A CONCEPTUAL FRAMEWORK DESIGN FOR IMPLEMENTATION OF VEHICLE–TO–GRID (*V2G*)

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MOTIVATION

- There are growing concerns around the world about energy independence and global warming issues
- The success of the Toyota Prius – with over 510,000 sold by November 2007 in the US – is a major driver in spearheading the development of battery vehicles (*BV*s) in the U.S. and Europe

OUTLINE

- 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 a conceptual framework

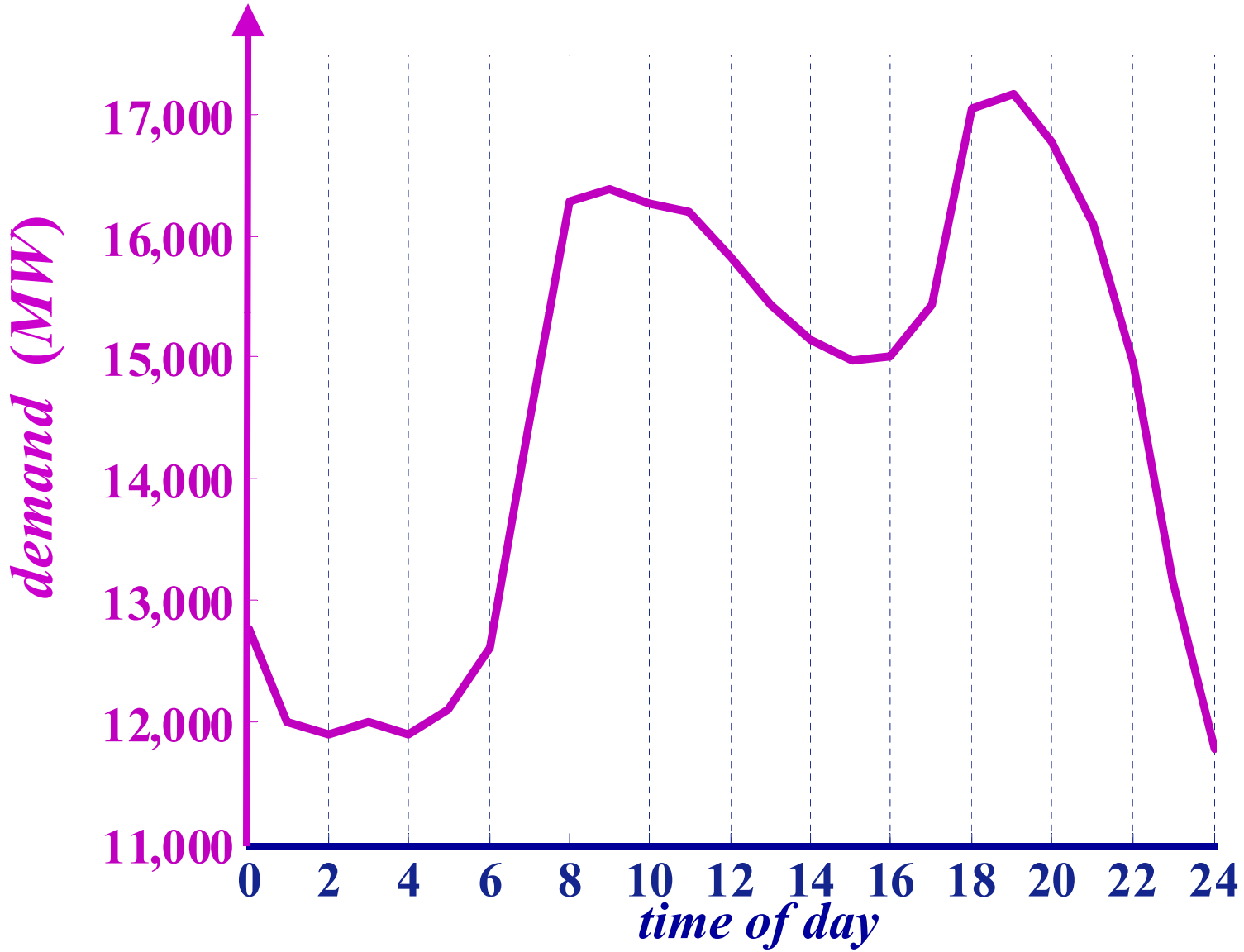
OUTLINE

- Major implementational issues
  - design of an incentive program
  - metering and communication/control needs
- Environmental aspects
- Concluding remarks

THE ELECTRICITY GRID

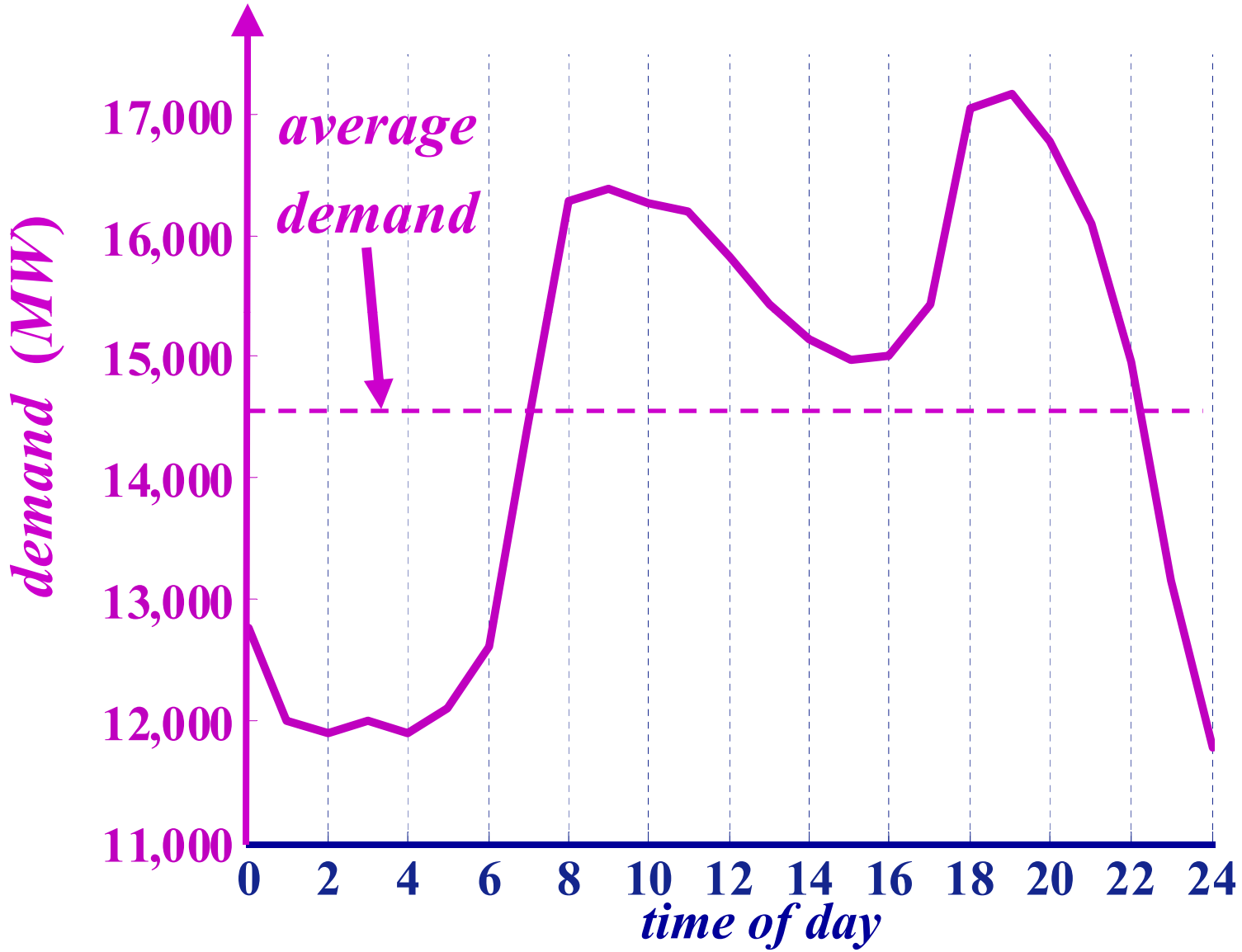
- Not all the *MWh*s are equal in terms of costs and prices
- The value of each *MWh* depends on the time of production/consumption
- The integration of *BV*s into the grid can fully exploit the opportunities to:
  - buy when the price is low
  - sell when the price is high
  - provide additional services needed by the grid

