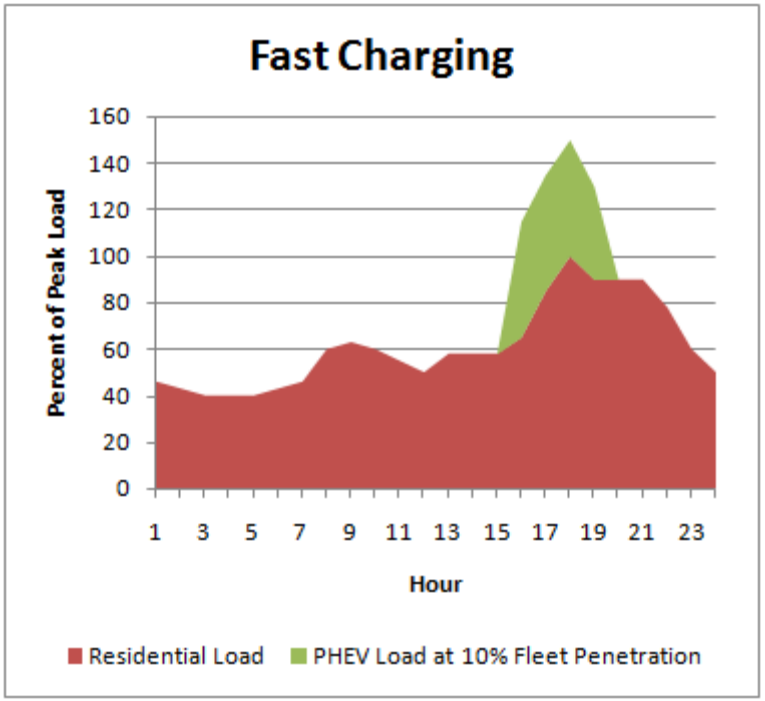
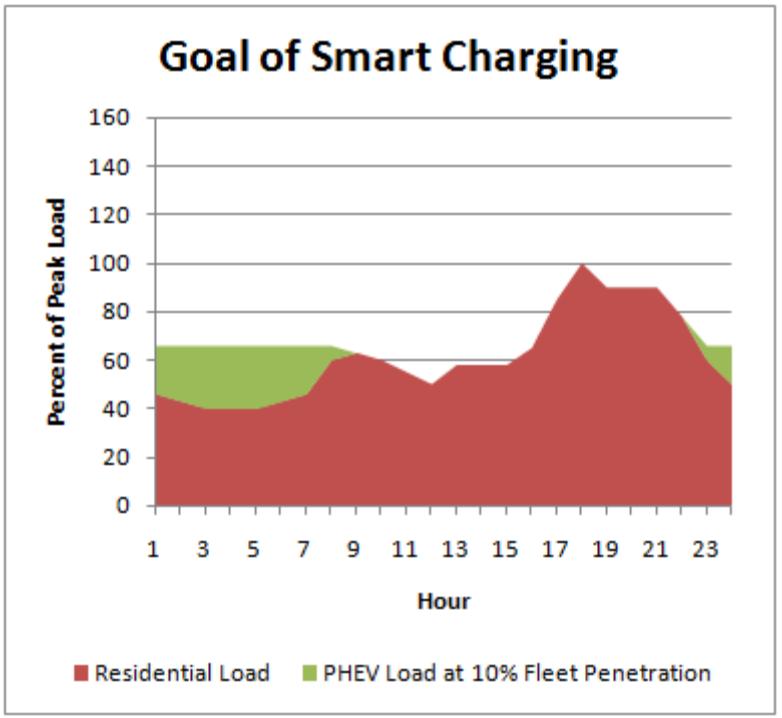
Optimal Charge Control of Plug-In Hybrid Electric Vehicles in Deregulated Electricity Markets

Why Bother?

- If no countermeasures are taken, peak load increases by 50% at a 10% fleet penetration of PHEVs.
- Fast charging increases consumer prices unnecessarily and causes tremendous investment requirements for utilities.
- Vehicle to grid support cannot be implemented with fast charging.

