Distributed Control of Electric Vehicle Charging

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EV market is growing rapidly

Forbes

'Dying' EV Industry Set for Growth

John Gartner, Contributor

Reuters posted an interesting "news" article on February 4th claiming that EVs face a dead end. This article was very selective in its reporting and missed an obvious fact: sales of plug-in vehicles in the U.S. more than tripled in 2012, and continue to outpace the growth of the supposedly more mainstream hybrids.

Despite the "public's lack of appetite for battery-powered cars," as Reuters pu it, 54,000 plug-in hybrid and battery electric cars (known collectively as plug-in electric vehicles, or PEVs) were sold in 2012, up from more than 17,000 in 2011. As the chart below shows, PEV sales in their two full years on the market are well ahead of where hybrids were at this point in their lifecycle, and we forecast that they'll stay ahead of hybrids in the years to come.

GREEN TRANSPORTATION

E.V. market passed 100,000 sales mark in 2012

Details Category: Green Transportation 19 Apr 2013
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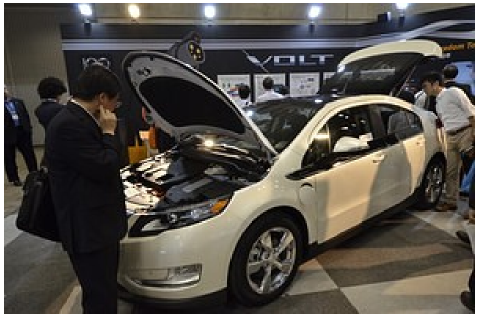
Global electric vehicle passenger car market grew more than twofold between 2011 and 2012, surpassing the 100,000 sales mark last year found the first Global E.V. Outlook report.

Released by the Electric Vehicles introduction and adoption of electr over 180,000 vehicles.

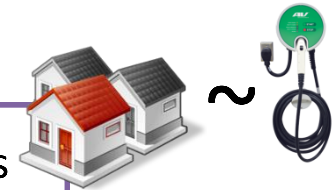
Forbes

Worldwide Electric Vehicle Sales to Reach 3.8 Million Annually by 2020



Since the launch of the Nissan Leaf and Chevrolet Volt, in late 2010, plug-in electric vehicles (PEVs) have become more widely available. Hybrid electric vehicles (HEVs), which first appeared a decade earlier, are now selling steadily. According to a new report from Pike Research, annual worldwide sales of these vehicles, collectively referred to as electric vehicles (EVs), will reach 3.8 million by 2020.

Electric Vehicles – Challenges & Opportunities



EV charging load is significant

spatial & temporal uncertainties

Electric Vehicles – Challenges & Opportunities

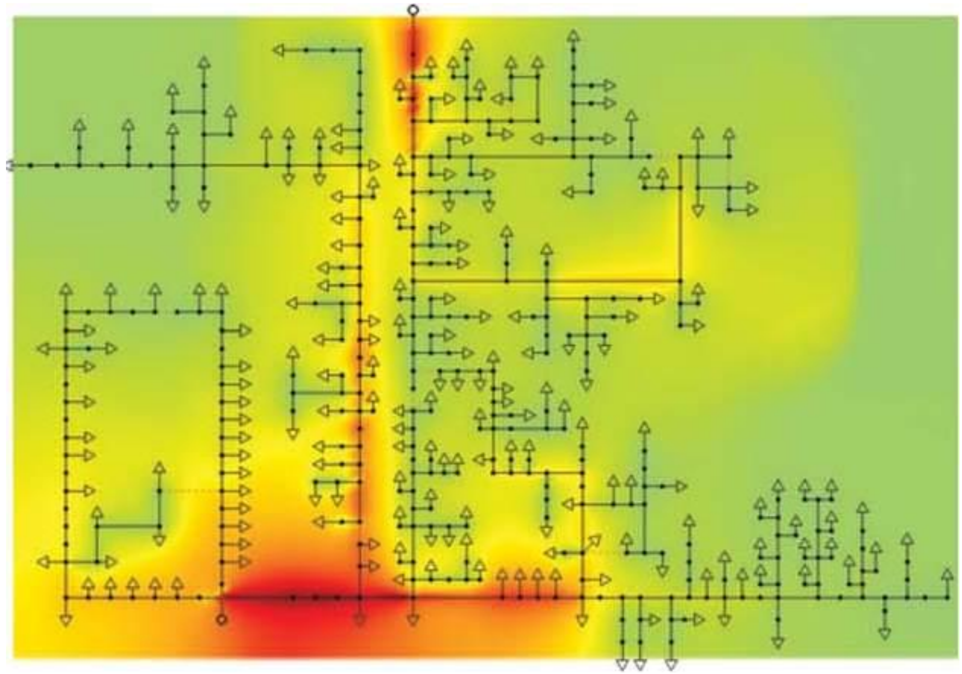
EV charging load is significant

spatial & temporal uncertainties

impact on the distribution network

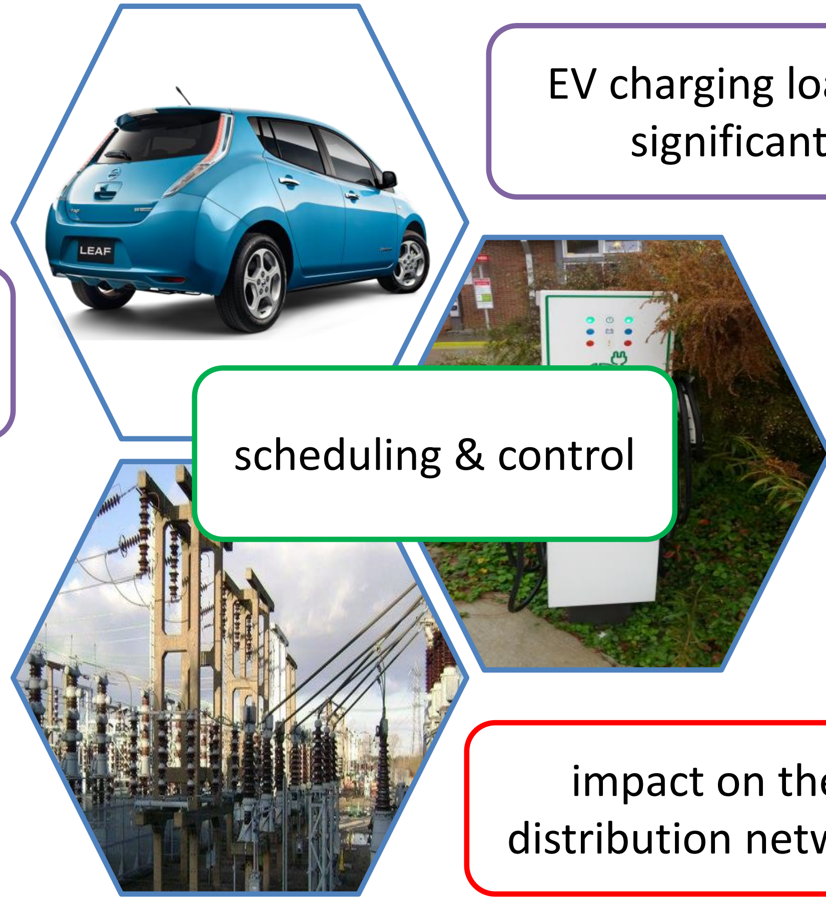
Impacts on the Grid

- Branch and transformer congestion
  - accelerates degradation of power apparatus
  - leads to overheating (risk of explosion)
  - may trigger the protection system
- Voltage swings at distant buses
  - affects the grid reliability



