A PRACTICAL FRAMEWORK FOR IMPLEMENTING THE VEHICLE–TO–GRID (*V2G*) CONCEPT

presentation by

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MOTIVATION FOR BATTERY VEHICLES

- There is growing awareness around the world about energy independence, sustainability and climate change issues
- Such awareness and the success of the *Toyota Prius* – with over 500,000 units sold by 2007 in the *US* – are major drivers in spearheading the popu-larity of battery vehicles (*BV*s) around the world

BATTERY VEHICLES

- **We include all vehicles that can be fully or partially fueled by electricity**

- ***Plug-in hybrid electric vehicles* (*PHEV*s) have a battery and an internal combustion engine; examples include**
  - ***Chevy Volt***
  - ***Prius Plug-in***

- ***Battery vehicles* (*BV*s) have no internal combustion engine but only a more versatile battery; examples include**
  - ***Nissan Leaf***
  - ***Fisker***

OUTLINE OF THE PRESENTATION

- Integration of *BV*s into the electricity grid
  - *BV*s as a load
  - *BV*s as a generation/storage device
  - role of aggregation
- Development of an implementation framework

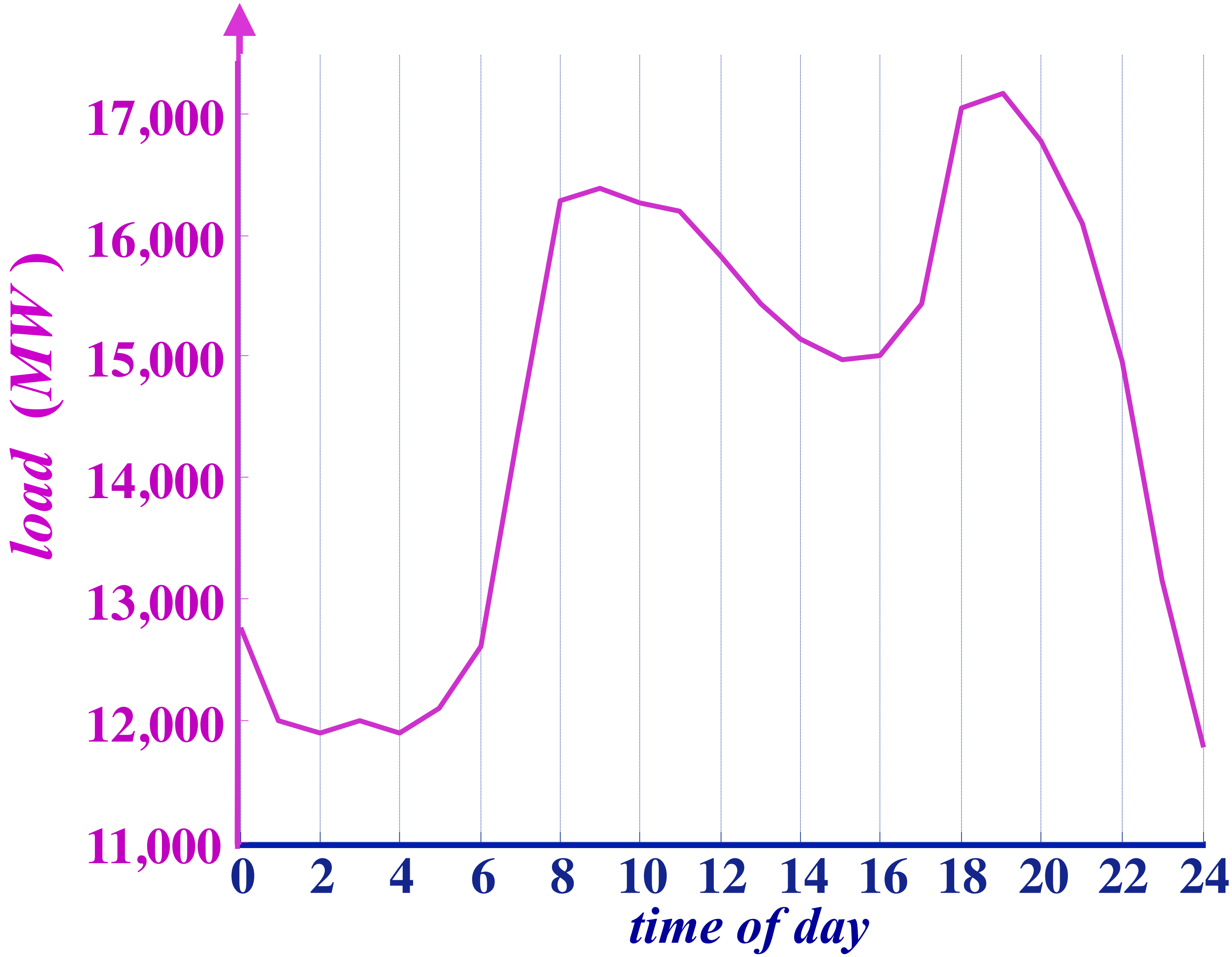
OUTLINE

- Key challenges in implementation
  - design of an incentive program
  - metering and communication/control needs
- Environmental tracking and monitoring
- Concluding remarks

THE ELECTRICITY GRID

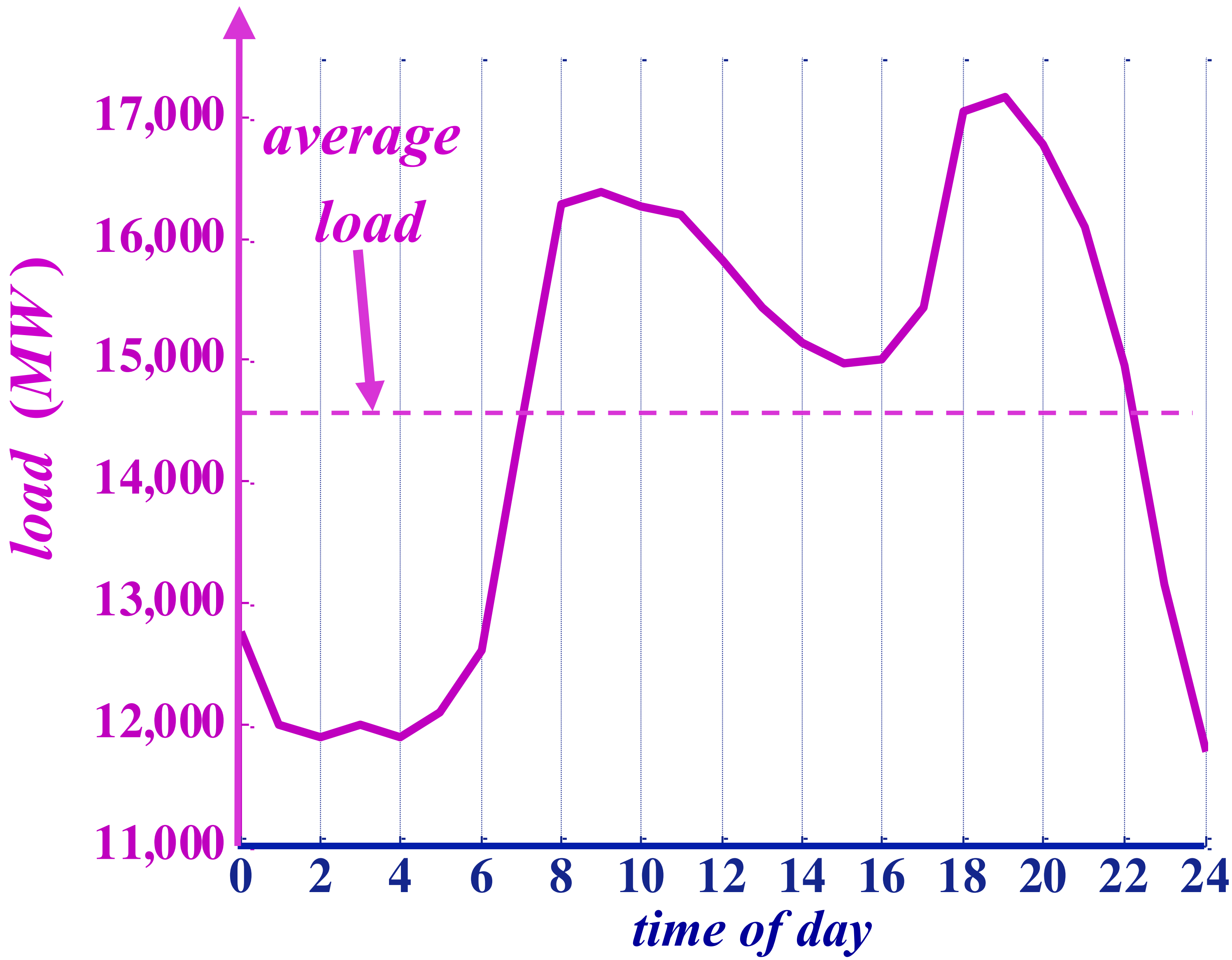
- The MWh costs and prices are unequal over time
- The value of each MWh depends on the time of production/consumption
- The integration of BVs into the grid can fully exploit the opportunities to:
  - buy electricity when the prices are low
  - sell services when the prices are high
  - provide additional services needed by the grid

LOAD AND *LMP*



Source: NE ISO

LOAD AND *LMP*



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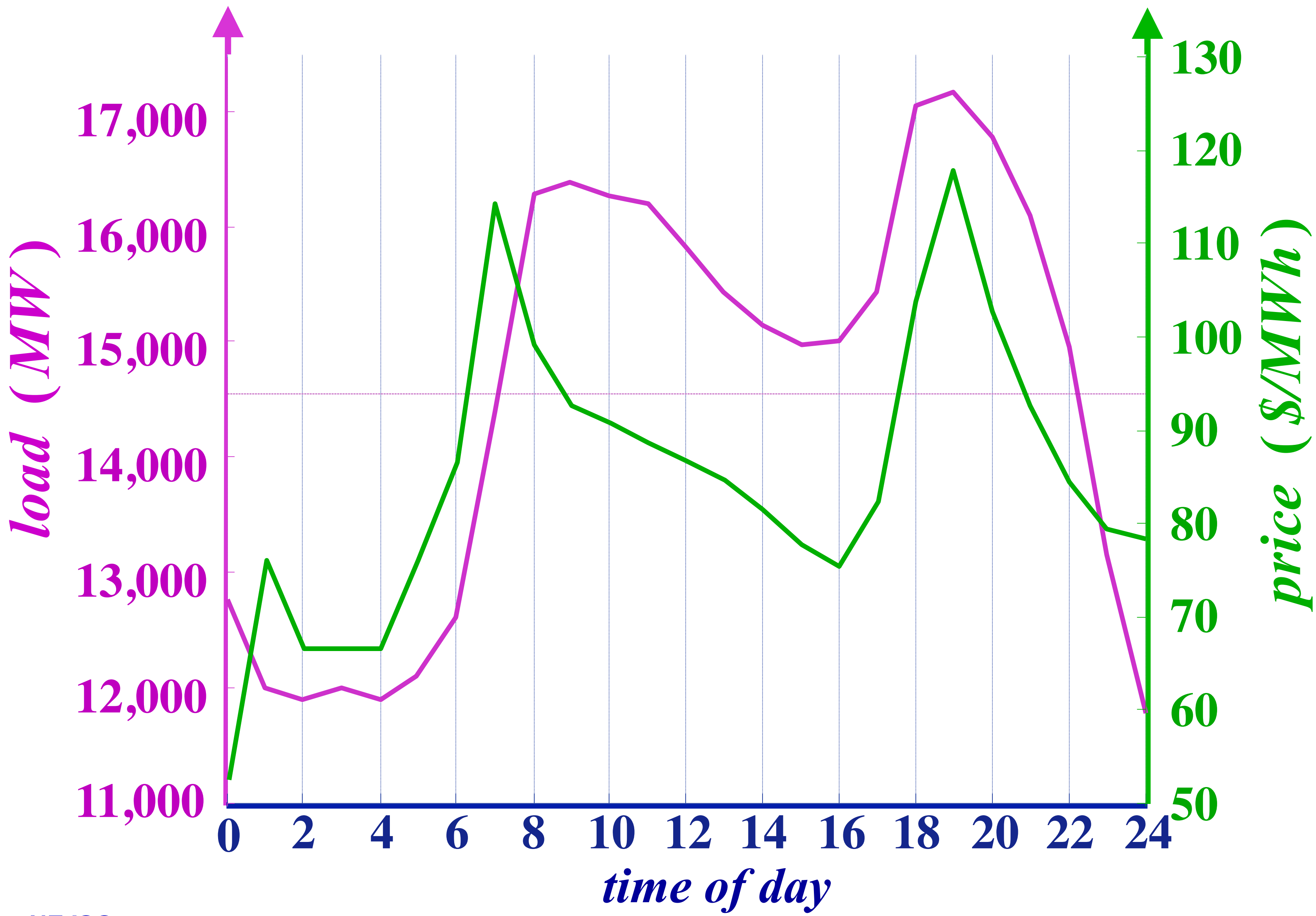
LOAD AND *LMP*



Source: NE ISO

LOAD AND *LMP*

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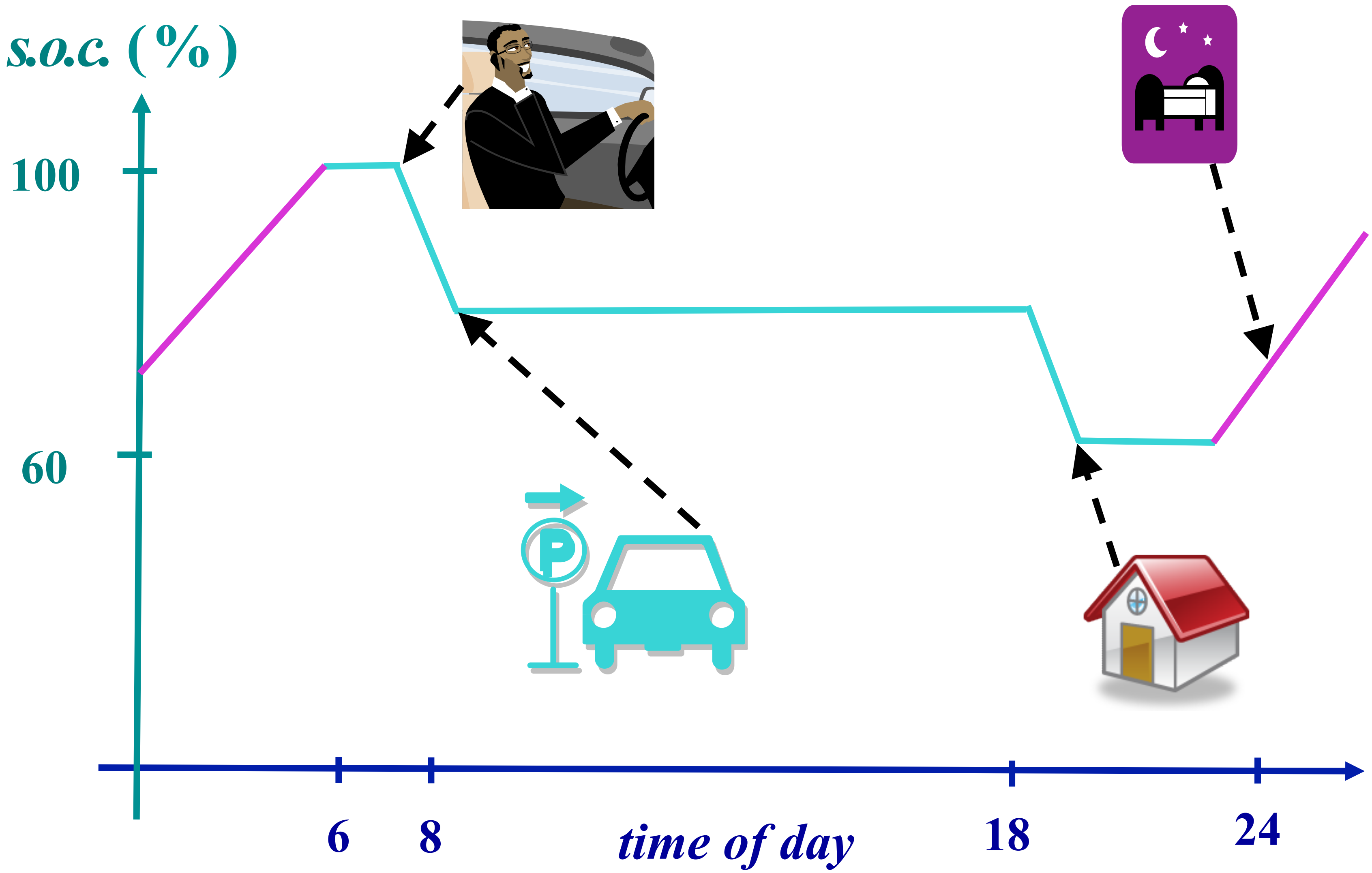
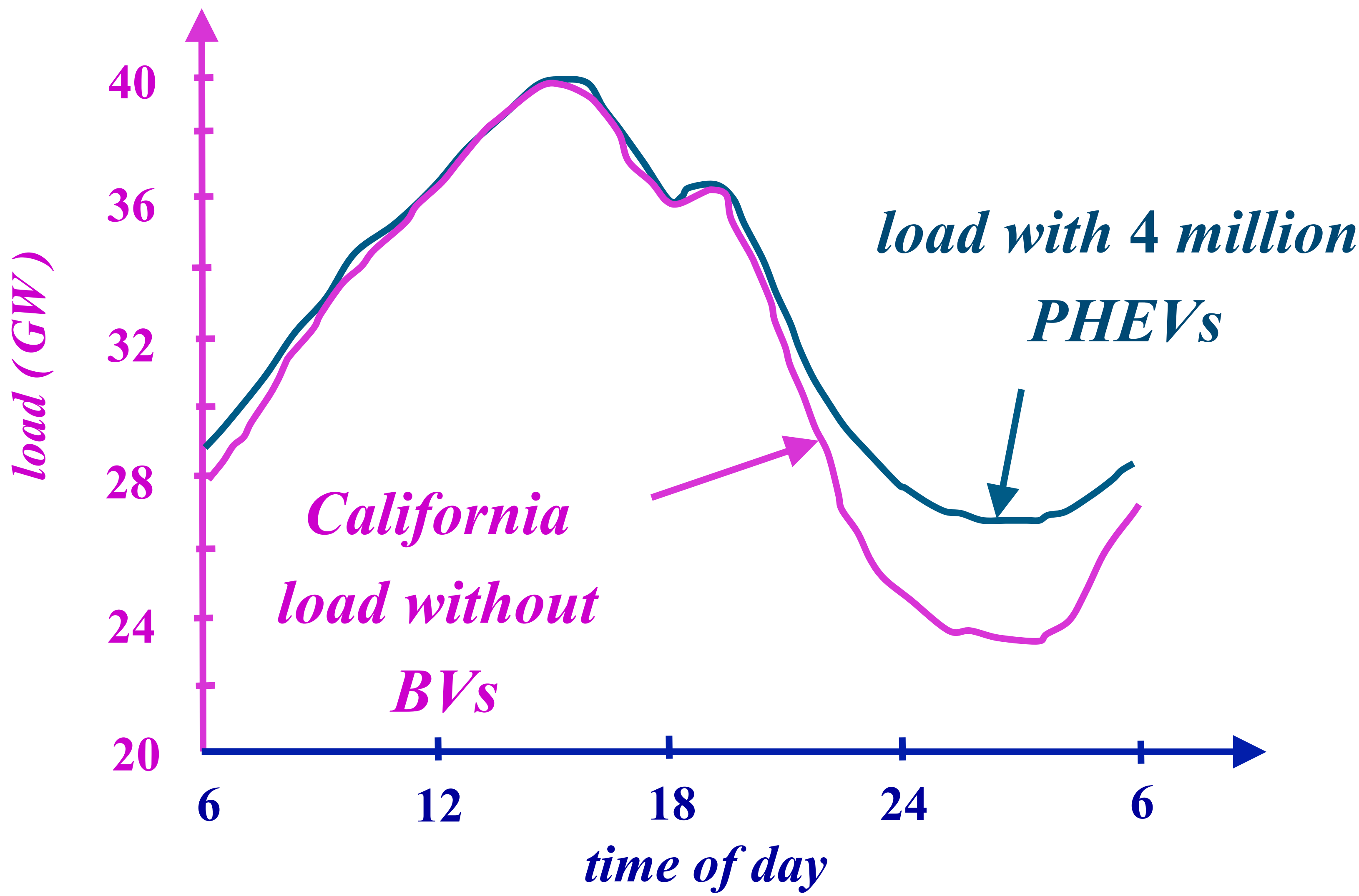
THE *BV* AS A "PURE LOAD"