Fast vs. Smart





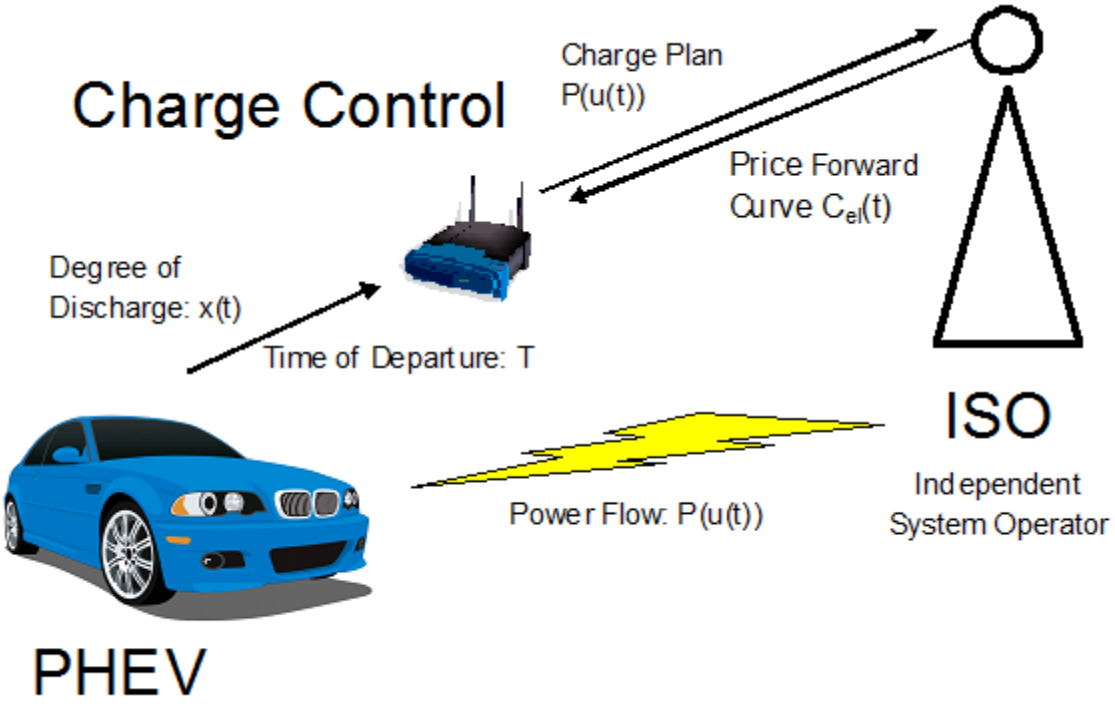
Idea

- Use sport market prices to charge vehicles
  - Consumers receive a lower price
  - Basic benefits of PHEVs can be exploited in the present market structure (ideal charge time allocation)
  - Implementation of Vehicle to Grid support is possible with few legislative effort (regulating power)

Assumptions

- Each consumer optimizes his charge curve individually
- No strategic behavior
- Consumers are price takers