Lopes, J.A.P.; Soares, F.J.; Almeida, P.M.R., "Integration of Electric Vehicles in the Electric Power System," *Proceedings of the IEEE* , vol.99, no.1, pp.168,183, Jan. 2011

Electric Vehicles – Challenges & Opportunities



EV charging load is significant

spatial & temporal uncertainties

scheduling & control

impact on the distribution network

State of the Art Approach: Scheduling

- Scheduling solutions typically solve a power flow problem

- They rely on
  - an accurate model of the distribution network
  - prediction of the home loads
  - prediction of arrivals and departures of EVs

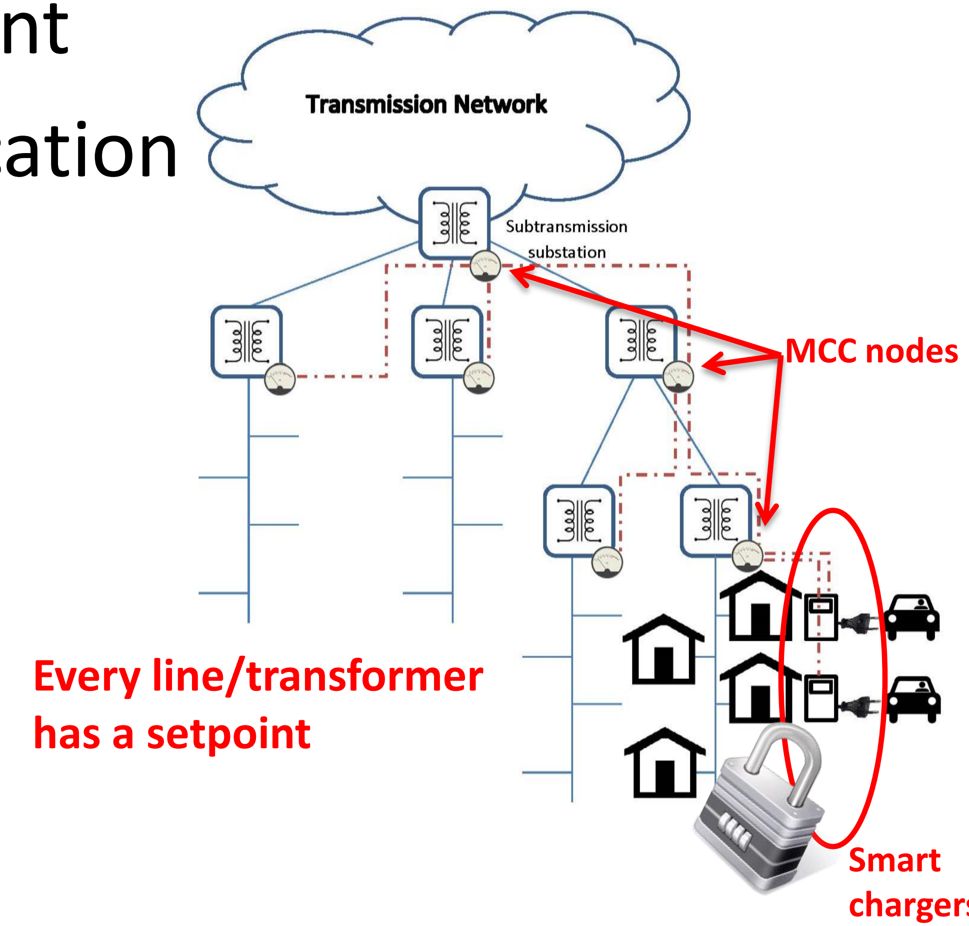
Our Approach is…

To adapt the charging rate of EV chargers to the available capacity of the distribution network in real-time using the same tricks as TCP congestion control

Real-time control is feasible in the smart grid

Smart Grid Enables Real-time Control

- Pervasive measurement
- Broadband communication
- Increased intelligence



We are inspired by the success of TCP congestion control

robustness

efficiency

scalability

fairness

responsiveness

stability

Optimal Control

A single snapshot optimization problem:

$$\max_{rate} \sum_{s \in \mathcal{S}} \log(rate_s)$$

utility of s

subject to

$$0 \leq rate_s \leq maxrate_s \qquad \forall s \in \mathcal{S}$$

$$EV\ load_l + home\ load_l \leq setpoint_l \qquad \forall l \in \mathcal{L}$$

Similar to **[Low99], [Kelly98]**

Optimal Control

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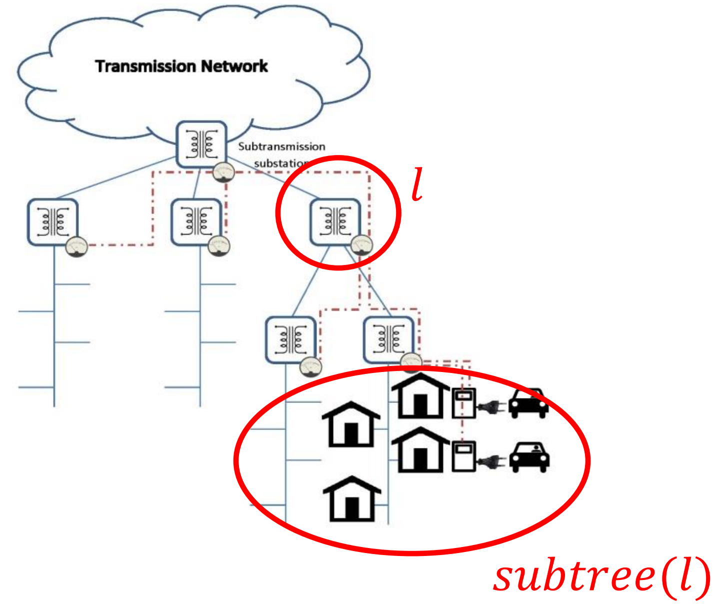