DEMAND AND *LMP*



Source: NE ISO

DEMAND AND *LMP*



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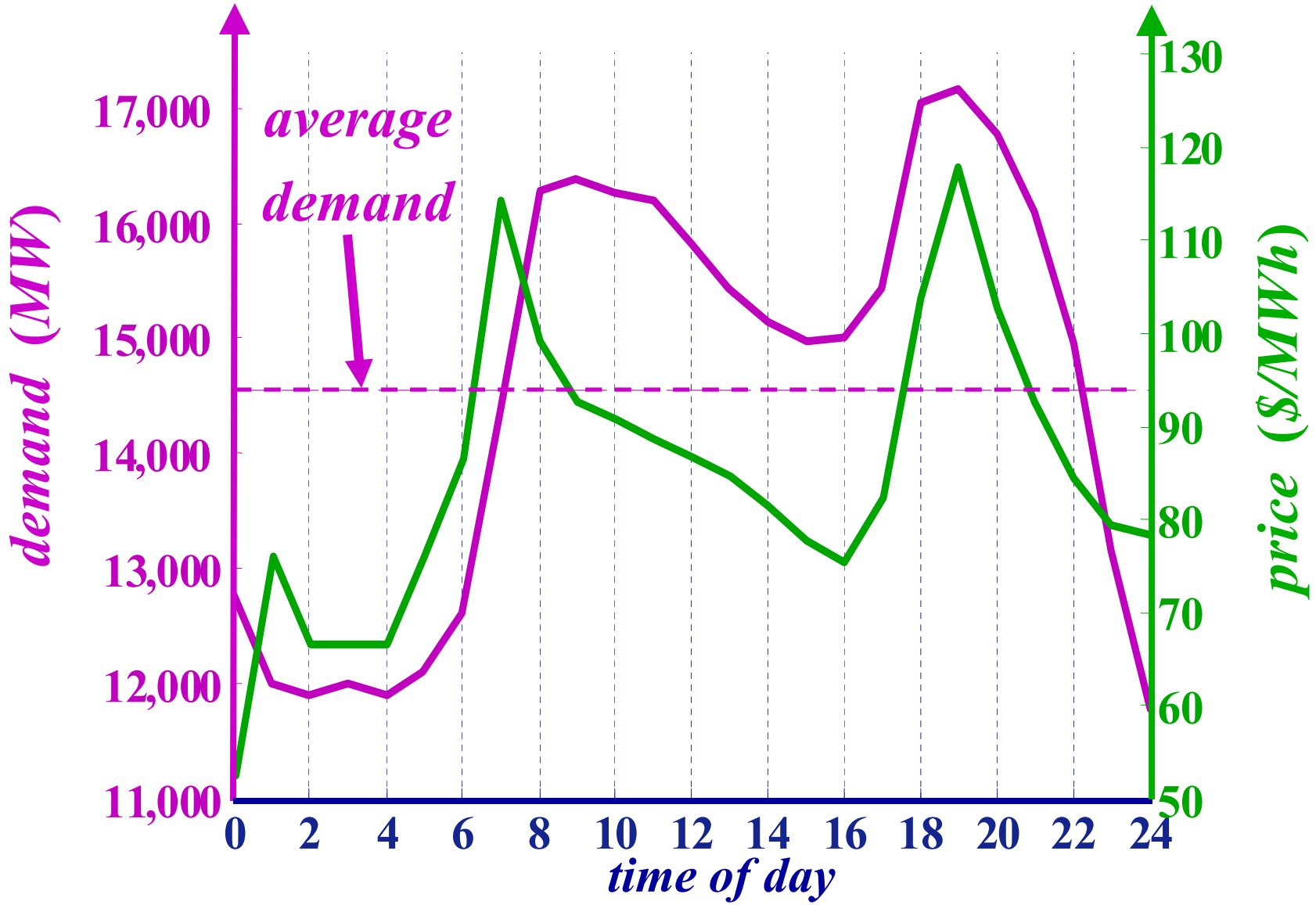

