

# • Optimal Strategies for Battery Switch Stations • for Electric Vehicles

M Armstrong, C El Hajj Moussa, J Adnot, A Galli & P Rivière

IAEE Venice September 2012

# •Recharging electric vehicles

## Literature

Most papers study the impact of recharging at home or workplace with or without smart meter.

Schneider et al (2011) studied 3 scenarios for recharging 1M EVs in Washington-Baltimore Metropolitan Area:

- unmanaged charging,
- consumer-incentivized recharging
- • getting a central operator to coordinate the recharging in response to real-time prices

As expected, third option leads to lower wholesale prices & reduces load peaks. Both socially desirable objectives.

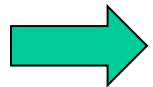
# •Recharging electric vehicles

The central network operator could control the recharging of batteries in cars but this requires a detailed knowledge of the state of each battery & of car owner's driving patterns, making it very difficult to optimise properly.

Instead we consider the case where batteries are exchanged at a battery switch station (where batteries are anonymous).

BSS operator has 2 ways of buying the power to recharge the batteries:

- By negotiating an energy purchase contract with an electricity supplier



- By buying & selling on the day-ahead market.

# •Recharging electric vehicles

We developed strategies for BSS to buy & sell power via the day-ahead market. They were optimised for a fleet of **300,000** EVs using market data from France for years 2010 & 2011.

- Impact of these strategies on day-ahead prices & volumes.
- How robust are these strategies?

## Unexpected result:

If arrival times of EVs are spread-out evenly over day and if the BSS works in V2G mode, the BSS can actually make an operating profit rather than just minimising the cost.

# •Proposed method

In order to buy/sell on market, BSS operator would have to place offers before 12 noon on the day before delivery.

As offers are contractually binding, BSS operator needs a strategy to decide how much to offer to buy/sell in each 1 hour period. We assume that he/she is a price-taker.

We consider two cases:

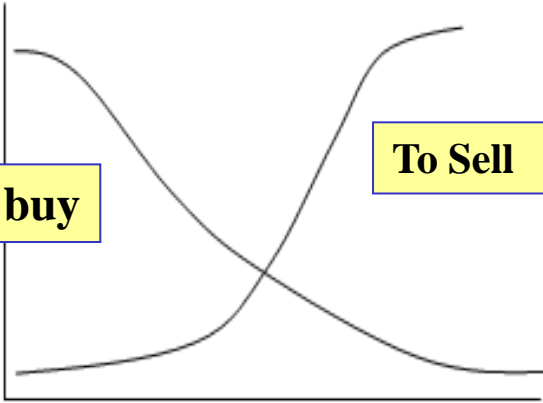
- vehicle-to-grid (V2G) ie selling as well as buying
- grid-to-vehicle (G2V) ie just buying

Offers to buy & sell

Price

To buy

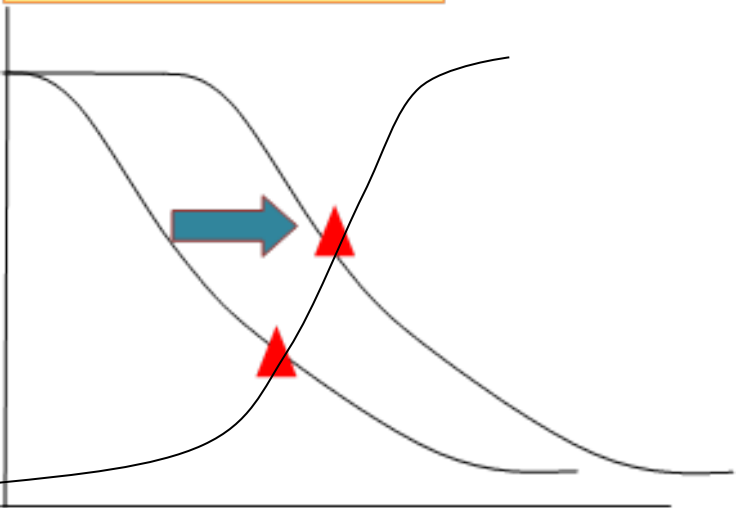
To Sell



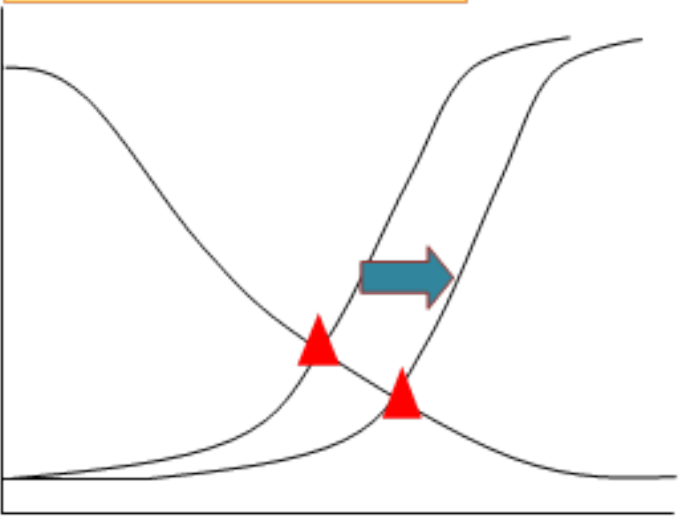
Buying more

Volume

Selling more



⇒ Higher price



⇒ Lower price

# •Proposed method

As electricity usage patterns vary on different days of week, we construct different strategies for each day. Public holidays must be taken into account.

To construct strategies we need a training set of observed data. It should be short enough to reflect current behaviour (ie seasonal): previous 4 weeks.

# •Arrival time of EVs

EVs come into to the BSS between 6am & 10pm.  
So all batteries must be recharged by 6am.

## In V2G mode

BSS sells electricity when the price is high & buys when it is low but must always have enough charged batteries ready. So the arrival time of EVs affects the strategies.  
Two scenarios: evenly spread out from 6 am to 10pm or worst case scenario, all EVs arrive at 6am.

## In G2V mode

EVs are recharged at night from 10pm until 6am. So their arrival time does not affect the strategies.