Information flow



Inside the Charge Controller

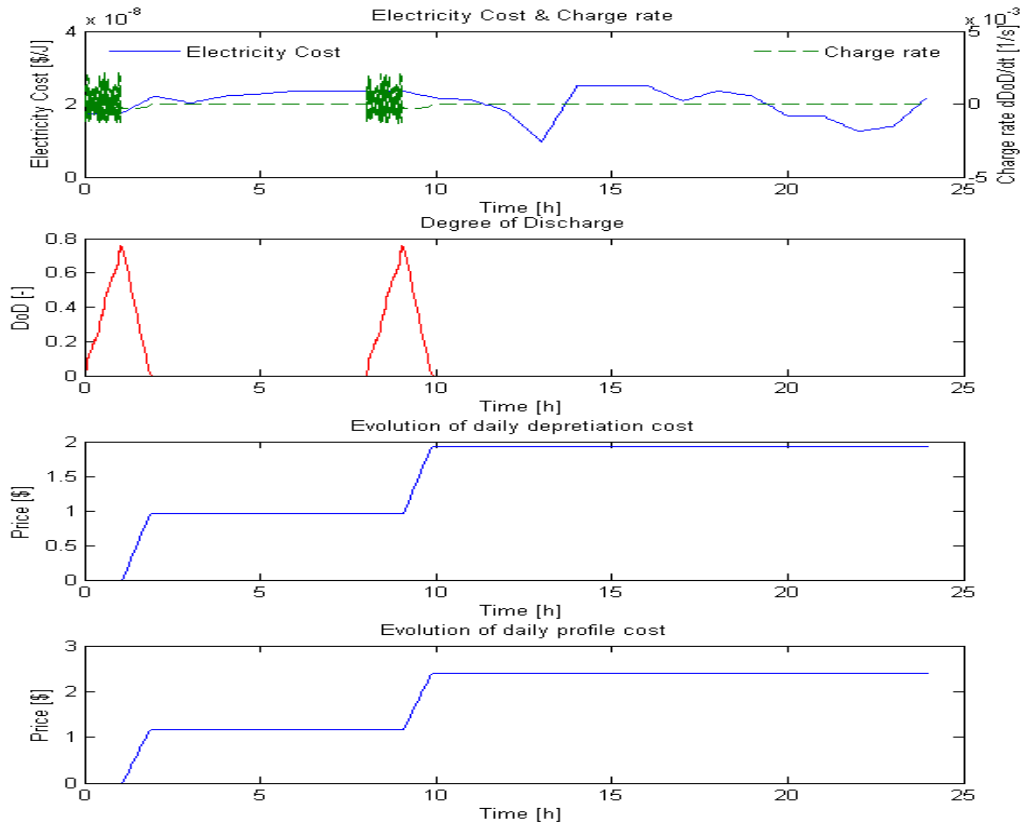
- Controller Objective
  - Find Control Law u(t) that minimizes:

$$J(u) = \varphi(x(t_b)) + \int_{t_a}^{t_b} L(x(t), u(t), t)\,dt$$

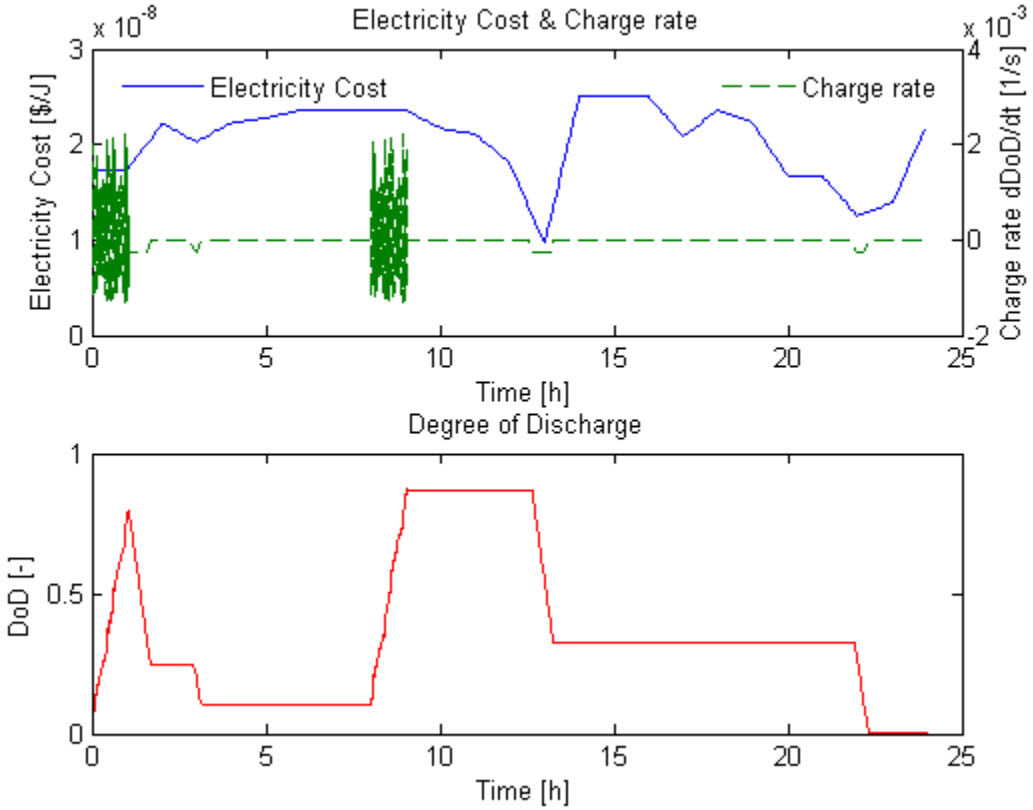
- Contraints

$$\dot{x} = f(x(t), u(t), t), \quad x(t_a) = x_a$$

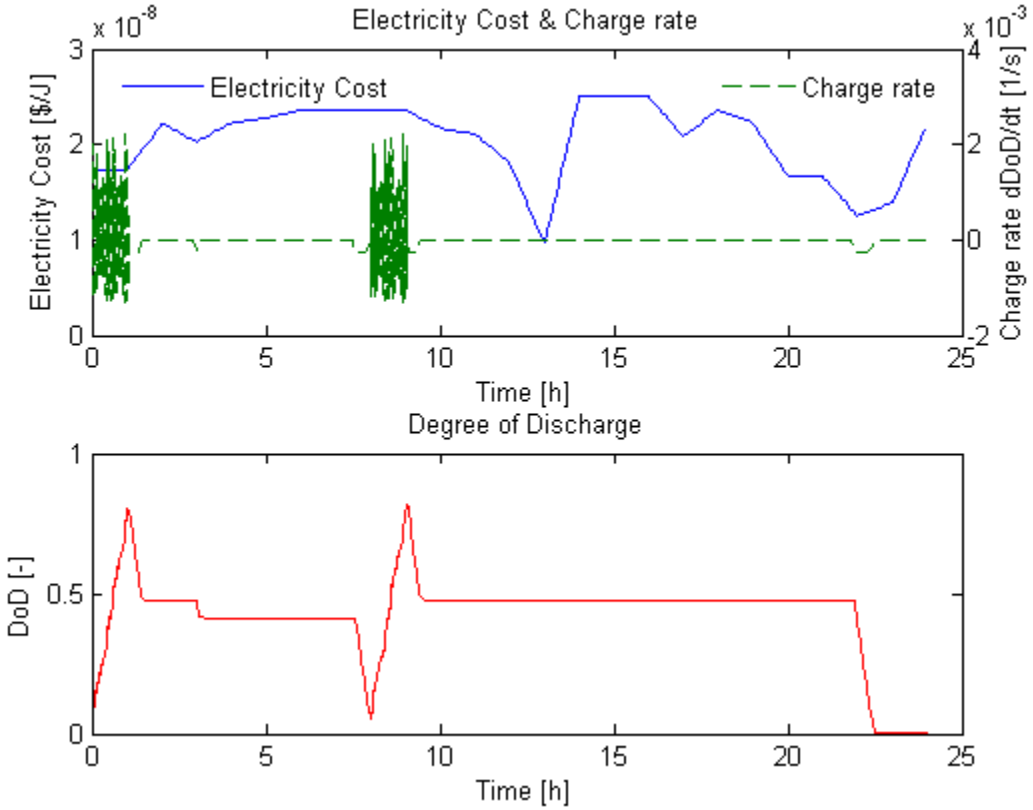
Fast Charge Curve



Smart Charge Curve



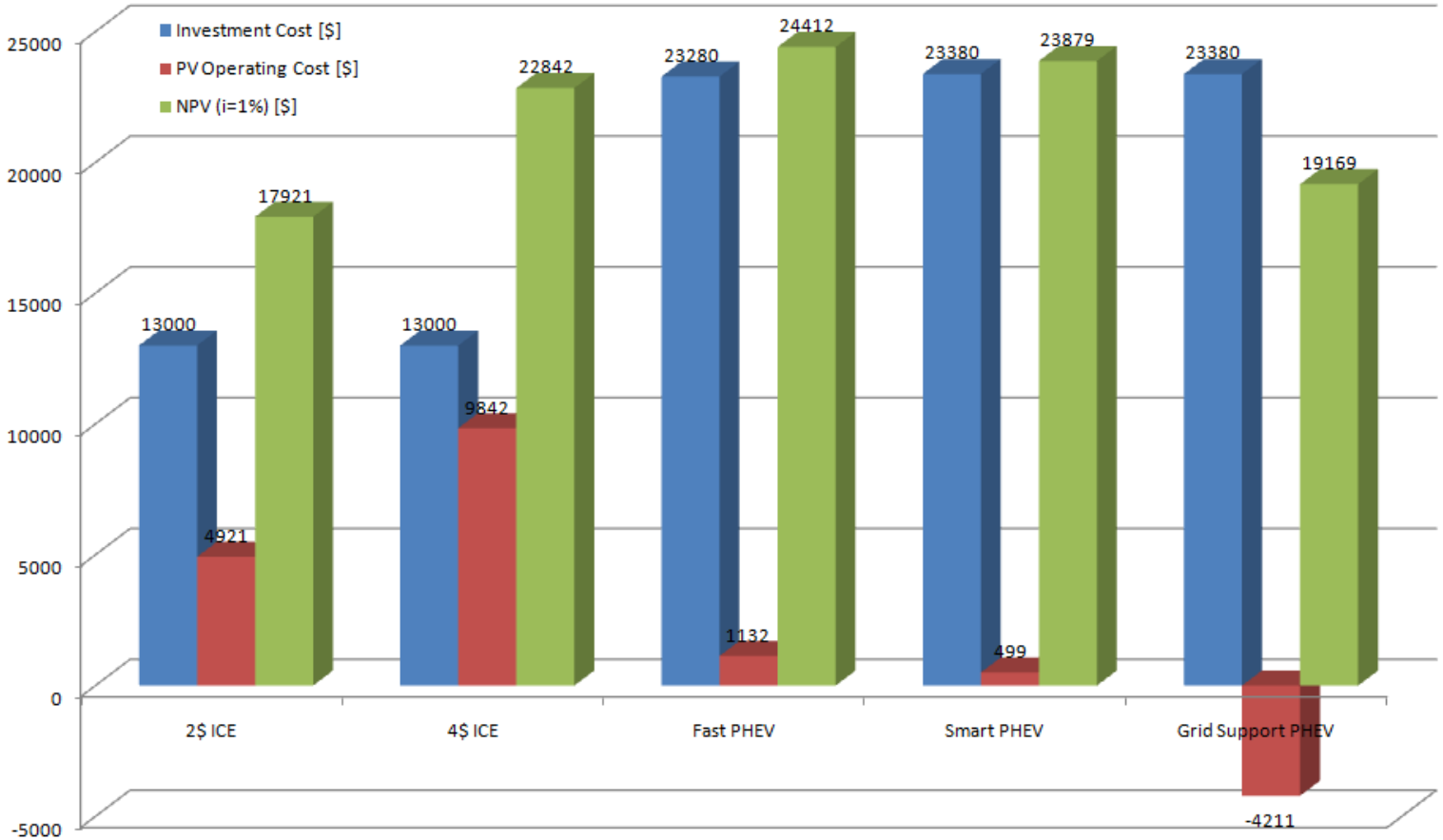
Smart Grid Support Optimization



Vehicle characteristics

Total distance [mi / km]	44.4 / 71	44.4 / 71
Vehicle Parameters		
Mass [kg]	1200	1300
Total Cost [$]	13’000	23’300
Drive Train		
IC-Engine power [kW]	100	10
Motor power [kW]	-	80
Generator power [kW]	-	10
Battery		
Total capacity [kWh]	-	4.5
Specific energy density [Wh/kg]	-	100
Maximum plug power [kW]	-	4
Specific cost [$/Wh]	-	2000
Cylce life [-]	-	7000
Energy Prices		
Gasoline low [$/gl / $/l]	2 / 0.53	2 / 0.53
Gasoline high [$/gl / $/l]	4 / 1.06	4 / 1.06
Electricity [$/kwh]	-	0.065
Regulation Up [$/kw-h]	-	0.012
Regulation Down [$/kw-h]	-	0.013

Present Value Comparison



Conclusions

1. Simple smart charging is profitable (600$) and succeeds at avoiding super peaks
2. Grid support is highly profitable and changes the economics of PHEVs (4200$) making them competitive to conventional vehicles even at 2$/gal
3. Physical models to estimate battery wear must be developed and integrated into the algorithm