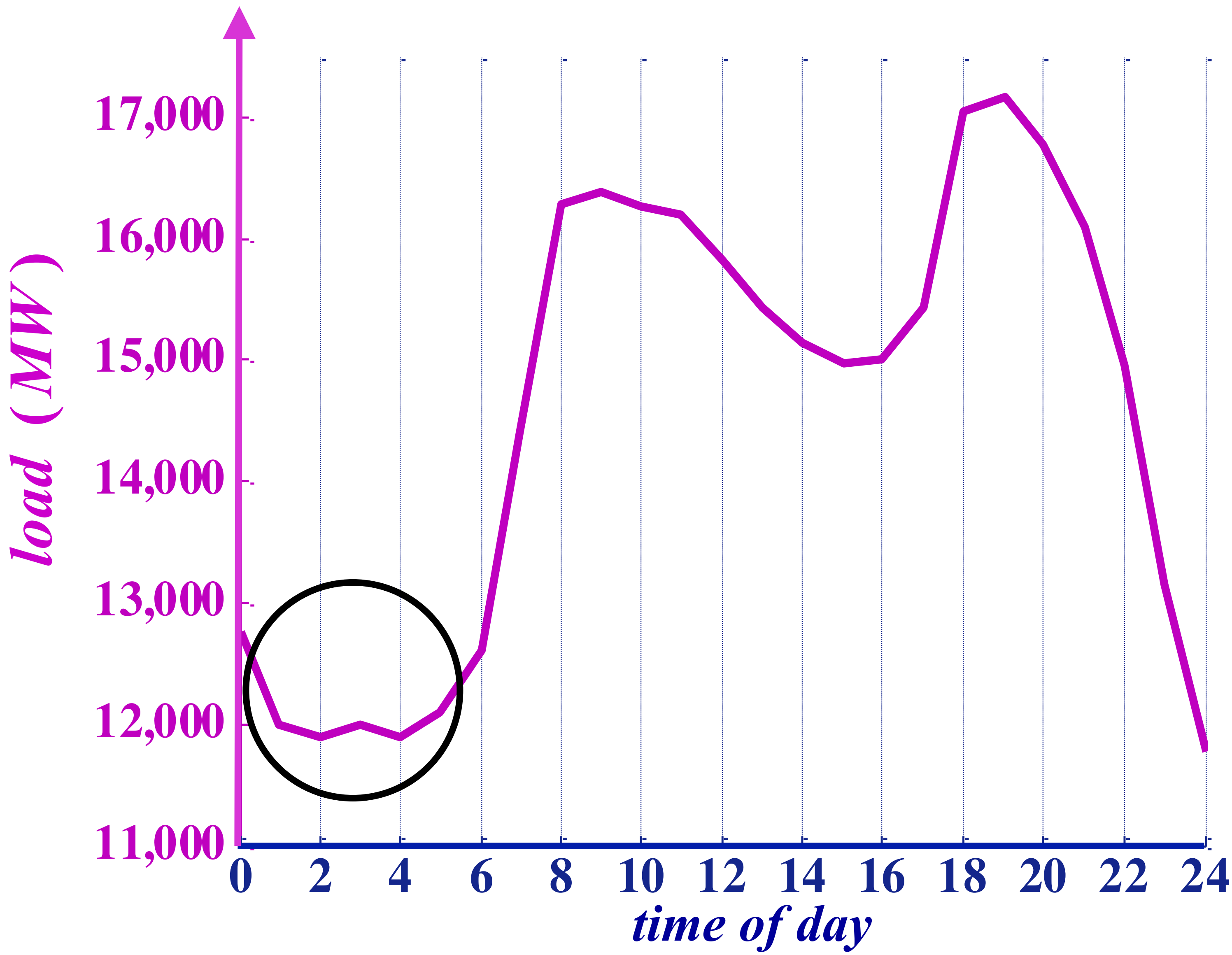


CHARGING THE *BV*s



Source: Lucy Sanna, "Driving the solution, the plug-in hybrid vehicle," EPRI journal, Fall 2005

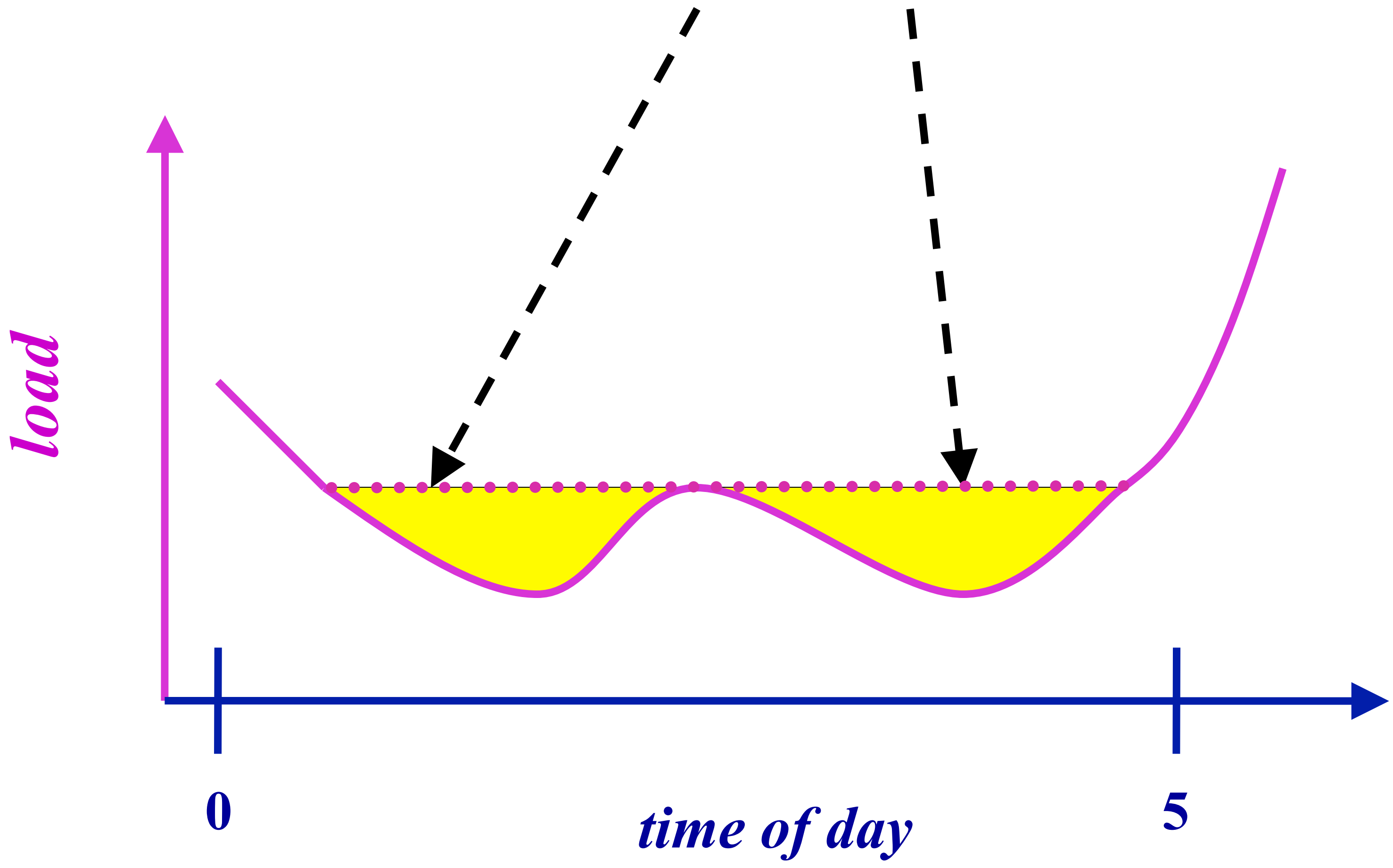
LEVELING THE LOAD



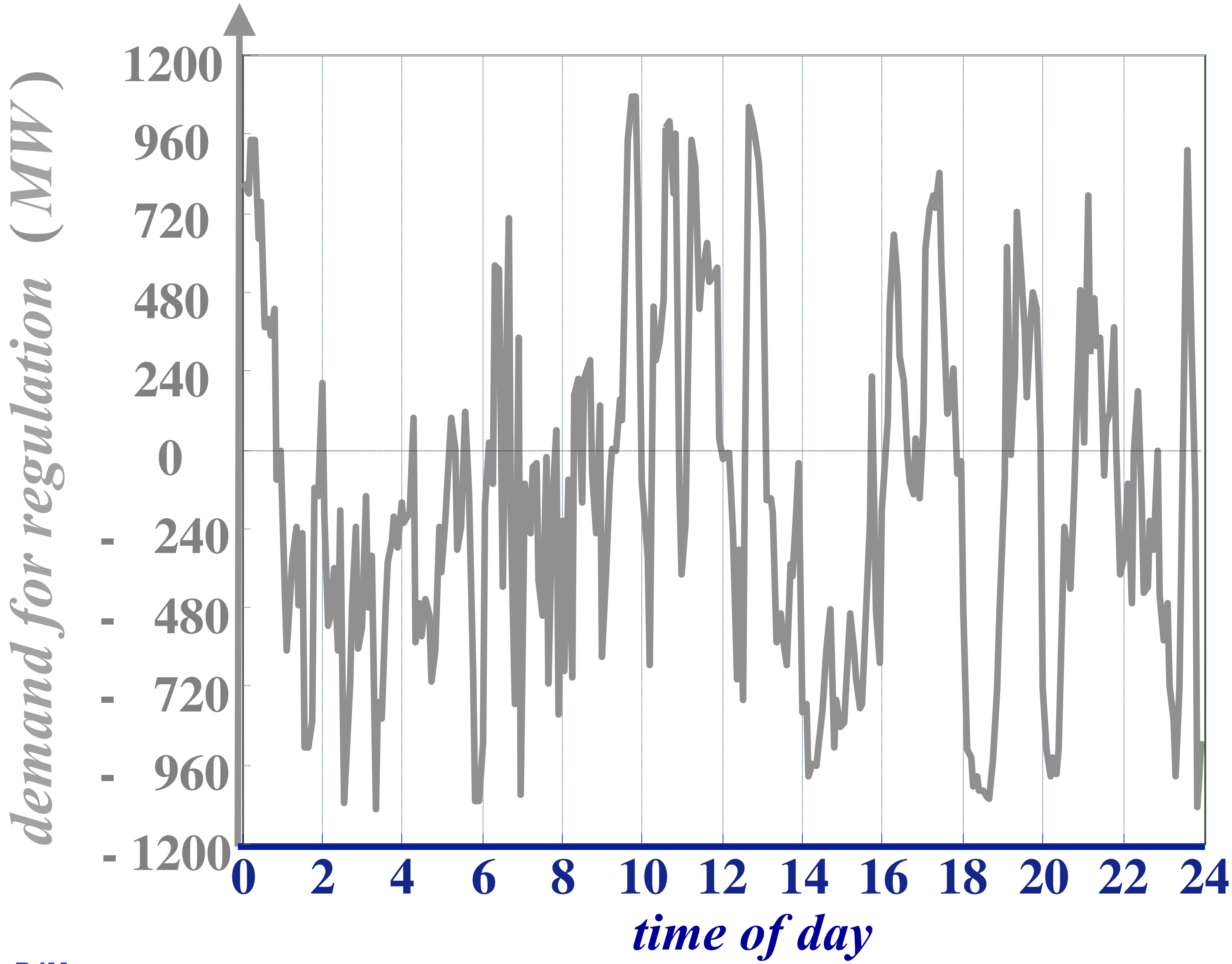
Source: NE ISO

LEVELING THE LOAD

controlled impacts of the charging of the BVs

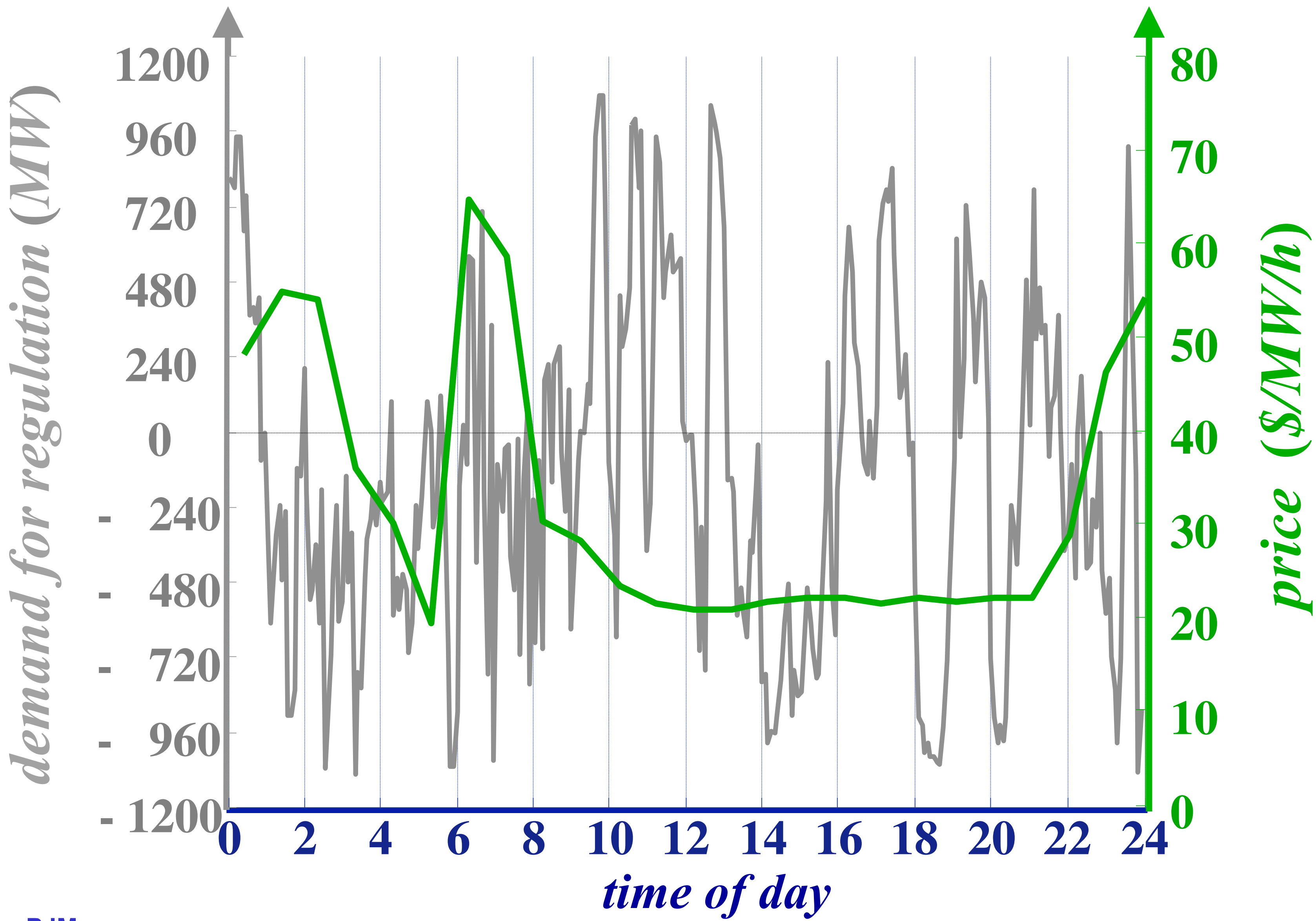


REGULATION SERVICE AND PRICING



Source: PJM

REGULATION SERVICE AND PRICING



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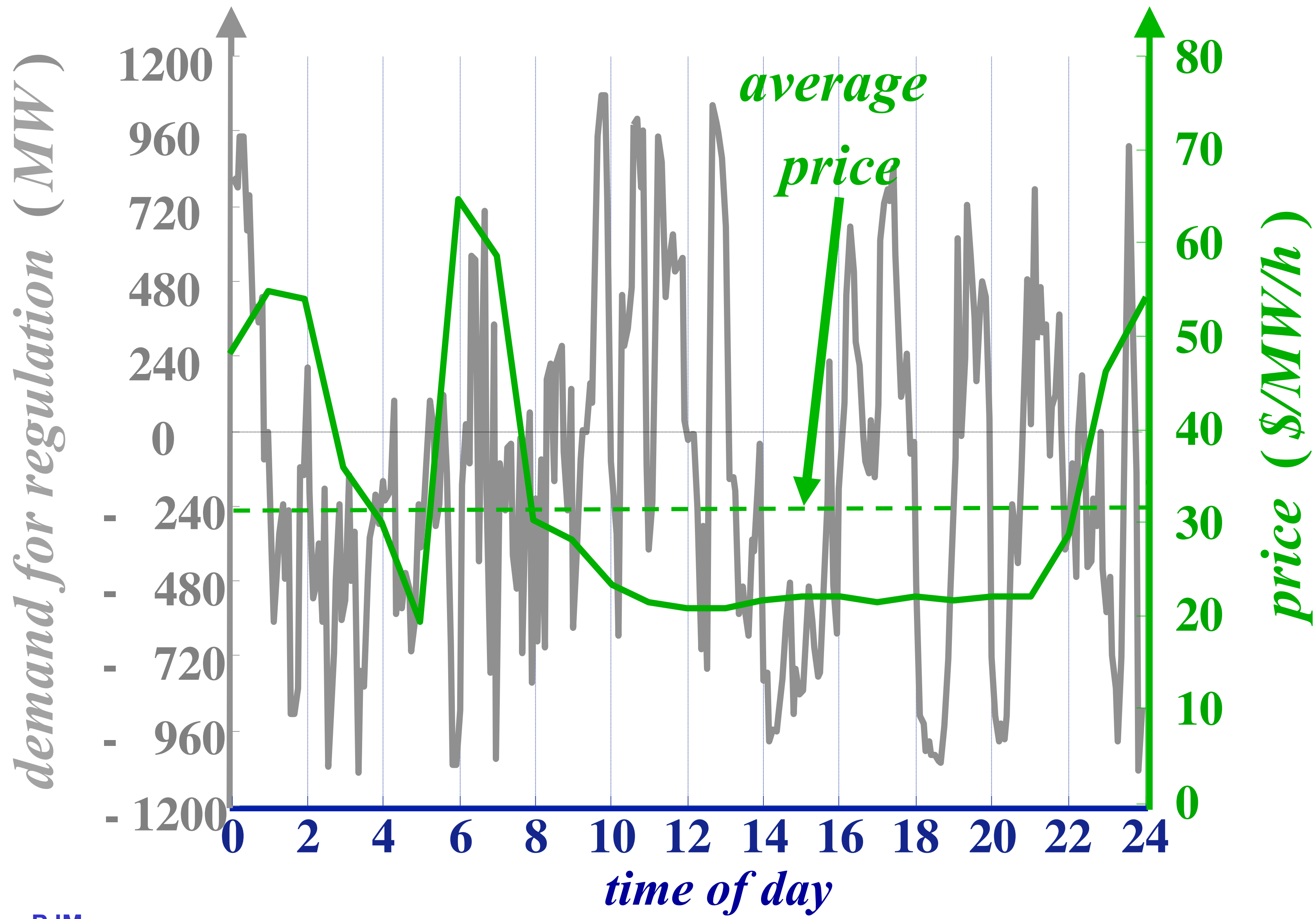
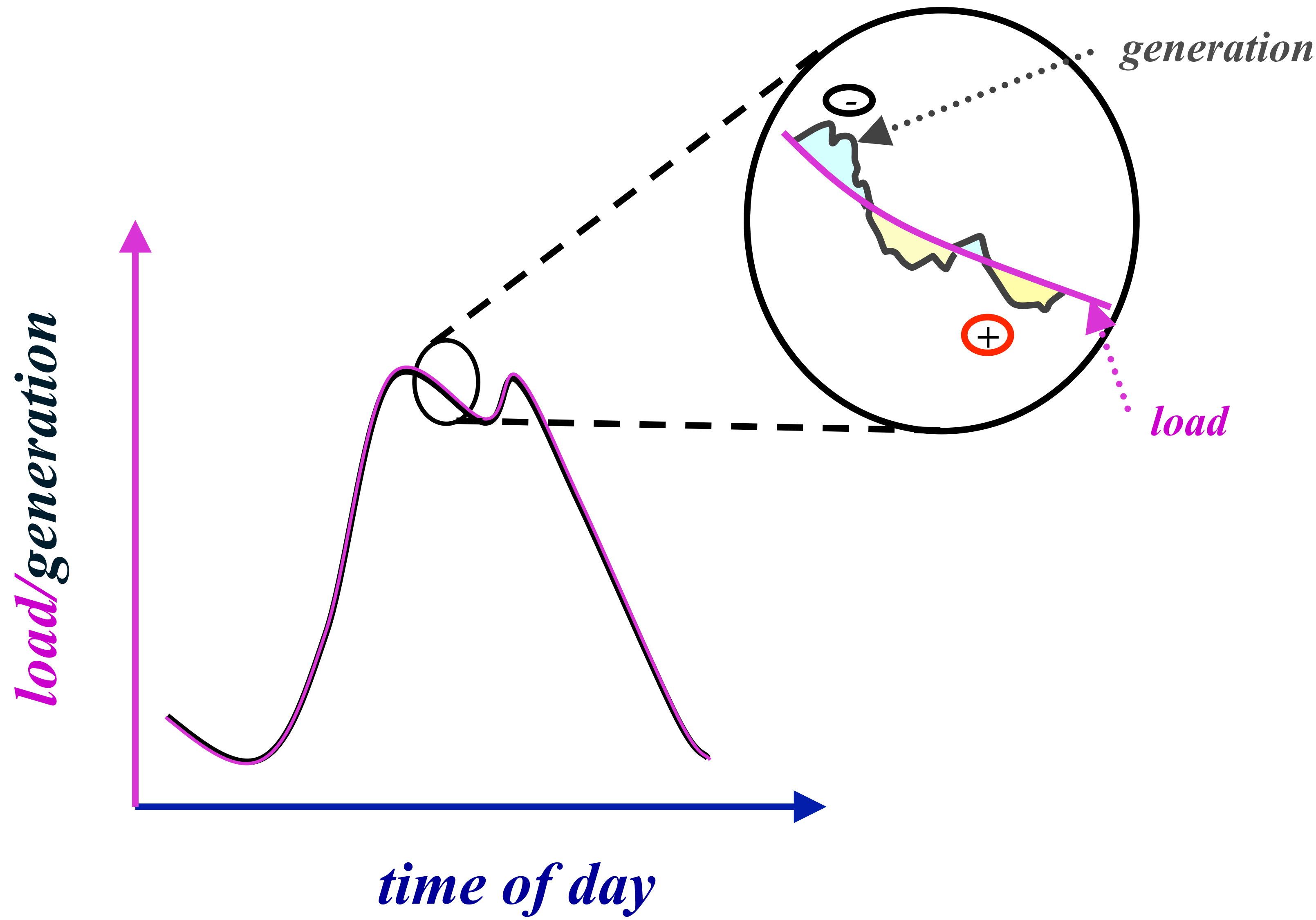


