UNIVERSITY OF WASHINGTON
ELECTRICAL ENGINEERING

Electric Vehicles Aggregator/System Operator Coordination for Optimal Charging Scheduling and Services Procurement

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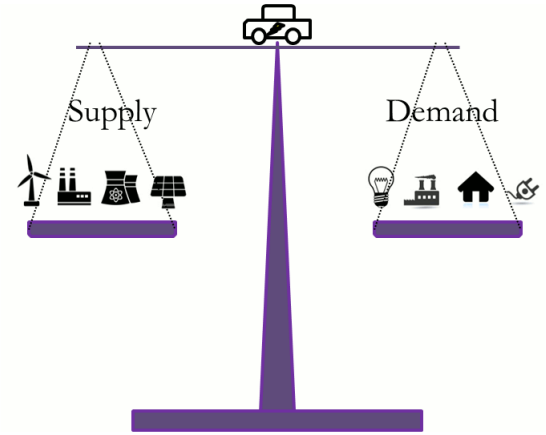
Introduction

- Decarbonisation of the transportation sector:
  - Electricity as energy carrier
  - Ideally, energy from RES
  - Large fleets of EVs will constitute a significant share of the wide system demand

- Advent of the Smart Grid
  - Demand will feature higher degrees of communication and control

Electric vehicles (EVs)

- Unlike most existing loads, EVs are equipped with a battery:
  - Waive their energy requirements in time
  - Energy storage
  - Provide ancillary services, e.g. reserve



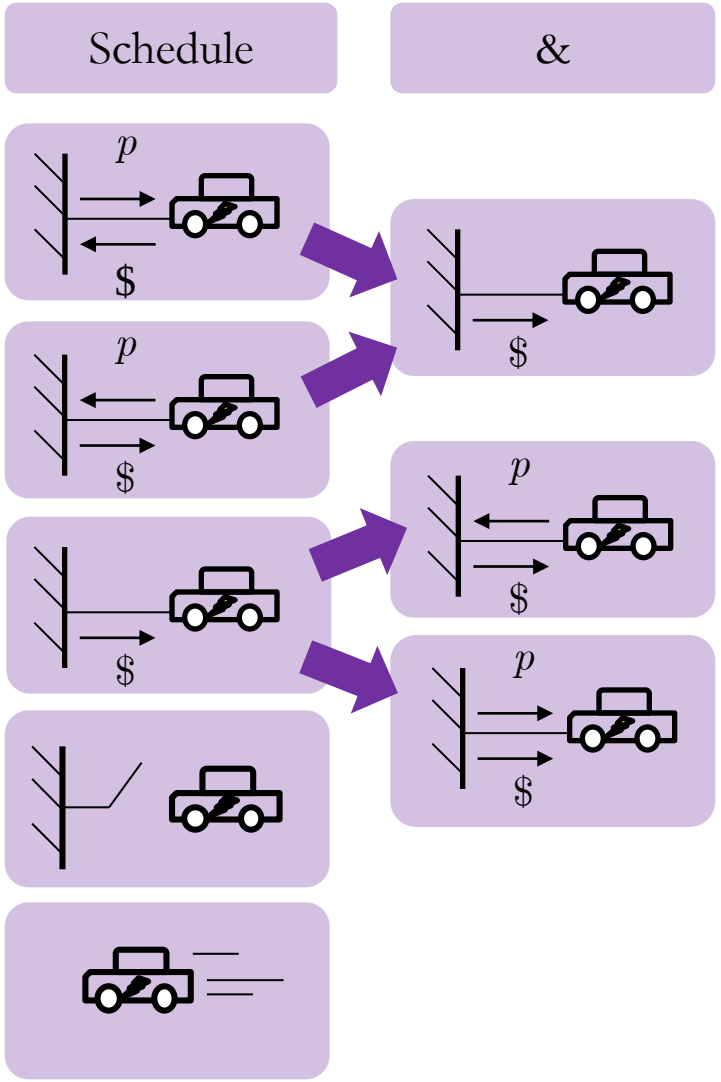
Impacts

- The pliant nature of the EVs as demand makes them good candidates to impact the system:
  - Technically: provide *flexibility* to the system
  - Economically: trading that *flexibility*

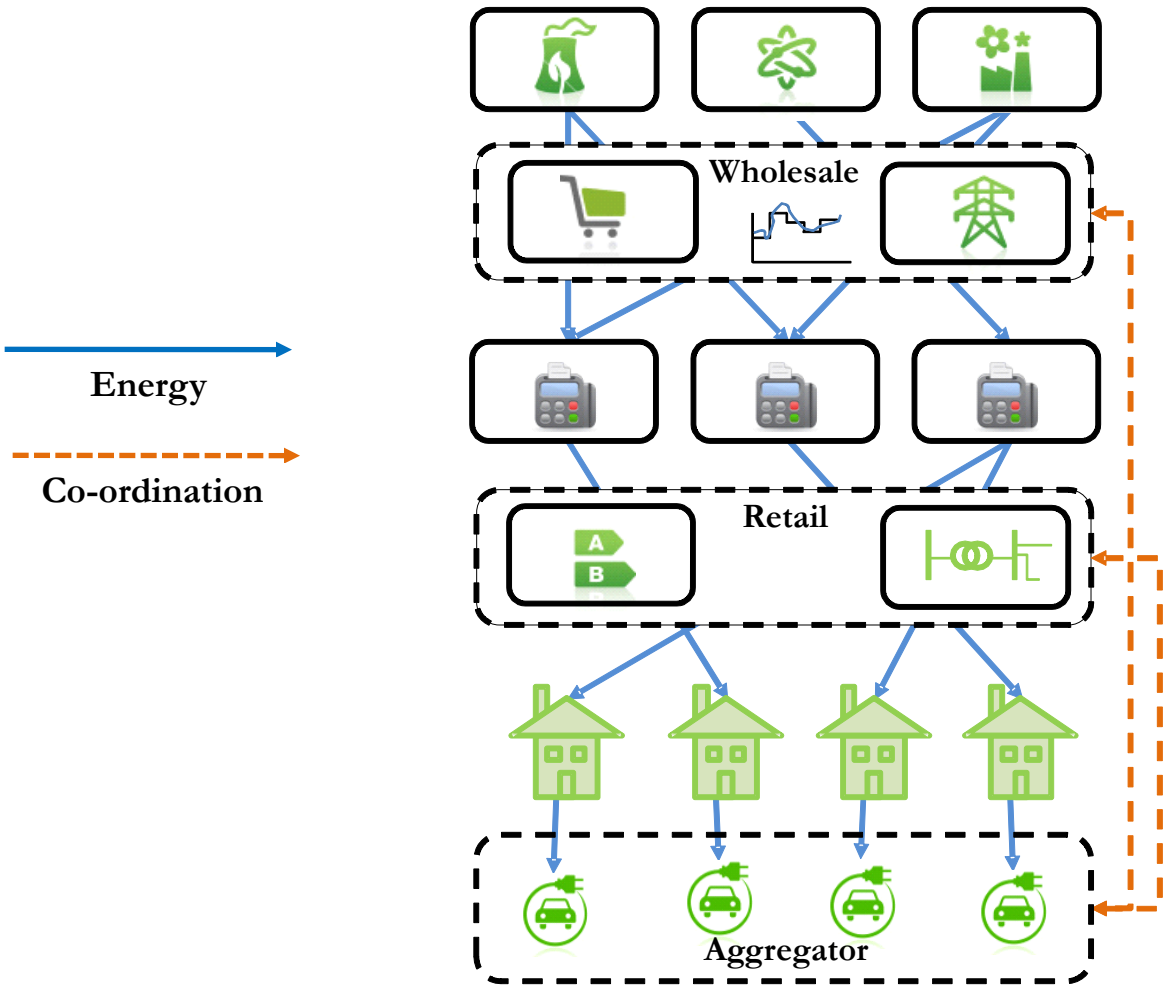
EVs operating modes

EV operating mode

- Vehicle charging
- Vehicle discharging (V2G)
- Vehicle plugged-in
- Vehicle unused
- Vehicle circulating