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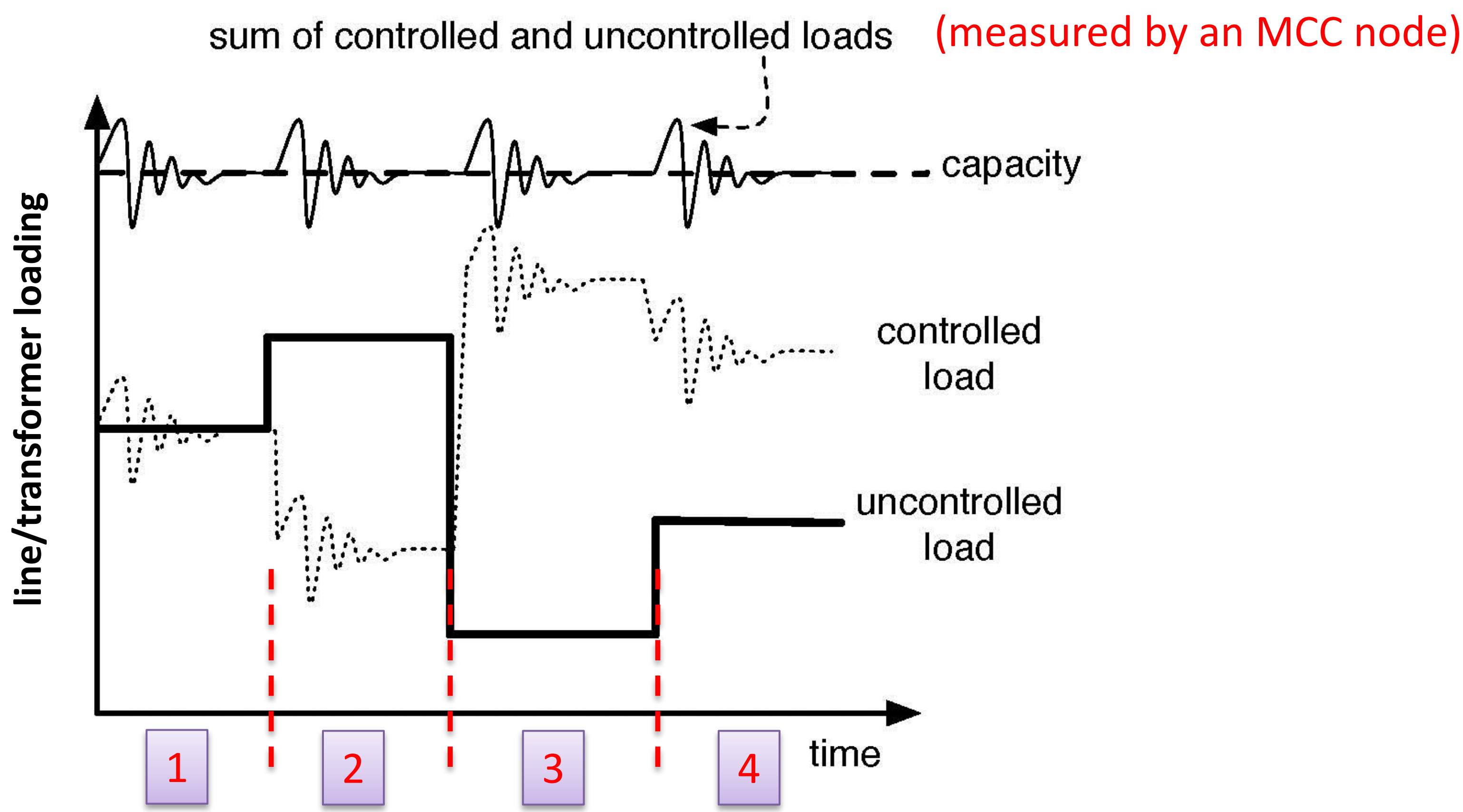
Optimal Control

Consider a series of snapshots



Distributed Control vs. Centralized Control

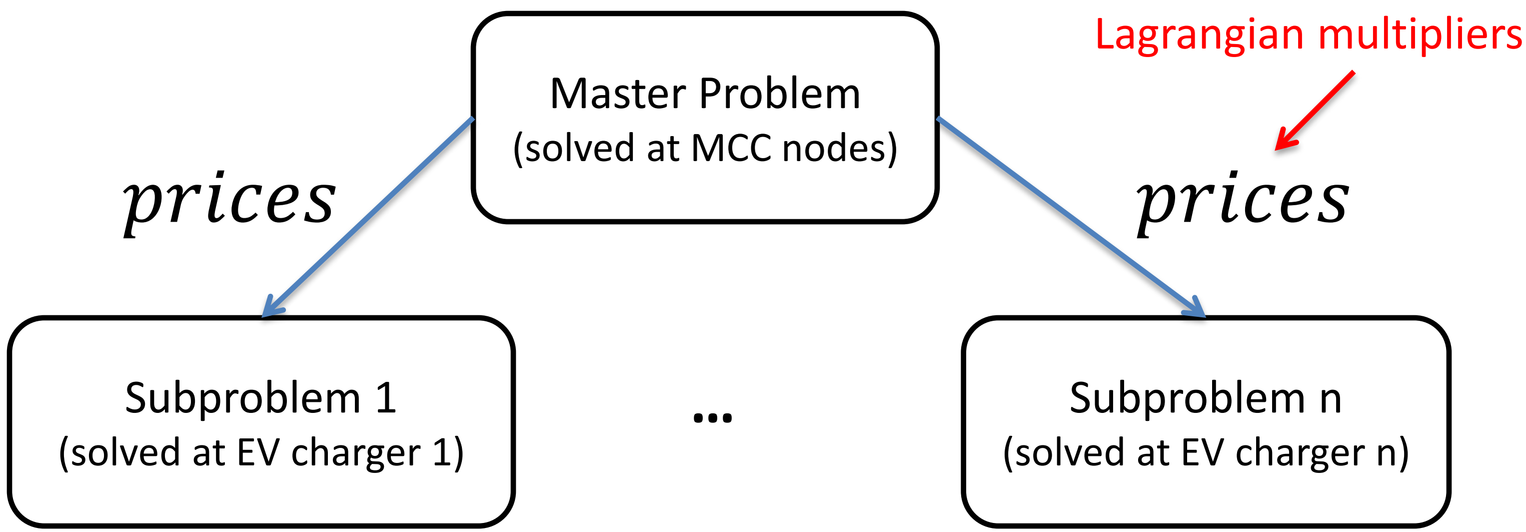
Pros:

- No single point of failure
- Scalability
- Charging rates do not change drastically
  - the stepsize bounds the change

Cons:

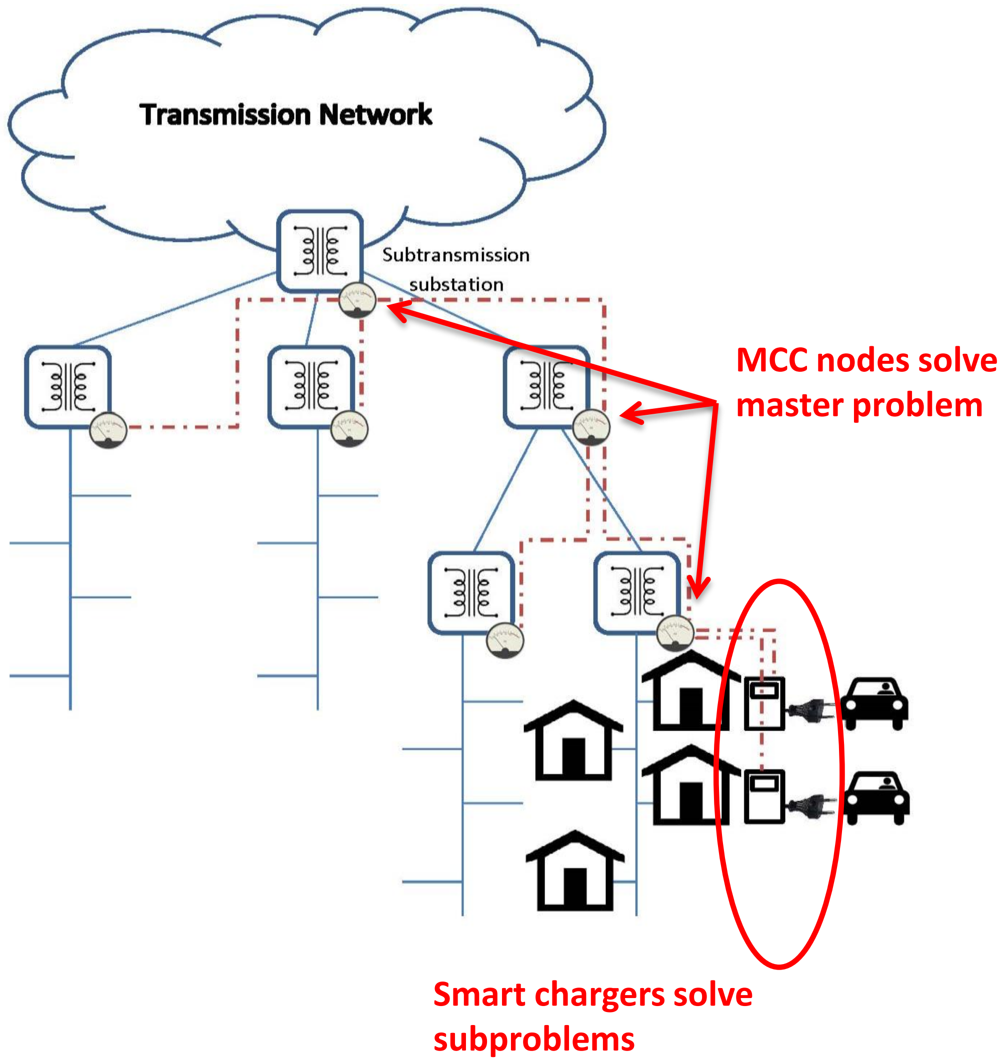
- Convergence time
- Communication overhead