# • Impact of recharging 300,000 EVs

## Assumptions

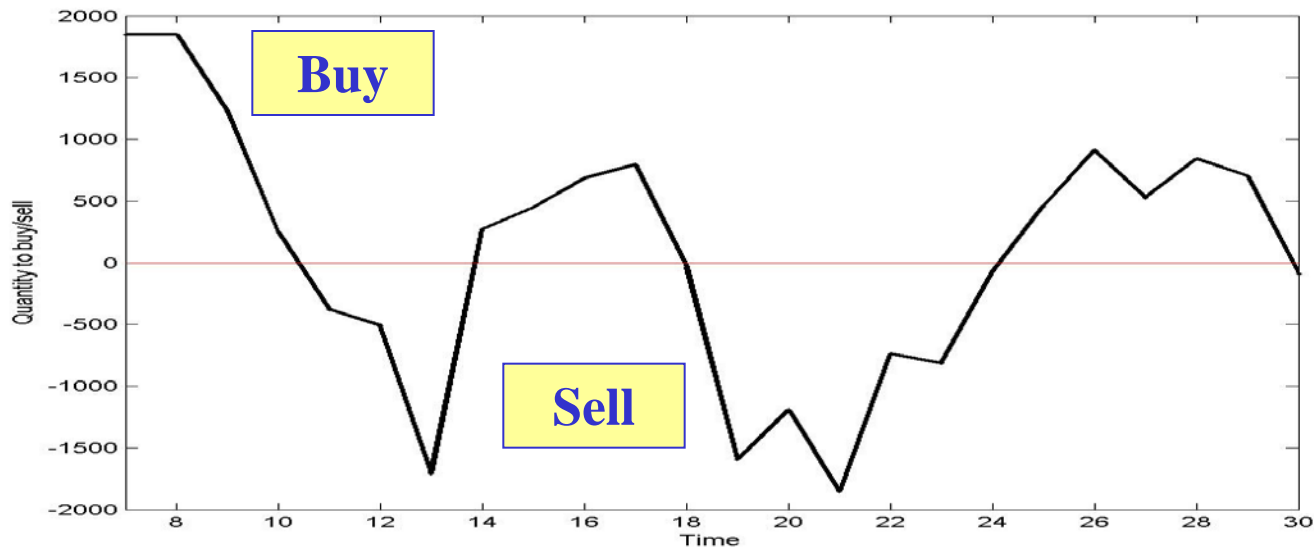
- EVs exchange their batteries twice per week
- Equal numbers come each day of week.  
$$\text{N}^\circ \text{ EVs per day} = 300,000 \times 2/7 = 85\,700.$$
- BSS has 100 000 spare batteries.

**Recharging so many batteries affects market prices & volumes.**

# • Results

## Optimal strategy

The optimal strategy gives amount that it would have been optimal to buy/sell each hour of day for each day for G2V mode and for V2G mode, i.e. USING the true data known afterwards. The associated cost is also computed.

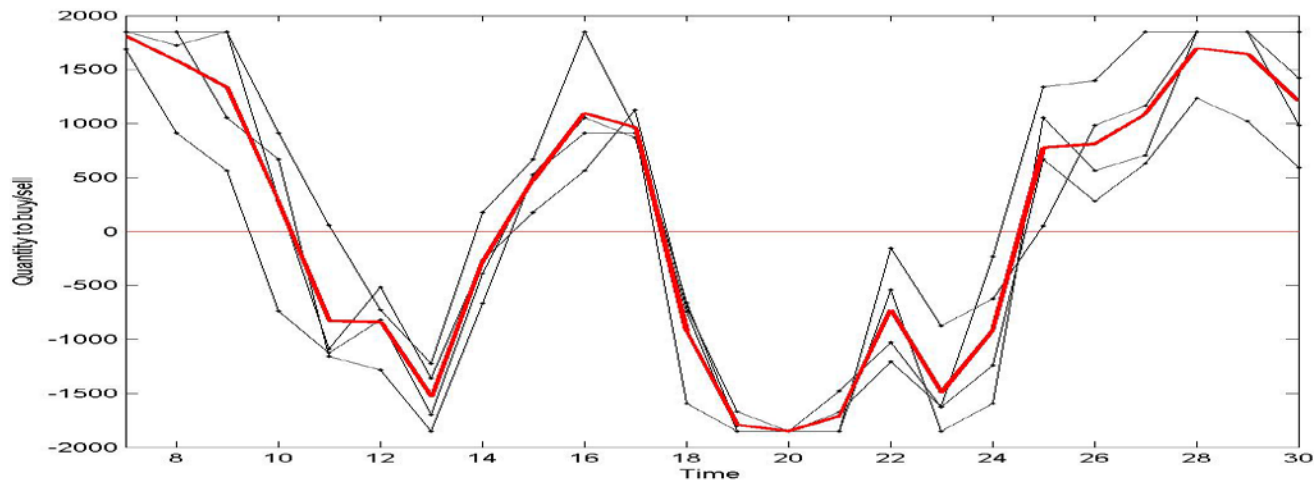


# • Results

## Proposed strategy

We compute the average of the optimal strategies on the same days in the training set (4 Thursdays, 4 Fridays etc) **USING** data available beforehand.

We compute the realised cost (or profit) if proposed strategy is used, **BUT USING** the true data known afterwards.