Source: PJM

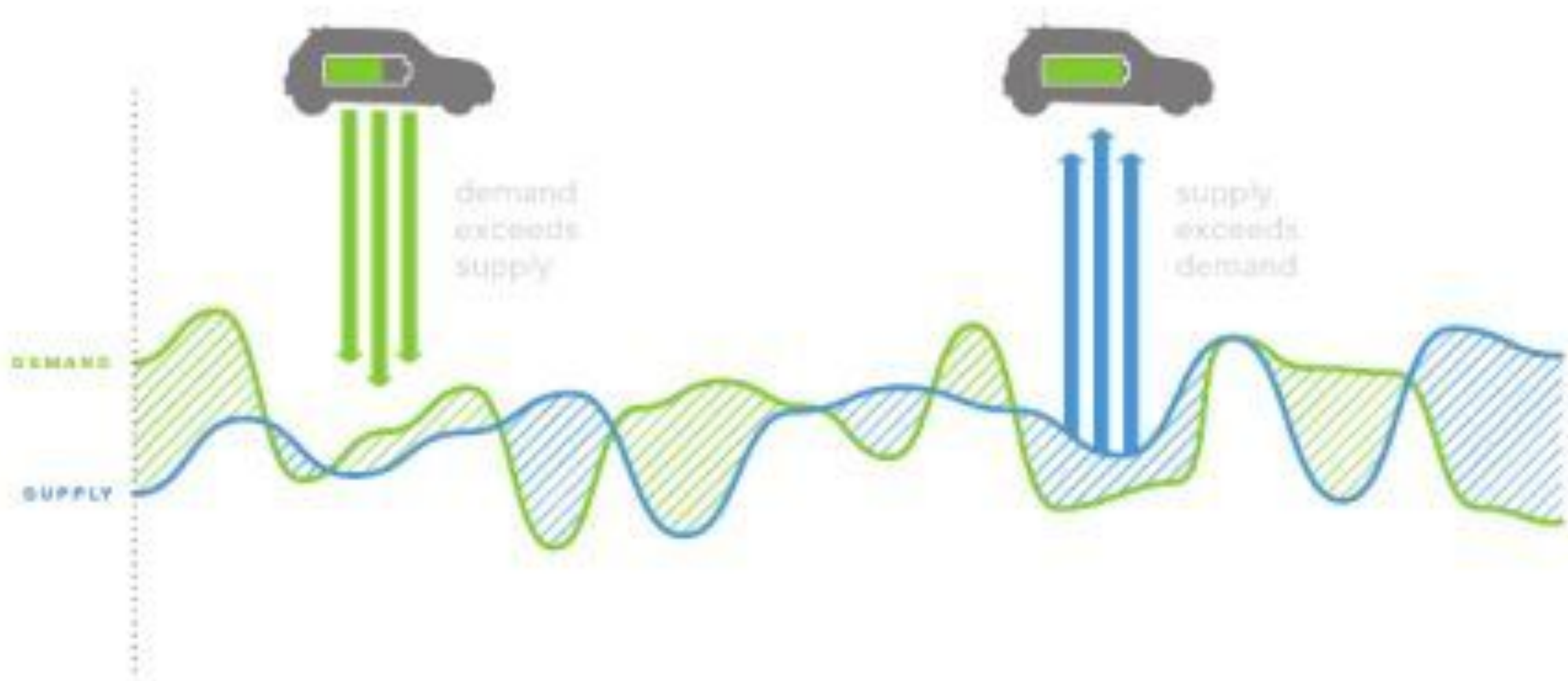
ROLE OF *BVs* IN FREQUENCY REGULATION

- A basic objective of the system operator is to ensure that the supply – demand equilibrium is maintained around the clock
- Imbalances lead to frequency fluctuations that need to be regulated
- The supply-demand imbalance is checked every 2 to 4 s

ROLE OF *BV*s IN FREQUENCY REGULATION



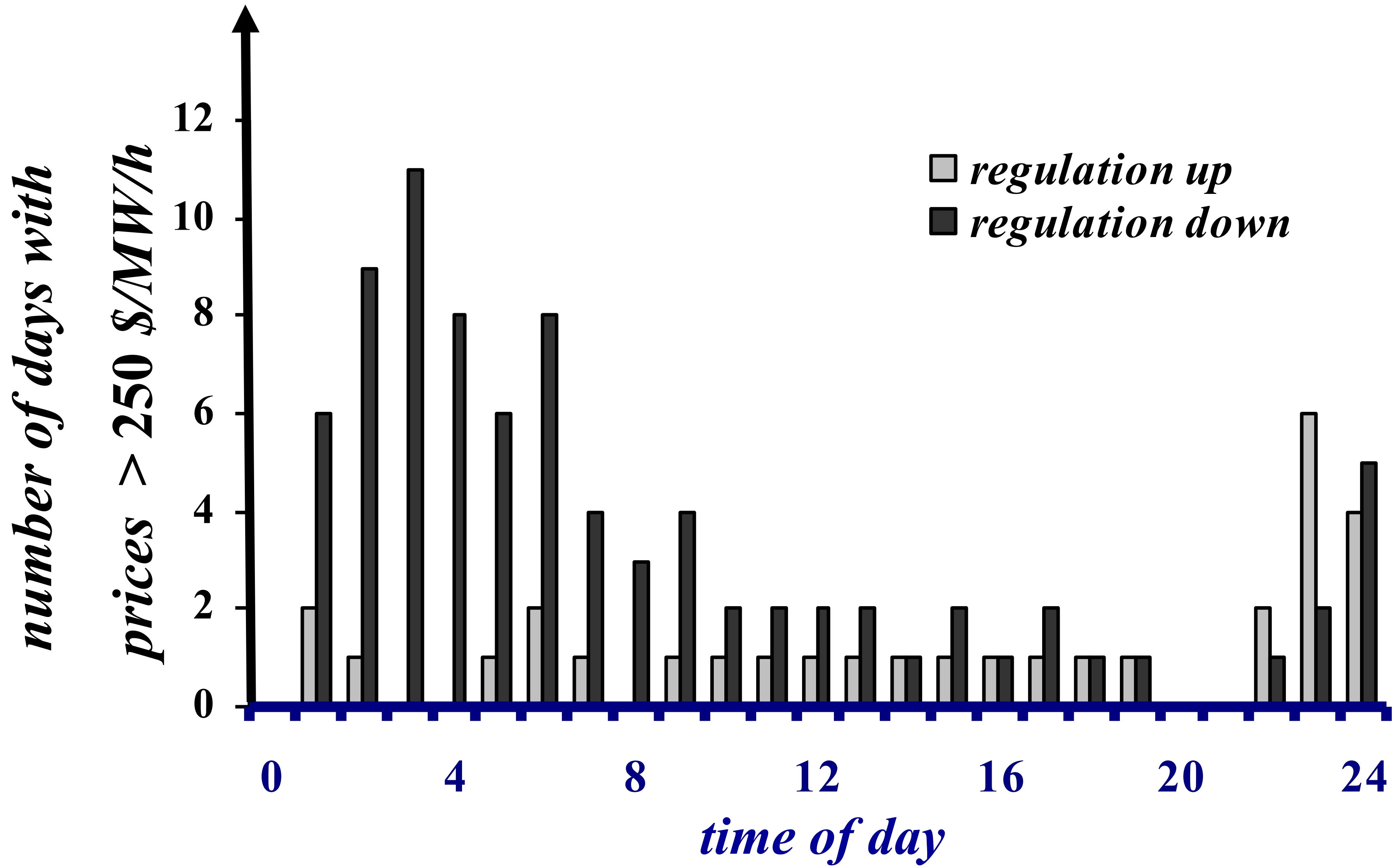
ROLE OF *BV*s IN FREQUENCY REGULATION



OFF – PEAK REGULATION

- Compliance with the unit commitment schedules becomes difficult during low load conditions that characterize the off – peak periods
- While the operator may not wish to turn off units, there may be no choice
- Wind integration further exacerbates the low load conditions
- The regulation prices are typically the highest, as many units are required to reduce their outputs

PEAK AND OFF – PEAK REGULATION

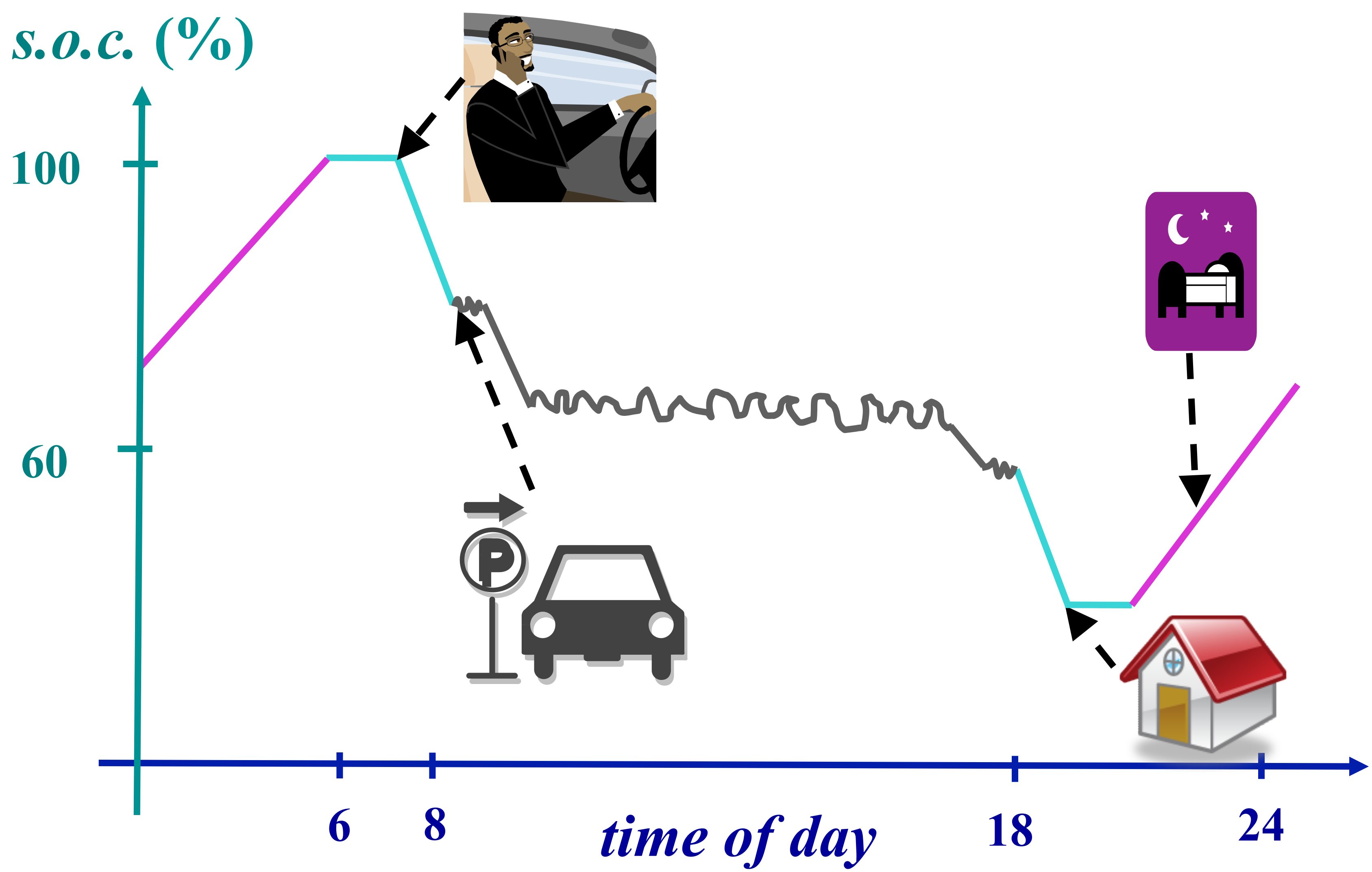


Source: CAISO

*BV*s AND FREQUENCY REGULATION

- Batteries have the ability to both **absorb** and **discharge** energy
- The **regulation capacity** provided by a single *BV* battery is relatively small
- Batteries have **very short response times** (on the order of *ms*)
- The **frequent switching** of a battery may, however, severely degrade its life expectancy

THE *BV* AS A "SUPPLY-SIDE RESOURCE"



BATTERY ISSUES

- The battery capability of a single BV is small in terms of kWh storage
- This capability limitation consequently restricts the "supply-side resource" capacity of each BV
- A key requirement for grid integration is the aggregation of BVs into a collection with the ability to palpably impact the grid

THE ROLE OF AGGREGATION

- The storage capability C for a typical BV is in the $10 - 50 \; kWh$ range
- If we consider the total discharge of the full battery over $5 \; h$, the output is in the $2 - 10 \; kW$ range
- The aggregator, who gathers together "many" BVs to result in a **nontrivial aggregated output and load**, can play an important role in the effective integration of BV s into the grid so as to **beneficially impact** both supply and demand-side issues

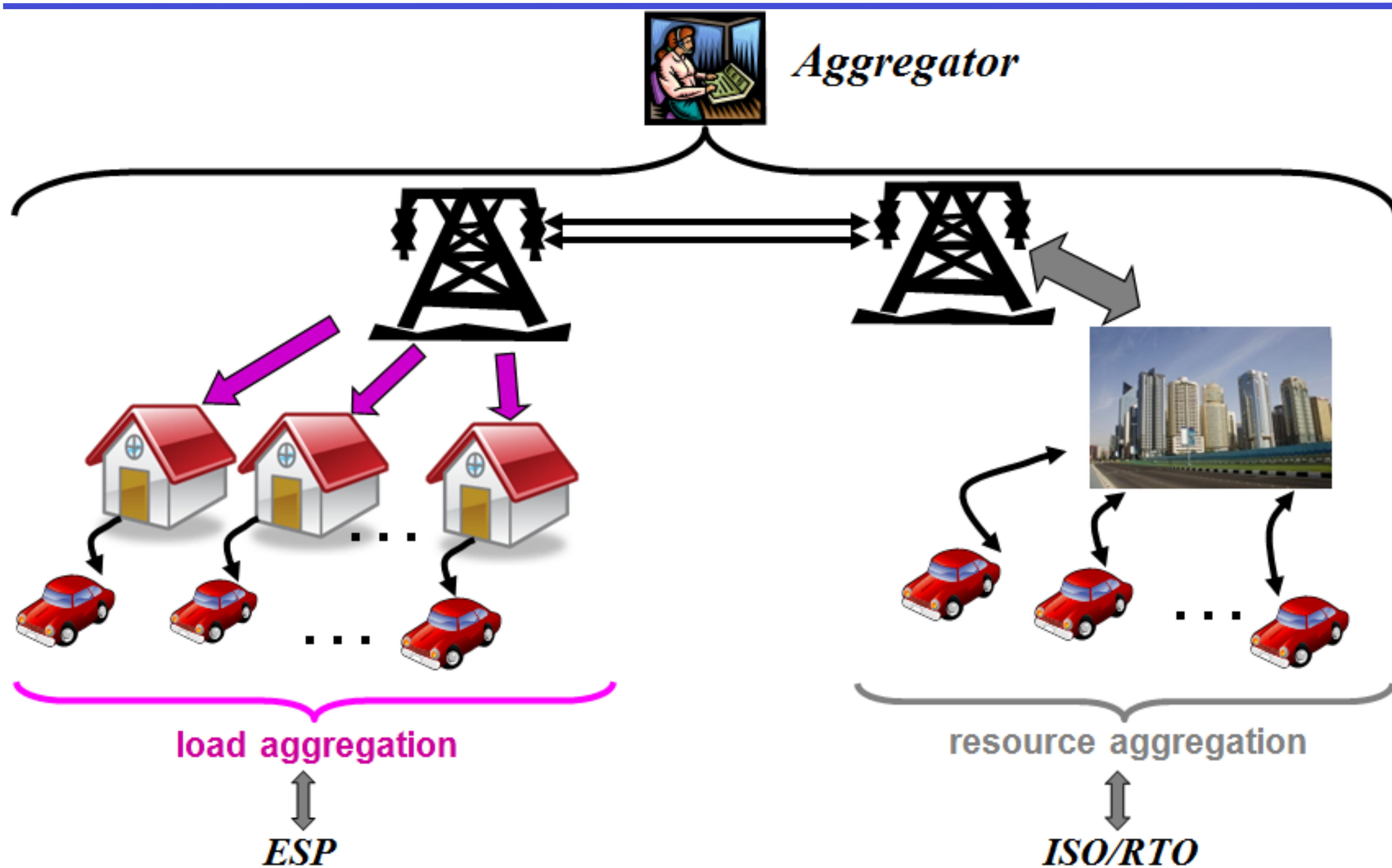
V2G FRAMEWORK

- Load aggregation
- Resource aggregation
- Explicit representation of uncertainty
- Communications/control layer construction
- Development of incentives

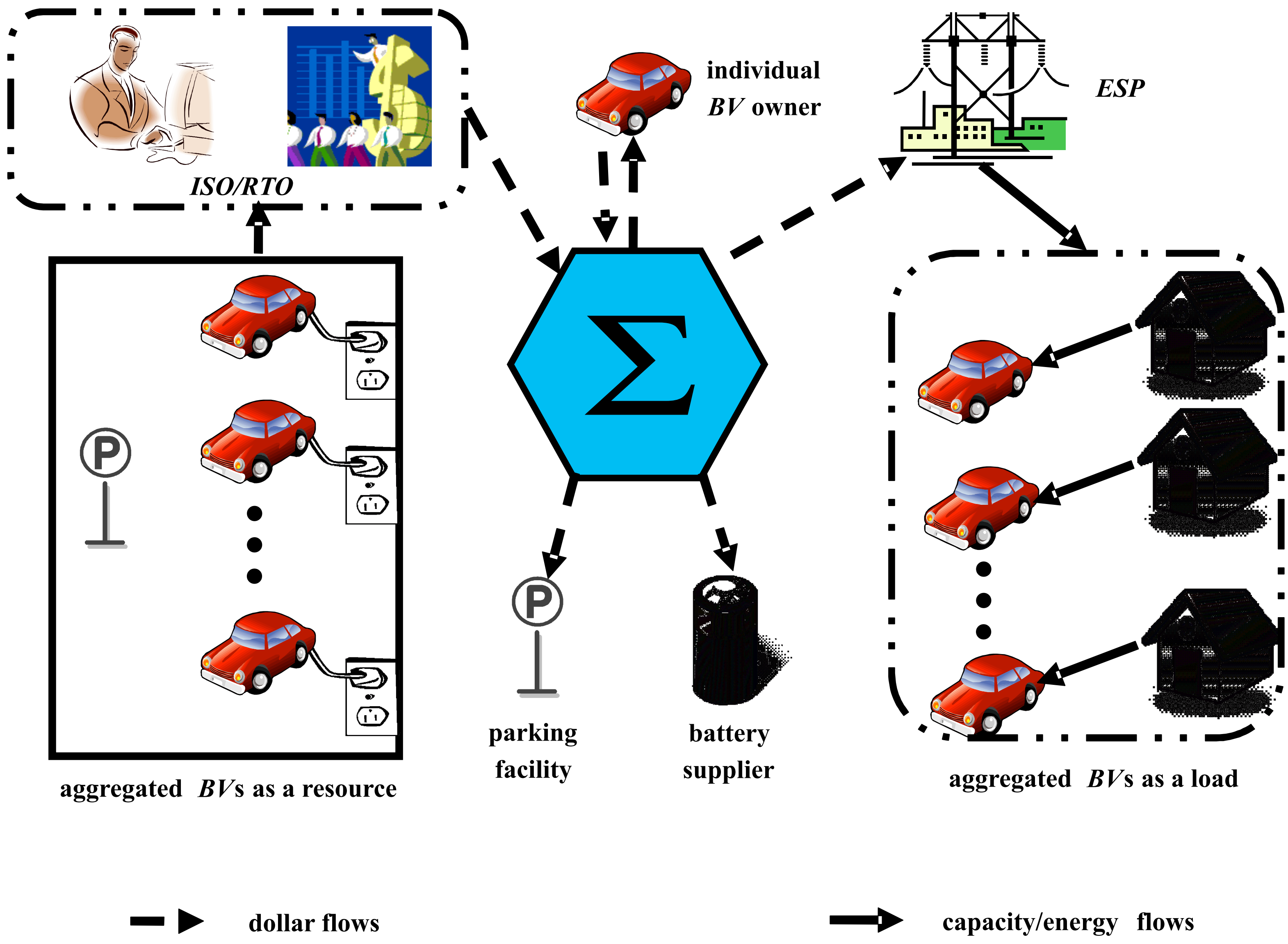
PRINCIPAL PLAYERS IN THE *V2G* INTEGRATION