Dual Decomposition & Control Rules

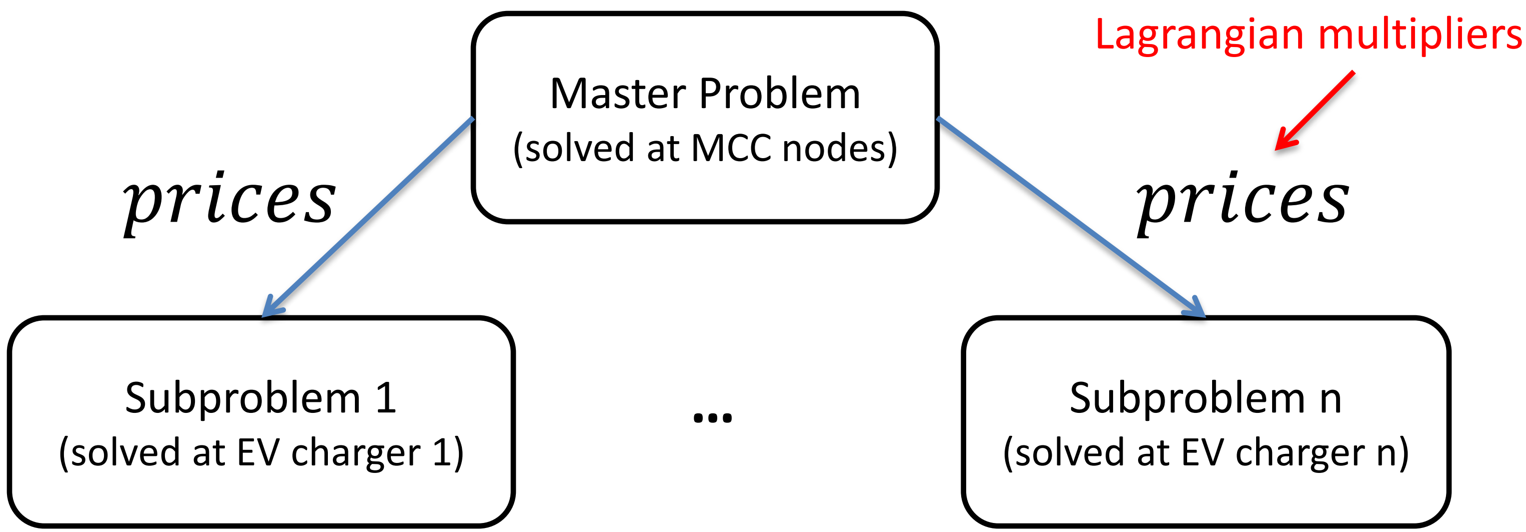


- Two phases are repeated in every iteration of the algorithm

Dual Decomposition & Control Rules



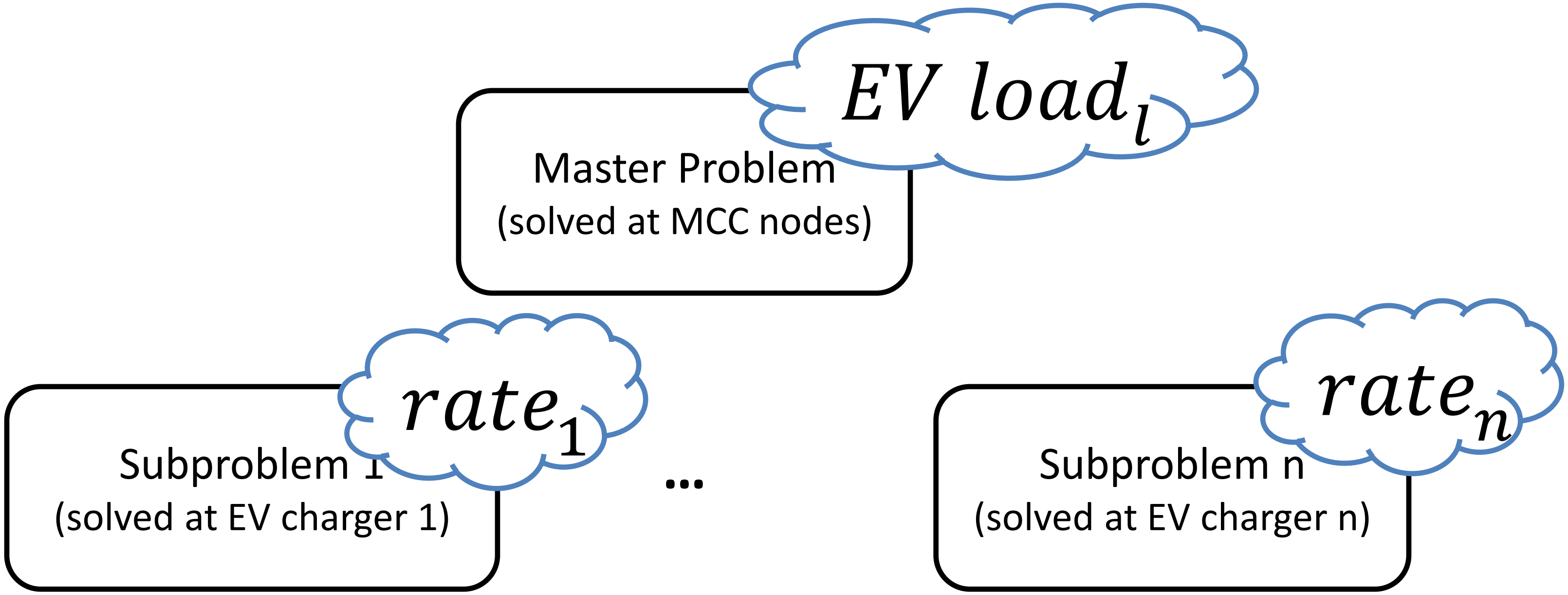
Dual Decomposition & Control Rules



1. MCC nodes update congestion prices and send them to downstream EV chargers

$$price_l \leftarrow \max\{price_l - stepsize \times (setpoint_l - load_l), 0\}$$