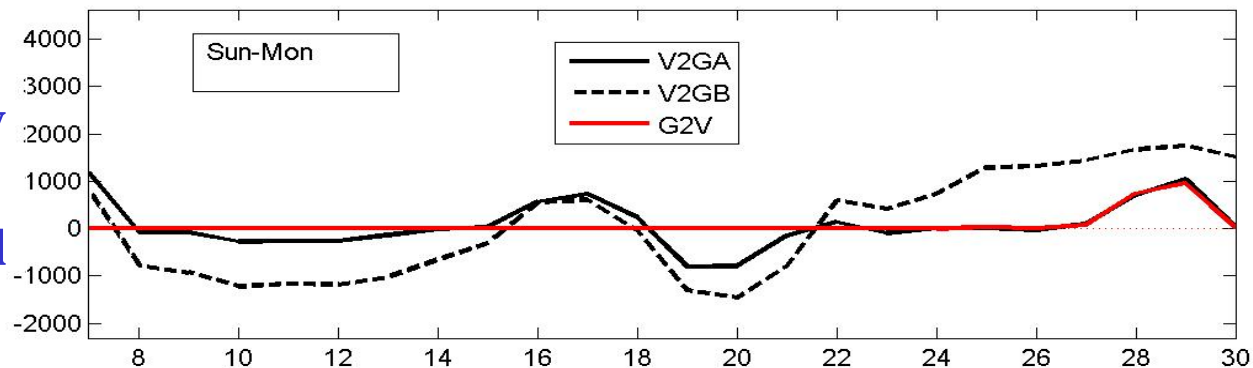
# • Results

## Optimal strategy: winter 2010

Optimal Schedules Jan-March 2010

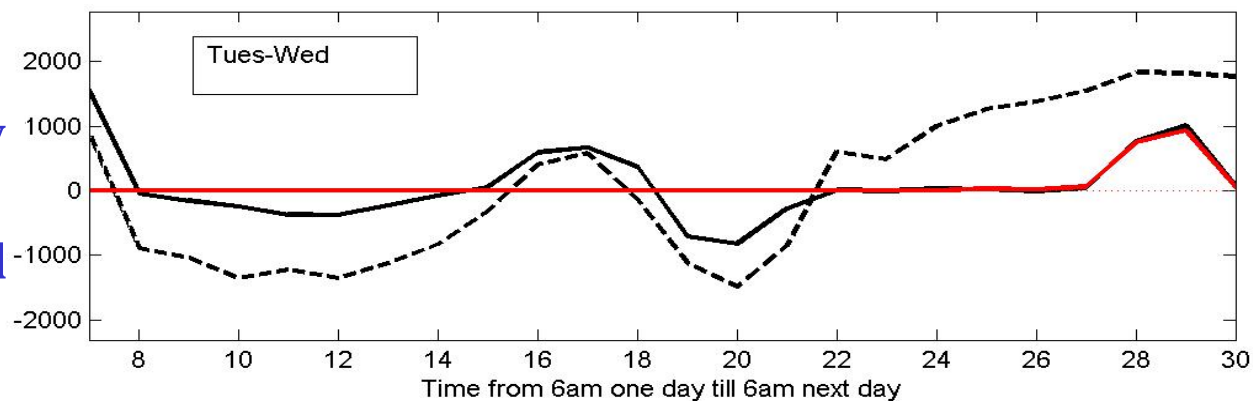
Quantity to buy

Quantity to sell



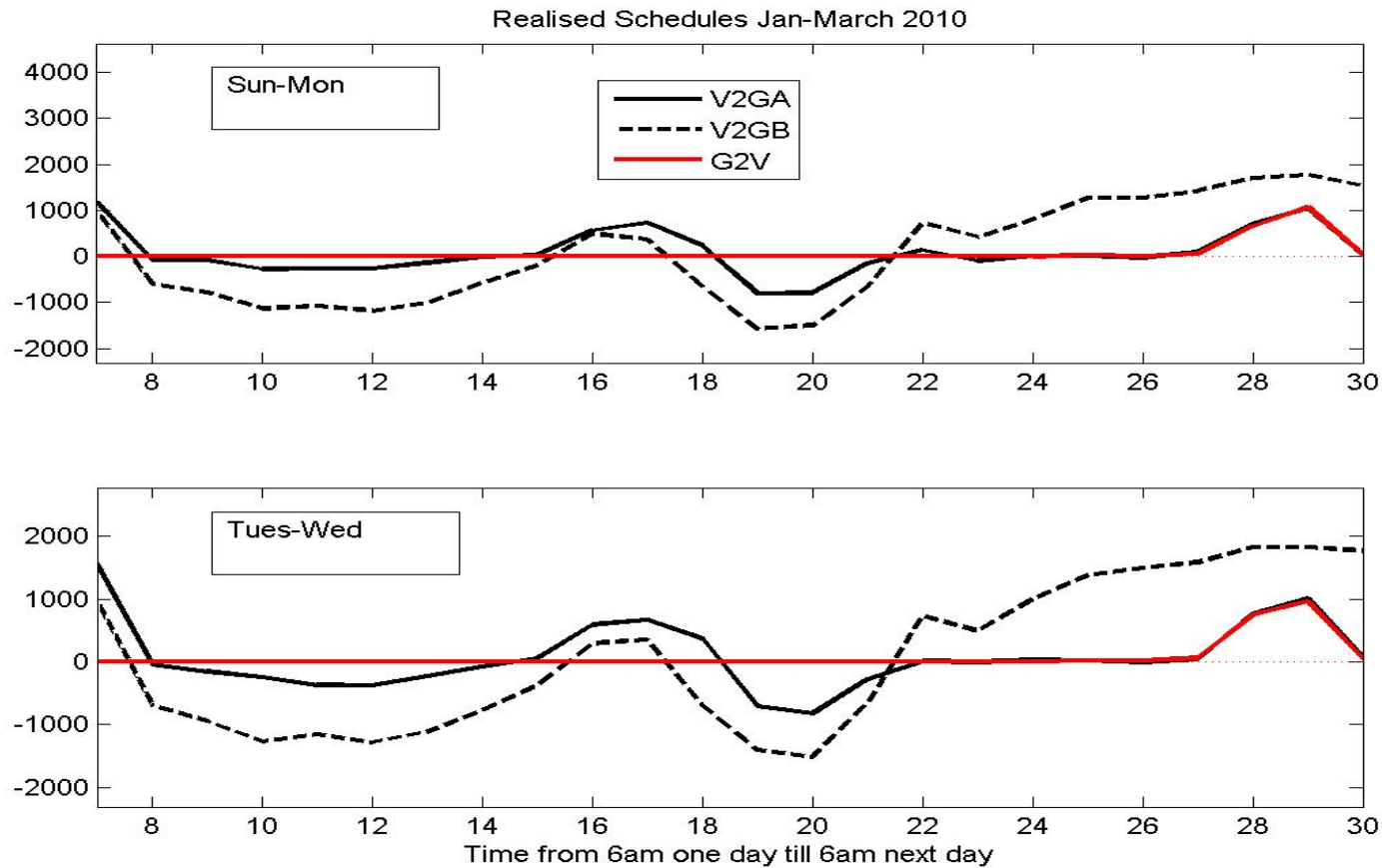
Quantity to buy

Quantity to sell



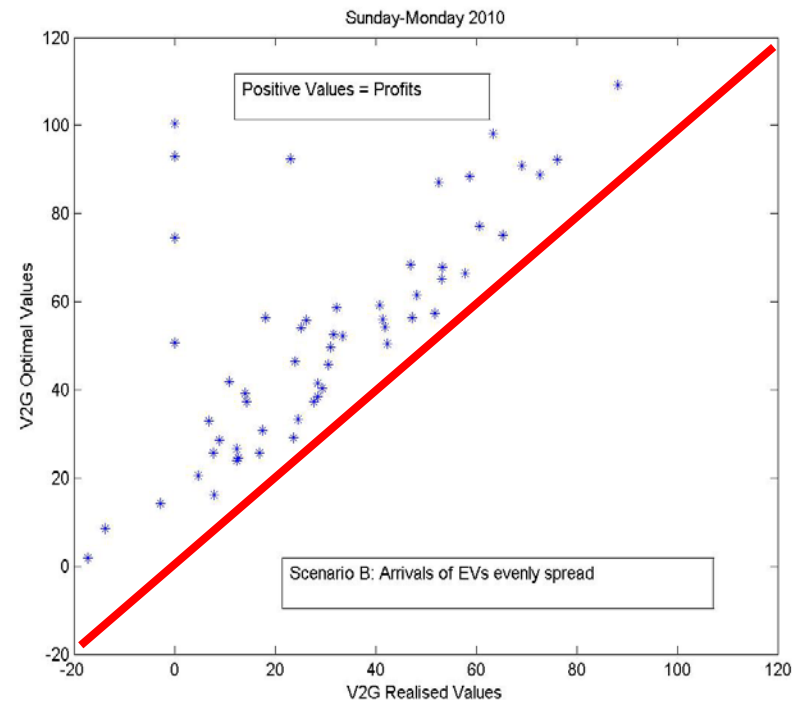
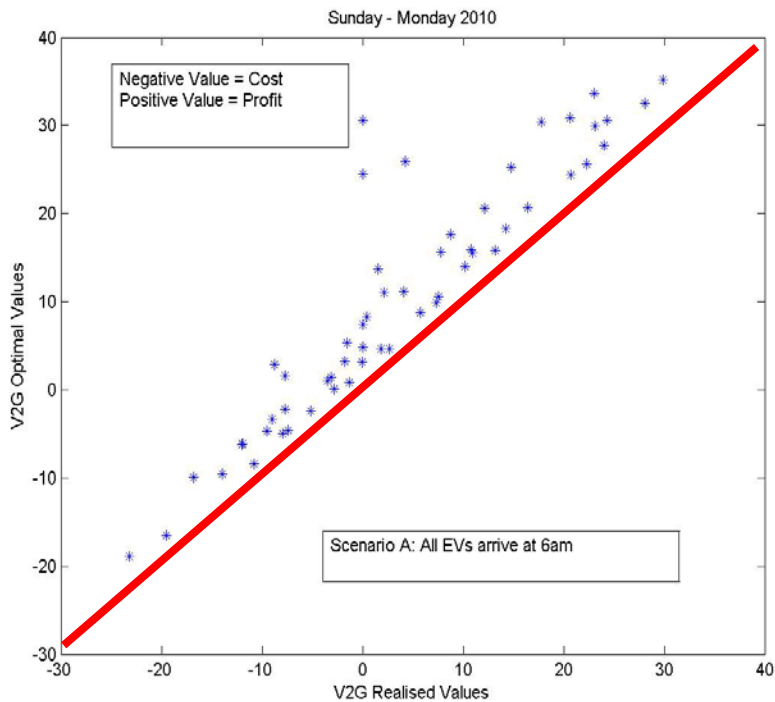
# • Results