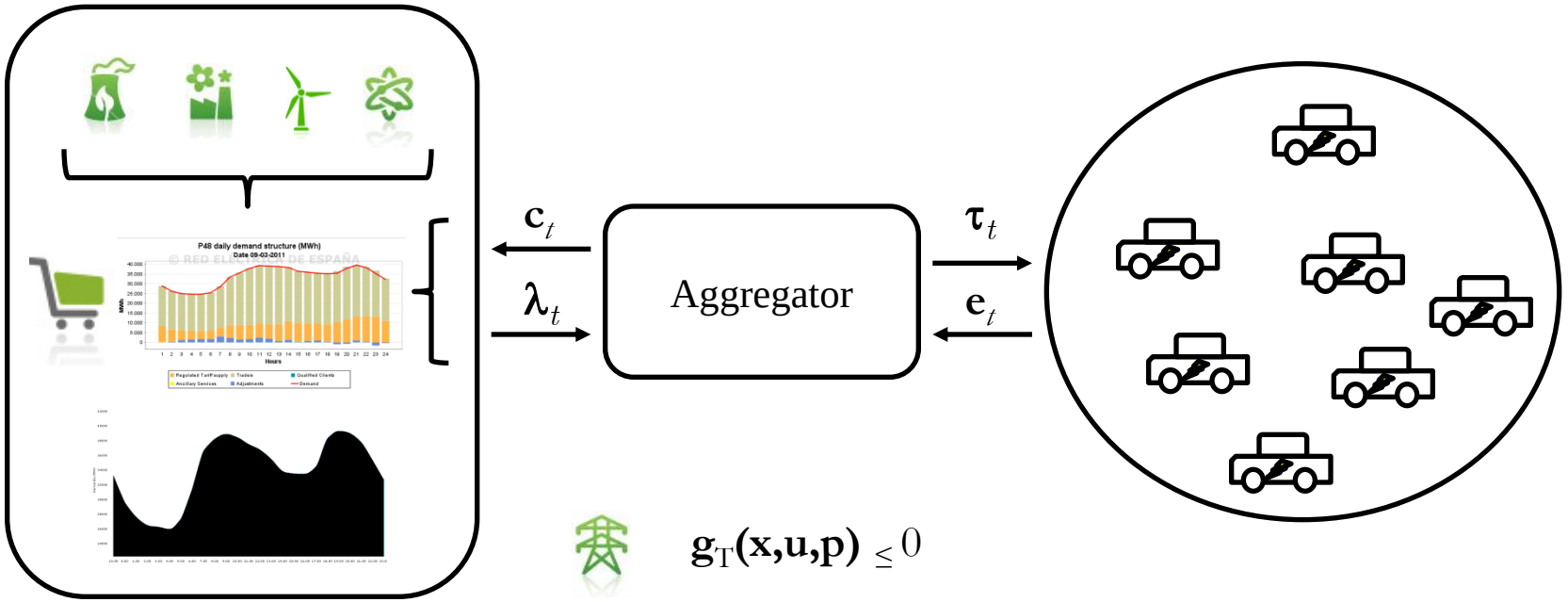


Power system + EVs



Aggregator

- Bridge between EVs and power system players:



Interaction Aggregator & SO

- **Generation scheduling**
  - Minimize total operating costs
    - Power balance constraint (including EVs' charge and discharge)
    - Security: system reserve requirements (unforeseen events)
    - Units technical operating constraints:
      - Minimum up- and down-times
      - Up and down ramp rate limits
- **EVs scheduling**
  - Sell flexibility services to the system
    - EVs' energy requirements
    - EVs operating constraints:
      - State of charge
      - Charging and discharging rates

From day-ahead to real-time

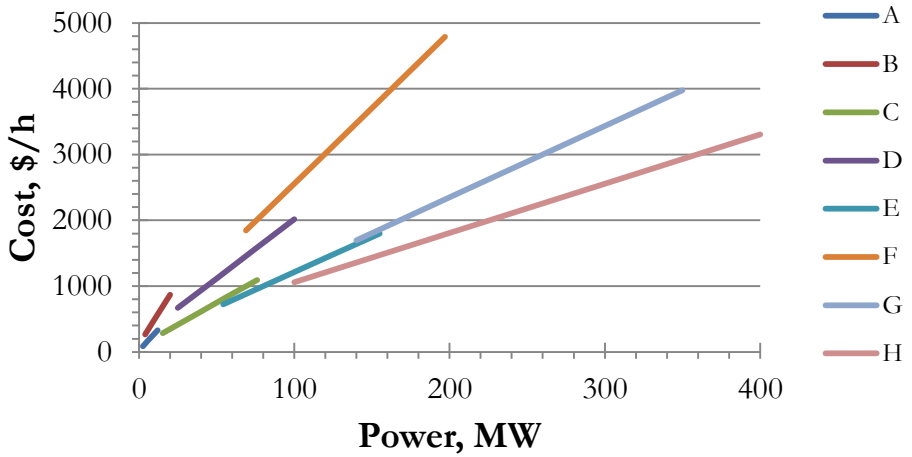
- Schedules are performed a day-ahead on the basis of:
  - Wind power generation forecast
  - Demand forecast
  - Forecasted EVs availabilities
- Deviations between forecasts and actual values materialize in real-time
  - Conventional generation deployment to meet net demand deviations
  - Deployment of EVs' flexibility services as a function of the agreed prices the day before

Test system

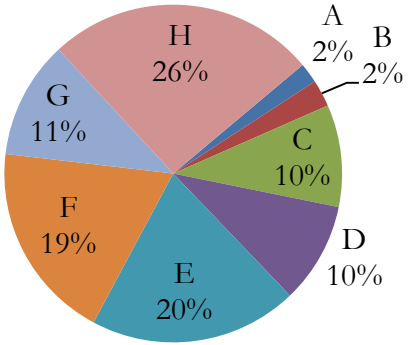
- IEEE-RTS omitting hydro generation
  - 26 Units, 3105 MW installed