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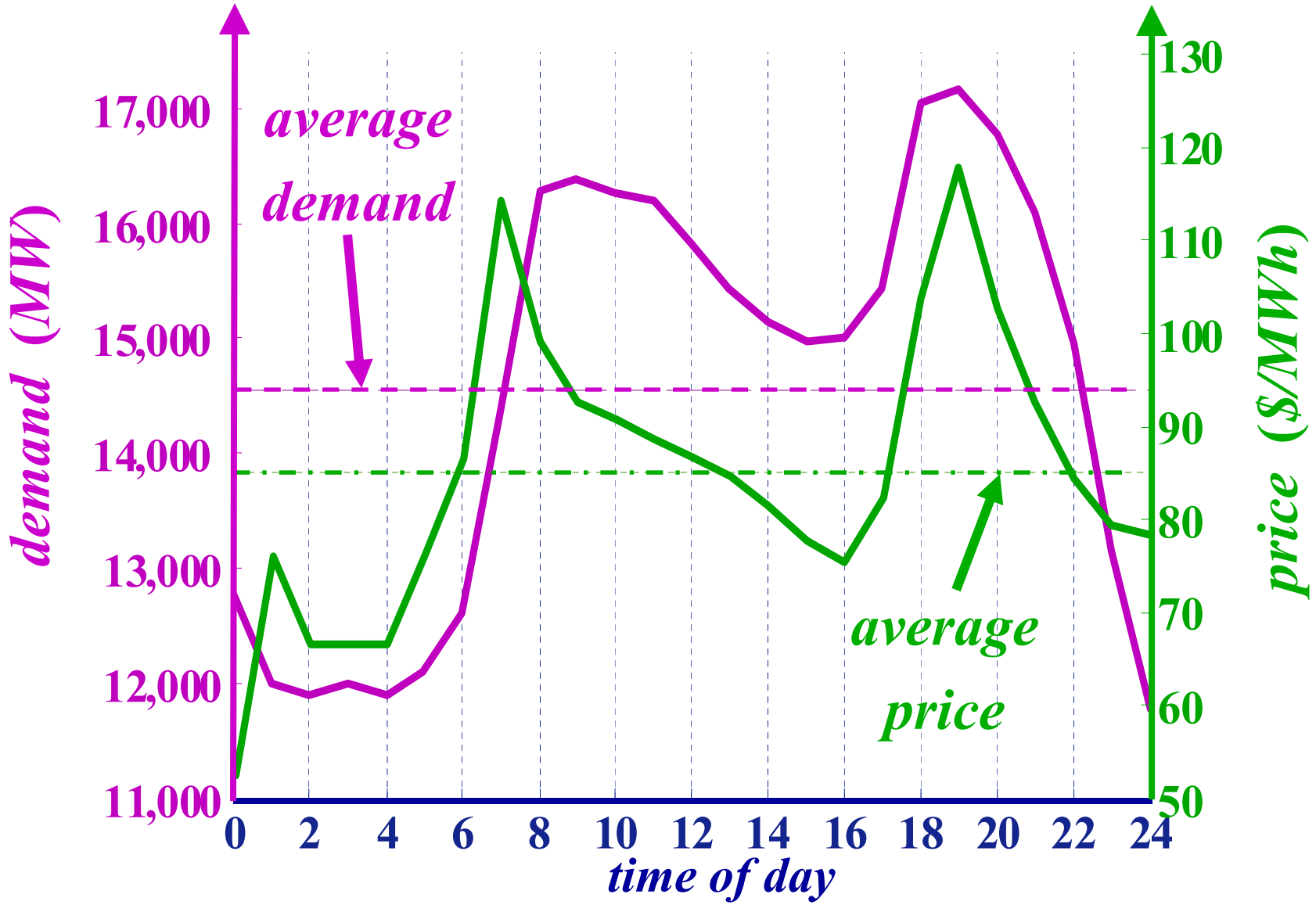
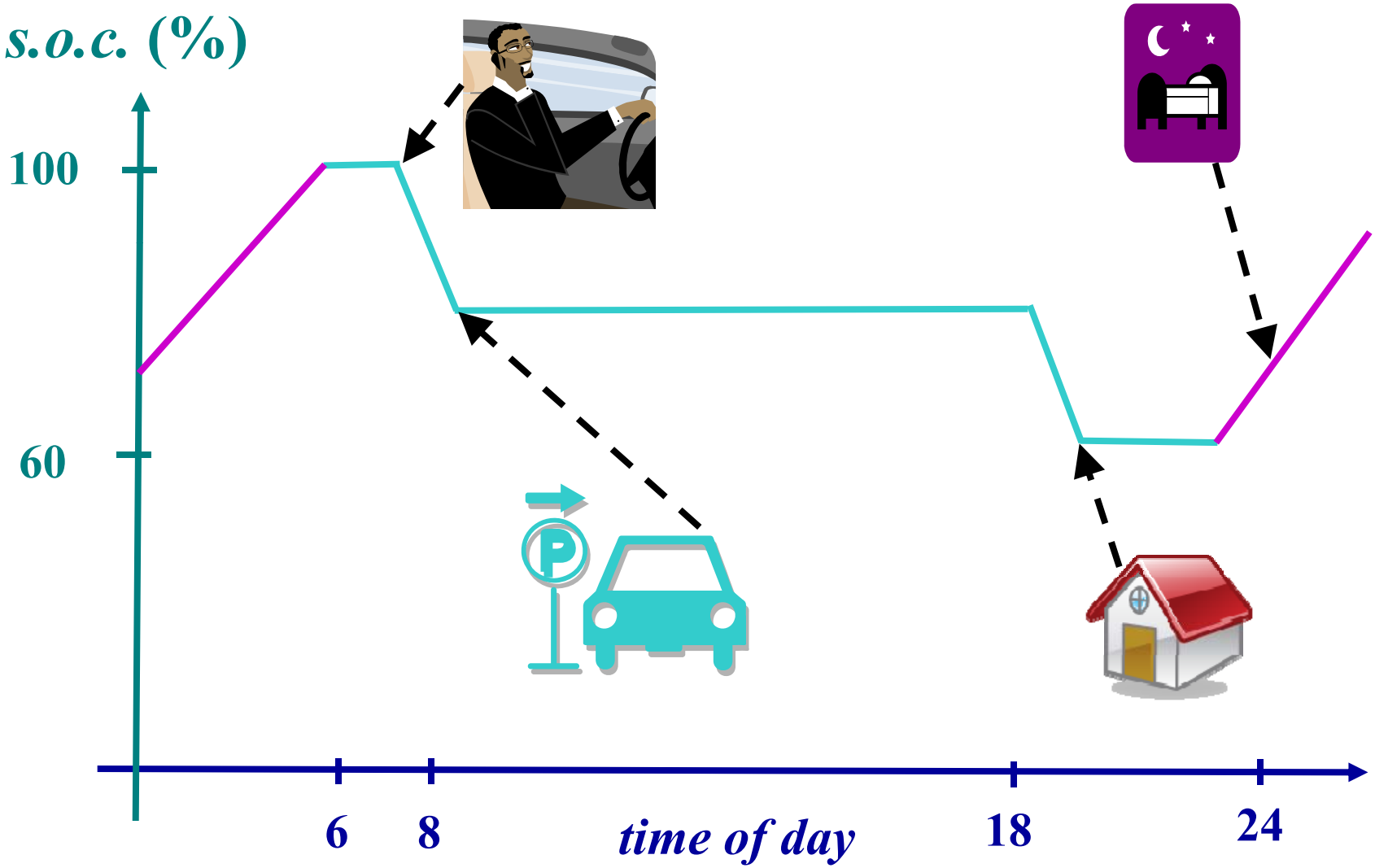
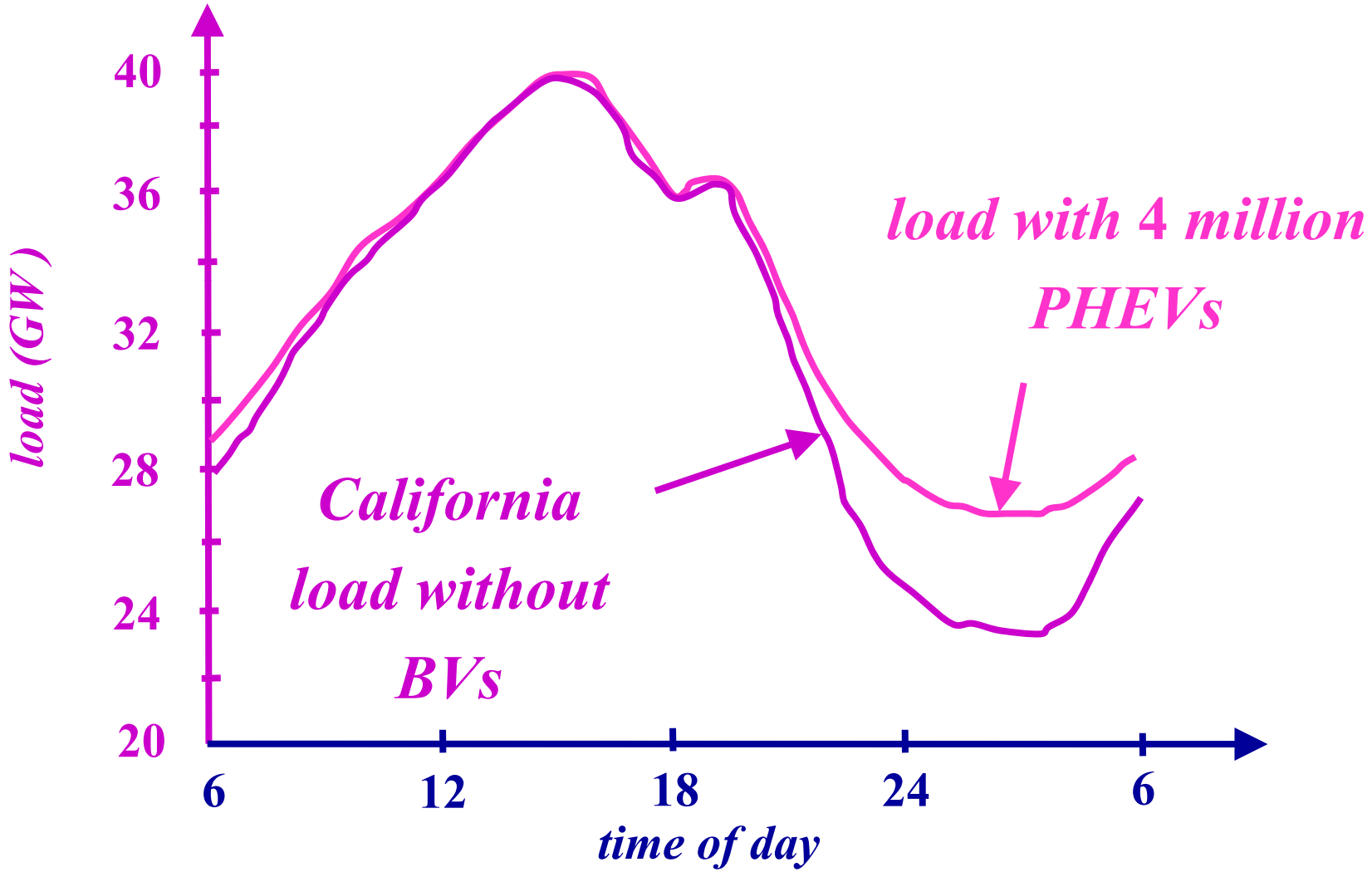