## Realised strategy: winter 2010



# • Results

## Optimal Value versus realised value: Sun to Mon 2010



# •Results: comparison with power purchase contract

Realised Value					
2010	No losses	%5 Losses	2011	No losses	%5 Losses
G2V	-21.87 M€	-21.96 M€	G2V	-22.74 M€	-22.86 M€
V2G A	-9.99 M€	-10.16 M€	V2G A	-14.35 M€	-14.57 M€
V2G B	27.37 M€	26.39 M€	V2G B	6.48 M€	6.48 M€

**Negative value = cost; Positive value = profit**

**Benchmark baseload price: 40 €/per MWh (NOME Law)**

**Cost of same quantity = 27 M€**

**Here G2V cost = 22 M€(2010) 23 M€(2011)**

# •Conclusions

- As expected, recharging the EVs by switching batteries drops the electricity price in peak hour & reduces peak loads, which are both desirable for society as whole.
- It would be cheaper for the BSS to buy power through the day-ahead market (G2V) than at NOME law price.
- In the V2G case, the BSS might actually be able to make a profit (rather than having to pay for power) if arrivals of EVs are evenly spread throughout day.

Design tariffs to encourage EV owners to do this



• **Any questions?**

# •Conclusions

---

**BSS will be required to provide emergency backup to extend range of EVs.**

**Will government subsidies be required for them?**

**The fact that in the V2G case, the BSS might actually be able to make a profit by selling power on day-ahead market has policy-making implications.**

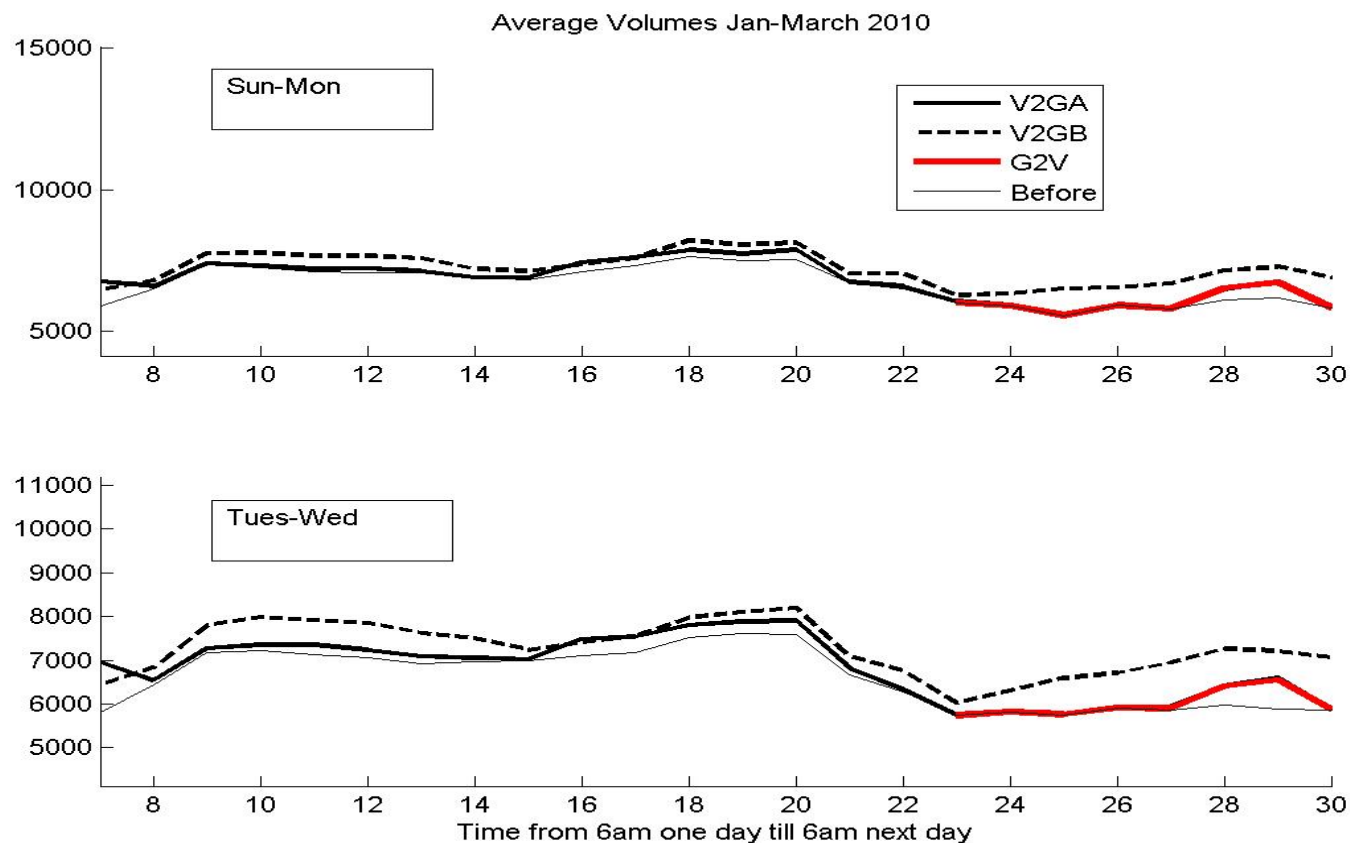
# • Results

## Optimum values versus realised values: 2010 & 2011

Optimum Value					
2010	No losses	%5 Losses	2011	No losses	%5 Losses
V2G A	-4.99 M€	-5.10 M€	V2G A	-8.24 M€	8.41 M€
V2G B	40.49 M€	40.15 M€	V2G B	25.67 M€	25.64 M€
G2V	-21.28 M €	-21.37 M €	G2V	-21.88 M€	-22.00 M€
Realised Value					
2010	No losses	%5 Losses	2011	No losses	%5 Losses
V2G A	-9.99 M€	-10.16 M€	V2G A	-14.35 M€	-14.57 M€
V2G B	27.37 M€	26.39 M€	V2G B	6.48 M€	6.48 M€
G2V	-21.87 M€	-21.96 M€	G2V	-22.74 M€	-22.86 M€

