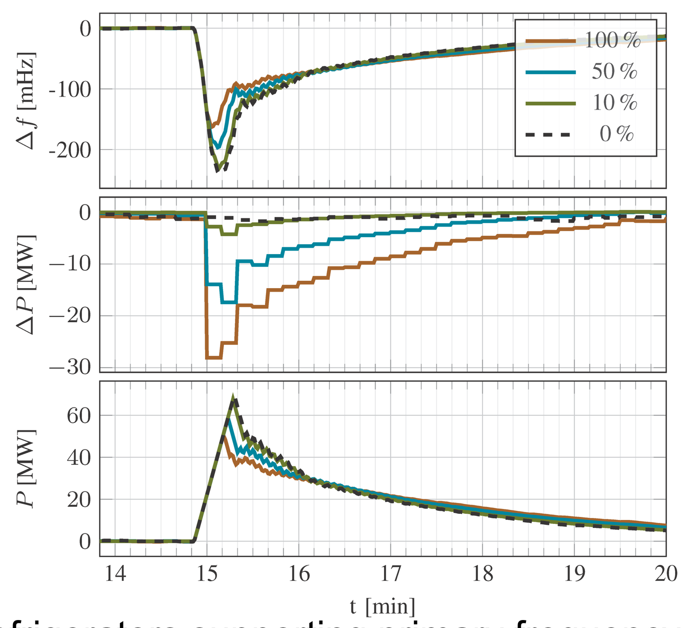
Dynamic heat pump model for evaluation of secondary frequency signal tracking [7].

Reserve Provision of TCLs

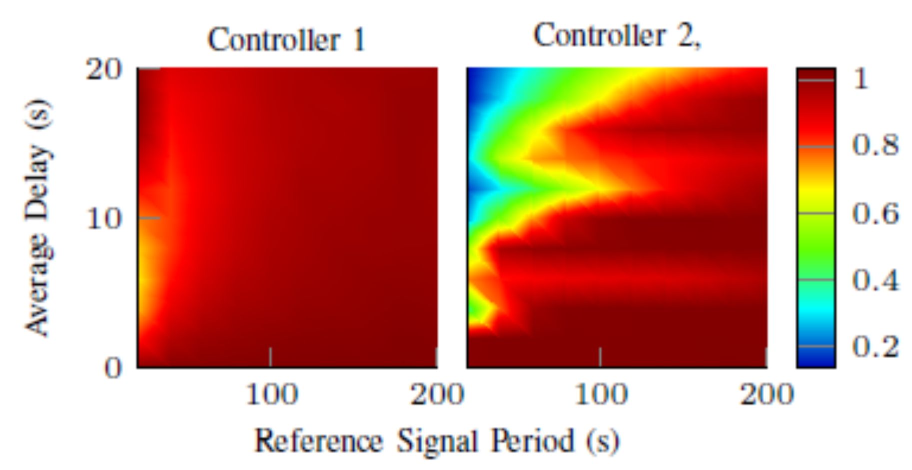
Household appliances, referred to as thermostatically controlled Loads (*TCLs*), provide thermal storage and therefore can shift their demand. They operate within a temperature dead-band. An aggregation of large number of TCLs can be controlled by turning them on/off prematurely or by adjusting their dead-band so that they can provide frequency reserves.



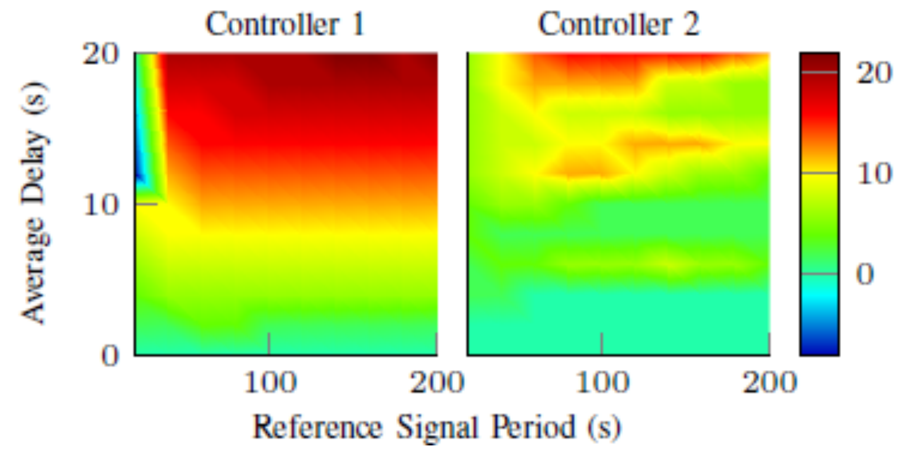
To Integrate TCLs for ancillary services we address
- Modeling of TCL aggregations [5]
- Strategies for minimal communication requirements
- State estimation and control
- Effects on power system dynamics
- Provision of Primary Control [6]



Refrigerators supporting primary frequency control. Increased share of participating refrigerators improves system frequency evolution (top) and reduces demand from conventional power plants (bottom) [6].



Relative amplitude (dimensionless) of controllers while tracking sinusoidal power set-points with a large aggregation of TCLs under communication delays. Left: the controller considers only the expected delay. Right: the controller considers the probability distribution of delays [8].



Controllers' lag (in seconds) for the same tracking case as above [8].

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