Source: NE ISO

THE *BV* AS A "PURE LOAD"

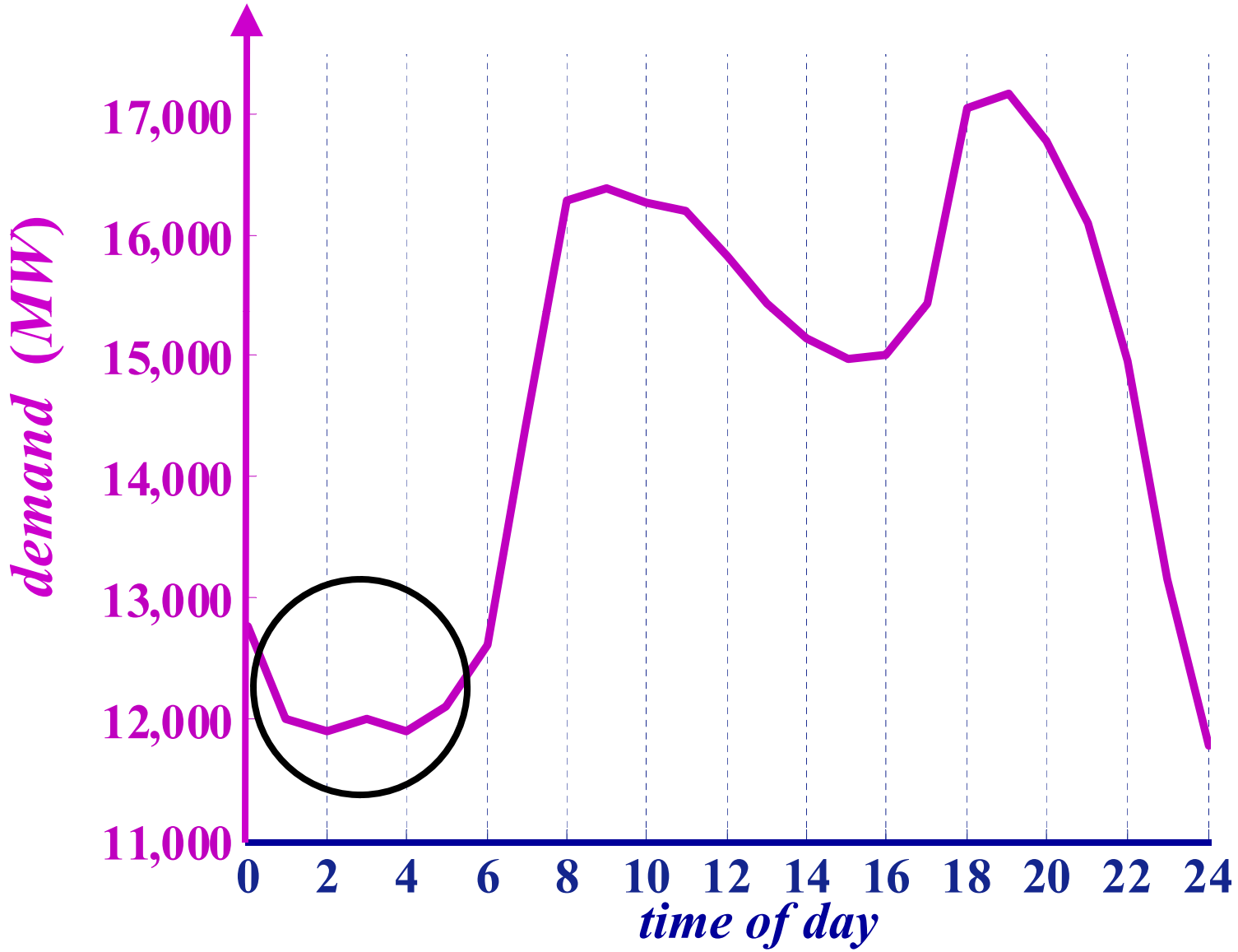


CHARGING THE *BVs*



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

LEVELING THE LOAD



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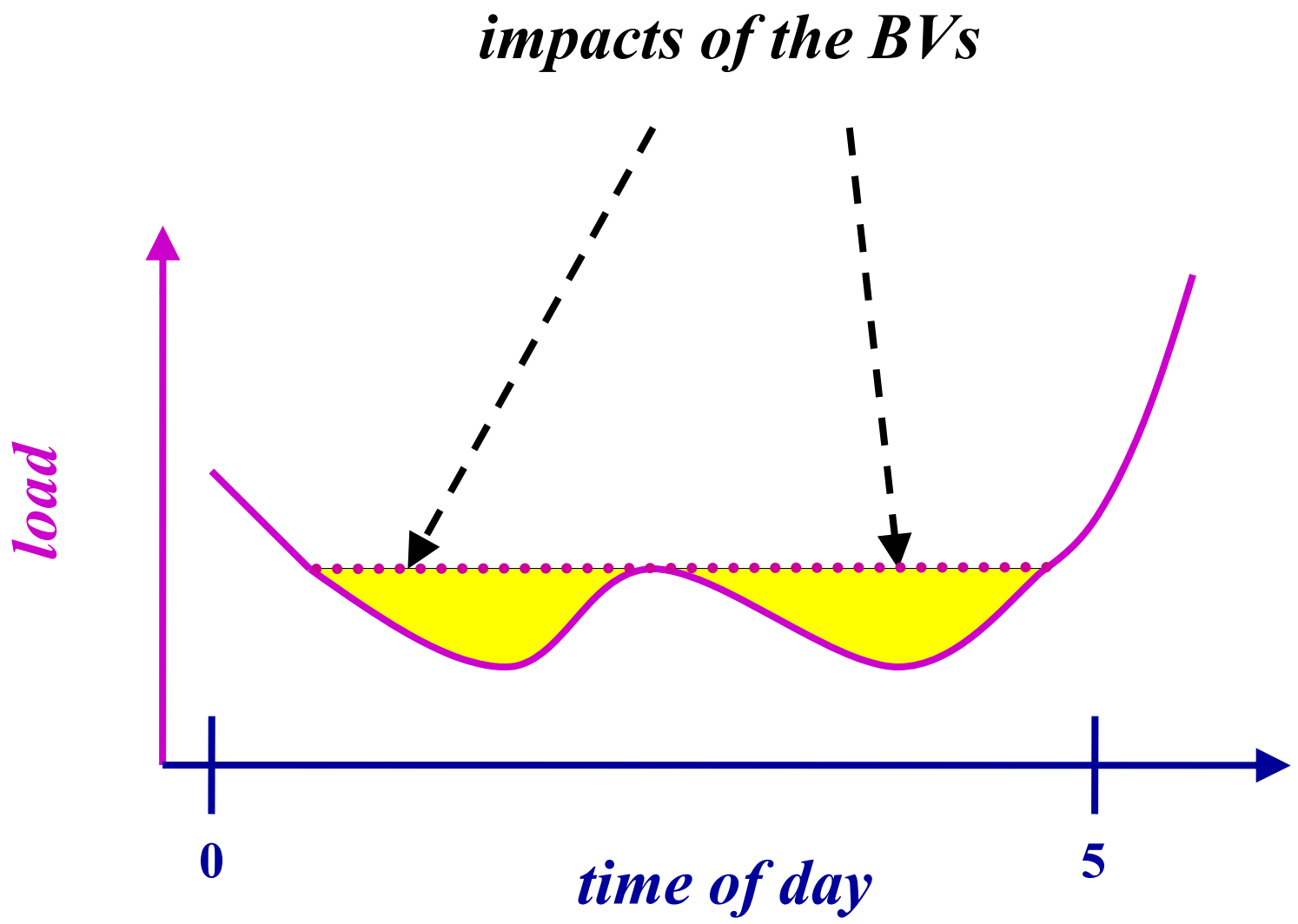
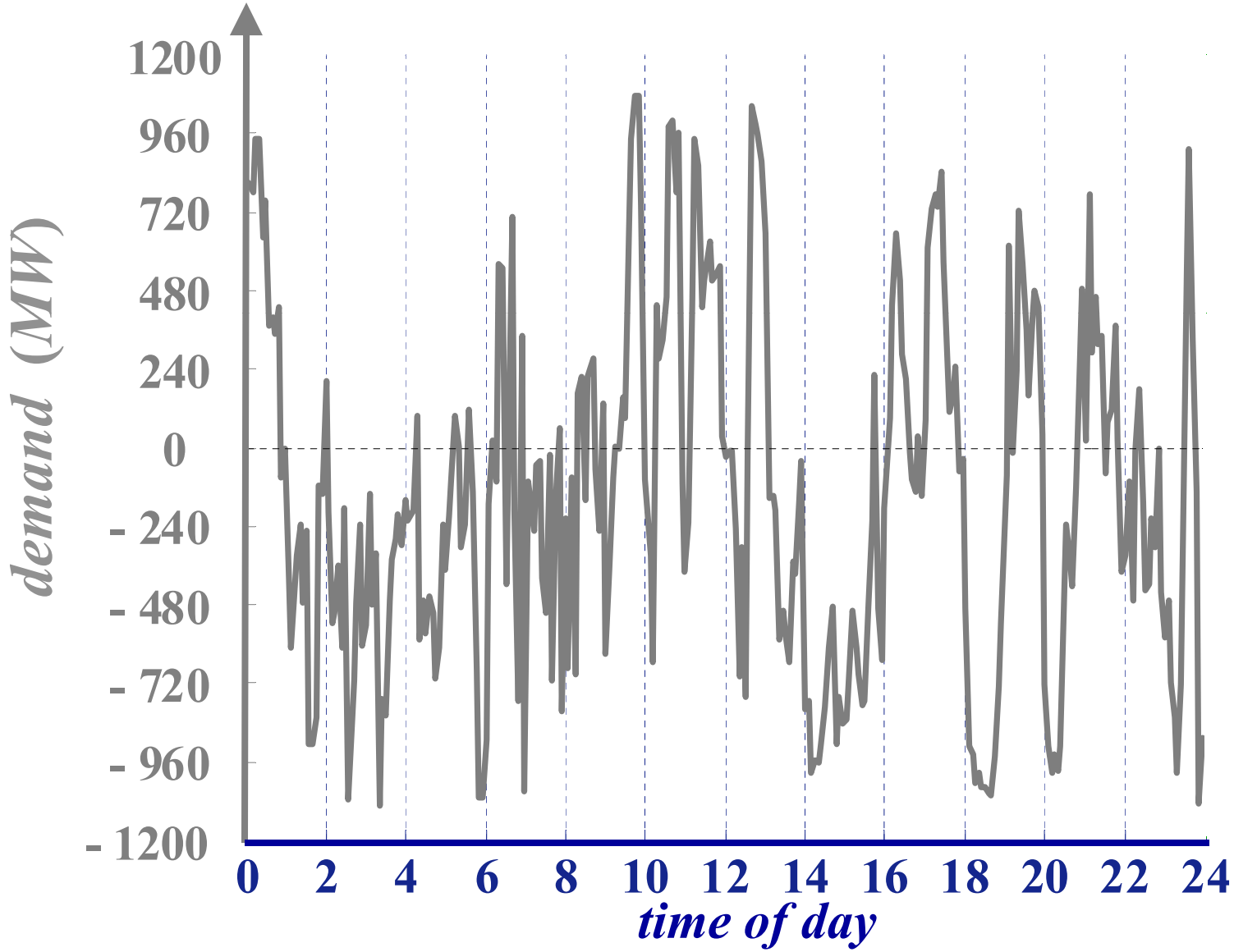


REGULATION SERVICE AND PRICING



Source: PJM

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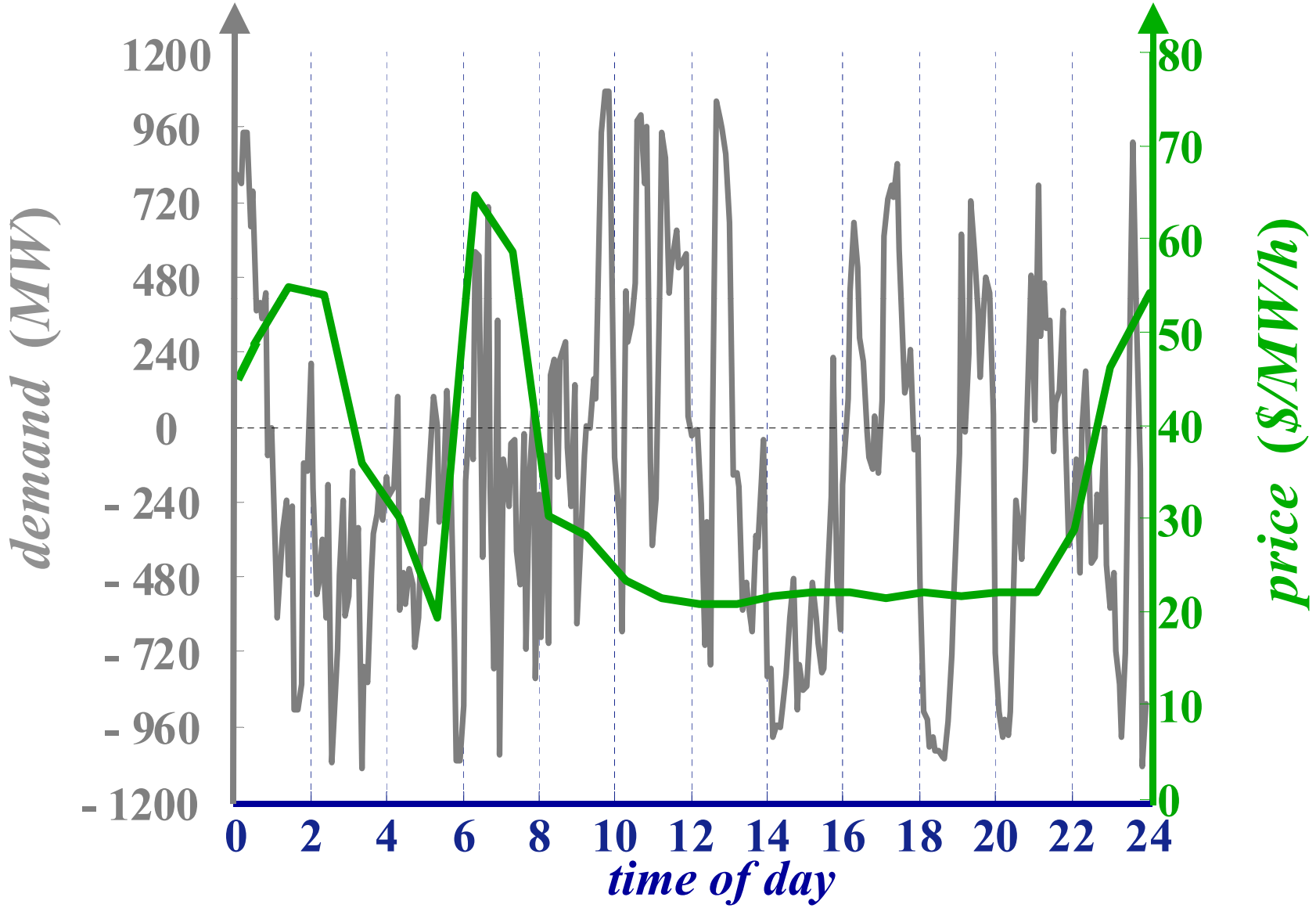