- Aggregator
- Aggregated *BV*s
- *ISO*/*RTO*
- *ESP*
- Local distribution company

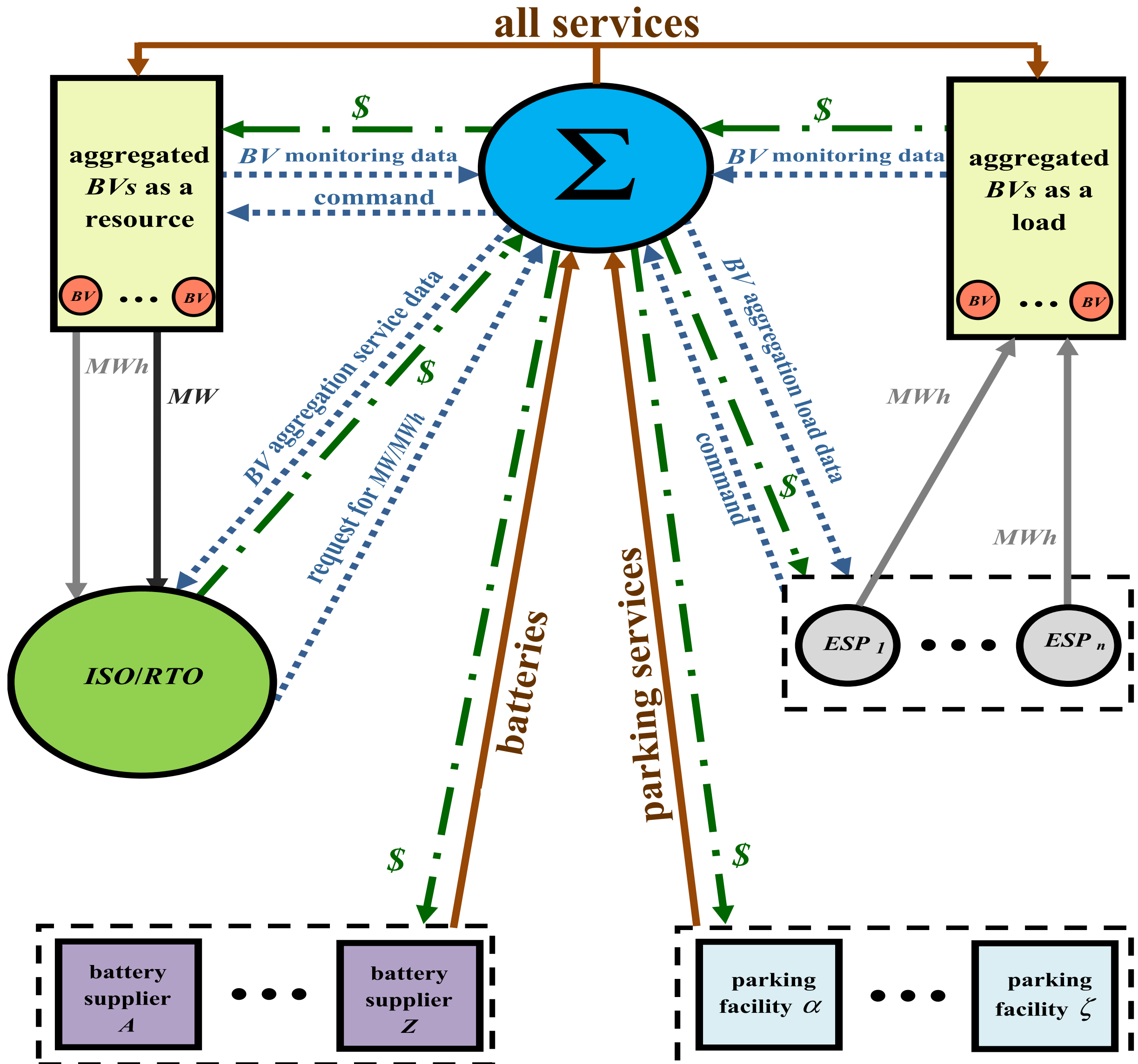
THE INTEGRATION FRAMEWORK



V2G PLAYER INTERACTIONS



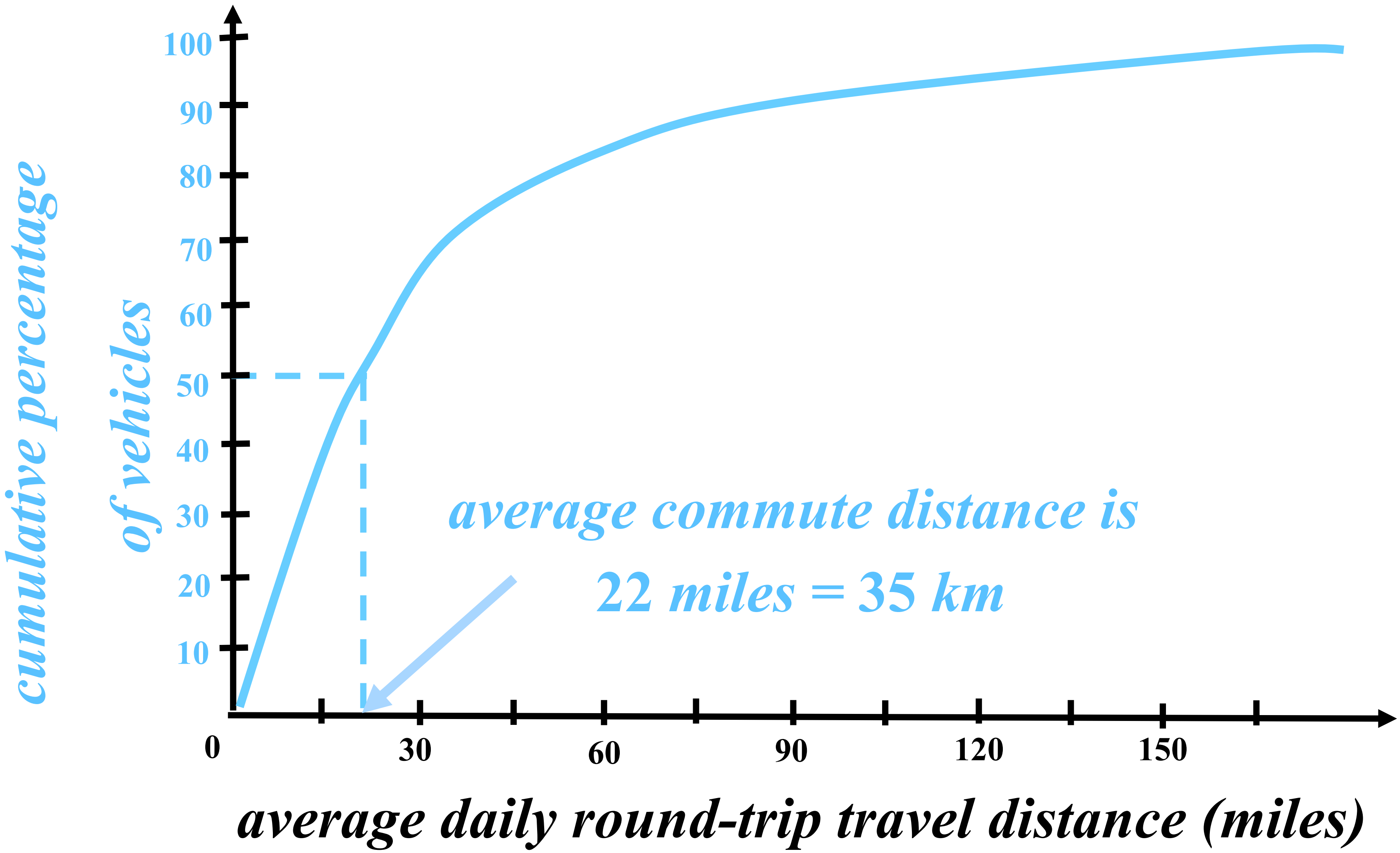
FLOWS IN THE *V2G* FRAMEWORK



REPRESENTATION OF SOURCES OF UNCERTAINTY

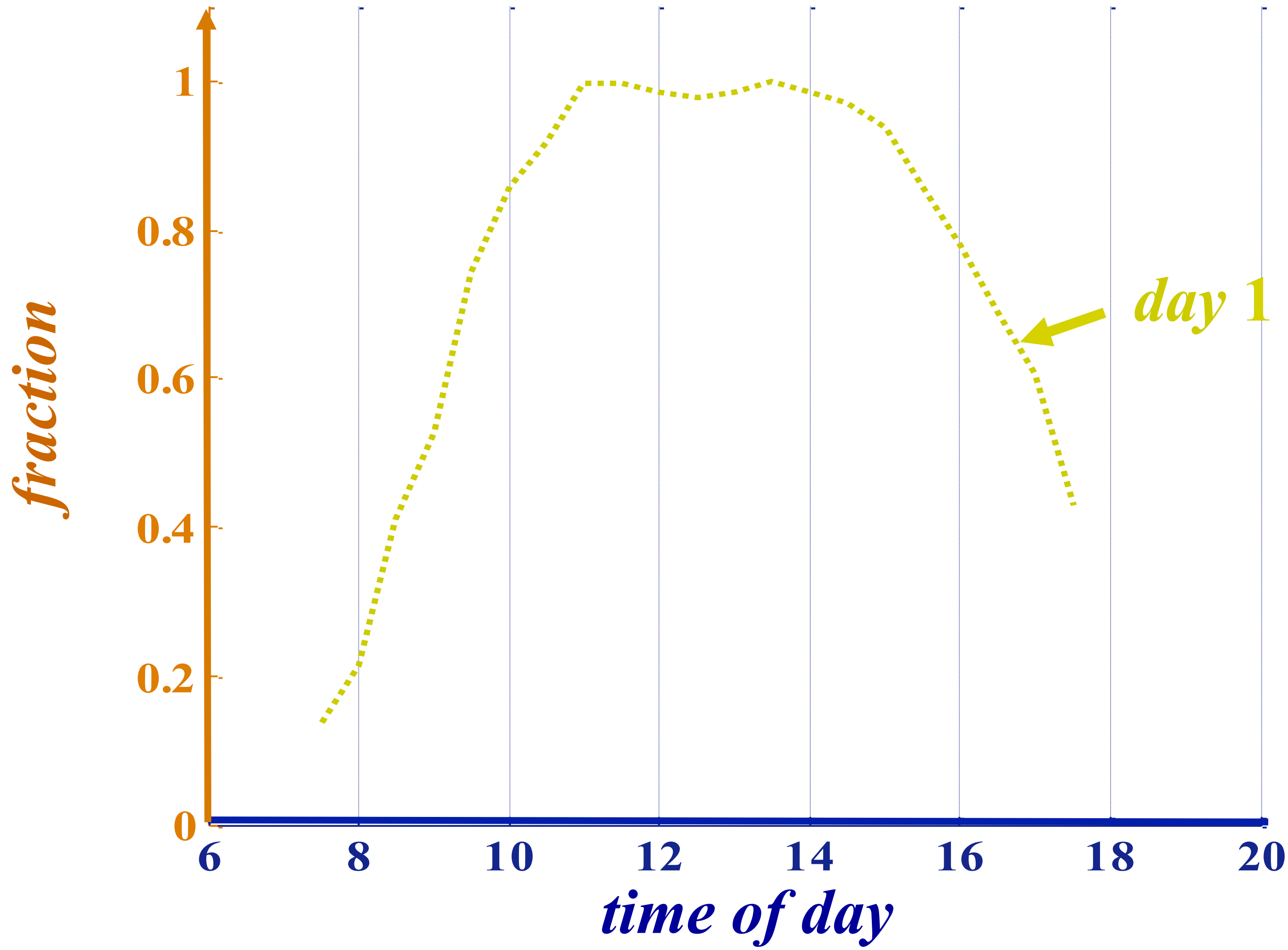
- We take into account various sources of uncertainty, including:
  - time of arrival
  - parking time
  - state of charge ($s.o.c.$)
  - storage capability of the BV battery
  - demand
- For the aggregated BVs, we make use of the *Central Limit Theorem* ($N > 30$) and represent the uncertainty by using various normally distributed random variables

DAILY COMMUTE DISTANCES



Source: Lucy Sanna, "Driving the solution, the plug-in hybrid vehicle," EPRI journal, Fall 2005

PARKING LOT UTILIZATION AS A FRACTION OF ITS CAPACITY



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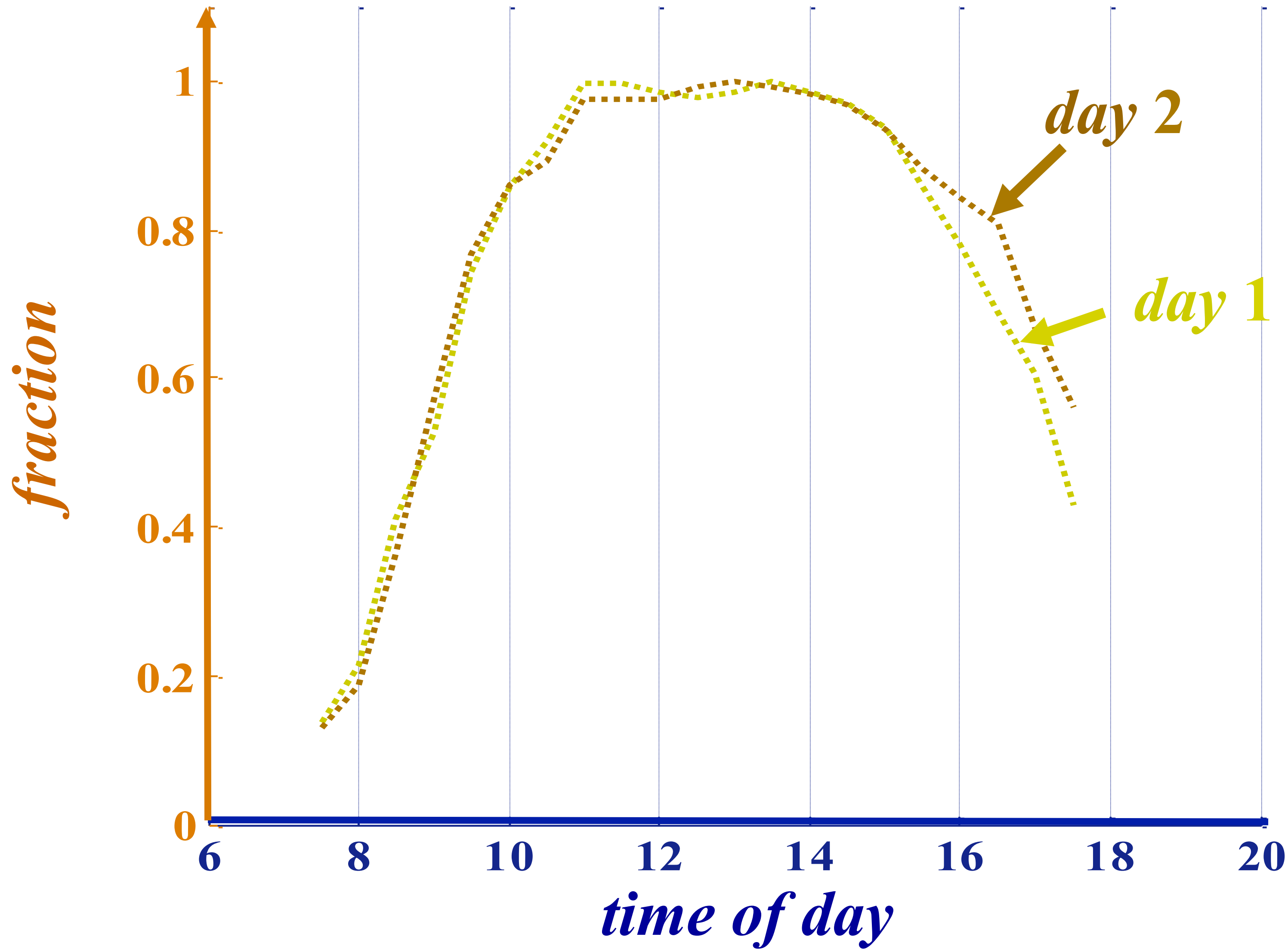