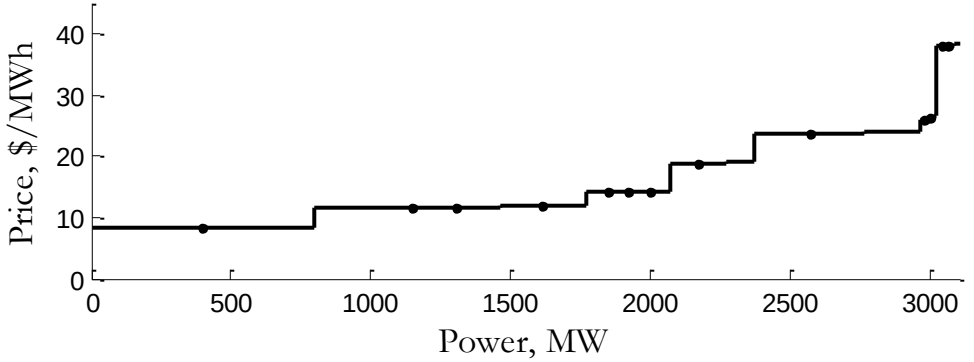
Group	# Units	Capacity (MW)	Fuel
A	5	12	oil/steam
B	4	20	oil/CT
C	4	76	coal/steam
D	3	100	oil/steam
E	4	155	coal/steam
F	3	197	oil/steam
G	1	350	oil/steam
H	2	400	nuclear