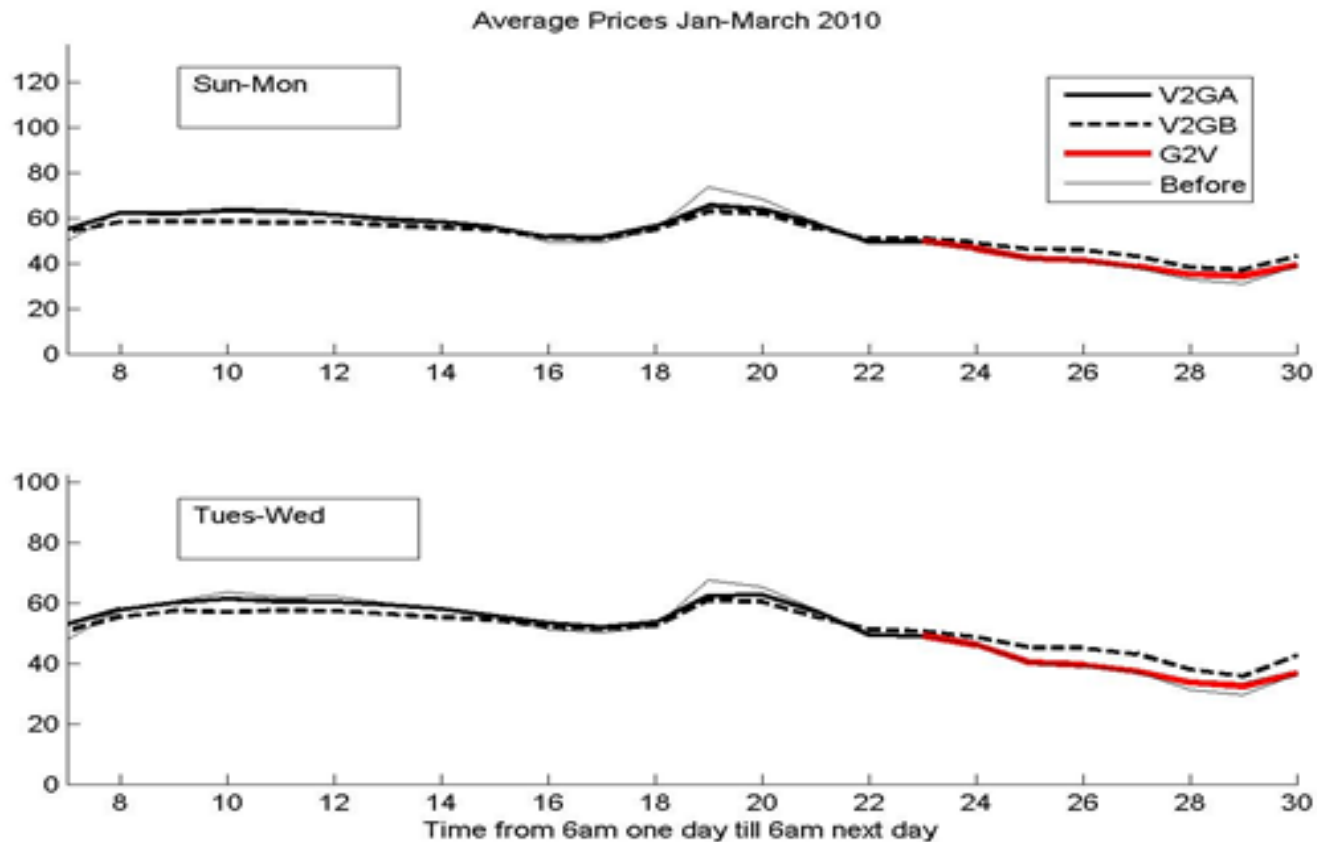
# • Results

## Average Volumes: winter 2010



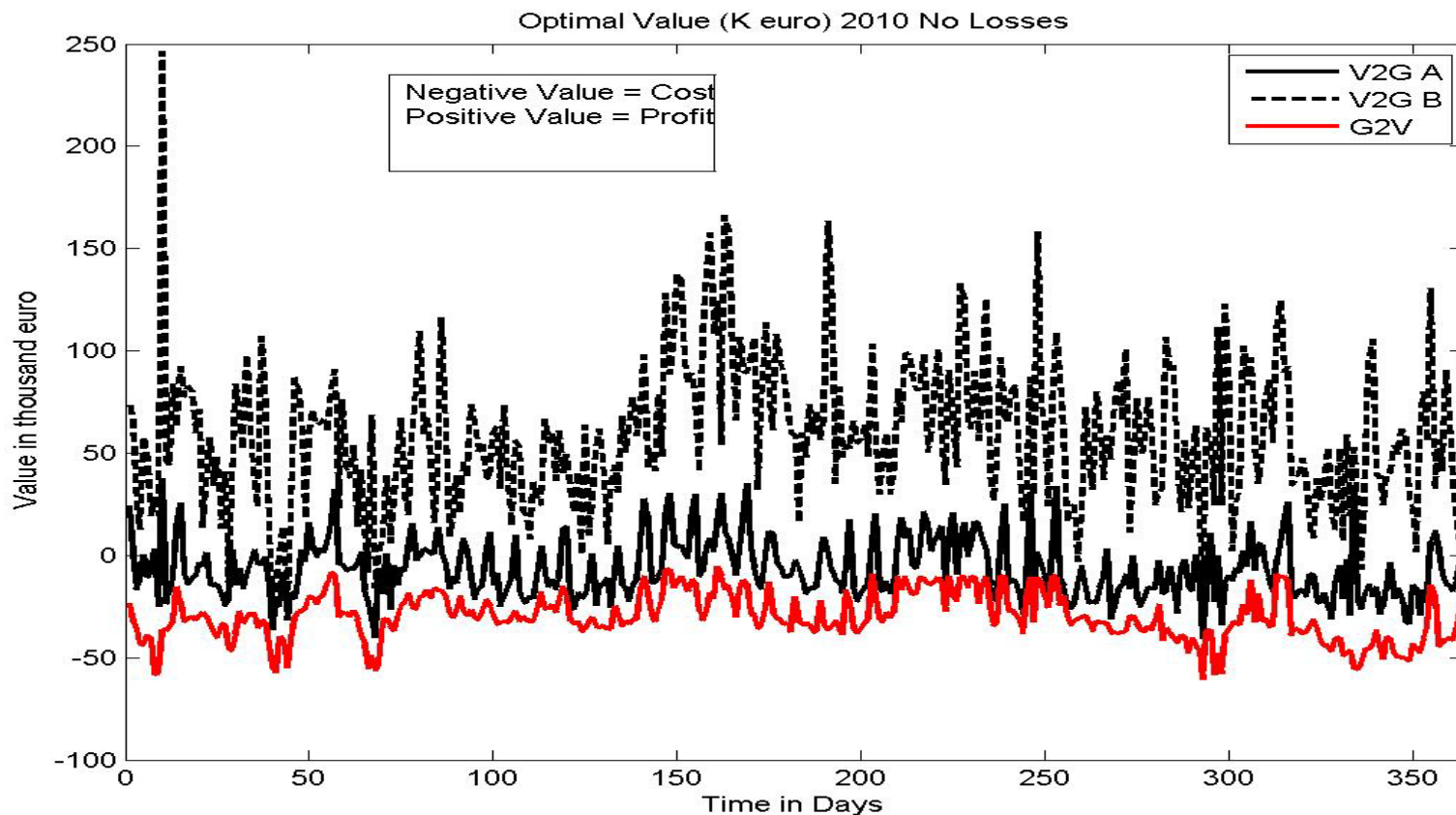
# • Results

## Average Prices: winter 2010



# • Results