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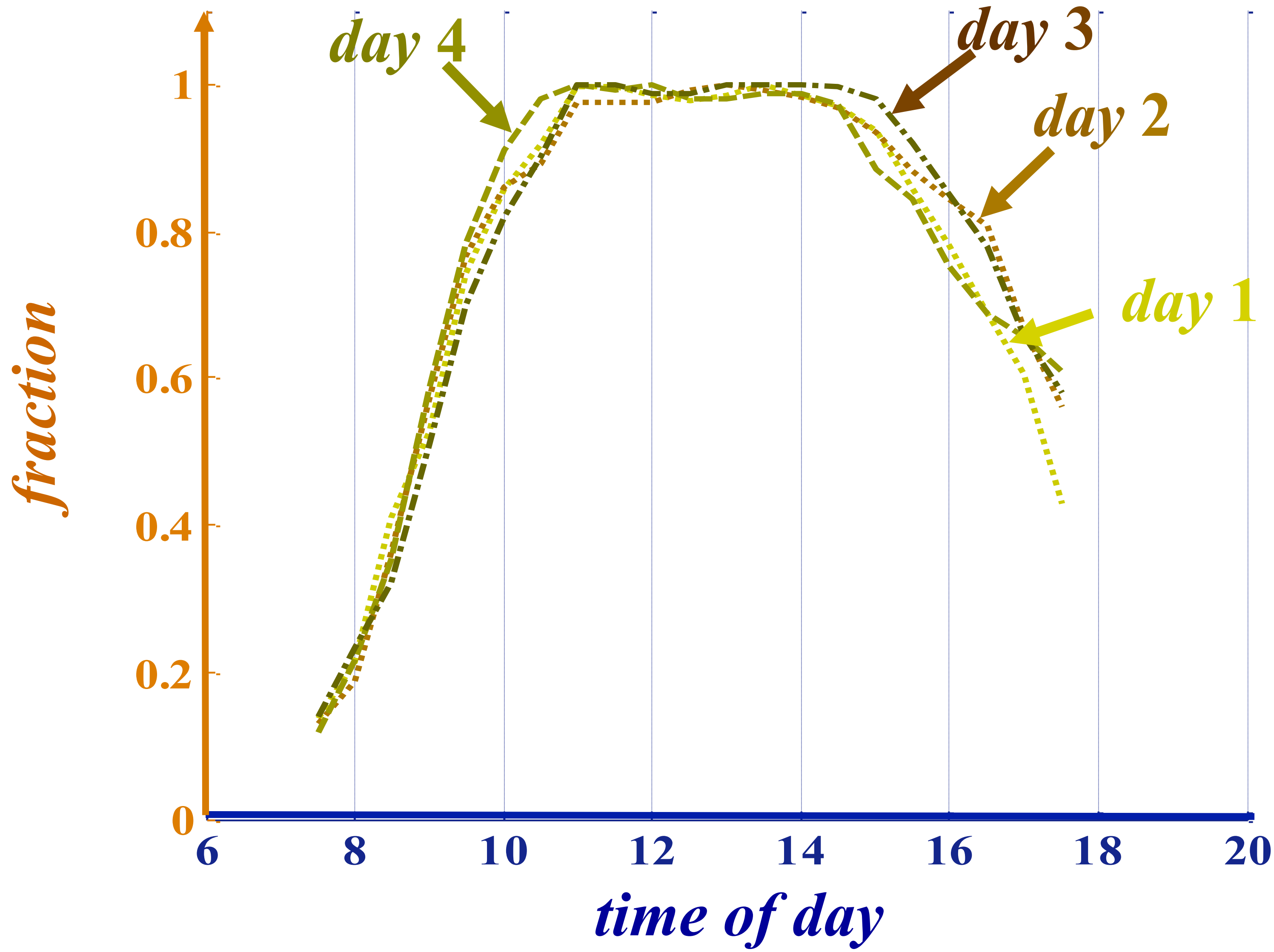
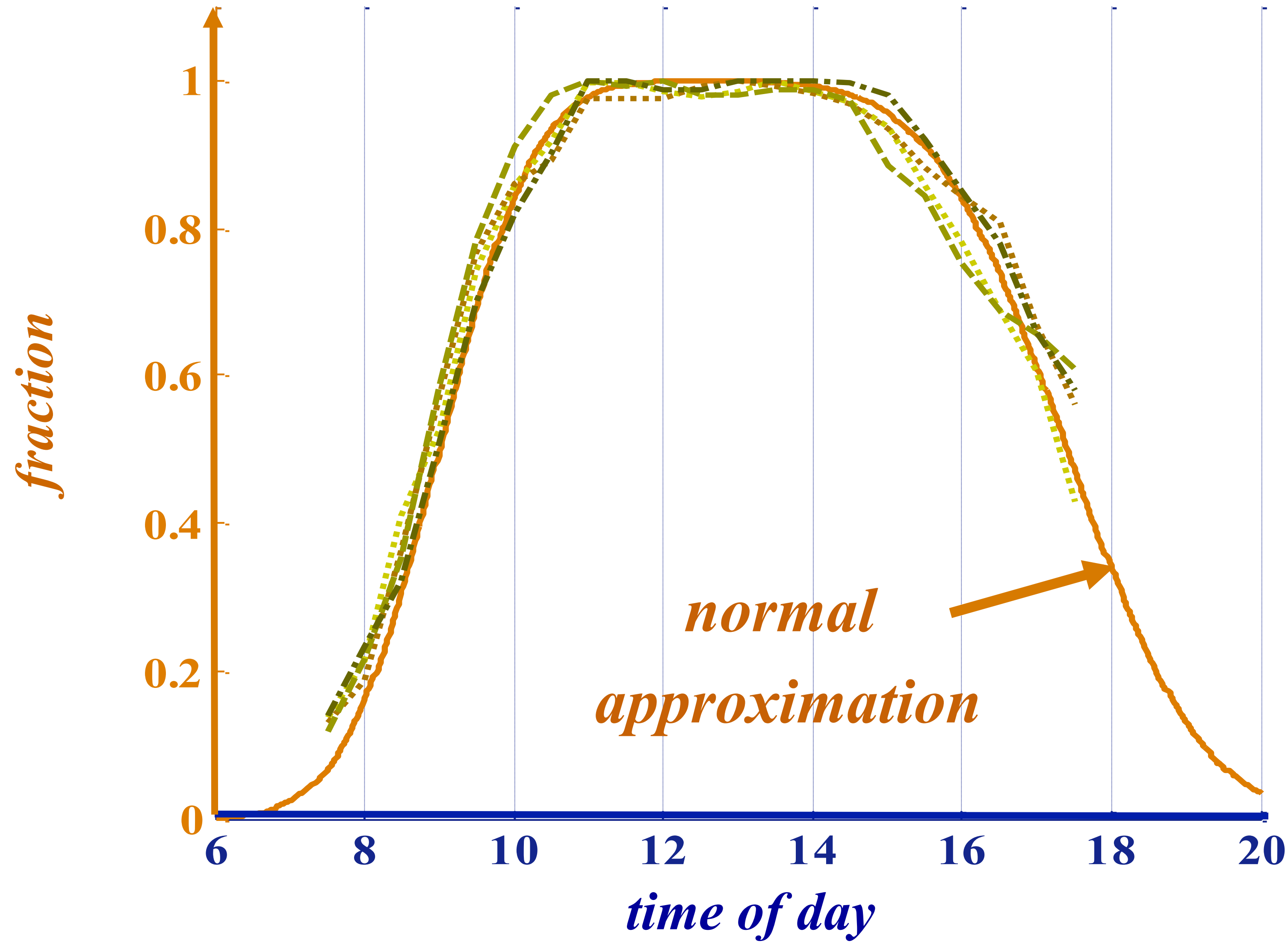
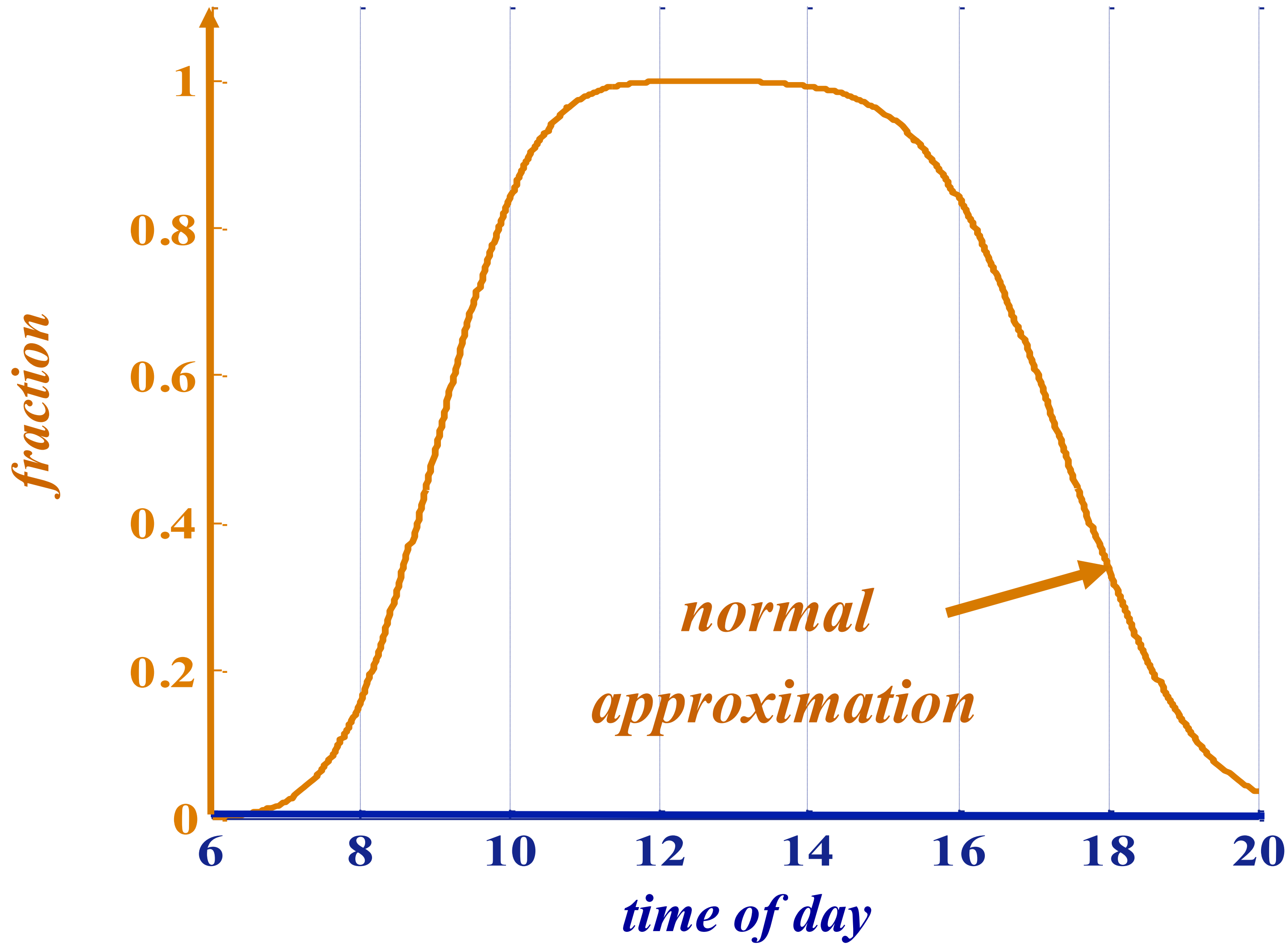


APPROXIMATION OF PARKING CAPACITY UTILIZATION

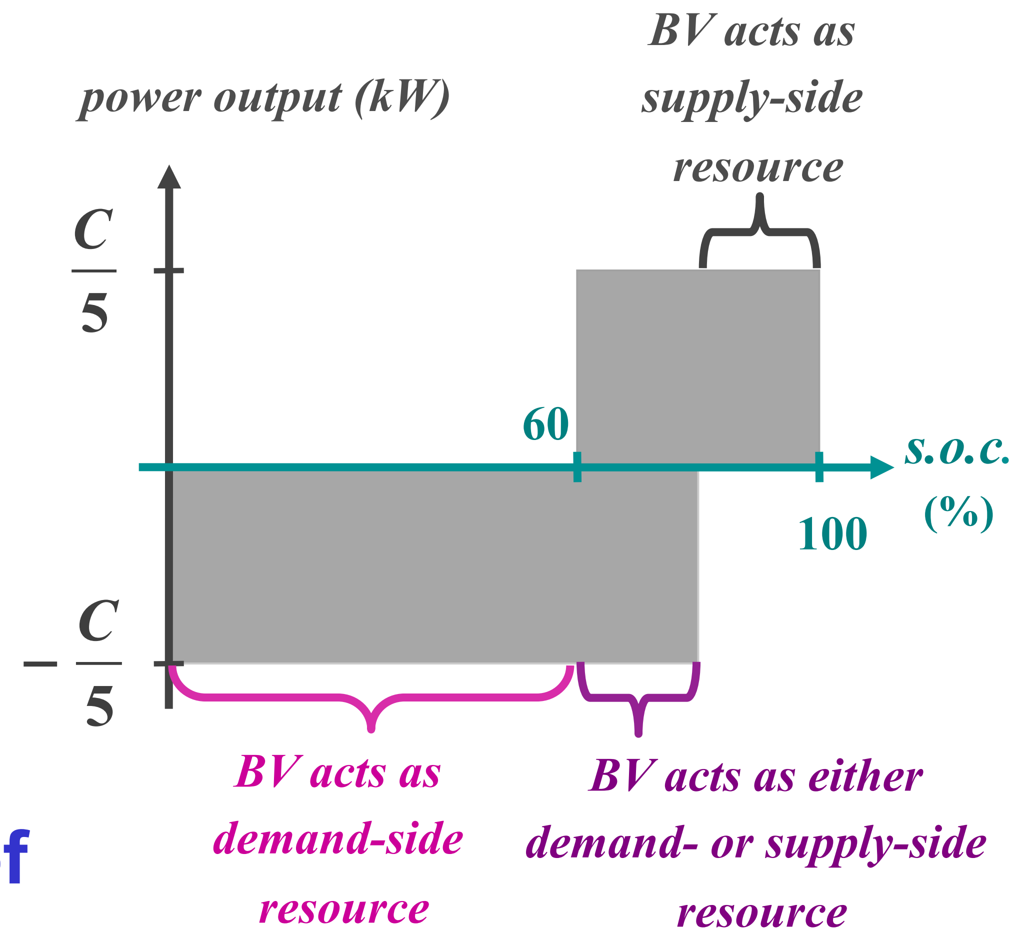


GAUSSIAN MODEL OF PARKING CAPACITY UTILIZATION



s.o.c. OF THE *BV* BATTERY

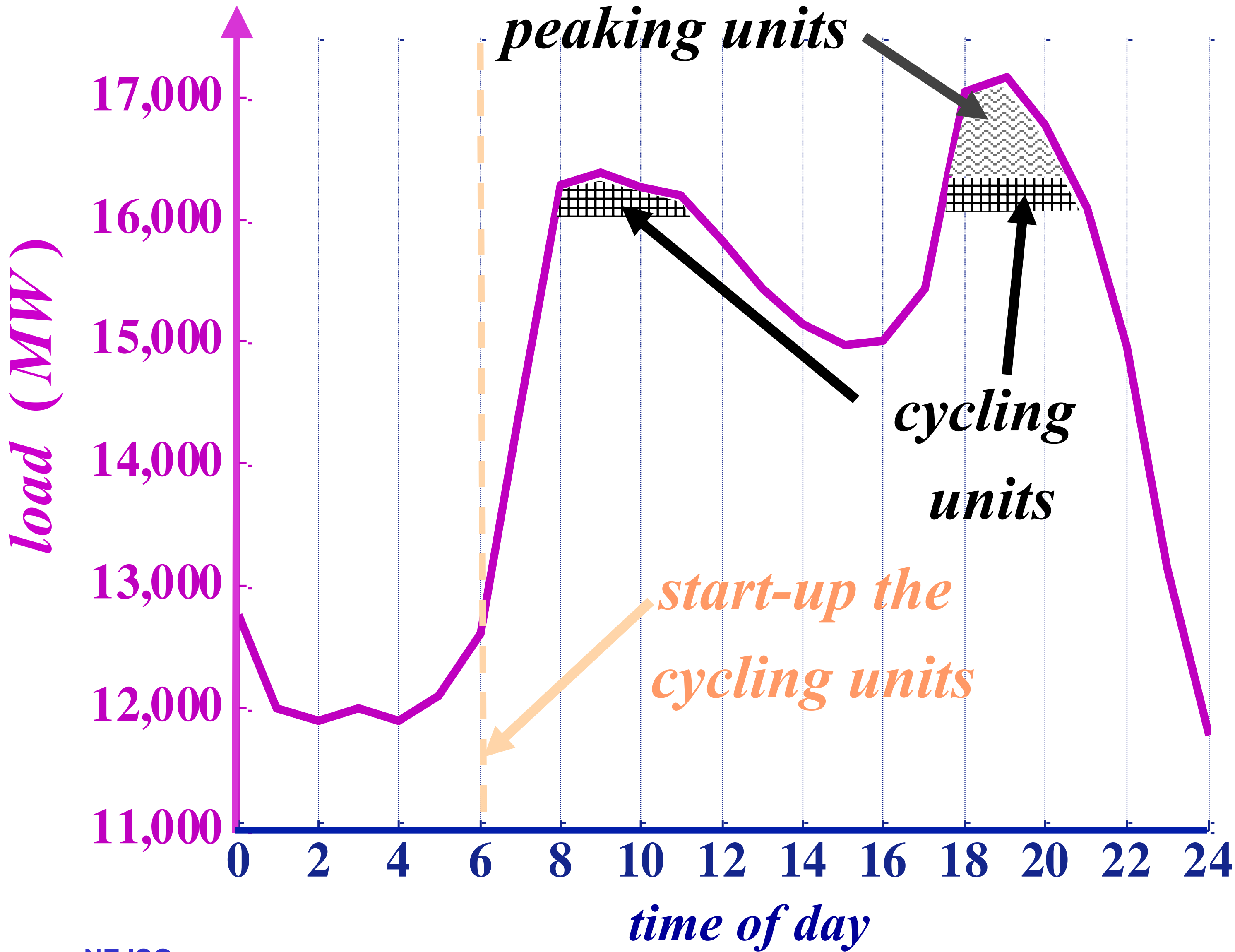
- The role of the *s.o.c.* is key to the effective management of the aggregated *BV* integration into the grid
- The utilization of a battery is a function of its storage capability



*BV*s PROVIDE IMPORTANT SERVICES

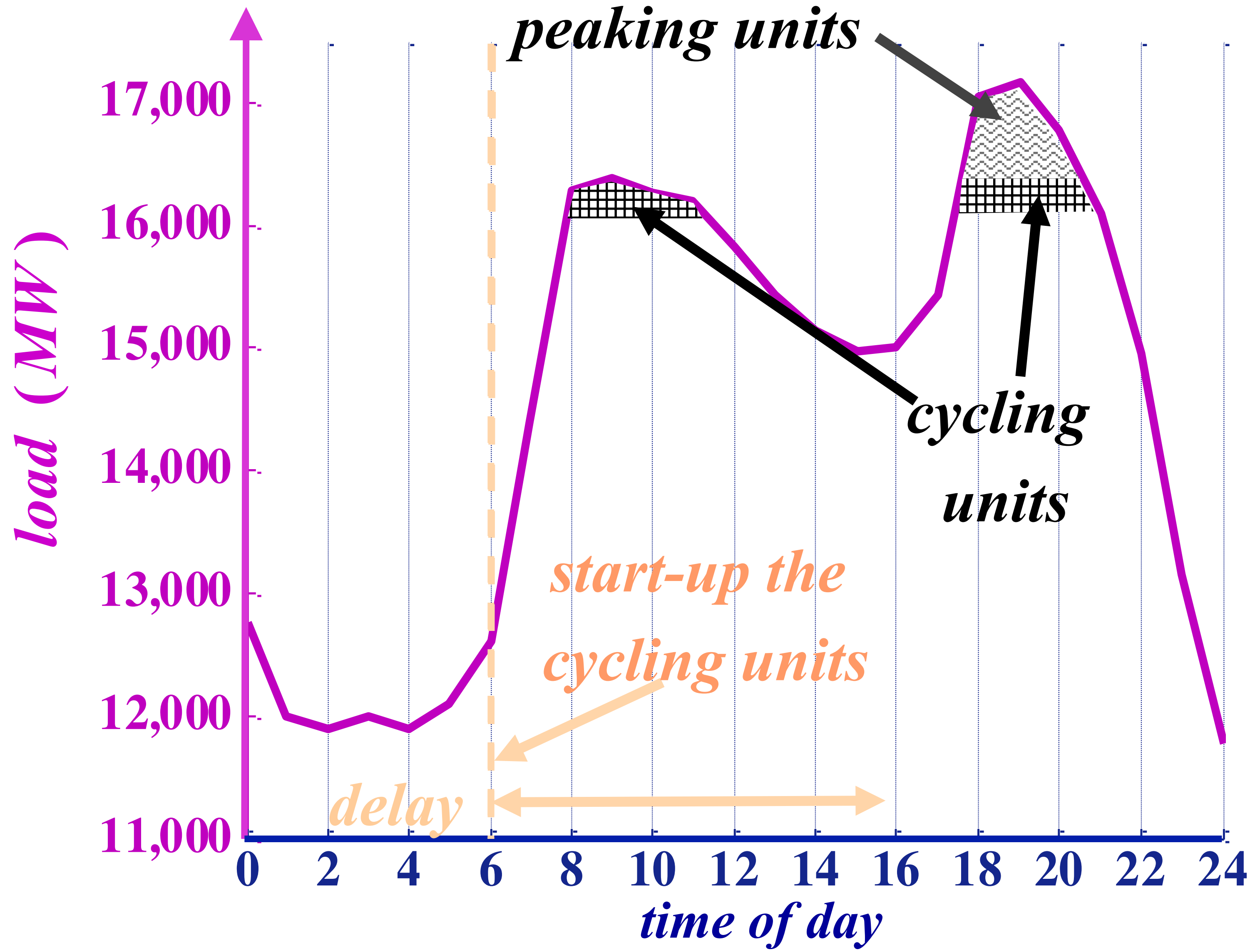
- The aggregated *BV*s can constitute a very important supply-side resource to the grid
- The *BV*s can provide considerable flexibility to the *ISO/RTO* in the scheduling of unit commitment
- As a result, the start-up of cycling and peaking units may be delayed or avoided; the provision of reserves is improved, with the need for reserves, during off-peak periods, reduced