Cost functions



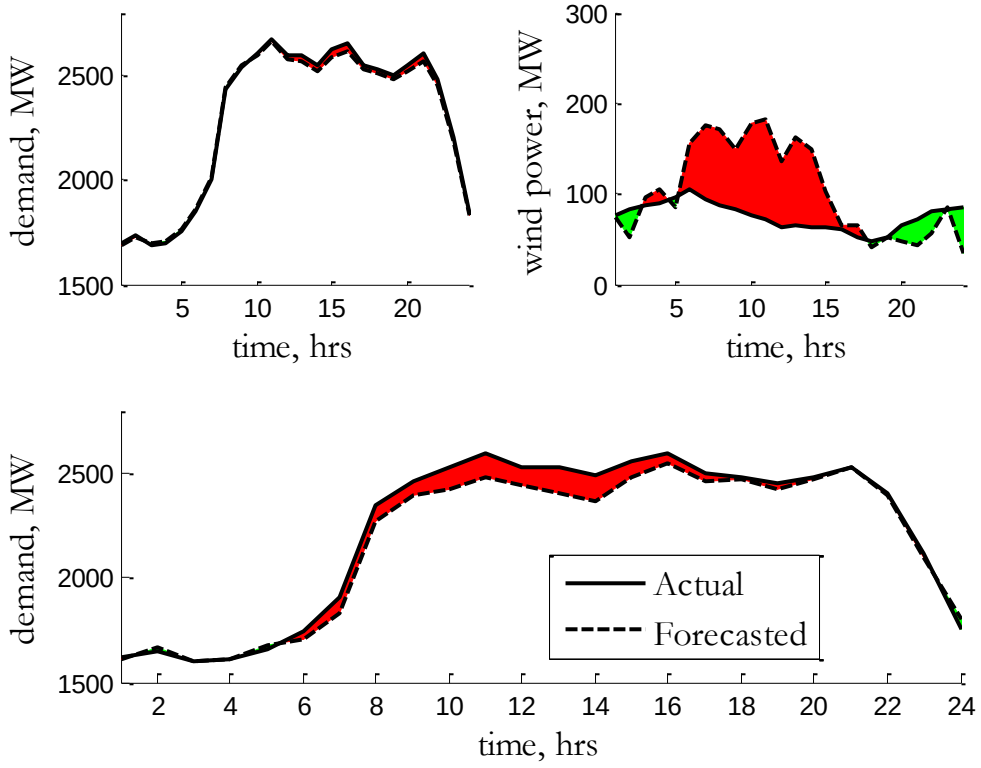
Composition





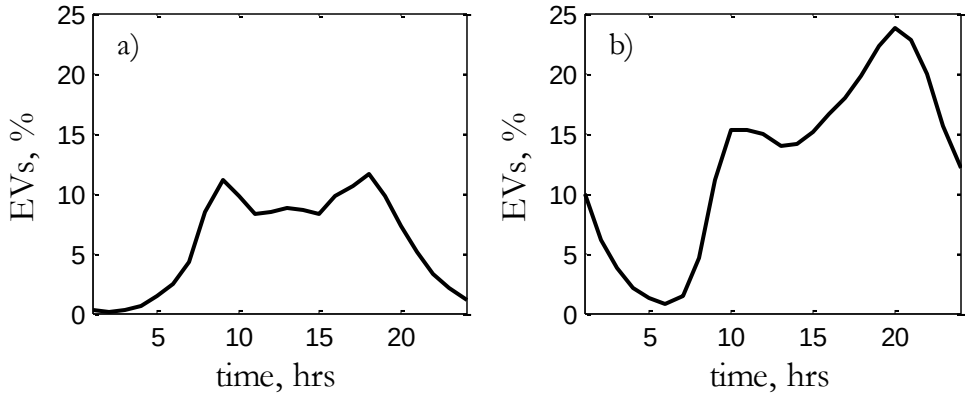
Demand and wind profiles

- Forecasted and actual values…

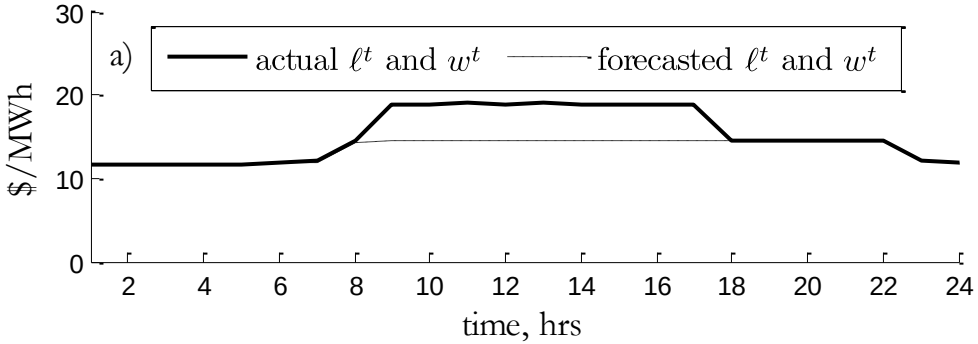


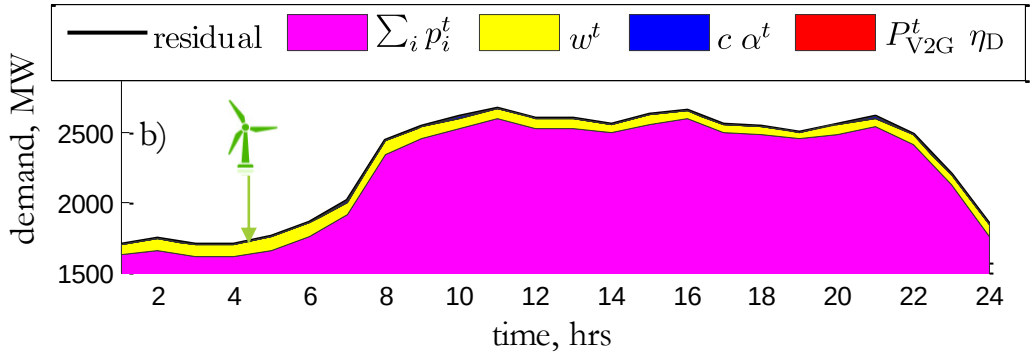
EVs' characteristics

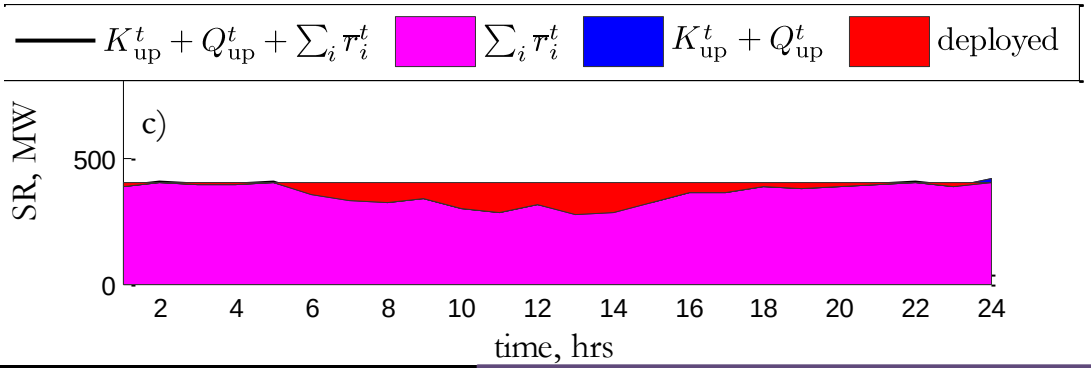
EV parameter	EV type			
	BEV	City-BEV	PHEV	Value
EV fleet composition (%)	37	10	53	100
Battery capacity (kWh)	35	16	18	24.1
Energy consumption (kWh/km)	0.2	0.12	0.2	0.192
EV range (km)	175	133	90	125.5
Average distance (km/day)				40.0
Daily consumption (kWh/day)				7.68
Charge/discharge rate (kW/h)				3.70
Total number of vehicles				689,475