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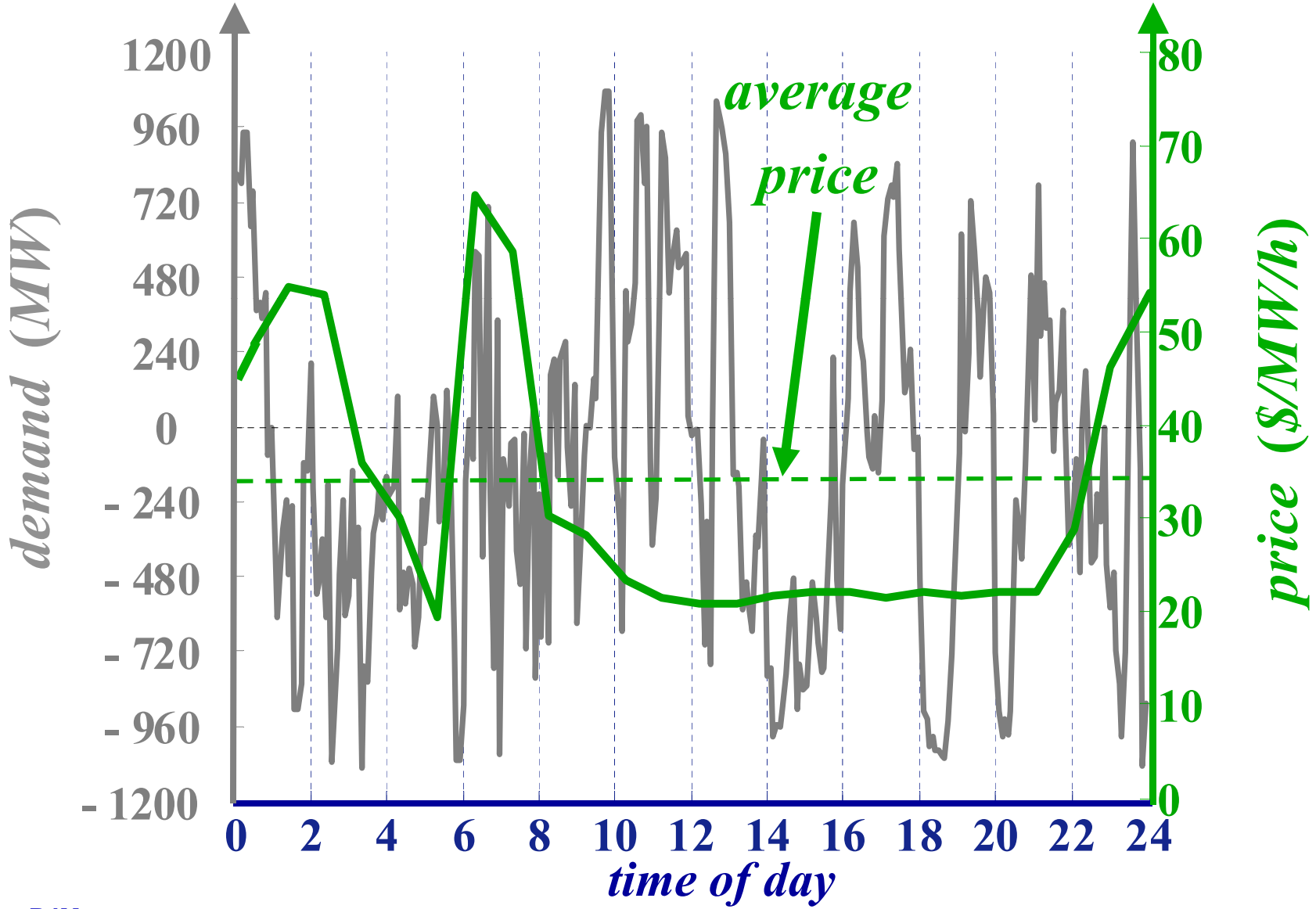
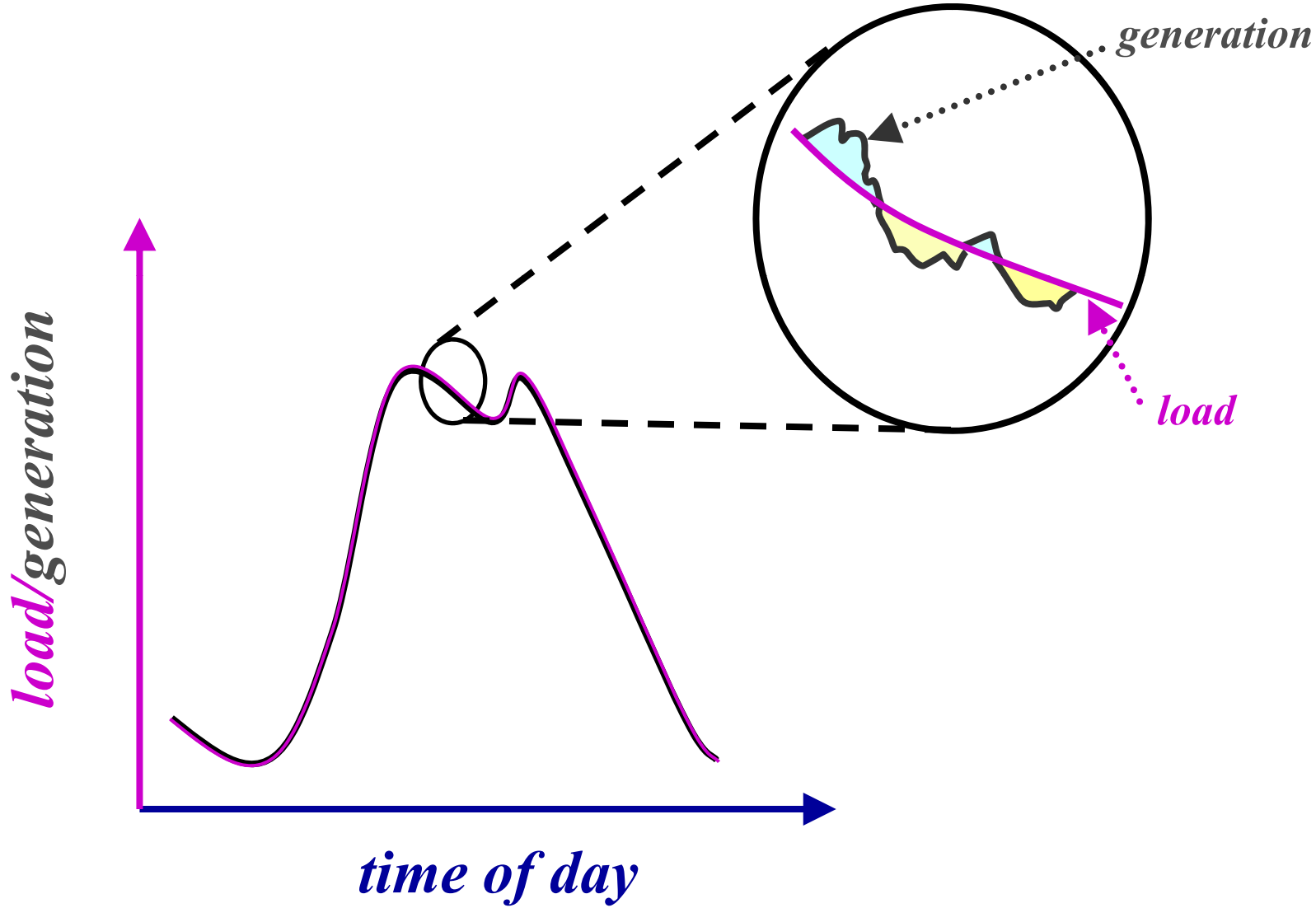