CYCLING UNITS WITHOUT *V2G*



Source: NE ISO

CYCLING UNITS WITH *V2G*



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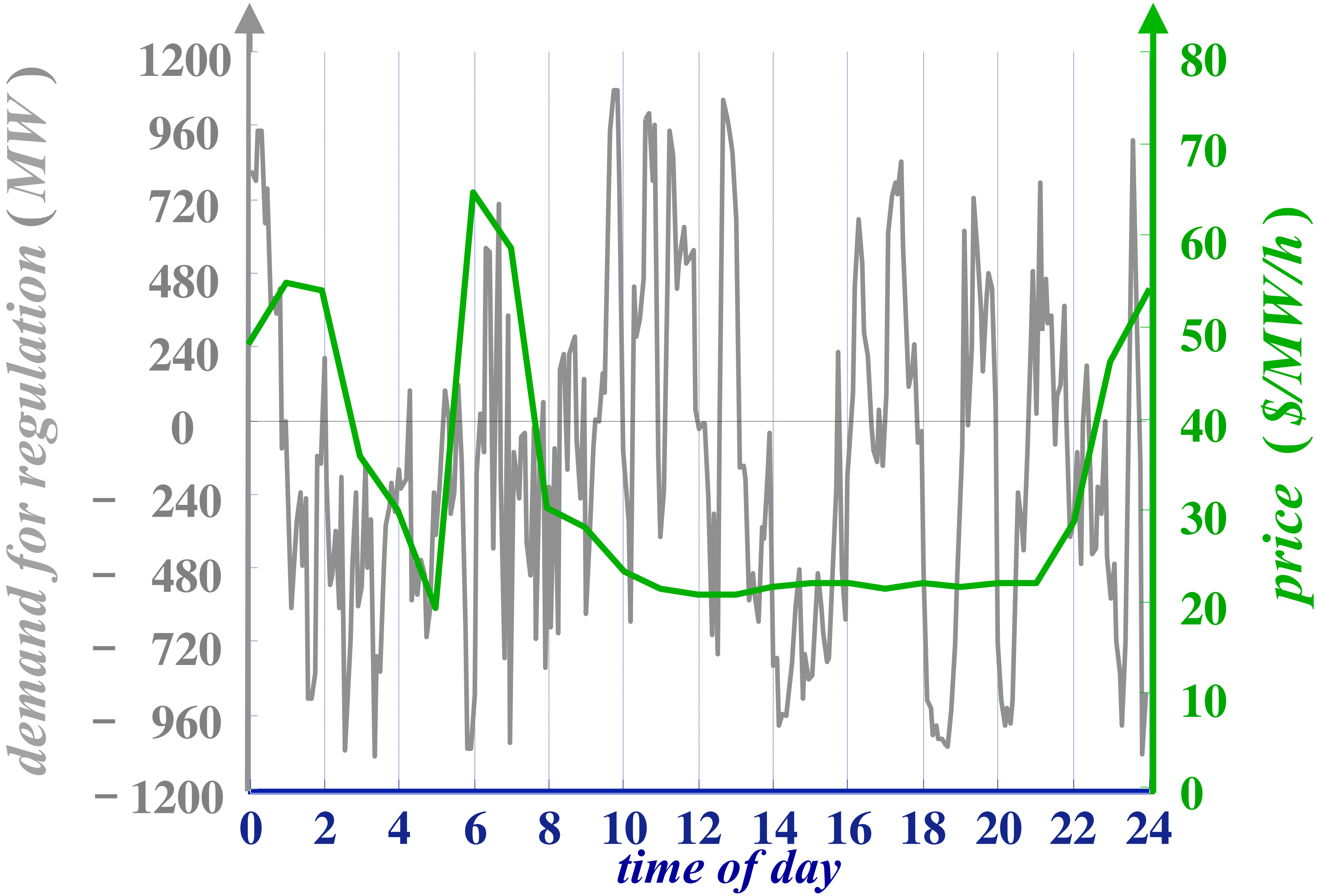
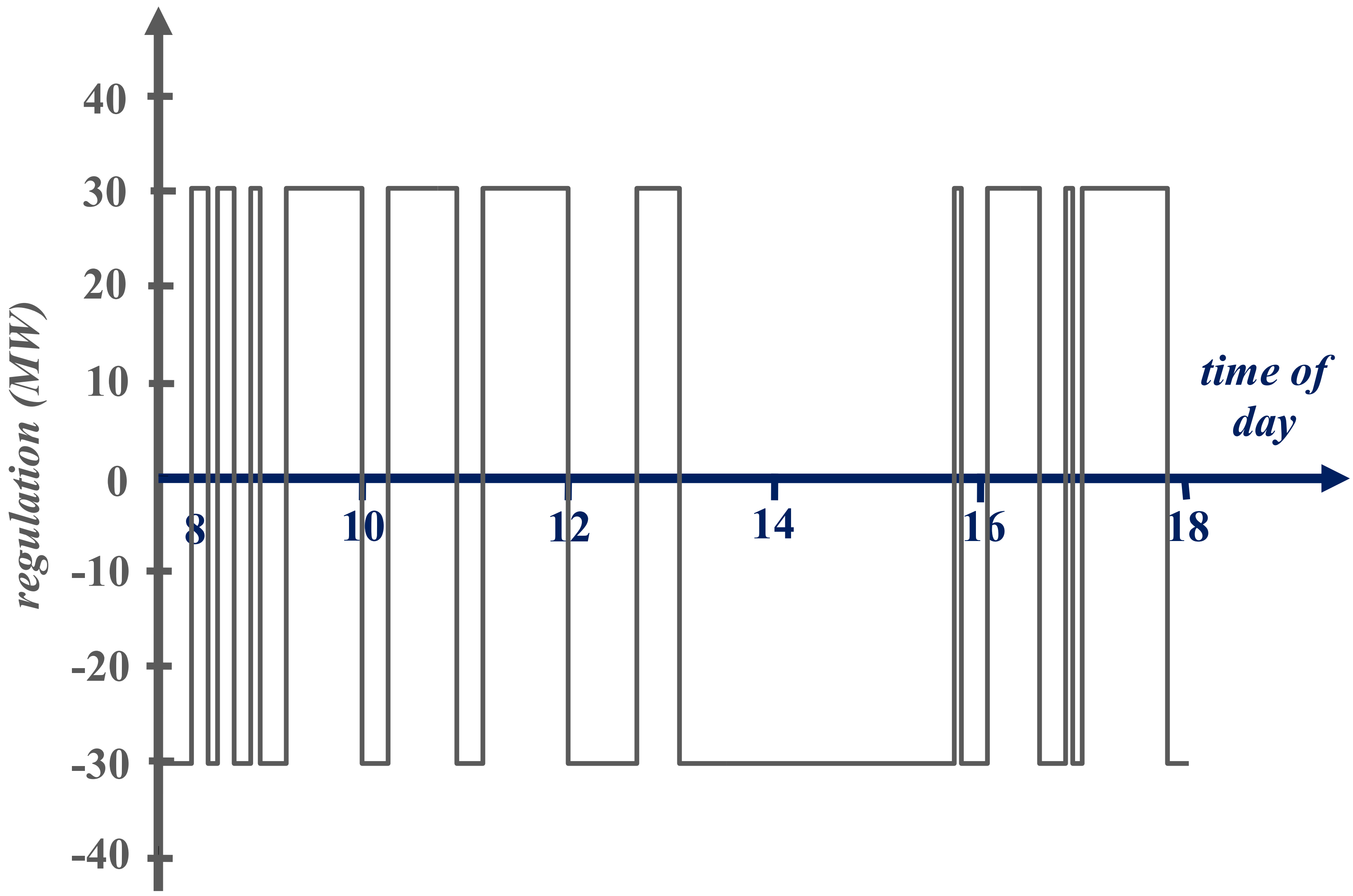
REGULATION SERVICE AND PRICING

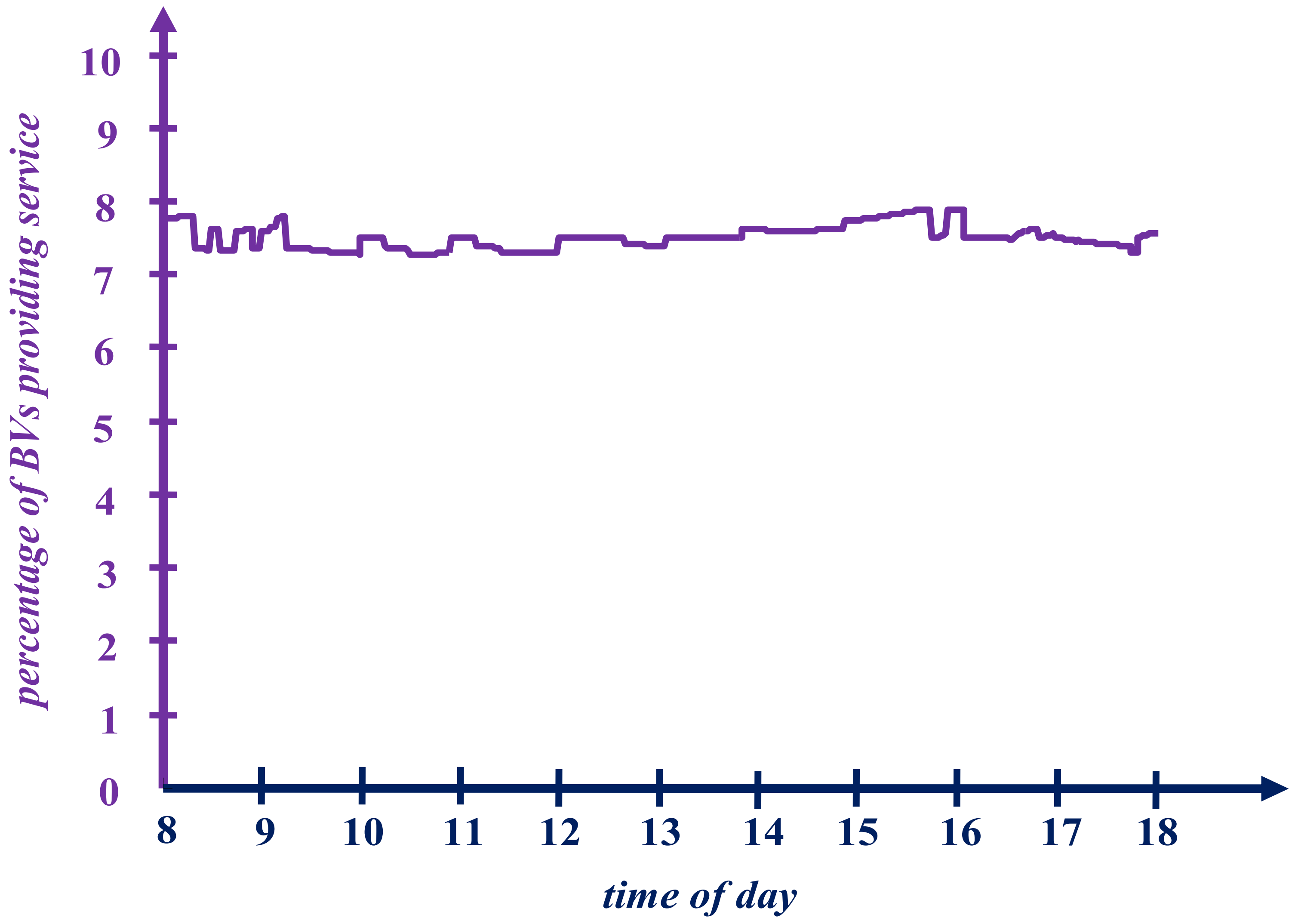


Source: PJM

DAY – TIME REGULATION SERVICE PROVISION BY 100,000 *BV*s



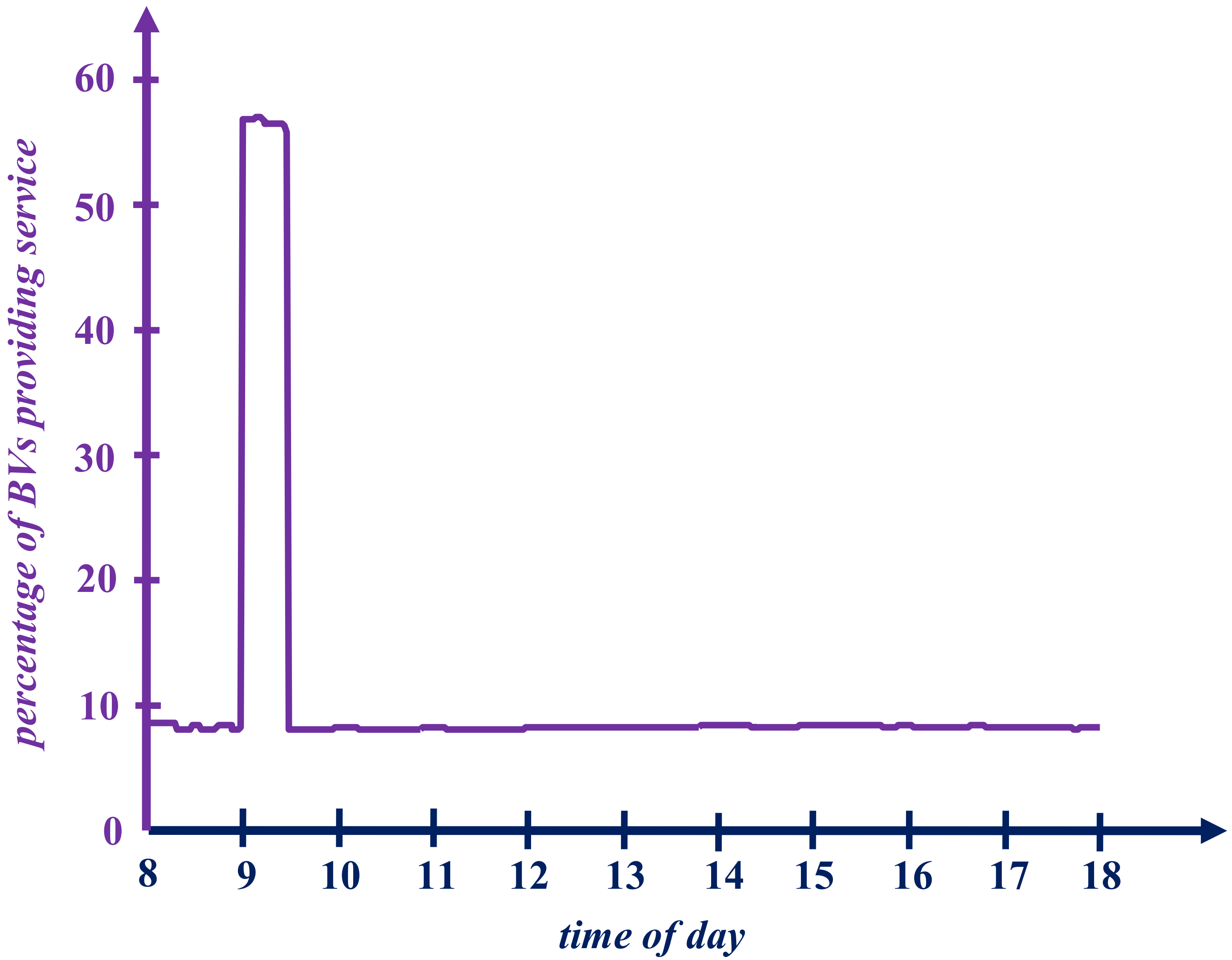
PERCENTAGE OF *BV*s PROVIDING THE REGULATION SERVICE



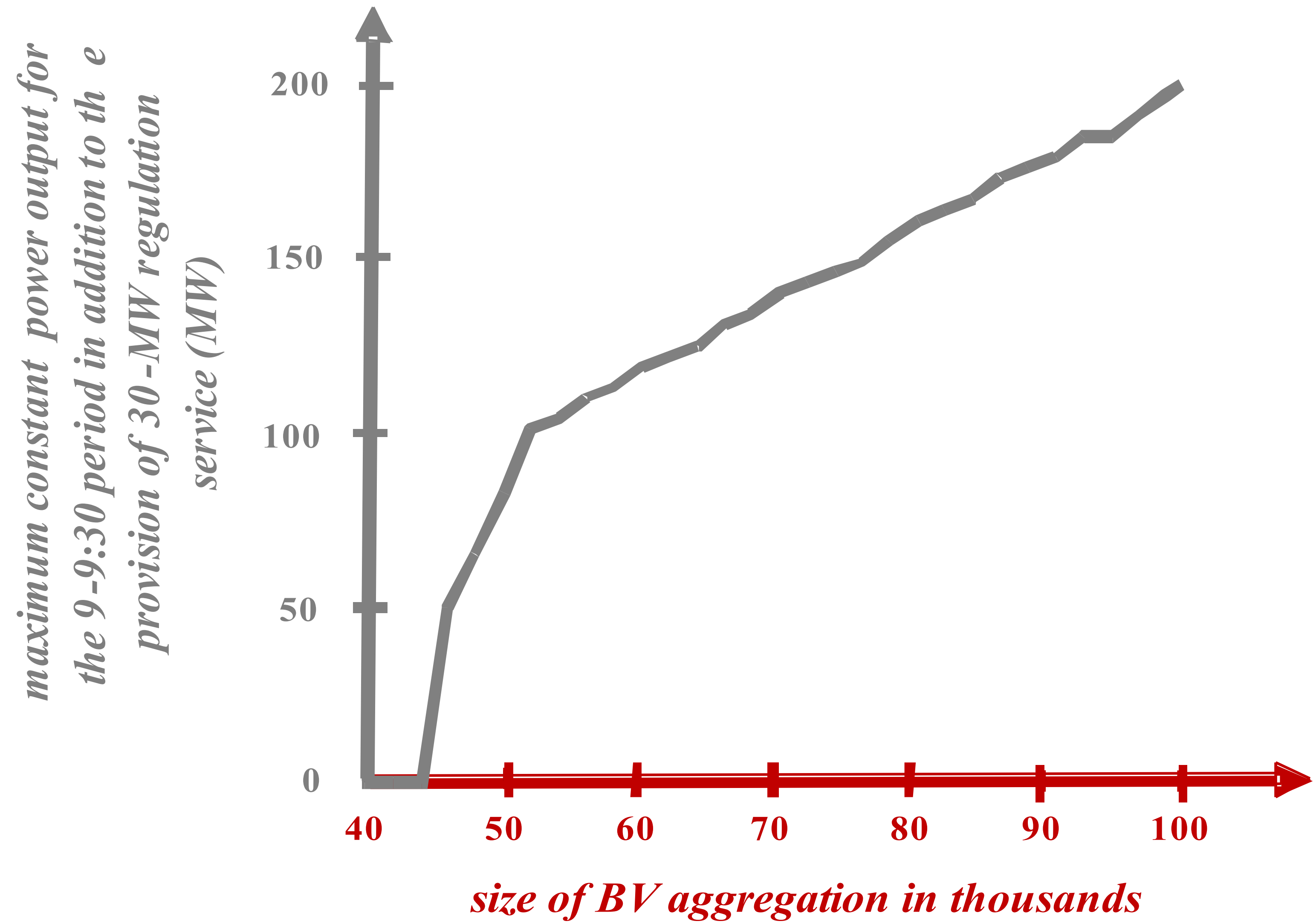
PROVISION OF LOAD SHAVING SERVICE IN ADDITION TO REGULATION

- The number of *BV*s providing regulation service remains rather low, with fewer than 10 % of the *BV*s in the aggregation providing service at any point in time from 8 *a.m.* to 6 *p.m.*
- We consider the provision of load shaving service in addition to the regulation service
- We show that the Aggregator can also provide 100 *MWh* of load shaving service at a constant power output between 9:00 and 9:30 a.m. with an aggregation of 100,000 *BV*s