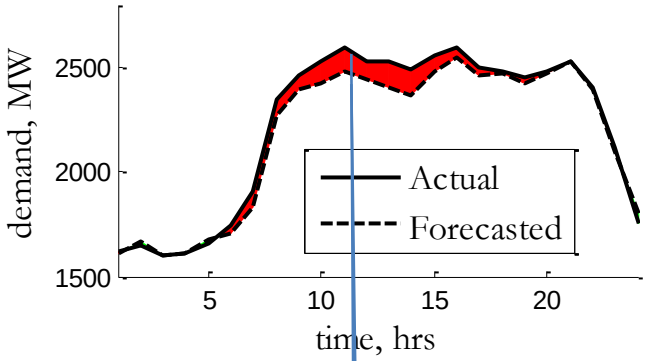


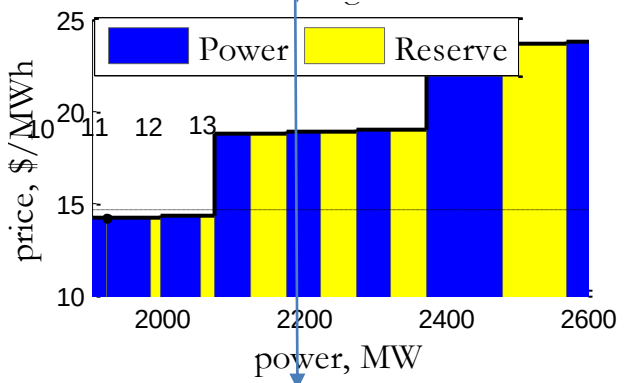
System with no EVs

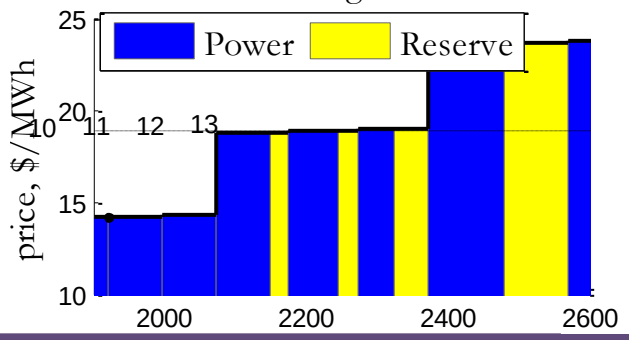




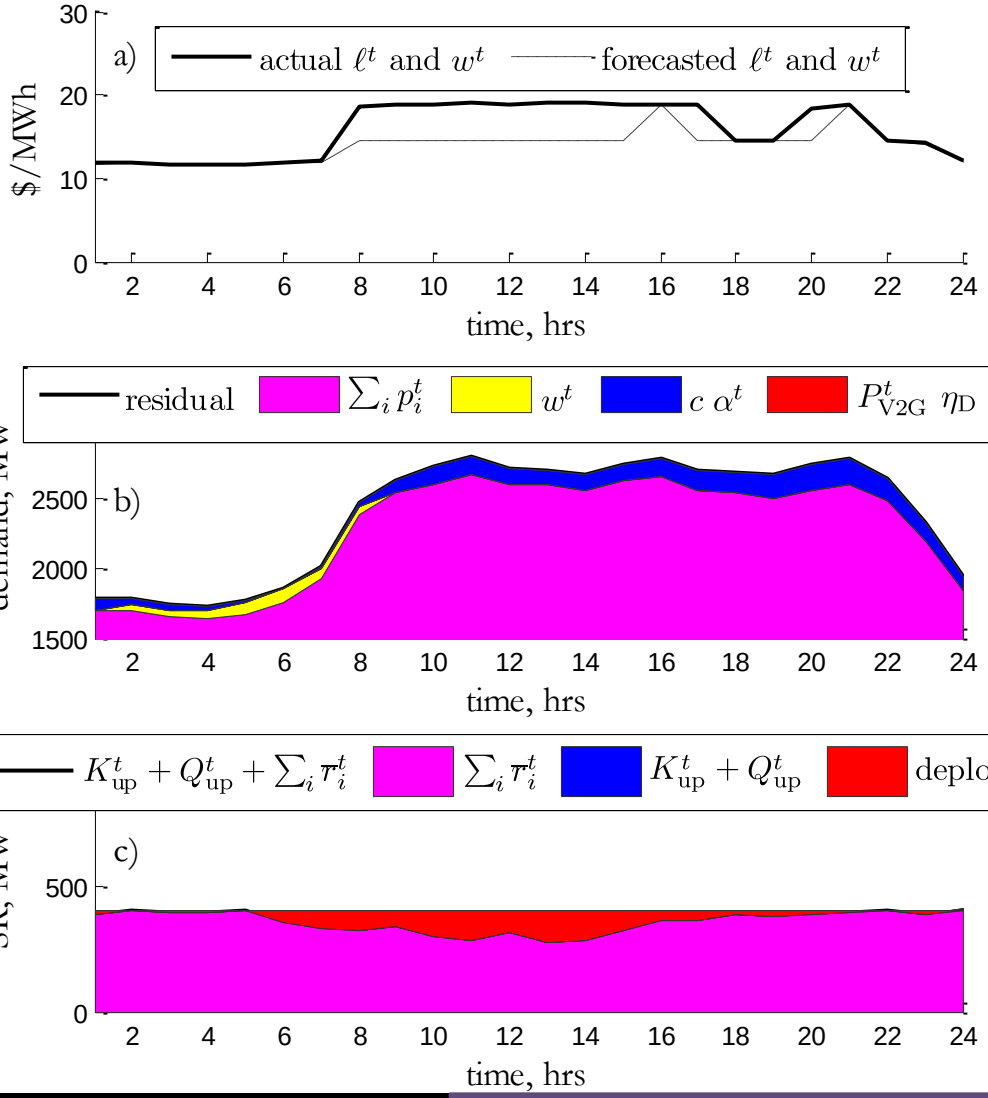


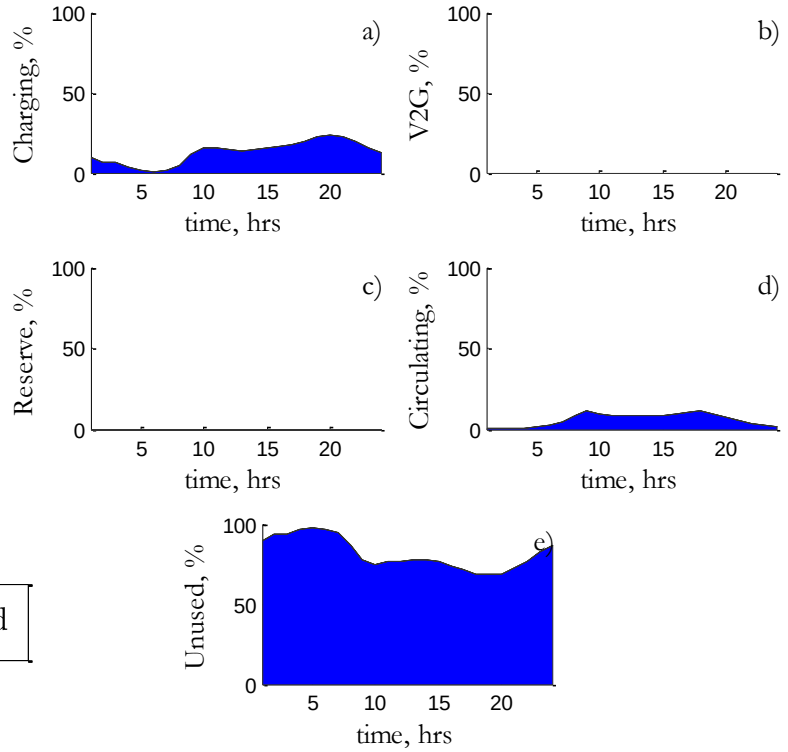






Uncontrolled EVs – 30% penetration





