Incentive-based Coordinated Charging Control of Plug-in Electric Vehicles at the Distribution-Transformer Level

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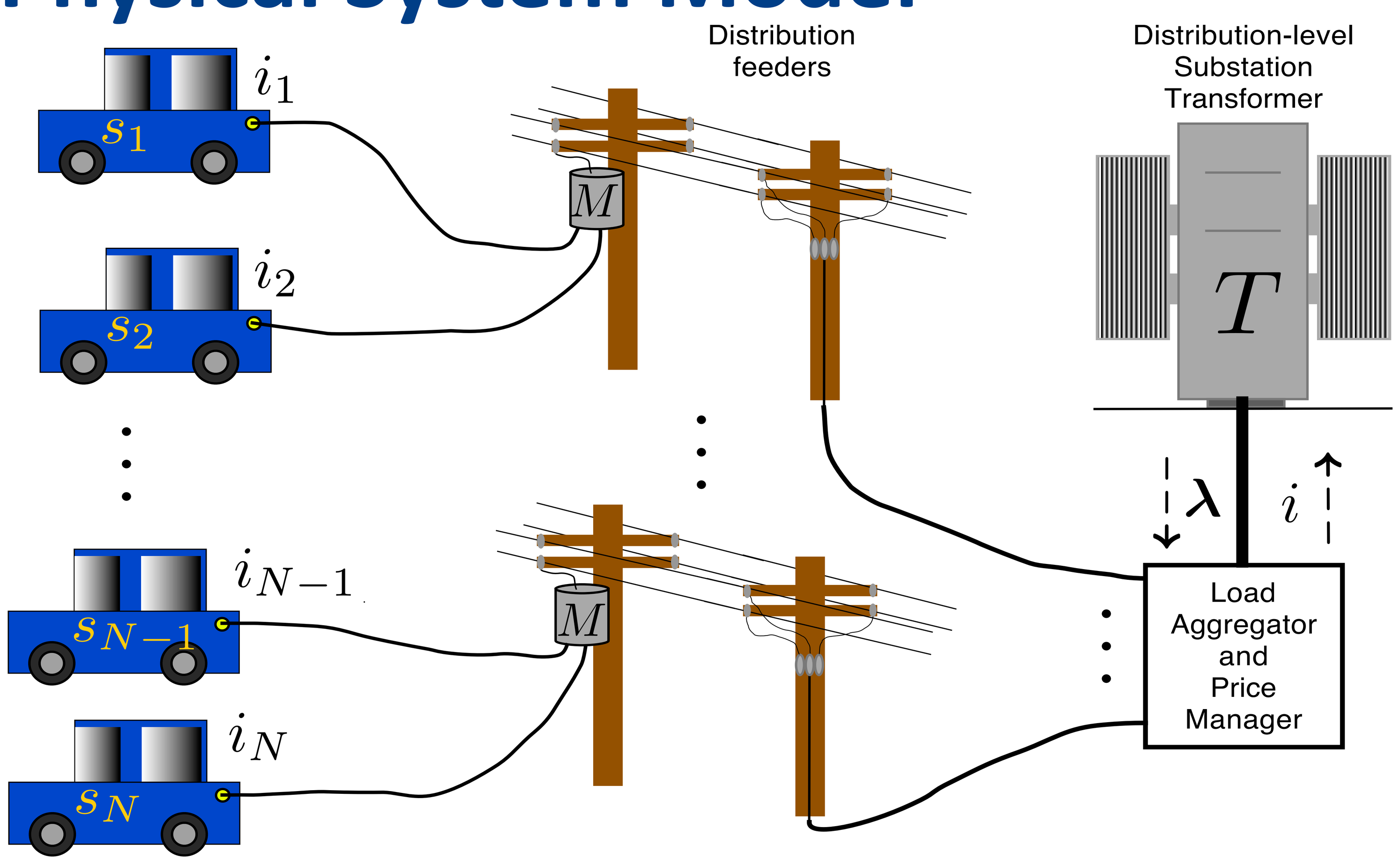
Motivation and Objective

- Plug-in electric vehicles (PEV) are forecasted to gain significant market share in coming years
- Utilities are aware that their networks may struggle to accommodate *en masse* uncoordinated charging.
- Overloading of transformers may result in transformer failure and black-out of full residential areas.
- Centralized charging control schemes are unrealistic
  - PEV-owners desire autonomy
- **Research objective**

Formulate a non-centralized coordinated PEV charging scheme that respects thermal restrictions of transformer at all times.