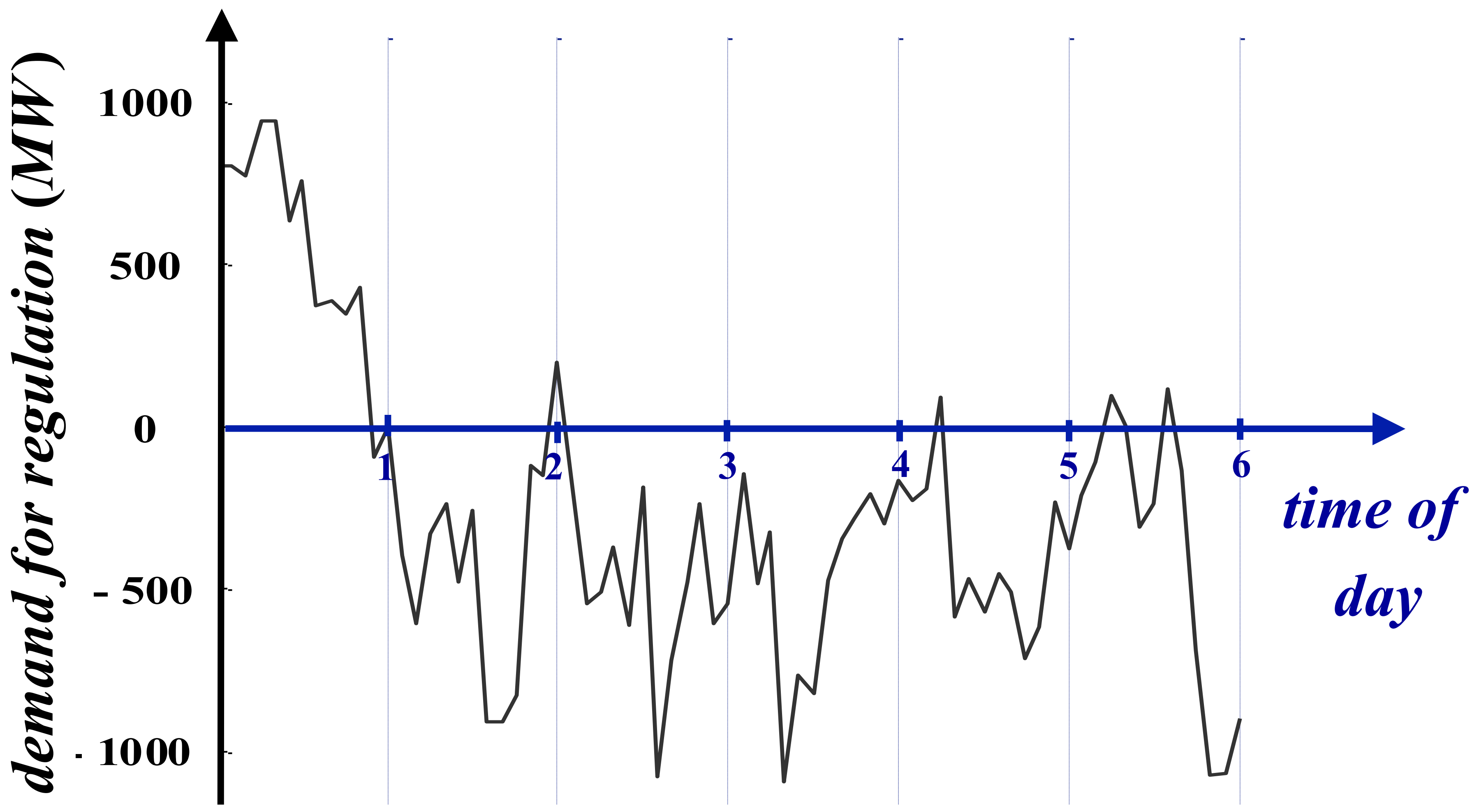
PERCENTAGE OF *BV*s PROVIDING LOAD SHAVING AND REGULATION SERVICE



ENERGY PROVIDED IN ADDITION TO THE REGULATION SERVICE



REGULATION DEMAND FOR OFF-PEAK CONDITIONS



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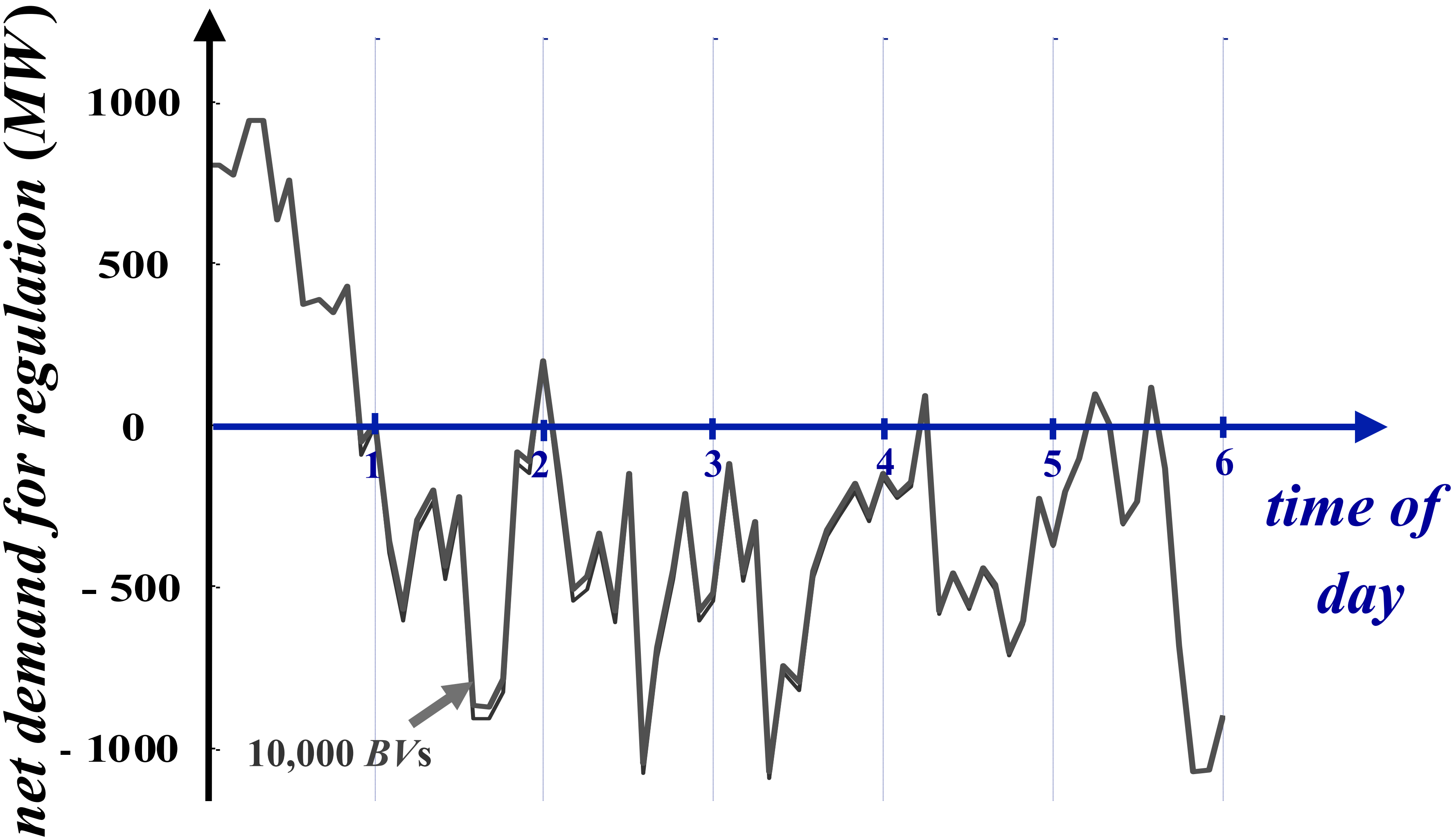

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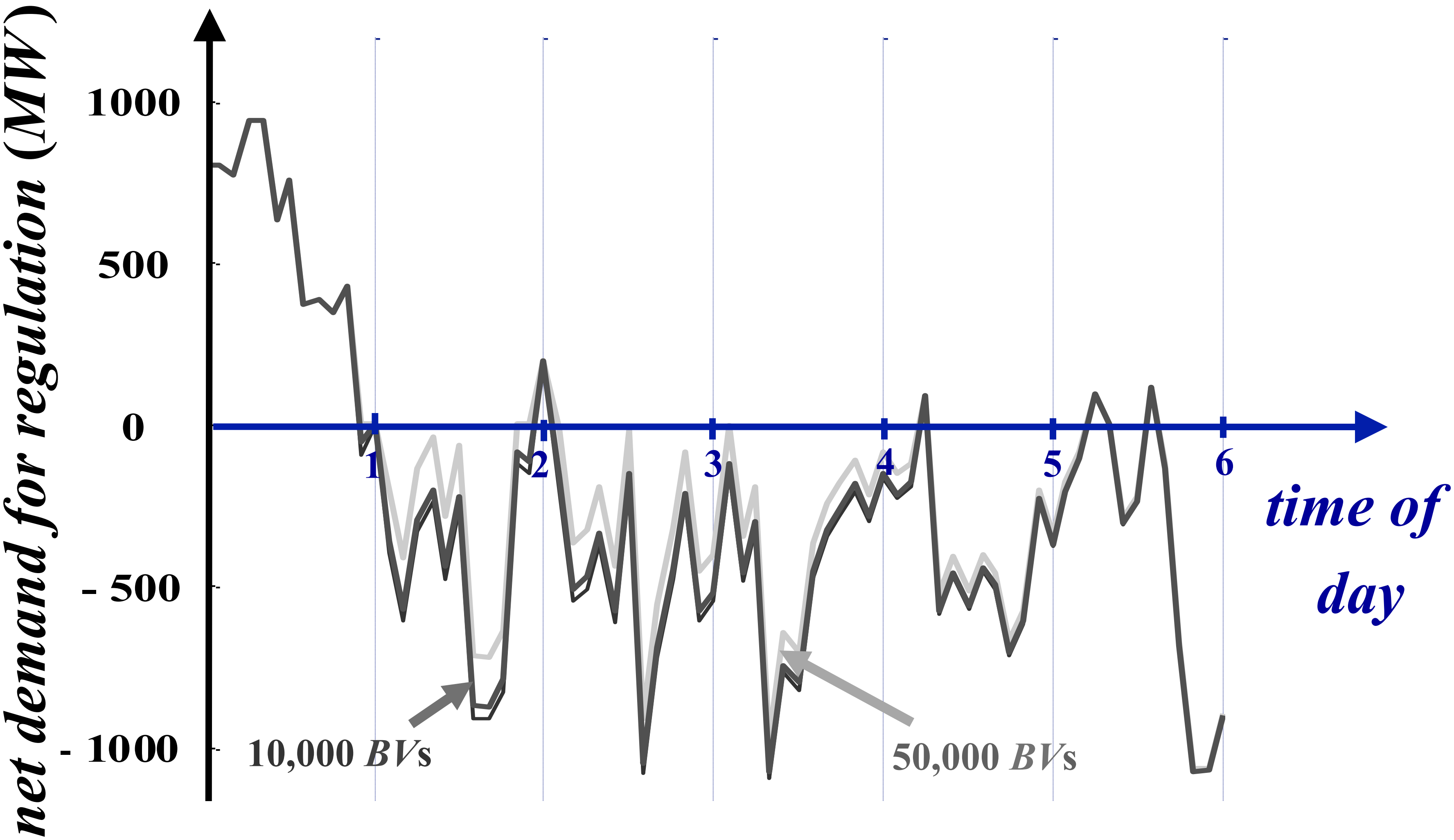

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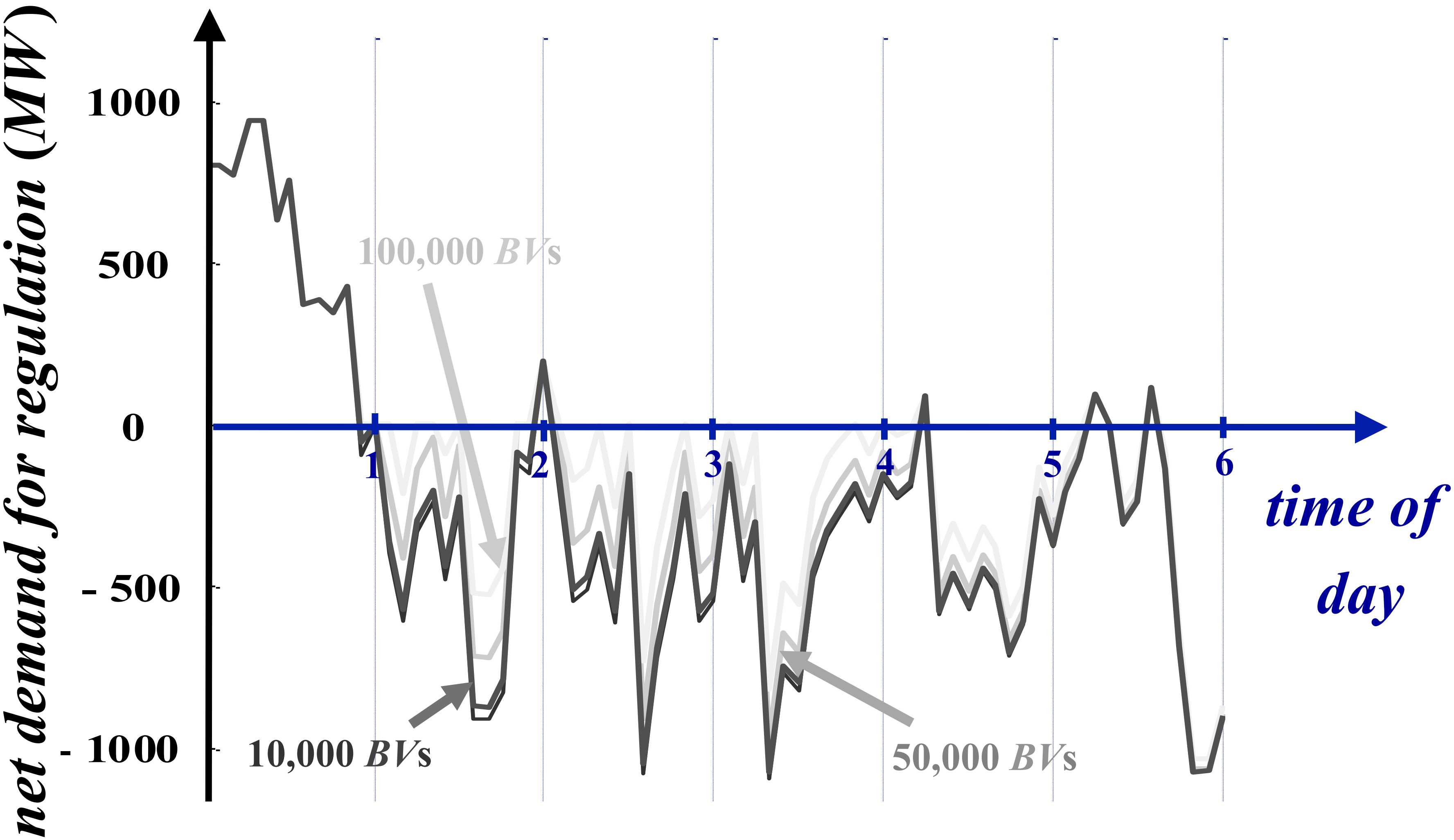

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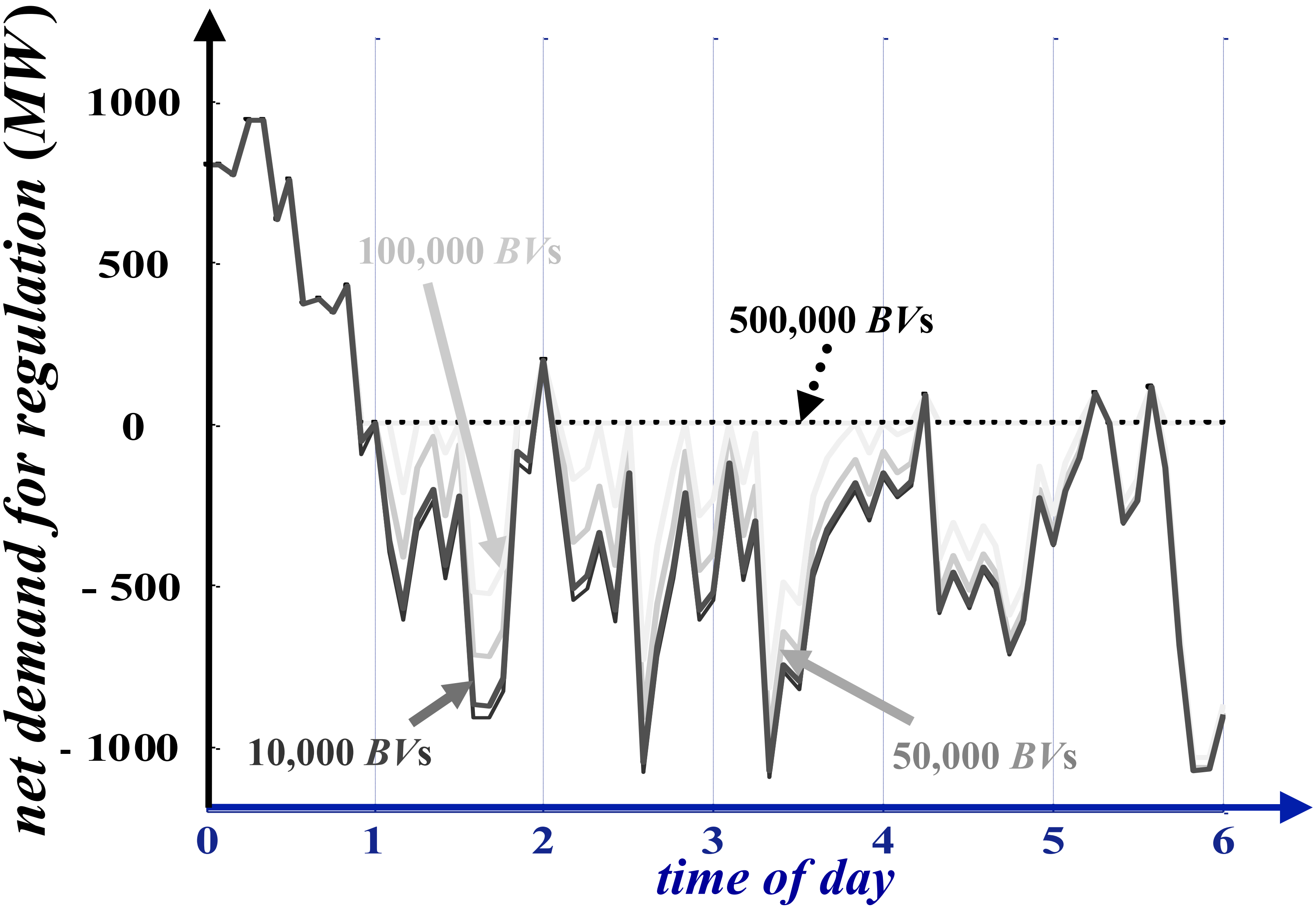


KEY IMPLEMENTATIONAL ISSUES

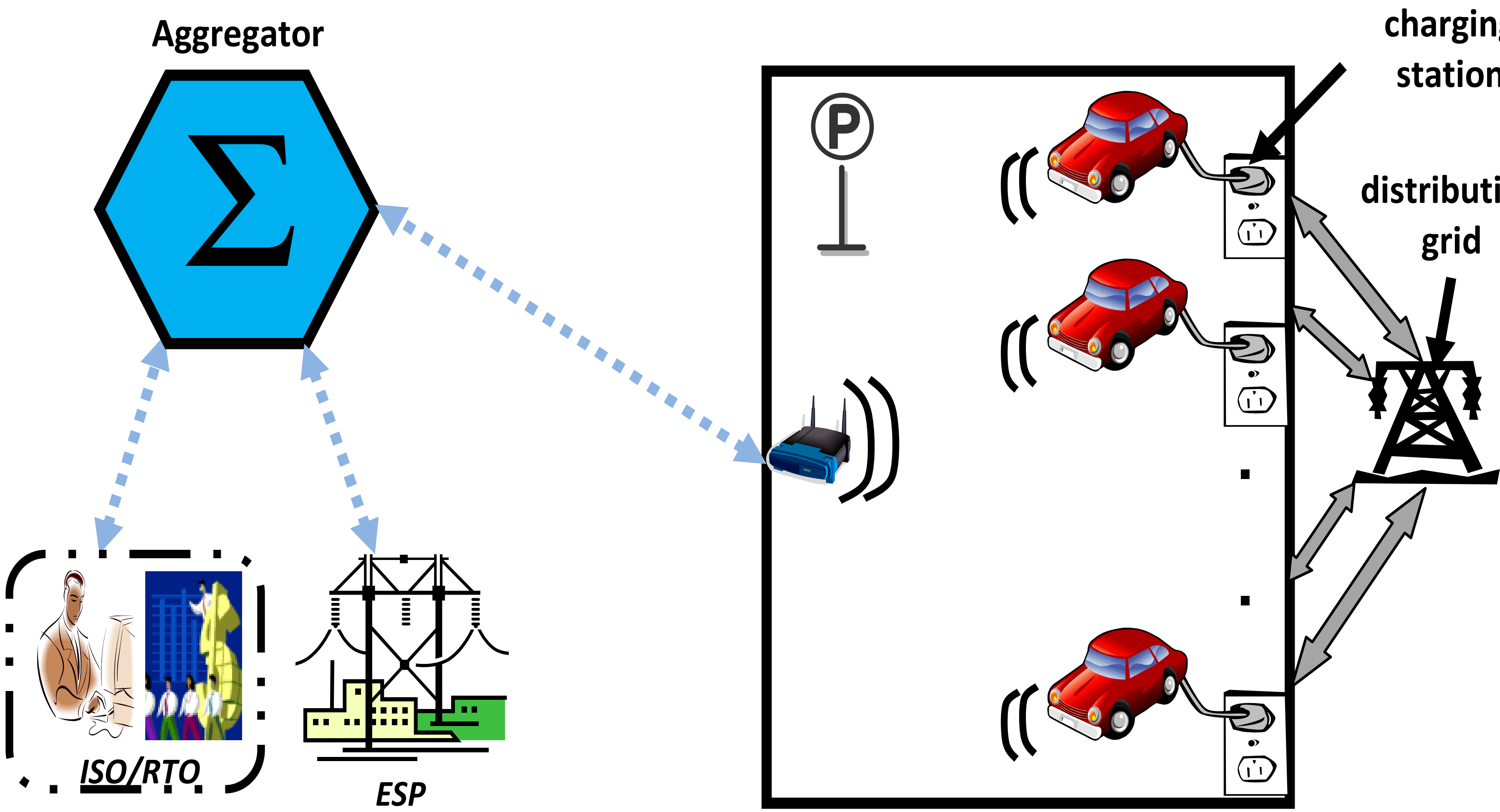
- Aggregation

- Information layer construction

- Incentive development

- Realization of environmental benefits

V2G COMMUNICATION AND METERING



ESSENTIAL COMMUNICATION / CONTROL SYSTEM REQUIREMENTS

- **Speed**: signals need to be sent every 1 to 2 s
- **Range**: every BV in a parking lot must be on the communication network
- **Measurement**: metering must be installed to enable payment for services
- **Reliability**: full utilization of all parked aggregated BVs
- **Security**: BVs make the network vulnerable to cyber attacks

ESSENTIAL COMMUNICATION / CONTROL SYSTEM REQUIREMENTS

- **Costs**: each BV has an implanted device and the costs per unit must be low for the large collection of aggregated BVs
- **Extendibility**: the communication layer must allow the integration of additional BVs
- **Interoperability**: a non-restrictive, flexible standard needs to be introduced and implemented

INFORMATION LAYER FLOWS

- ID of each *BV*
- Preferences/constraints of each *BV*
- Parking status of each *BV*
- Storage capability of the *BV* battery
- The *BV* battery *s.o.c.*
- Power flows from *BV* battery to the grid
- Measured value of metered quantities