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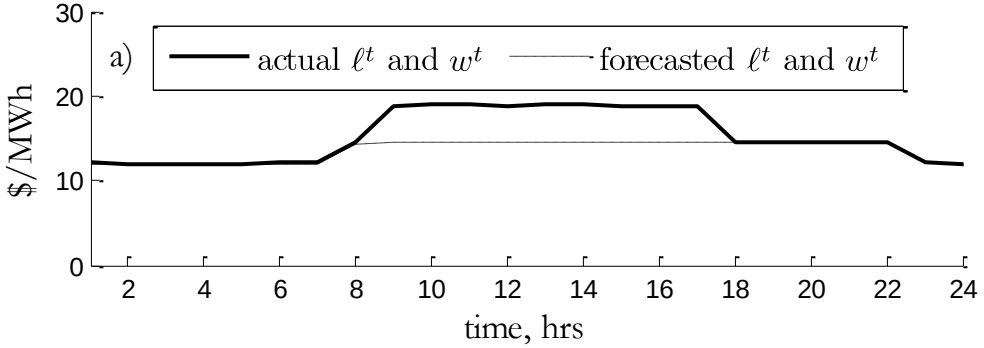
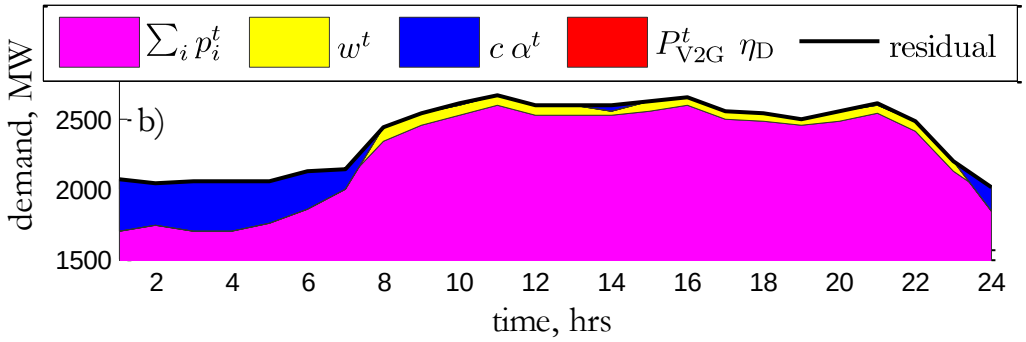
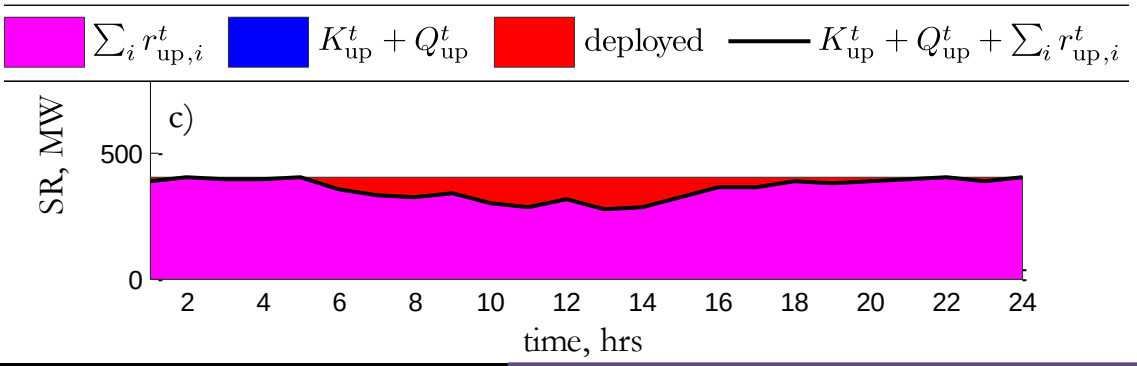
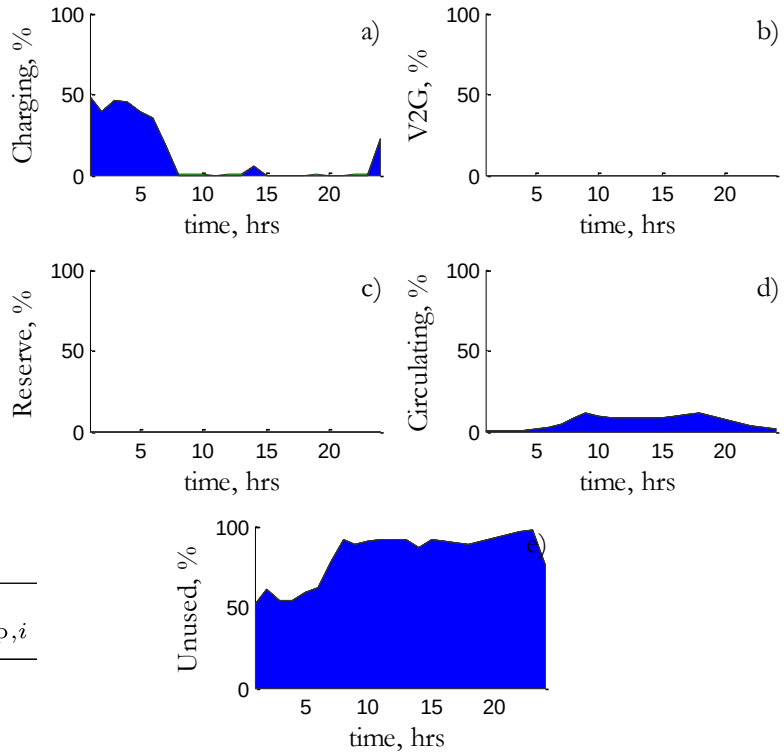
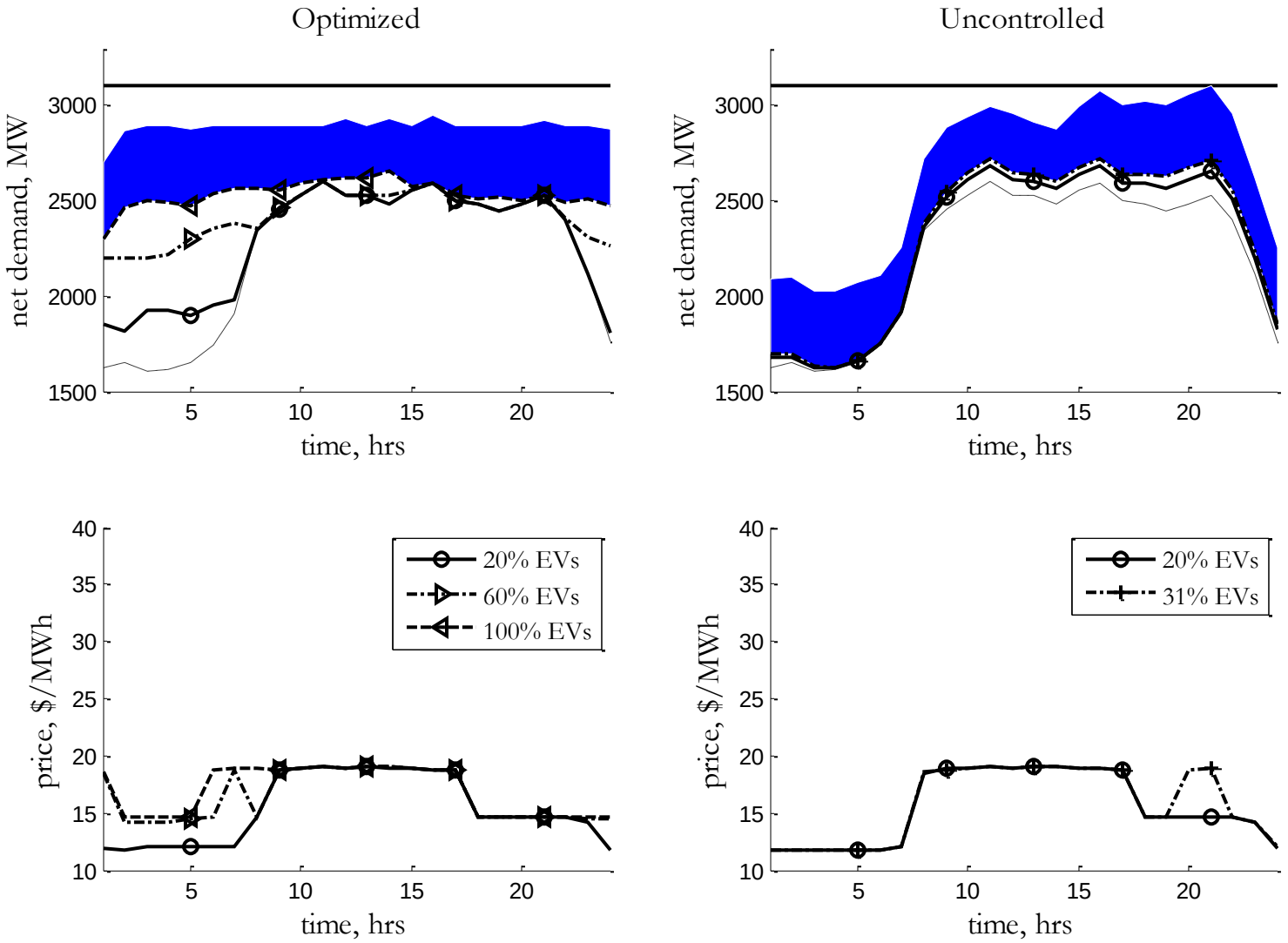