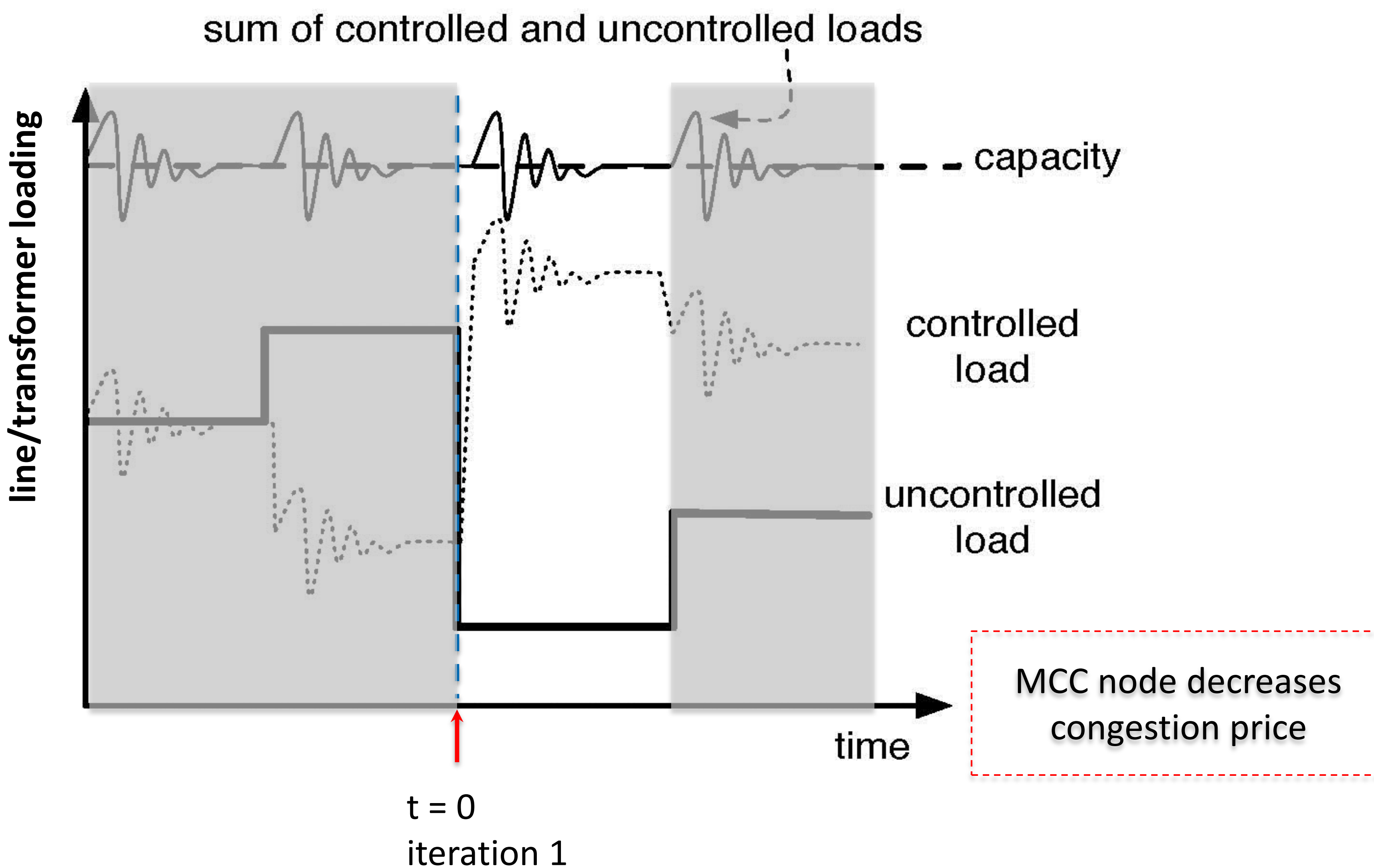
Dual Decomposition & Control Rules



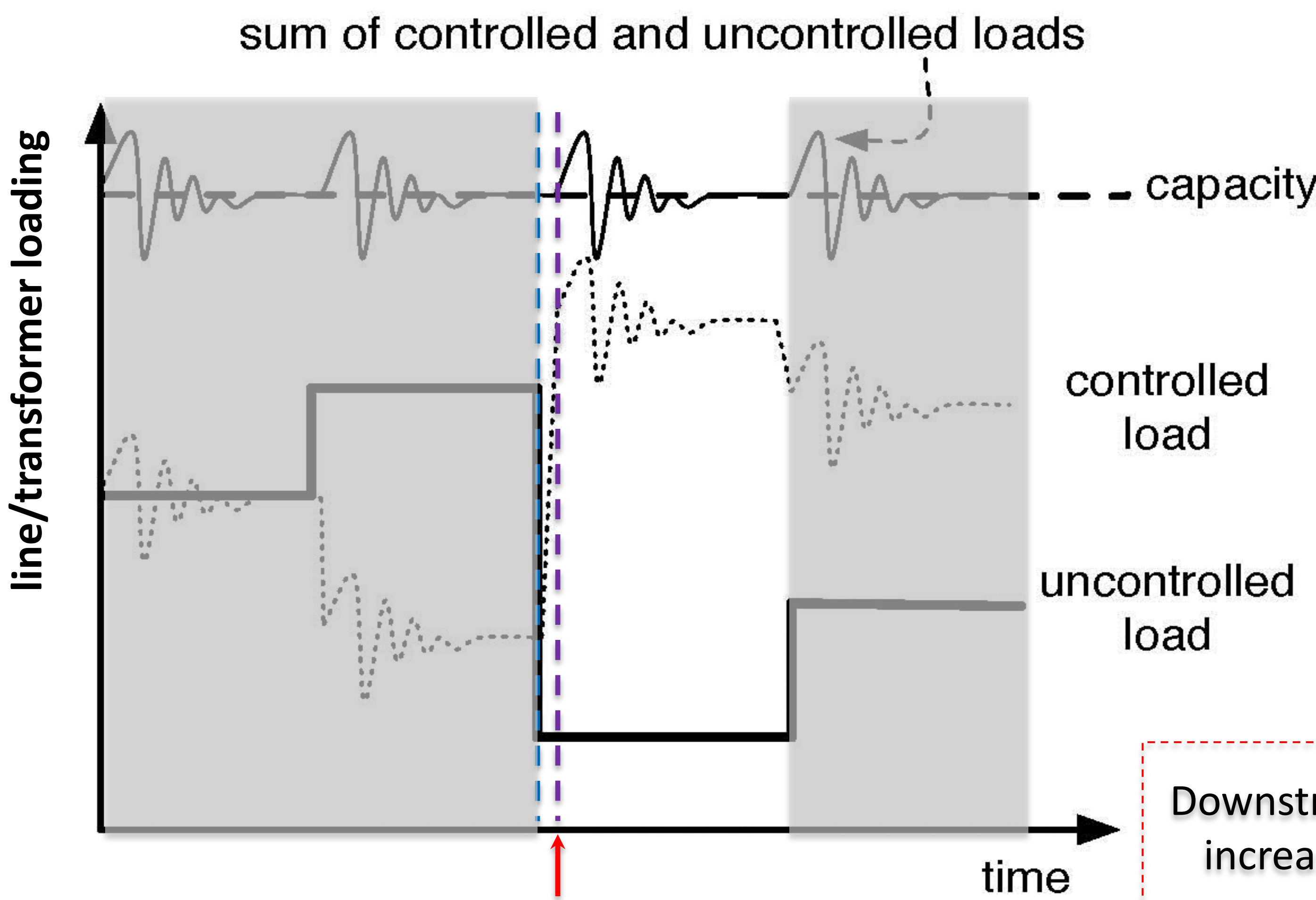
2. New rates are obtained from solving subproblems using new congestion prices