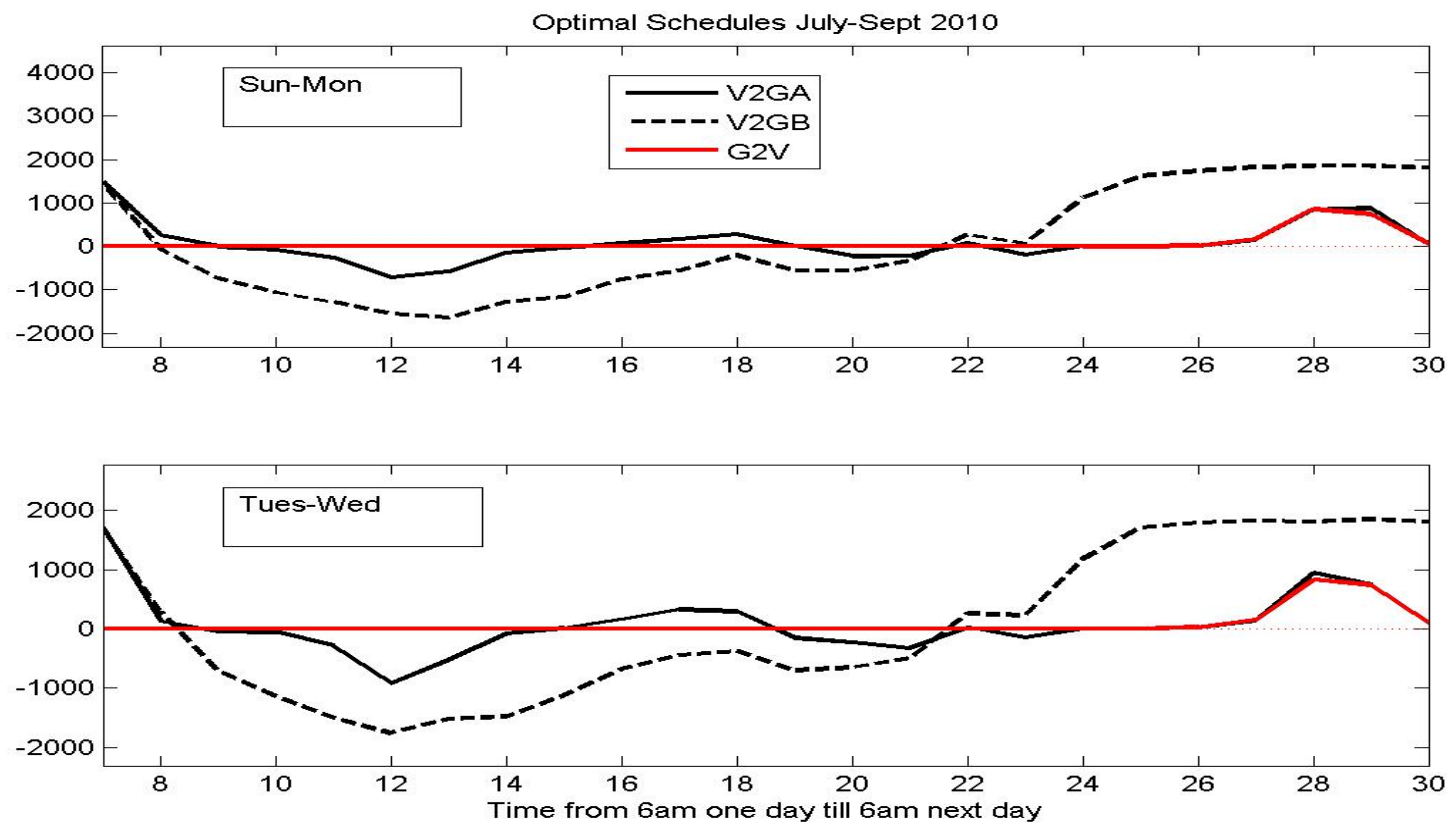
## Robustness of strategy



• **Any questions?**

# • Results

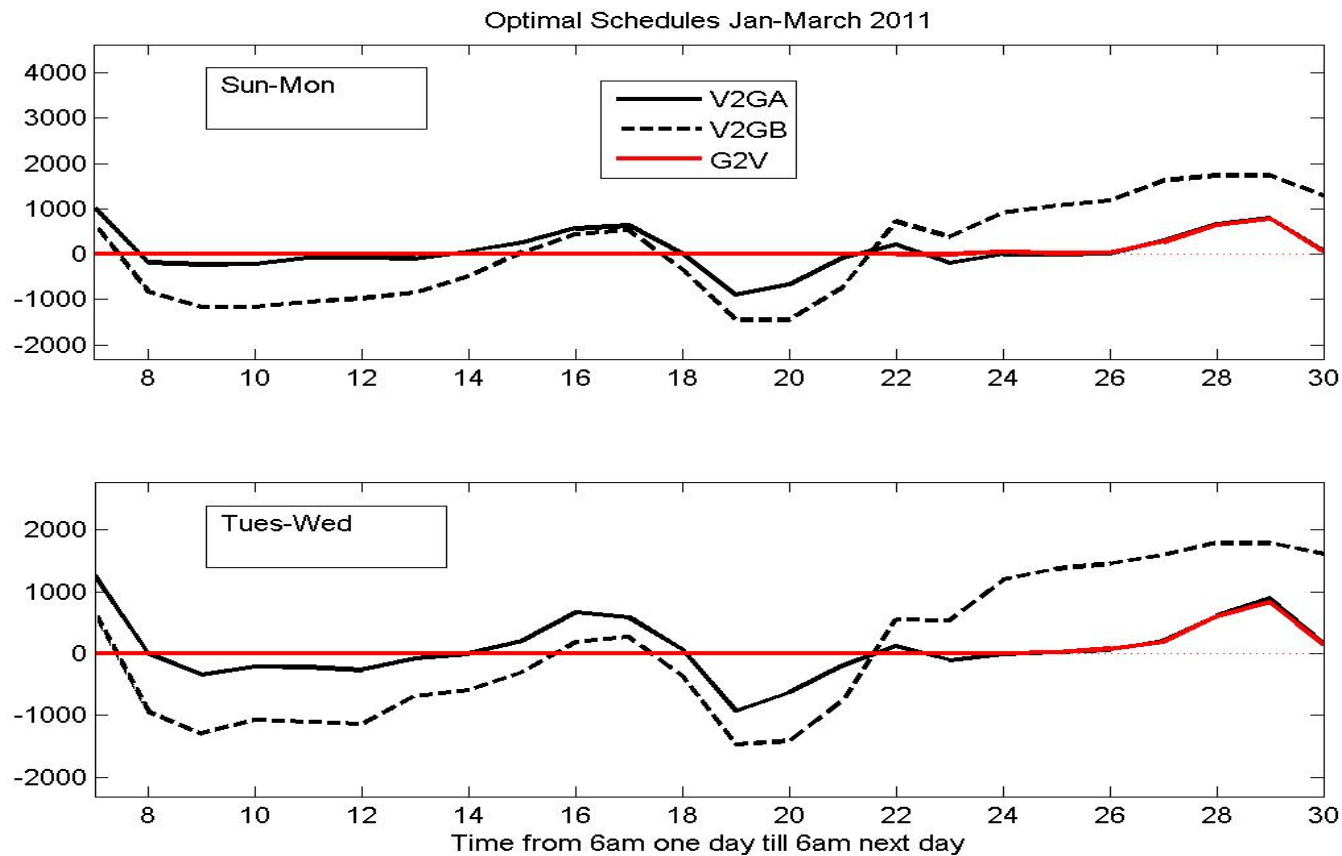
## Optimal strategy: summer 2010