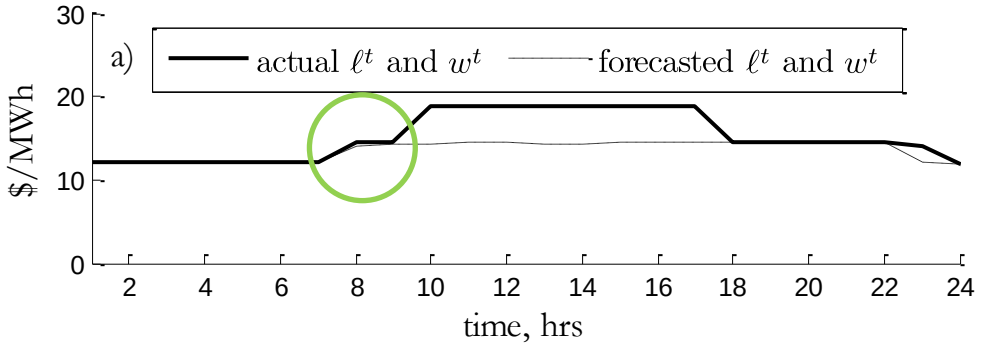


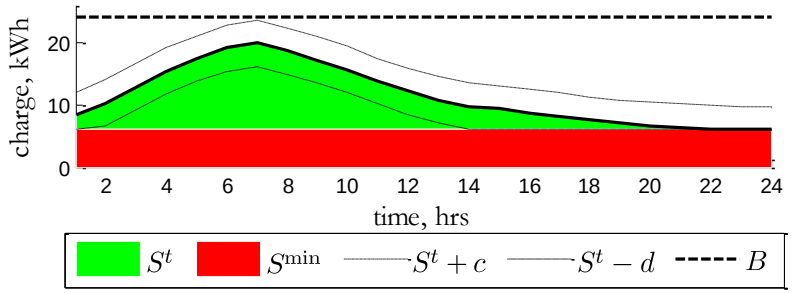


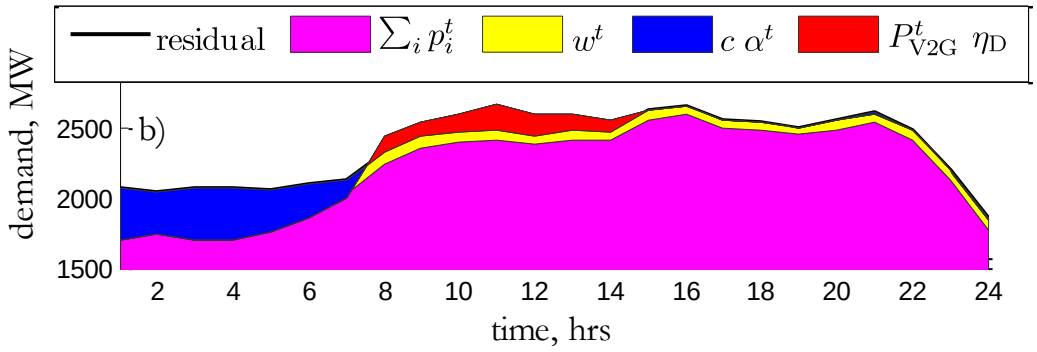
Effect of the EVs' penetration

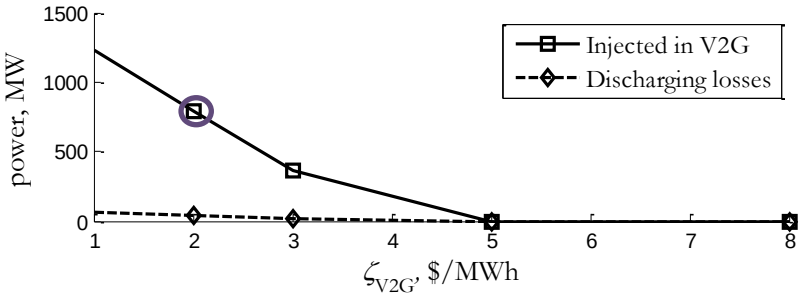


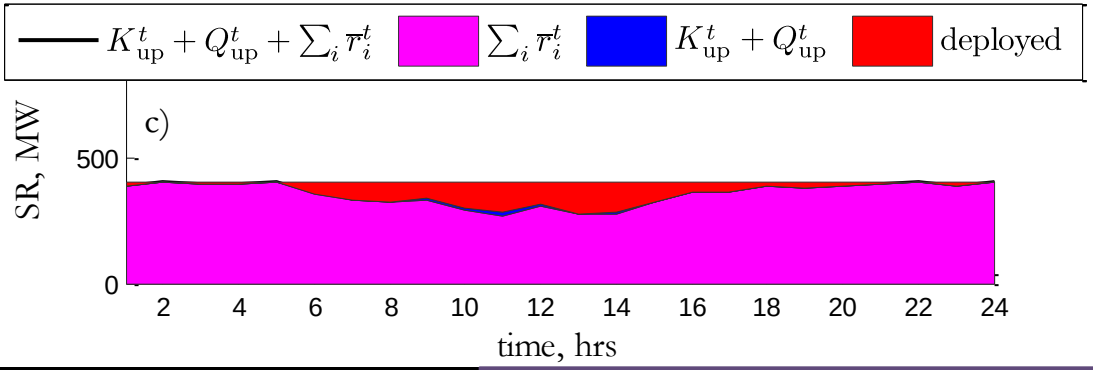
Effect of the V2G markup





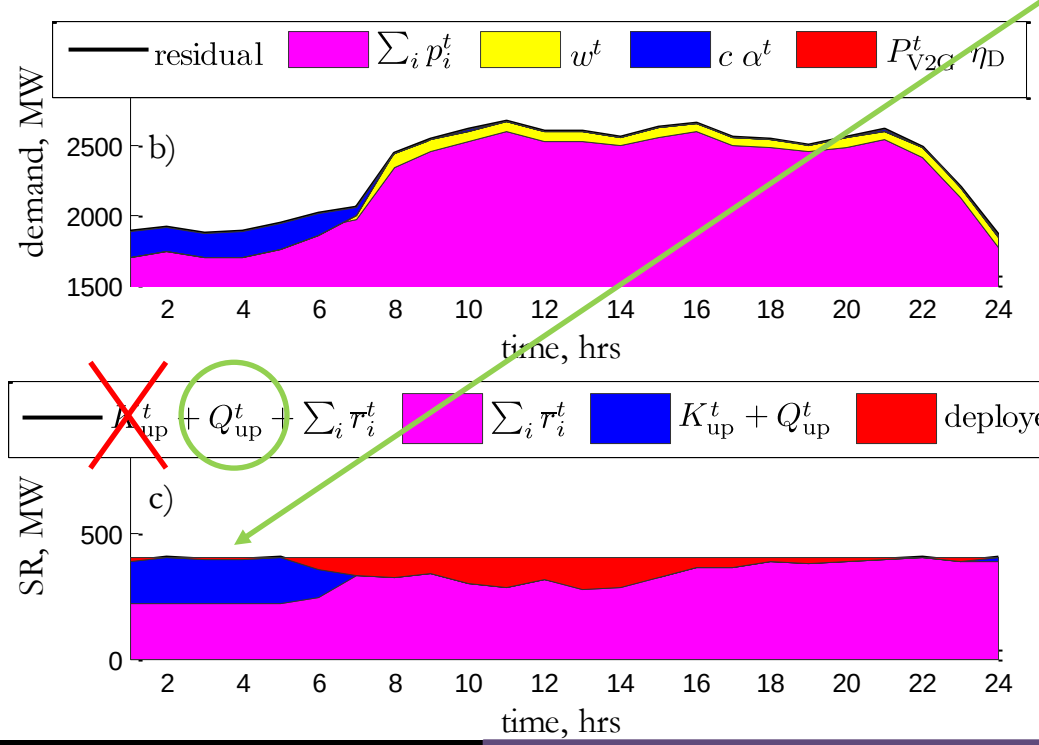


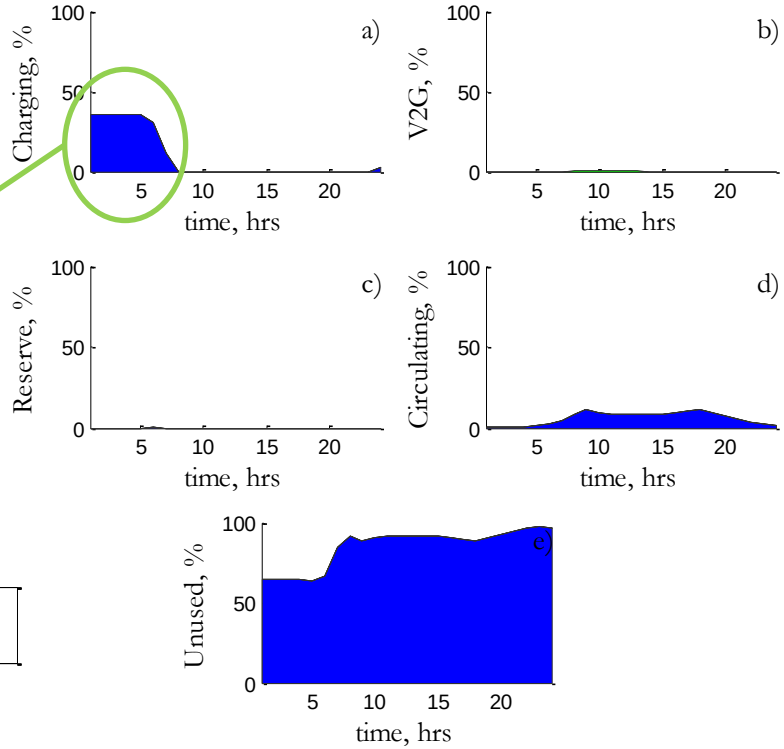




Effect of the pricing of the reserve from EVs

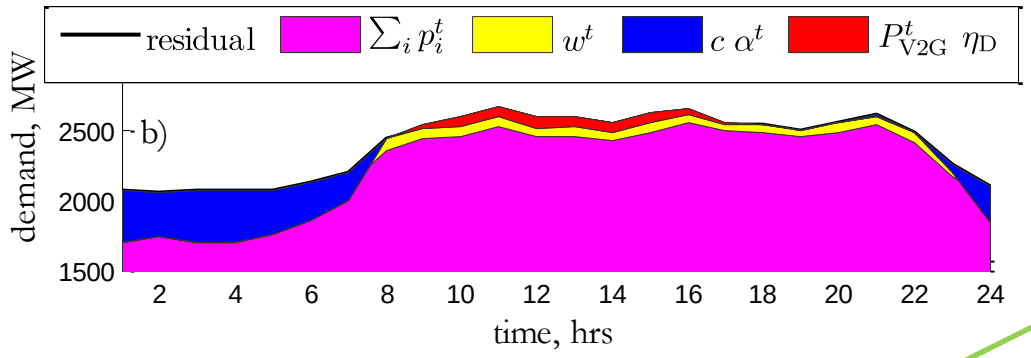
- The price of the reserve from the supply side is 20% of the bids of energy
- Reserve from EVs at 2 $/MW

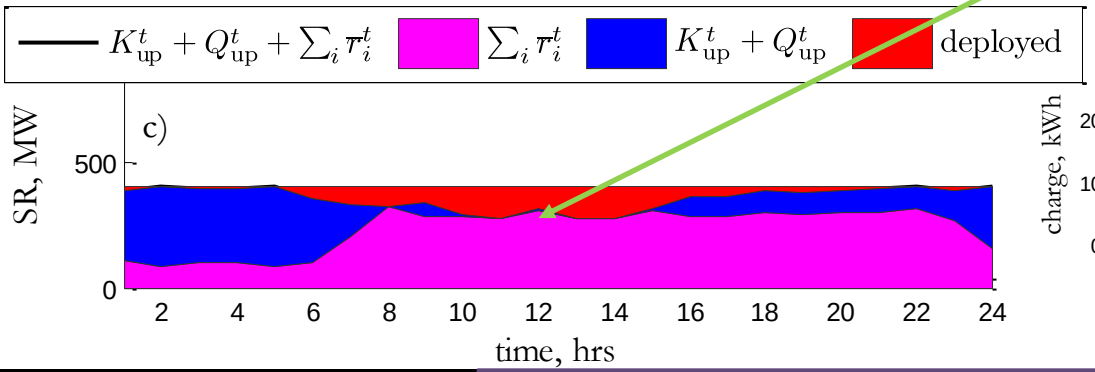


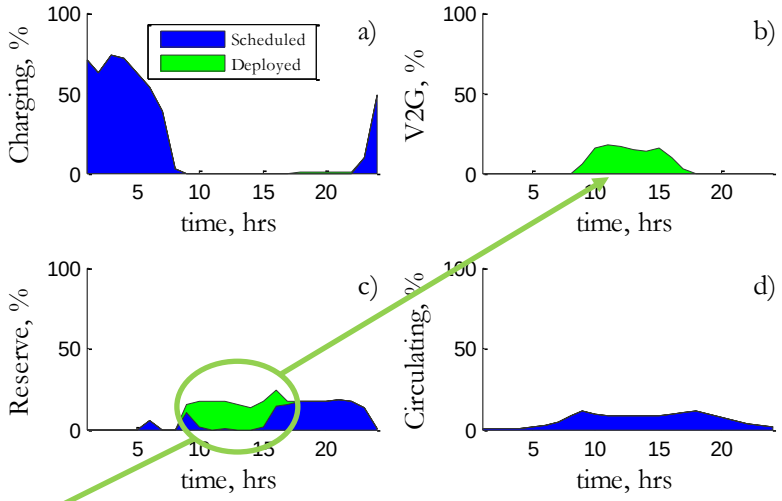


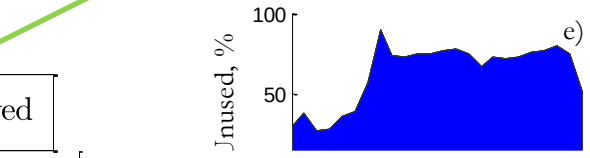
Reducing the exercise price for reserve deployment

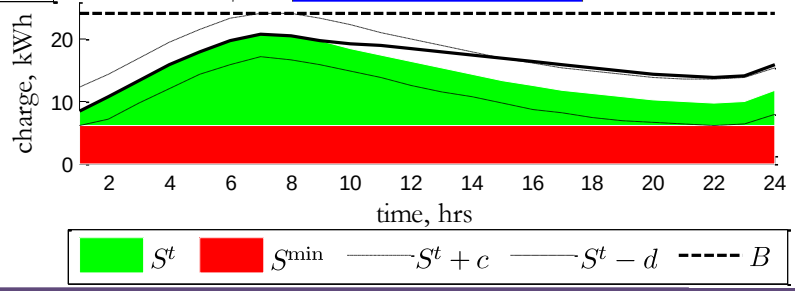
- Price of the reserve from the supply side at 30% of the bids of energy
- Reserve from EVs at 2 $/MW
- Exercise price at 5 $/MWh











Summary

- Presented the necessary adaptations to a typical US-style short-term forward electricity markets including EVs fleet aggregators
- The operating constraints of the EVs are explicitly modeled
- Represents adequately the collective operation of the EVs to attain benefits while reducing operating costs
- Several ancillary services and their deployment are represented: V2G, Reserve capacity as additional charge and interruption of scheduled charging/discharging

Conclusions

- If no coordination is implemented, only a limited amount of EVs can be successfully integrated in the system
- Implementing an approach such as the proposed, allows the integration of large volumes of EVs without needing to invest in generation assets
- The participation of the aggregator(s) as service providers determined by the services bids

Conclusions

- Charging process is scheduled at the cheapest periods
- Services from EVs are scheduled only if these are competitive with those from conventional sources
- V2G is attractive to avoid synchronization of expensive generation
- Reserve is in the form of interruption of charging is attractive, but it can only be offered when EVs are charging → light loads…
- Reserve as additional charge are attractive, but only when their supply equivalent is expensive