Physical System Model



- **Local PEV charging:**

$$s_n[k+1] = s_n[k] + \eta_n i_n[k] \quad \forall n \in \{1, \ldots, N\}$$

$$s_n[k] \in [0,1]$$

$$s_n[k] \geq S_n \quad \forall k \geq K_n$$

$$i_n[k] \in [i_{n,\min}, i_{n,\max}]$$

Set of all i_n that satisfy above $:= \Pi_n(s_n[0])$

- **Linearized transformer temperature (about $i = i^*$):**

$$T[k+1] = \tau T[k] + \gamma \left(\sum_{n \in \mathcal{N}} \frac{i_n[k]}{M} + i_d[k] \right) + \rho T_{\text{amb}}[k] - \frac{\gamma}{2} i^*$$

$$T[k] \leq T_{\max}$$

Exogenous disturbances

s_n	state of charge
i_n	charging rate
η_n	constant charging parameter
K_n	requested SOC target time
T	transformer temperature
$T_{\max}$	temperature limit
T_{amb}	ambient temperature
d	inelastic background demand
M	step-up voltage conversion factor
τ, γ, ρ	constant transformer parameters

Solution: Coordinated Charging Control

- **Open-loop Centralized Charging:**

$$\min_{i_1[k], \ldots, i_N[k]} \sum_{n=1}^{N} J_n(i_n)$$

← *Penalizes charging rates and deviations from reference charge level (quadratic)*

subject to

$$i_n[k] \in \Pi_n(s_n[0]) \quad \forall k$$

$$\mathbf{\Phi} T[0] + \mathbf{\Psi} \left(\sum_{n=1}^{N} \frac{i_n[k]}{M} \right) + \mathbf{\Psi}_d \hat{\mathbf{v}} \leq T_{\max} \mathbf{1}_{K+1}$$

Complicating constraint prevents full separability!

Disturbance forecast

Lagrangian Relaxation + Dual Ascent Method

- **Open-loop Incentive-based Coordinated Charging:**

Control (pseudo-price) signal

Local Charging Problem

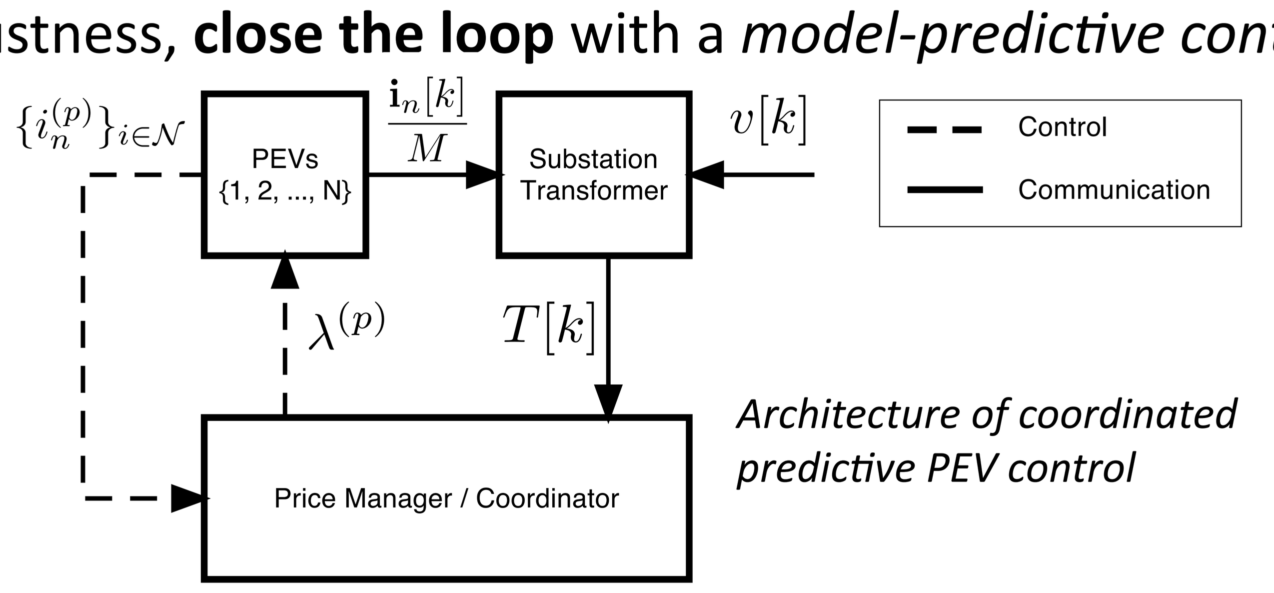
$$i_n^{(p)}[k] = \arg\min_{i_n \in \Pi_n(s_n[0])} J_n(i_n) + \left(\lambda^{(p)}[k]\right)^\top \Psi i_n[k] \quad \forall n$$