Source: PJM

ROLE OF *BV*s 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*

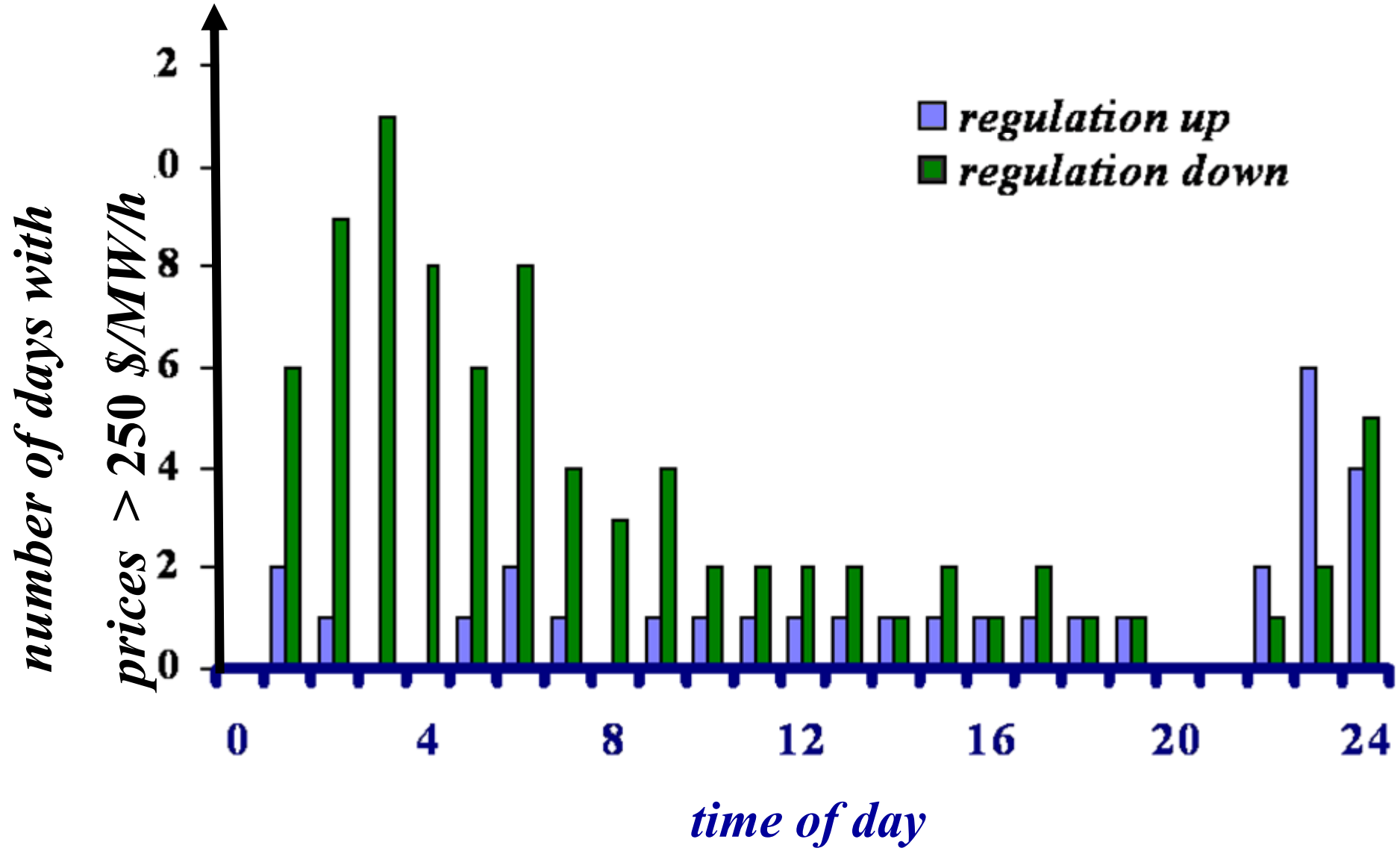
ROLE OF *BV*s IN FREQUENCY REGULATION



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 these conditions
- The regulation prices are, typically, the highest as many units need to reduce their outputs

PEAK AND OFF – PEAK REGULATION

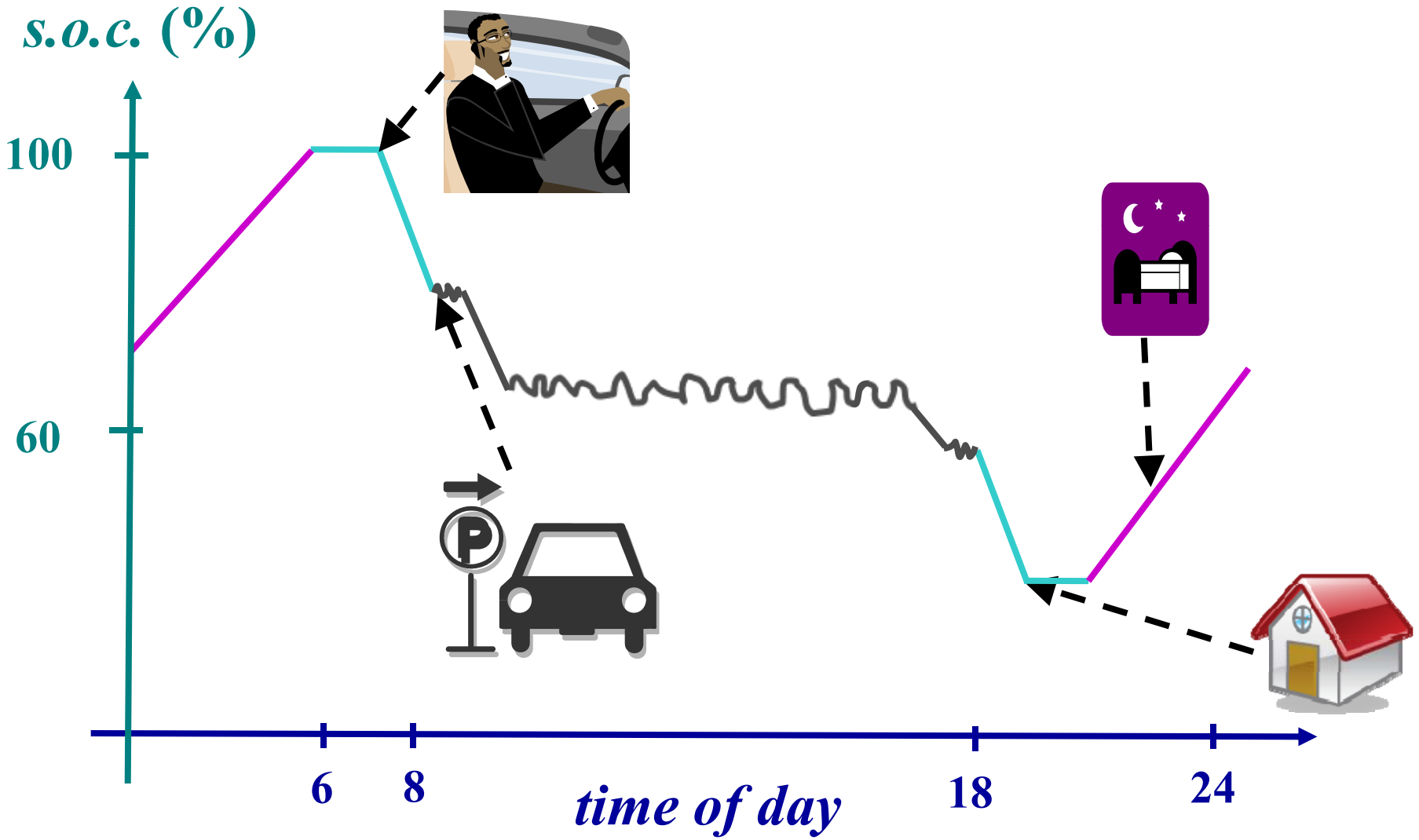


Source: CAISO

*BV*s AND FREQUENCY REGULATION

- Batteries have the ability to both absorb and discharge energy
- The regulation capacity quantity provided by a battery is relatively small
- Batteries have very short response times (of the order of *ms*)
- The frequent switching of batteries may, however, severely impact their life expectancies