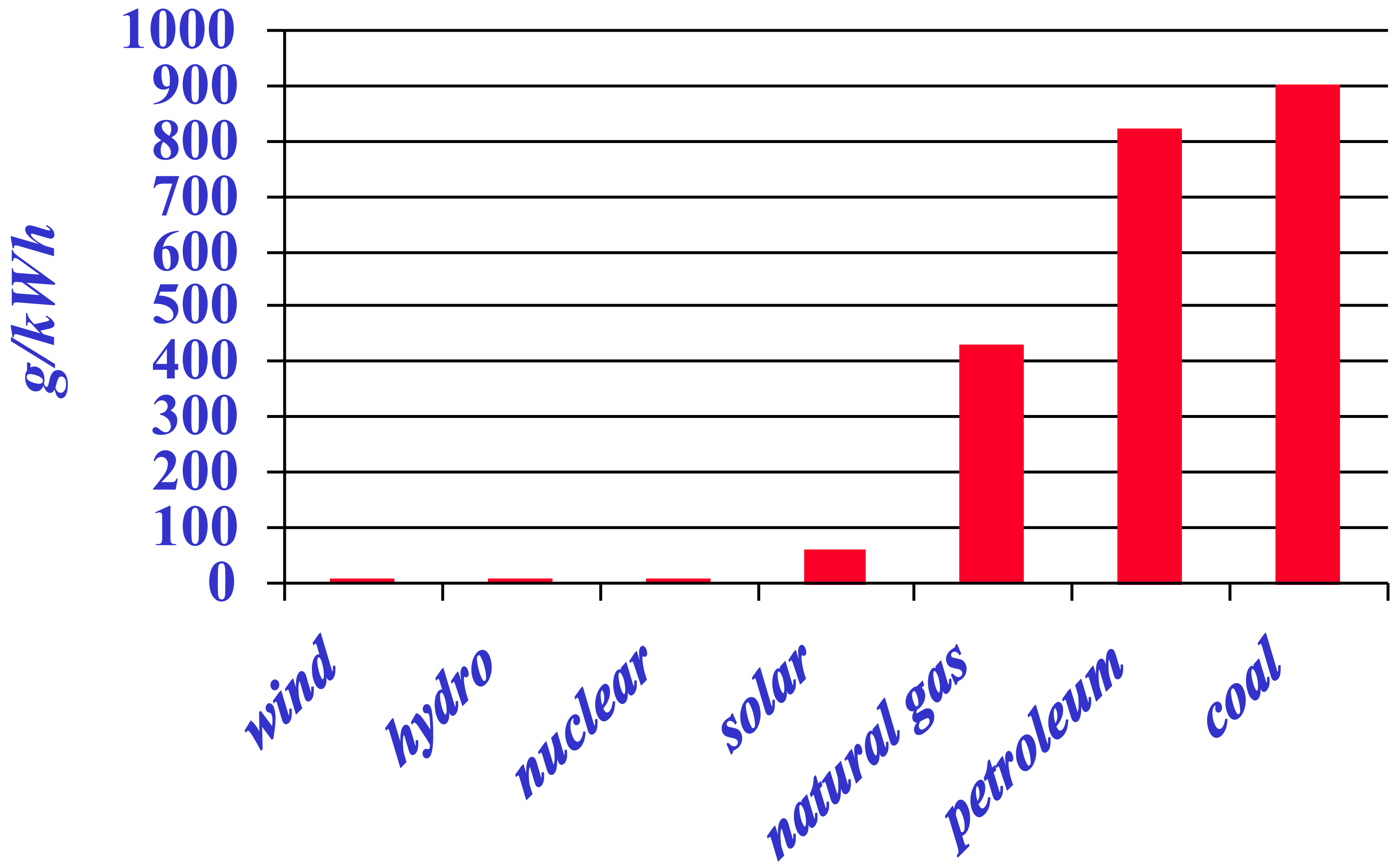
THE ROLES OF THE AGGREGATOR

- Development of the parking infrastructure
- Maintenance of the batteries and the network
- Creation of relationships with the *BV* and battery manufacturers
- Interface with *ISO/RTO*

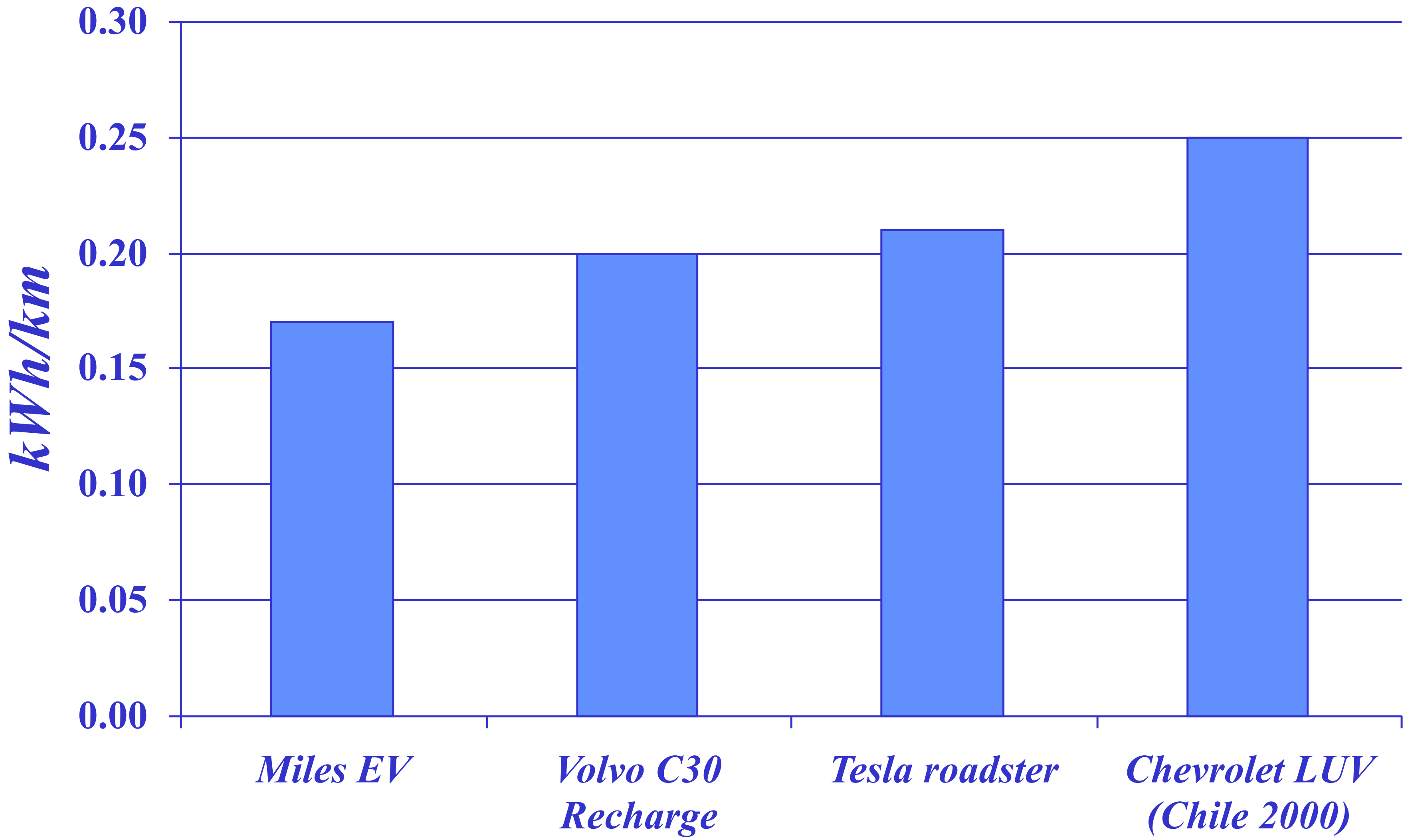
VALUE ADDED BY THE AGGREGATOR

- Provides a "package deal" to the aggregated *BV*s in terms of:
  - parking facilities
  - service acquisition and provision
  - charging of *BV*s
  - battery service
- Allows "one-stop shopping" for potential *BV* participants
- Acts as the "representative" for the provision of environmental benefits from reduced emissions

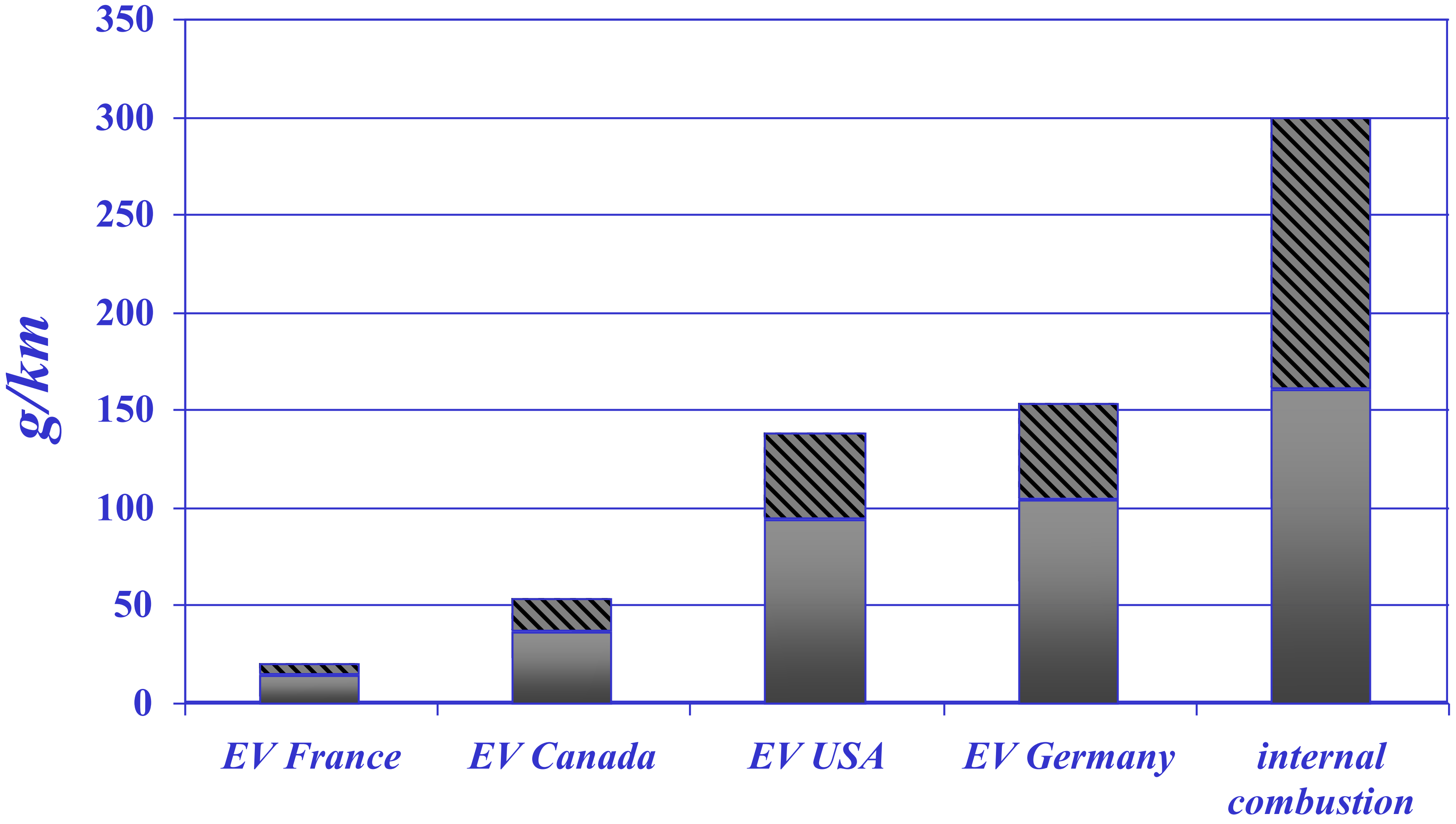
CO_2 EMISSION BY PLANT TYPE



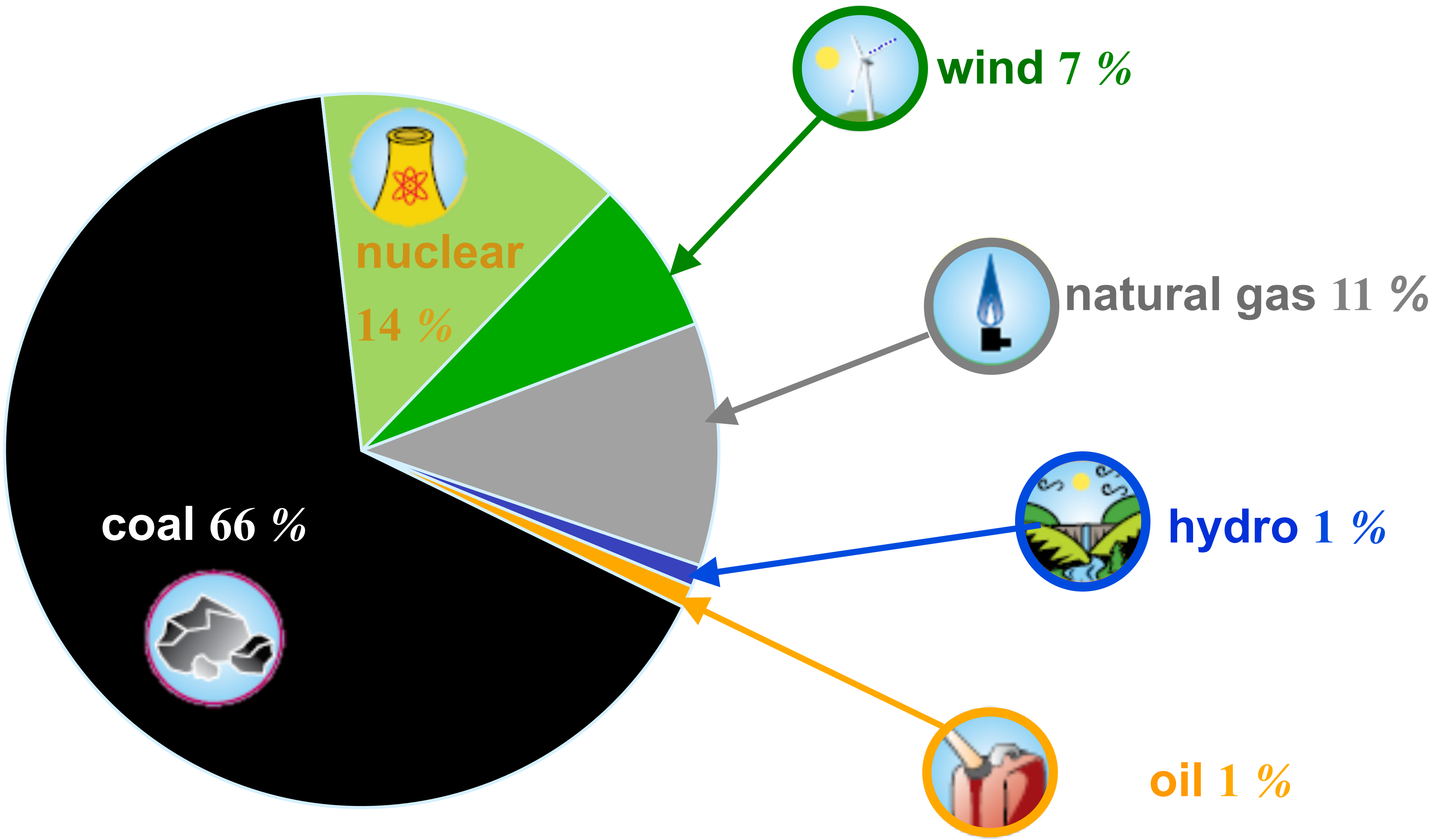
ENERGY CONSUMPTION UNDER MIXED CONDITIONS



VEHICLE CO_2 EMISSIONS

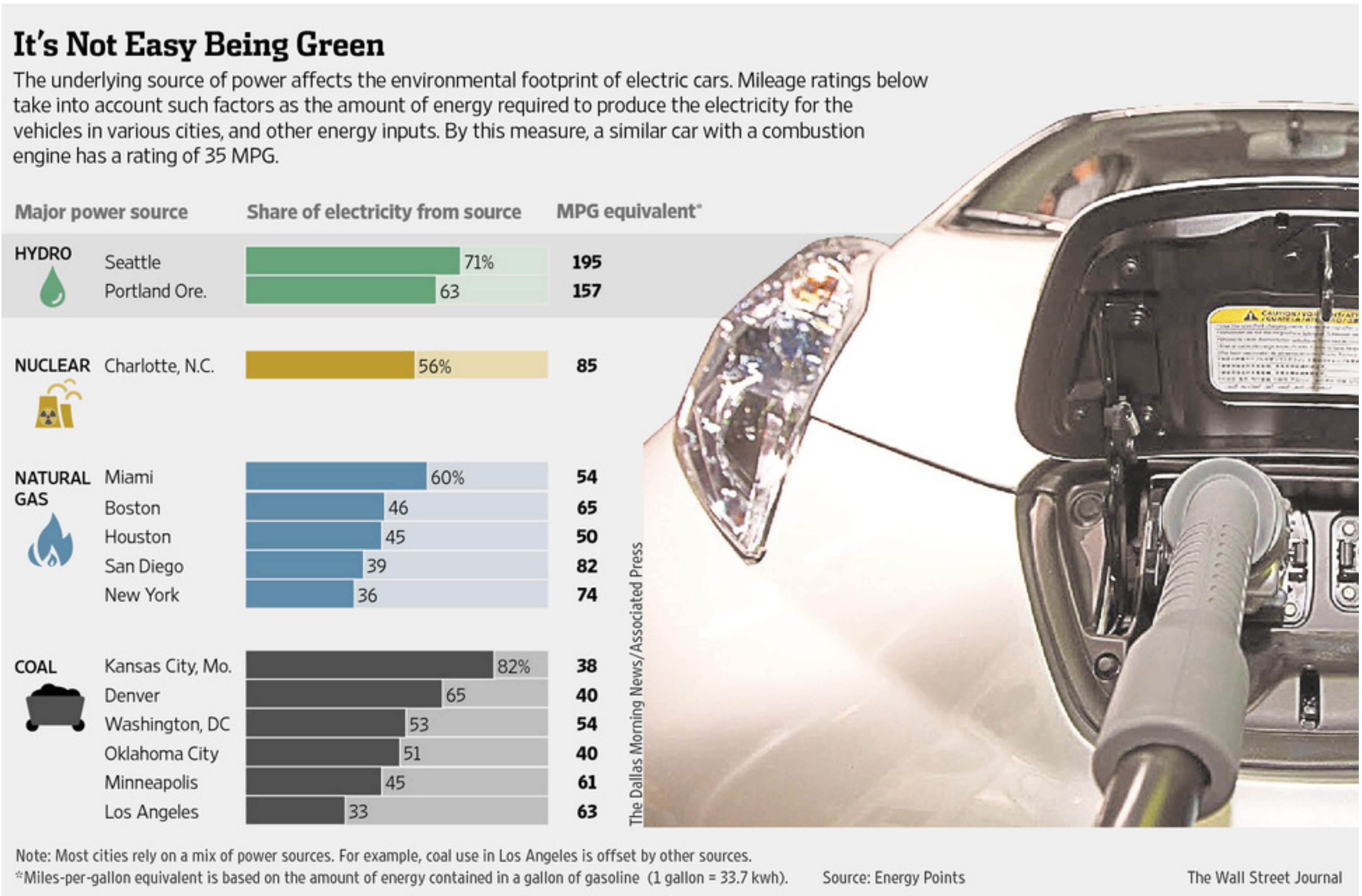


AMEREN IP NET GENERATION BY ENERGY SOURCE FOR 2014



Source : Ameren IP, October 2014 retrieved at https://www.ameren.com/-/media/Corporate-Site/Files/billinserts/2014-10-FOE.pdf?la=en

VARYING COSTS OF *BV* CHARGING



Source: Wall Street J., Aug. 30, 2014 available at http://online.wsj.com/news/interactive/CHARGERS0830?ref=SB10001424052970203858004580103452981095016

FUTURE WORK

- Improvement of the *BV* selection for the provision of higher energy and regulation performance
- Design and implementation of a secure and economic communication/control architecture
- Design of an effective incentive program for high *BV* participation and retention

CONCLUDING REMARKS

- Integration of *BV*s helps the grid both as loads in off-peak periods and as supply sources during the day
- The Aggregator can provide beneficial services to *ESP*s and *ISO*/*RTO*s
- Aggregators are key new players in the effective implementation of *V2G* concept
- The *BV* Aggregator has the potential to harness sizeable benefits for the grid through *V2G*

REFERENCES

- C. Guille and G. Gross, "A Conceptual Framework for the Vehicle-to-Grid (*V2G*)Implementation," Energy Policy, November 2009, pp. 4379 - 4390.
- C. Guille, "A Conceptual Framework for the Vehicle-To-Grid (*V2G*) Implementation," MS Thesis, ECE Department, University of Illinois, Urbana, September 2008; available at: http://energy.ece.illinois.edu/gross/papers/Dissertations/Guille.pdf