Price Manager

$$\lambda^{(p+1)}[k] = \left[\lambda^{(p)}[k] + \alpha^{(p)} \left(\mathbf{\Phi} T[0] + \mathbf{\Psi} \left(\sum_{n=1}^{N} \frac{i_n^{(p)}[k]}{M} \right) + \mathbf{\Psi}_d \hat{\mathbf{v}} - T_{\max} \mathbf{1}_{K+1} \right) \right]_+$$

Iteration-dependent step-size parameter

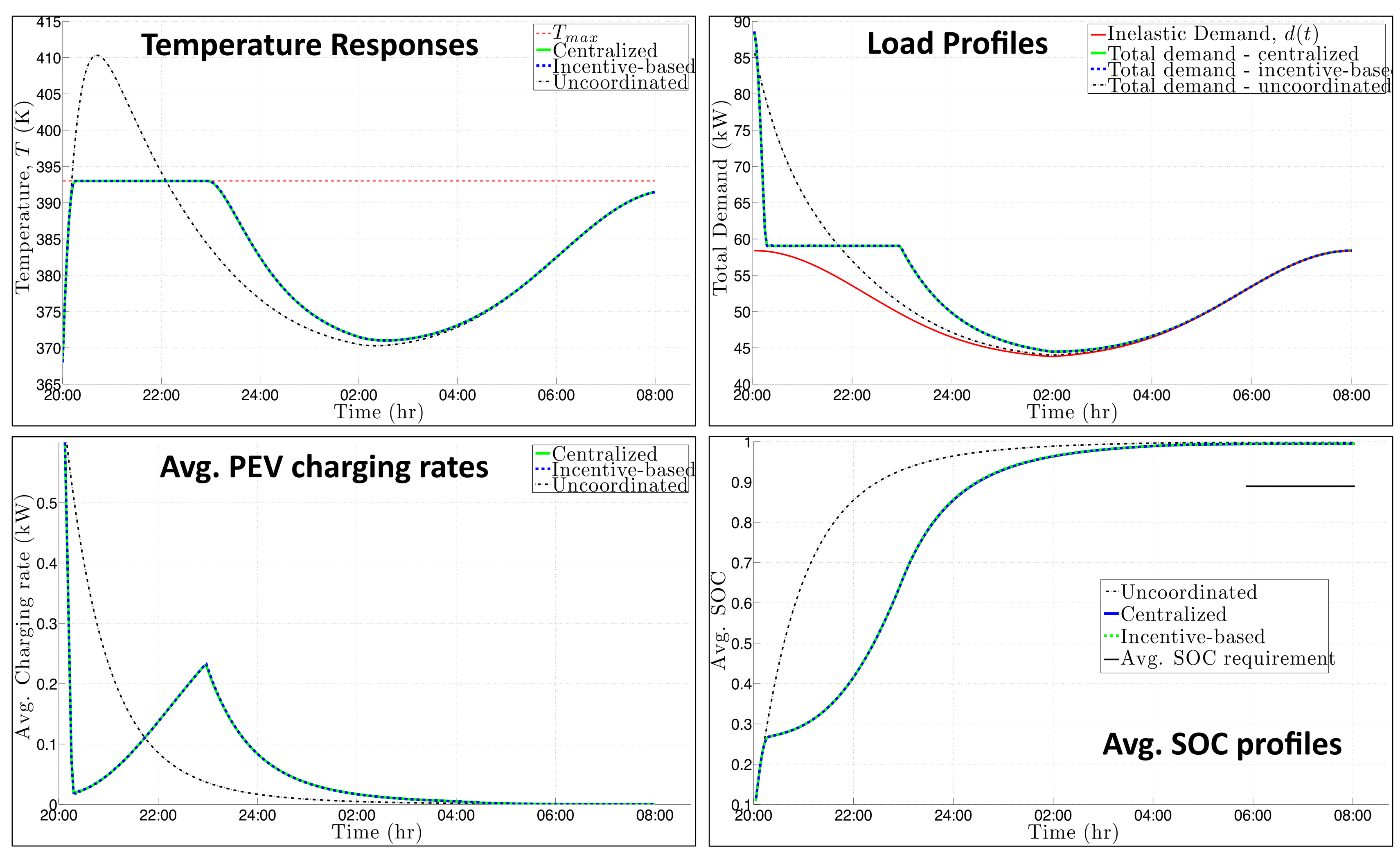
- Centralized solution is recovered in non-centralized way as $p \to \infty$
- To increase robustness, **close the loop** with a *model-predictive control (MPC)* scheme:



Architecture of coordinated predictive PEV control

Case-study

- Incentive-based charging control satisfies thermal constraint and achieves **near-optimal performance**



Future Work

- Improve rate of convergence of incentive-based method
- Investigate robustness of MPC scheme
- Study nonlinear representations of temperature dynamics

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