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



BATTERY ISSUES

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

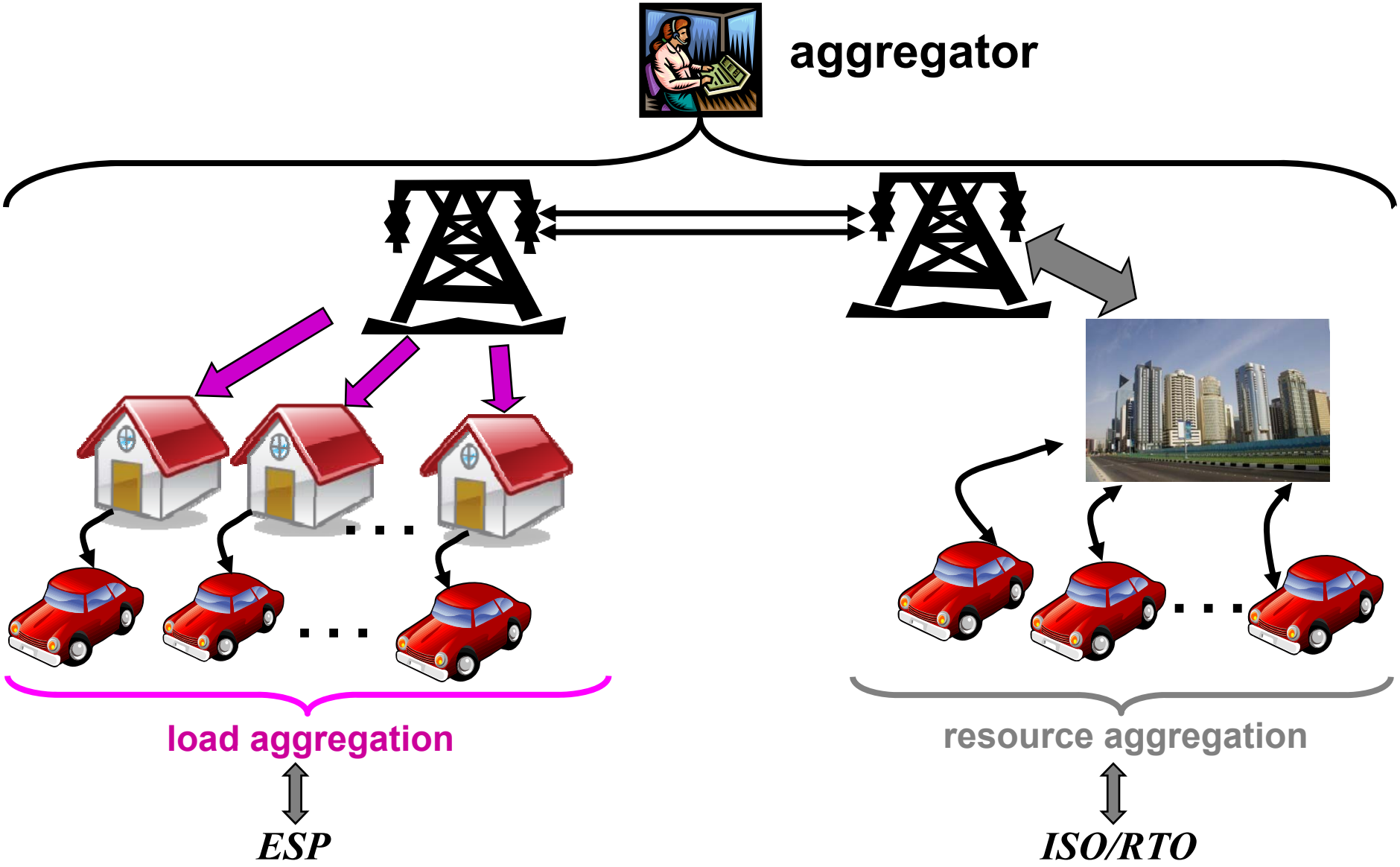
V2G CONCEPTUAL FRAMEWORK

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

PRINCIPAL PLAYERS IN THE *V2G* INTEGRATION

- *BV*
- Aggregator
- Aggregated *BV*s
- *ESP*
- *ISO/RTO*

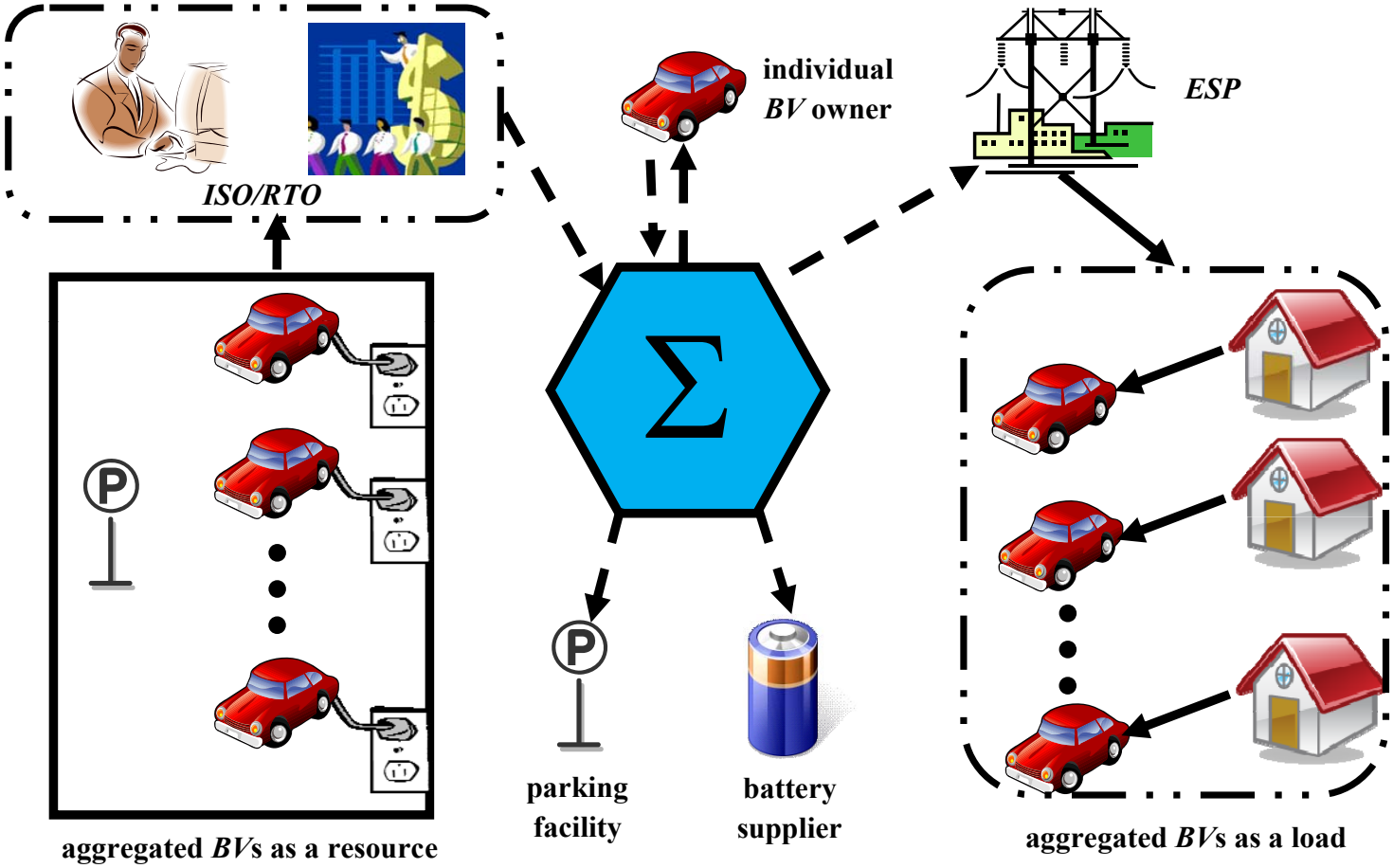
THE INTEGRATION FRAMEWORK



THE ROLE OF AGGREGATION

- The storage capacity C for a typical BV is in the $1 - 30$ kWh range
- If we consider the total discharge of the full battery over 5 h, the output is in the $0.2 - 6$ kW range
- The aggregator, who gathers together "many" BVs to result in a nontrivial aggregated output and load, interfaces with the ISO/RTO on supply-side issues and the ESP on demand-side issues