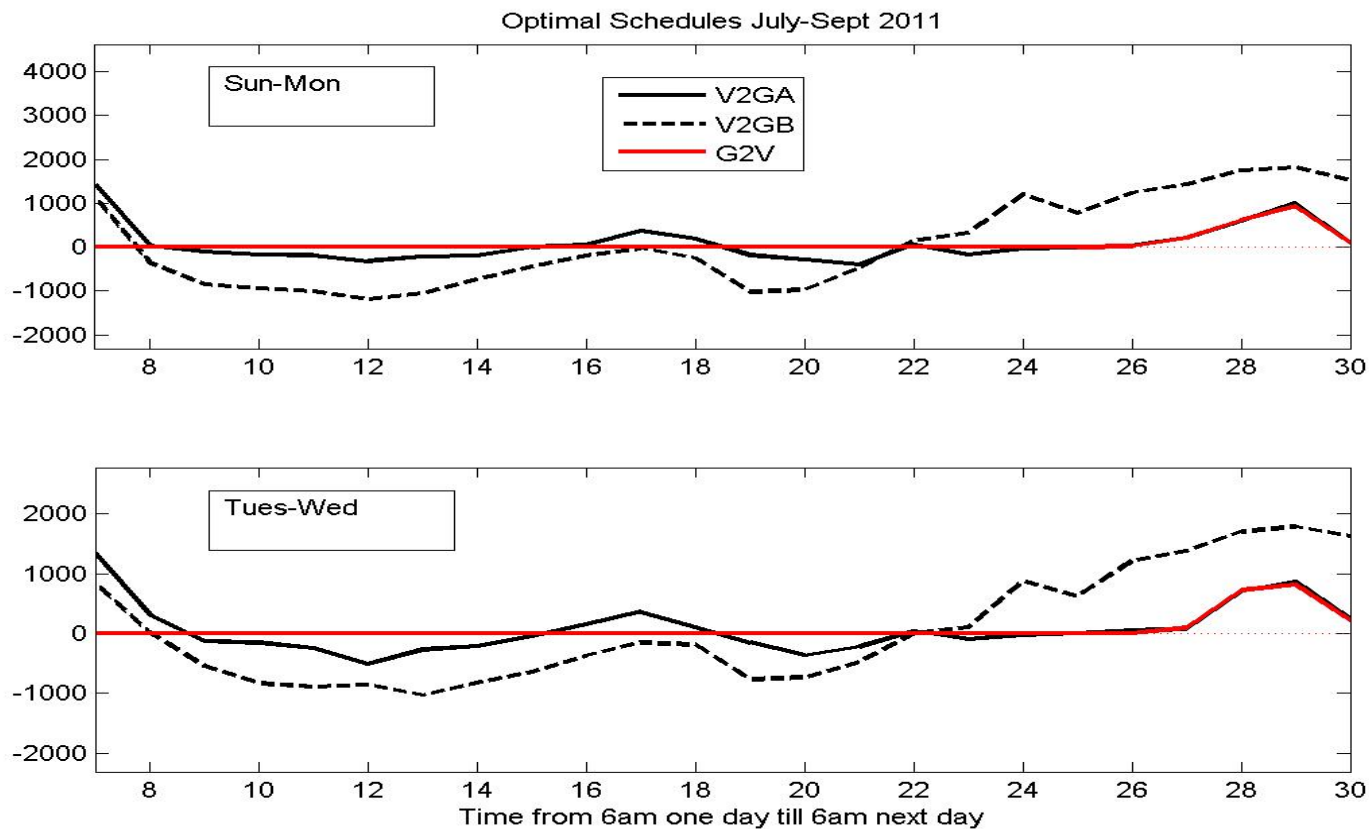
# • Results

## Optimal strategy: winter 2011



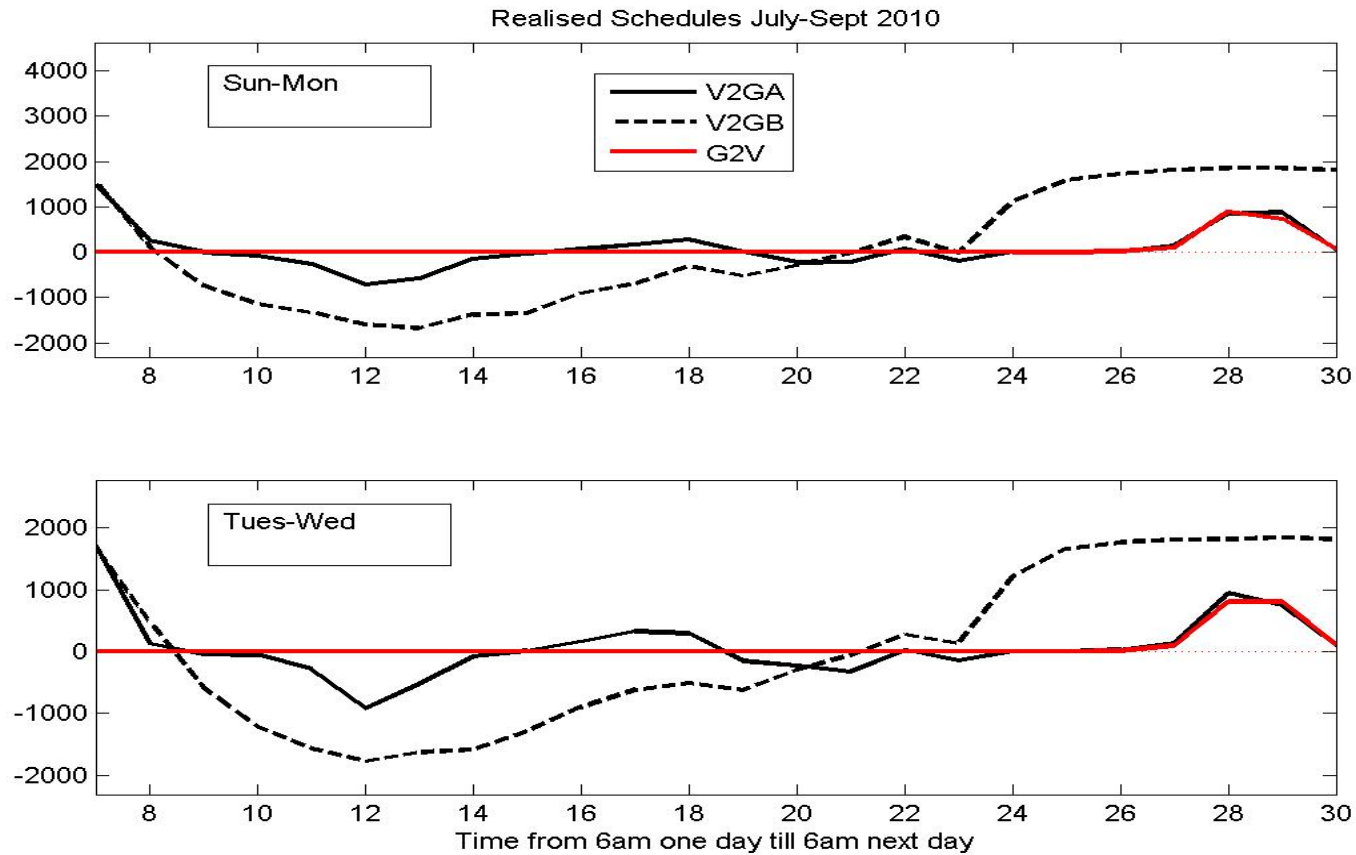
# • Results

## Optimal strategy: summer 2011