$$rate_s \leftarrow \min\left\{\frac{1}{path\ price_s}, maxrate_s\right\}$$

Measurement/Control Timescale



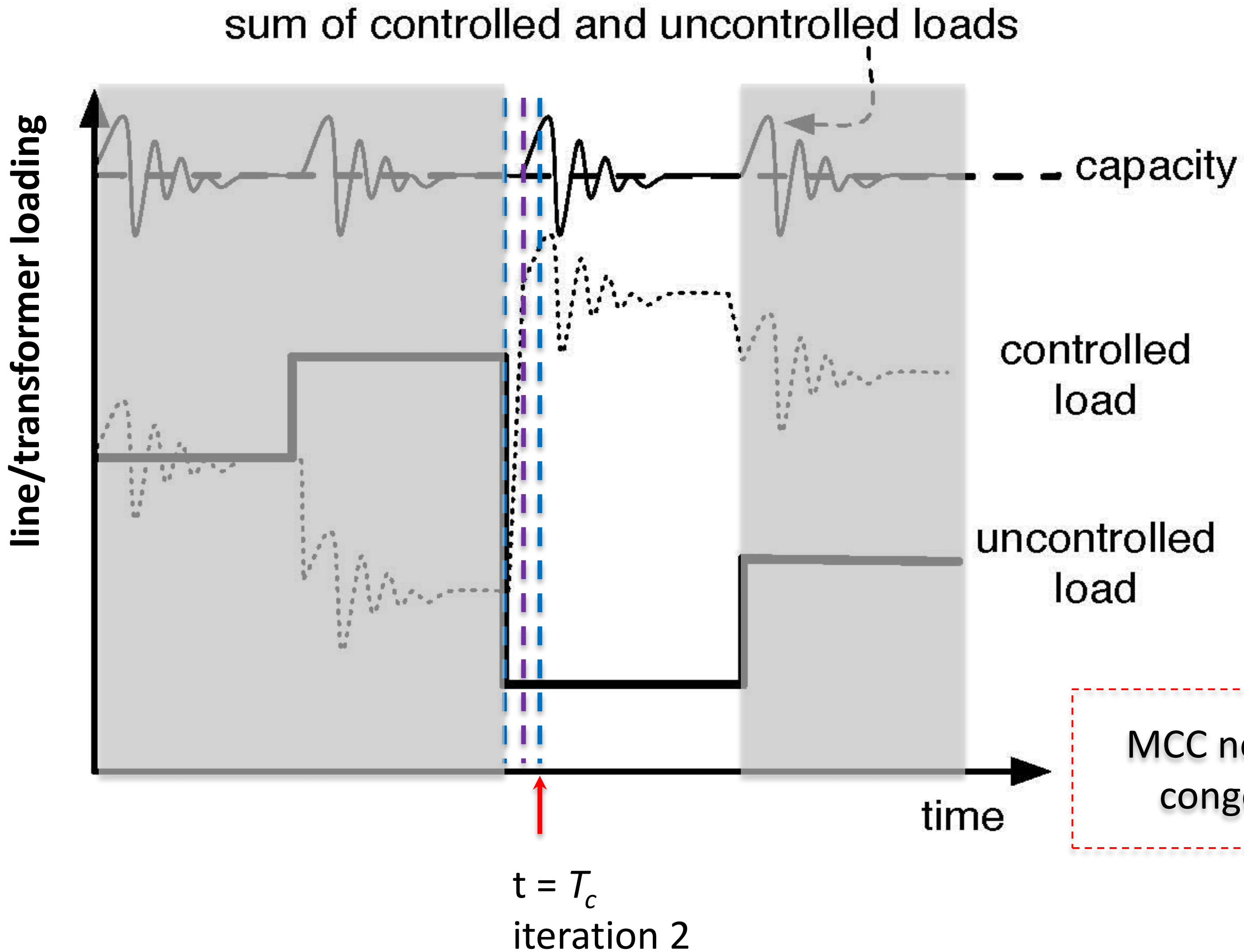
Measurement/Control Timescale



Downstream chargers increase their rate

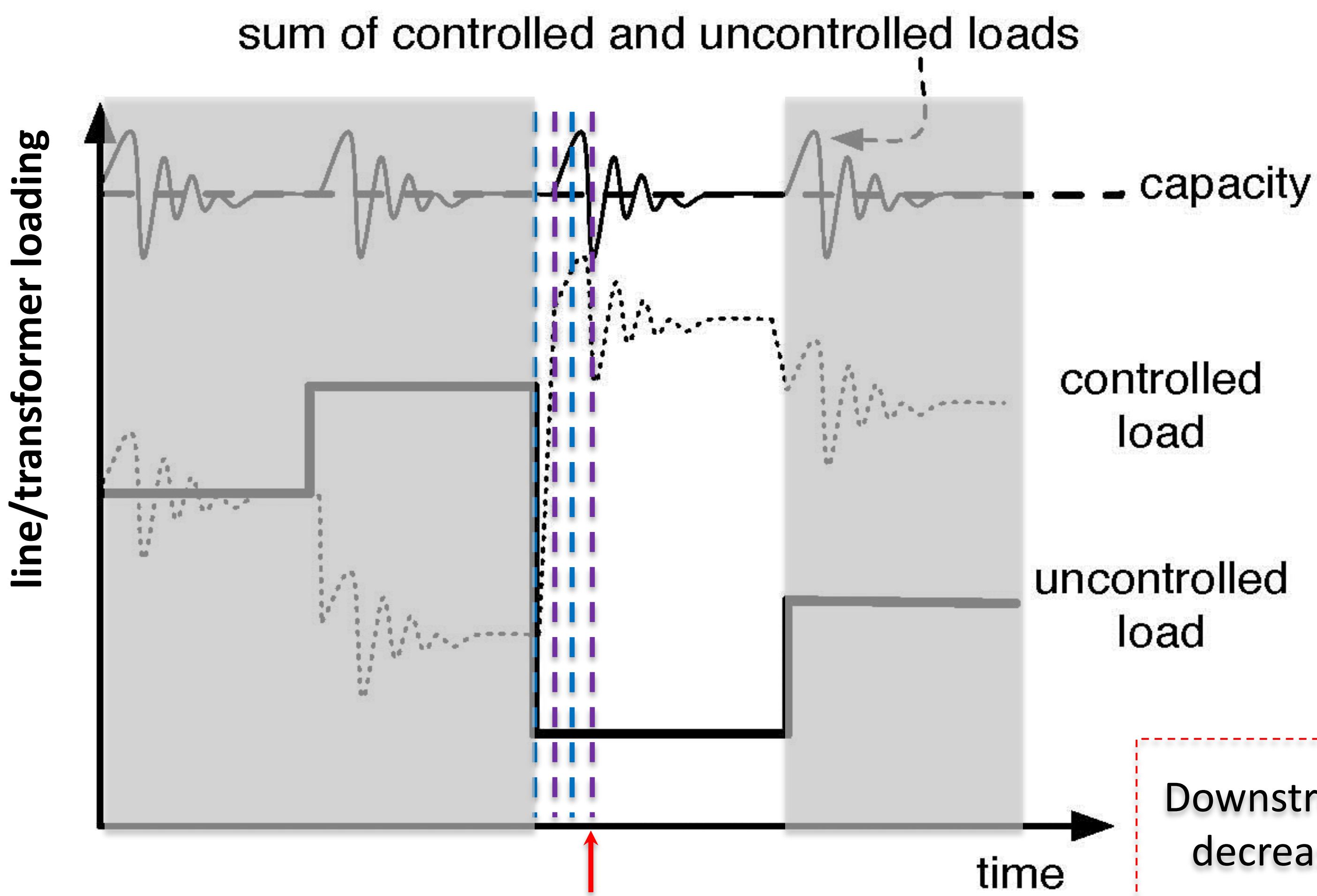
t = *delay*
iteration 1

Measurement/Control Timescale



MCC node increases congestion price

Measurement/Control Timescale

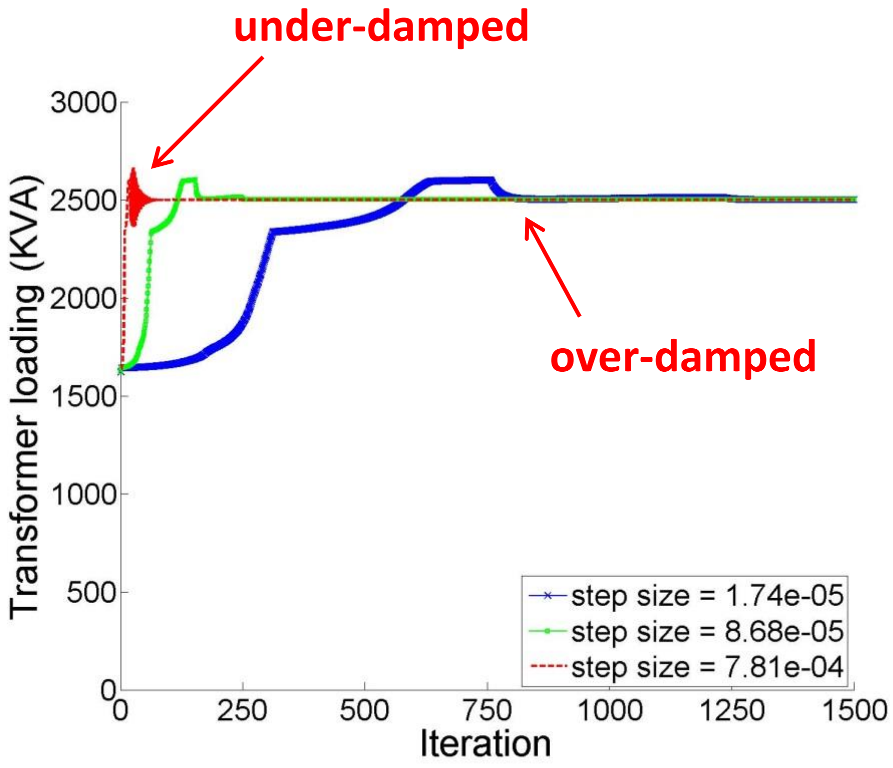


t = T_c+*delay*
iteration 2

Downstream chargers decrease their rate

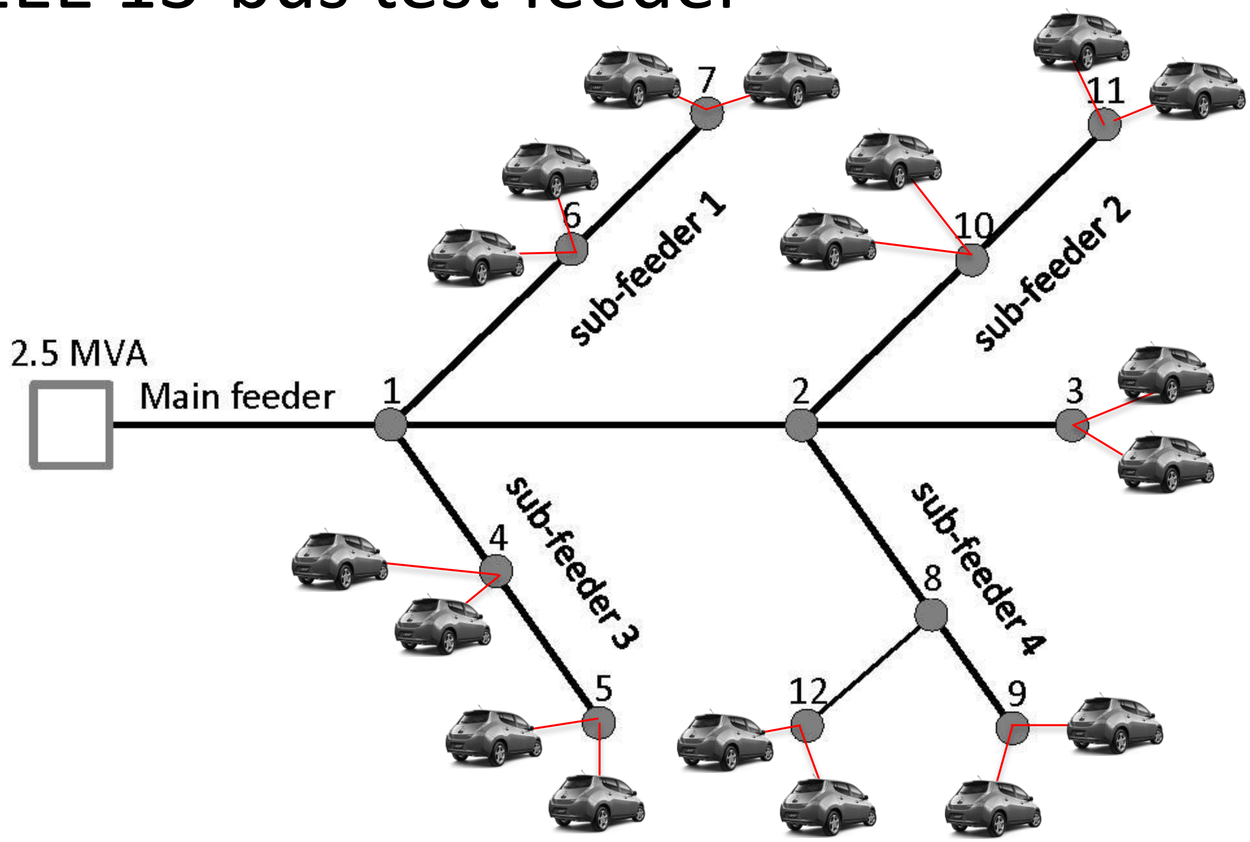
Stability

- Control is stable for $stepsize \leq stepsize^{*}, T_c \geq delay$
- The rate of convergence depends on both $stepsize, T_c$



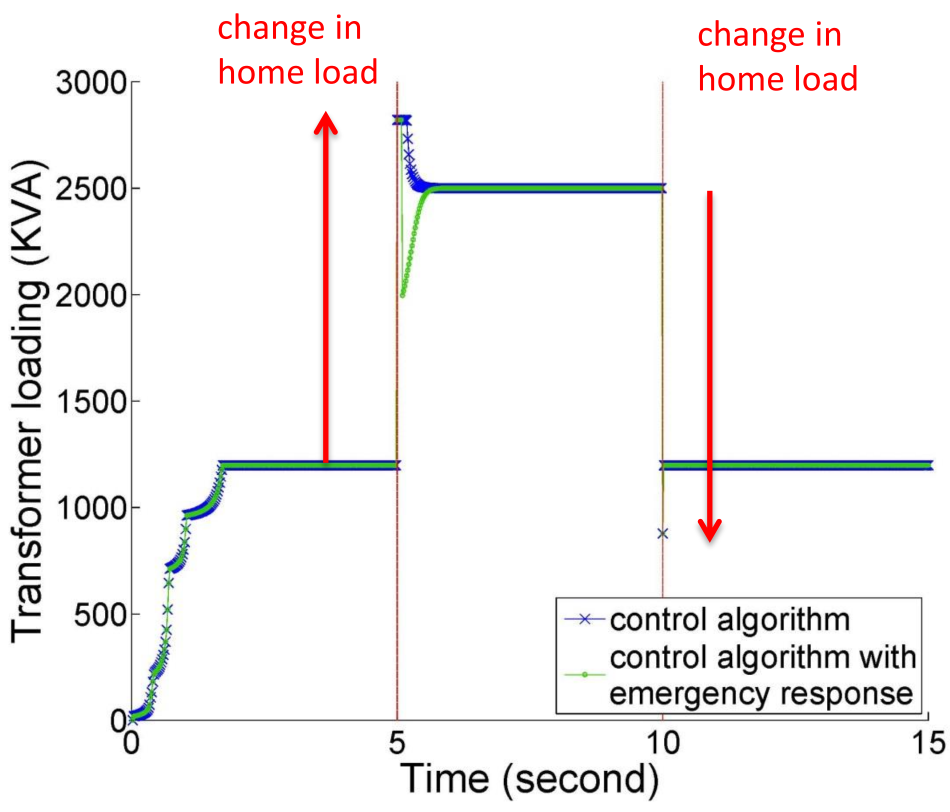
Simulation

IEEE 13-bus test feeder



Operation Modes of the Algorithm

- Normal operation mode
- Emergency response mode



Conclusions

- Controlling the EV charging load reduces the need for over-provisioning
- Pervasive measurement and broadband communication in a distribution network motivate real-time control of elastic loads
- Using explicit congestion notification, the EV charging load can be controlled in real-time

Guidelines for Setting Control Parameters

- T_c must be as small as possible
  - But in practice $T_c \gg delay$
- $stepsize$ must be as large as possible
  - $stepsize = stepsize^*$
- $setpoint$ can be chosen such that overshoots do not cause line or transformer overloading