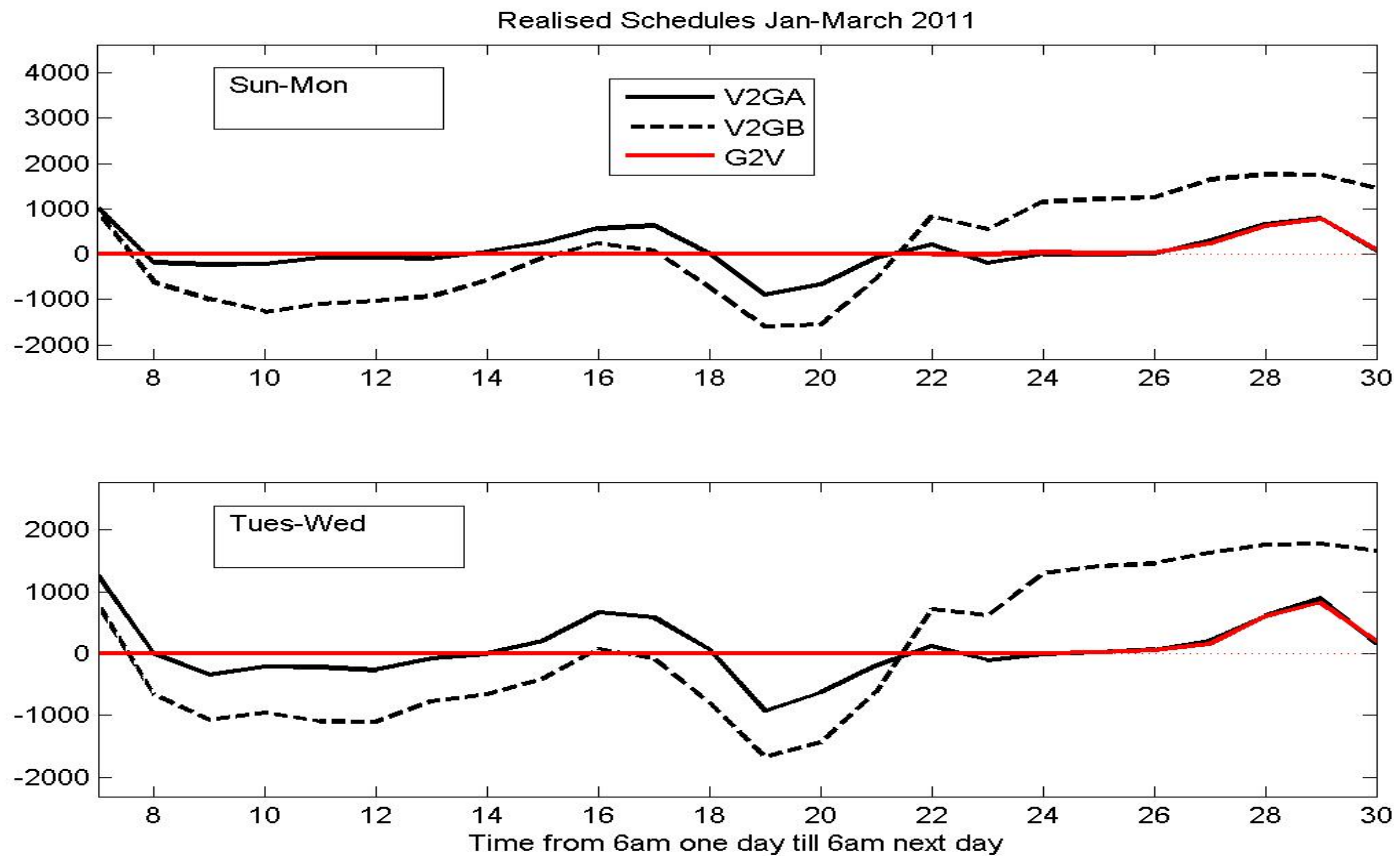
# • Results

## Realised strategy: summer 2010



# • Results

## Realised strategy: winter 2011



# • Results

## Realised strategy: summer 2011