FLOWS IN *V2G* INTEGRATION



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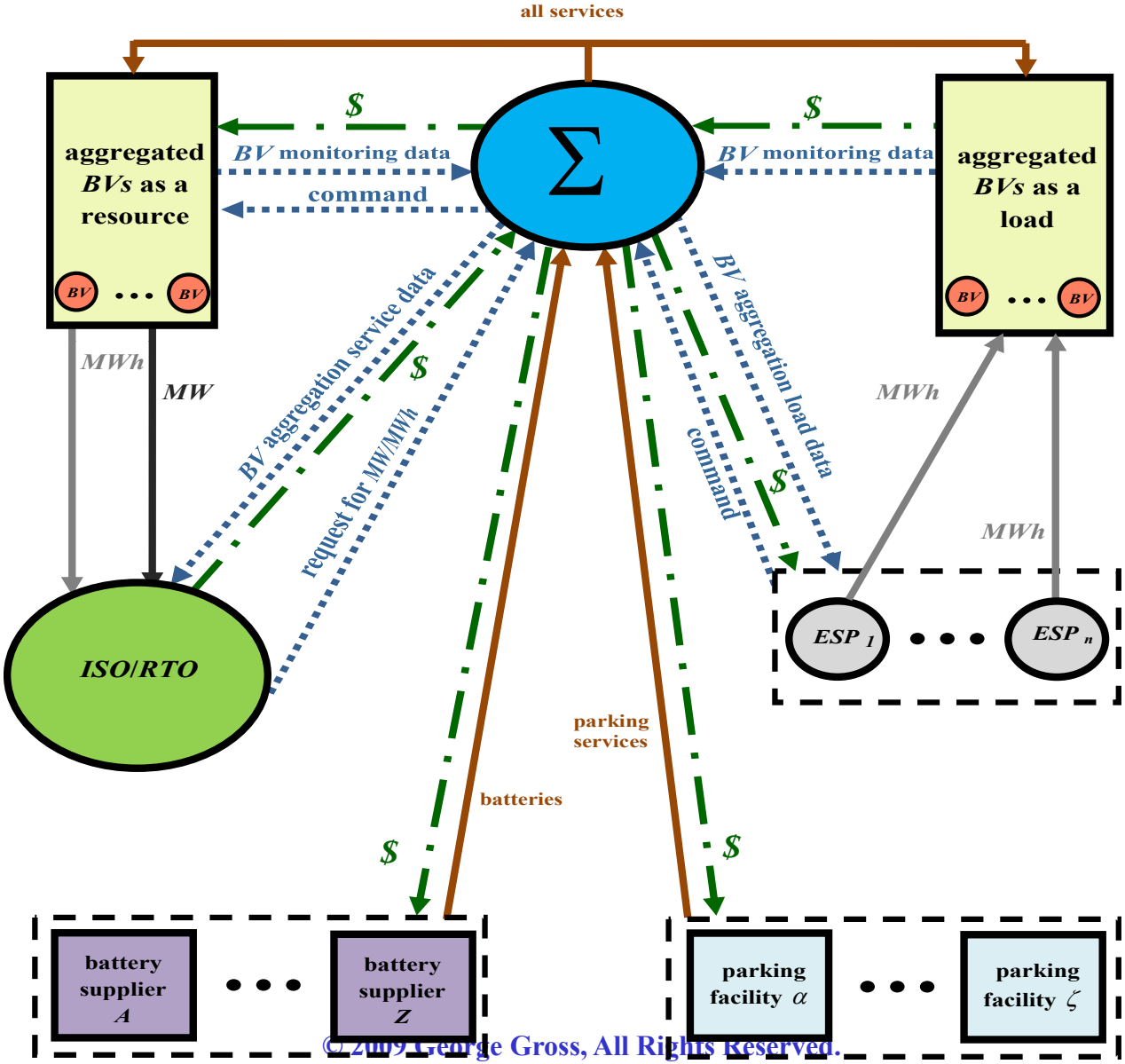
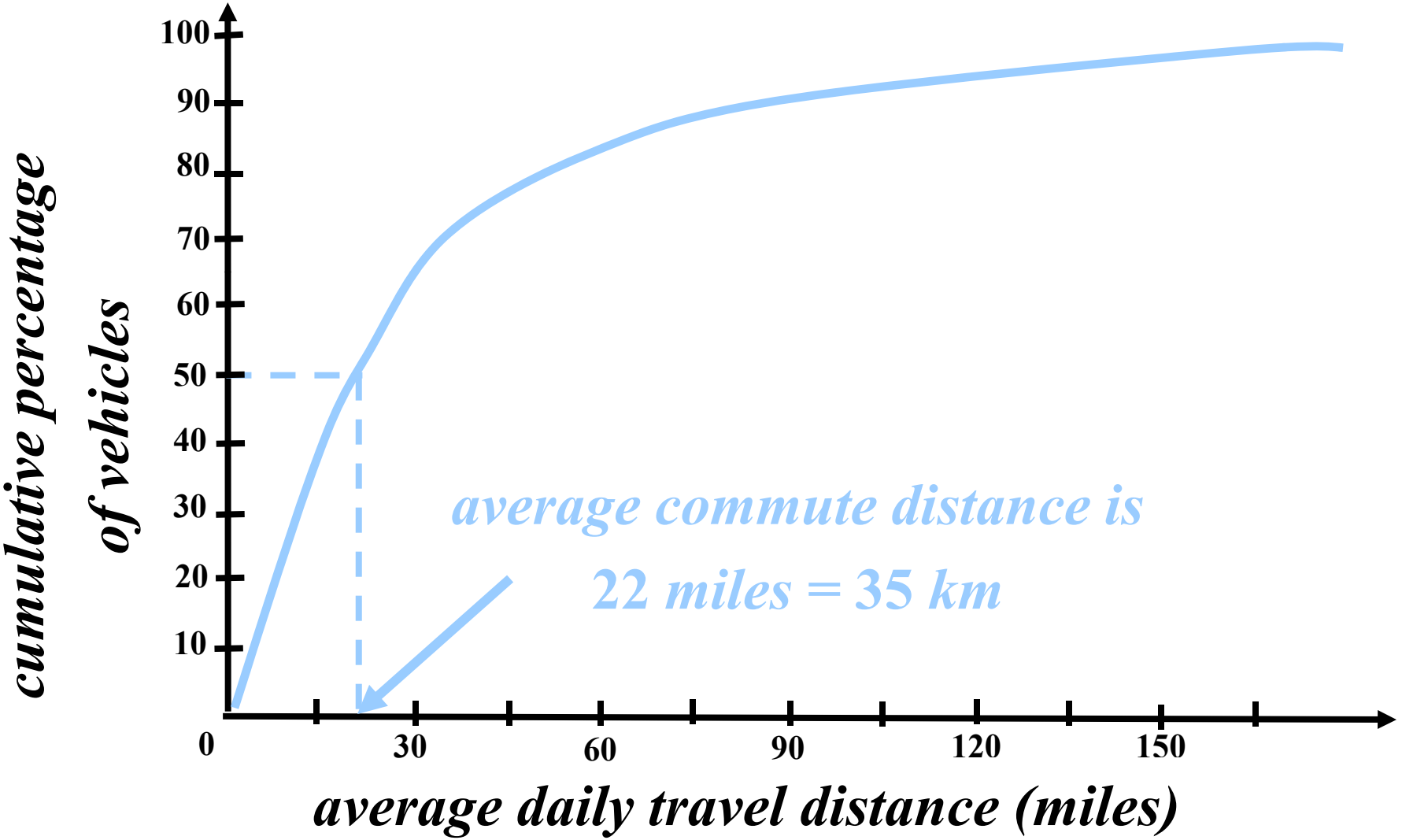


REPRESENTATION OF UNCERTAINTY SOURCES

- We take into account various sources of uncertainty, including:
  - time of arrival
  - parking time
  - state of charge
  - storage of the vehicle
  - demand
- For the aggregated *BV*s, we use the *Central Limit Theorem* ($N > 30$) to justify the representation of the various random variables by normal distributions

DAILY COMMUTE DISTANCES



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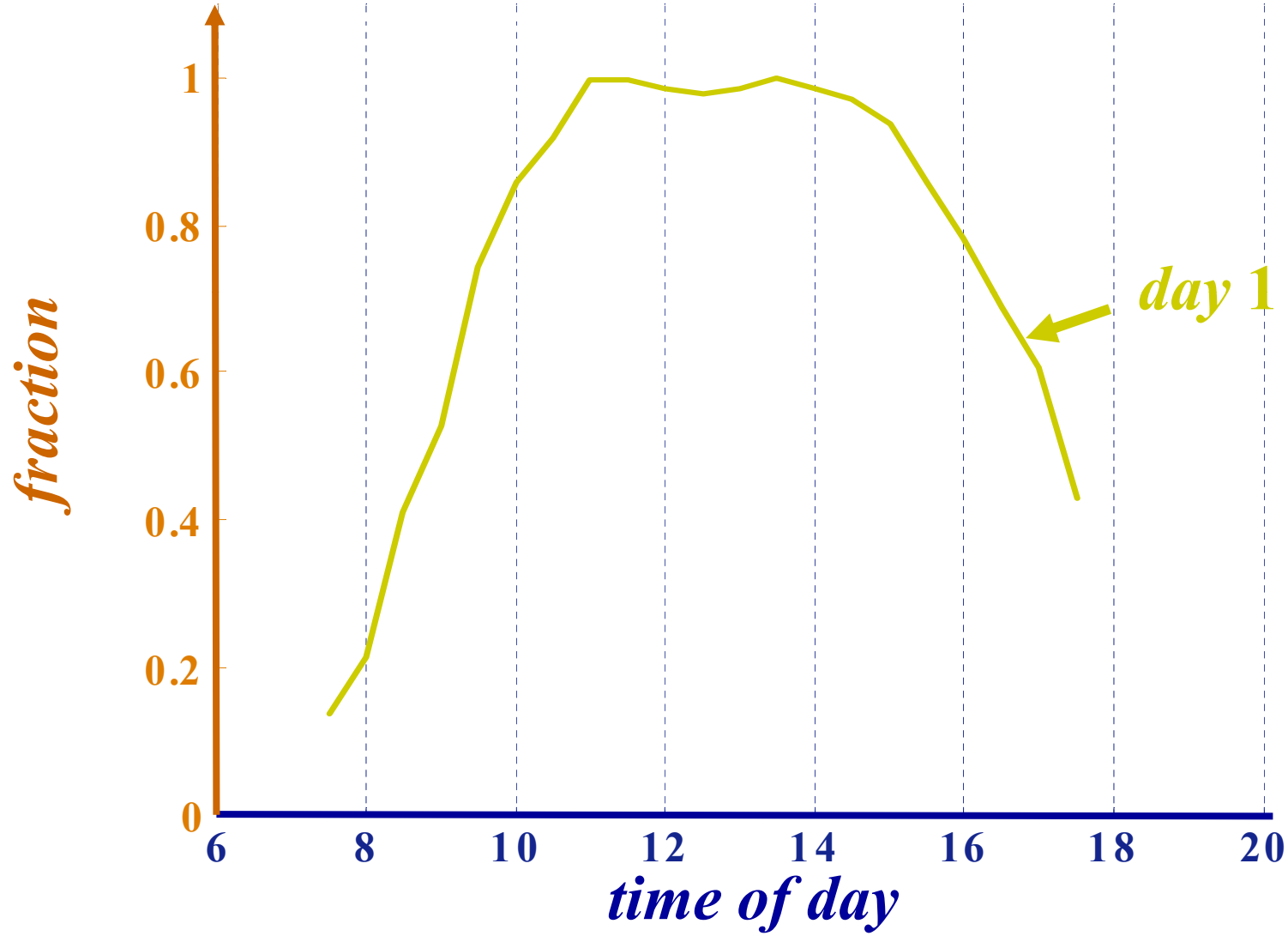
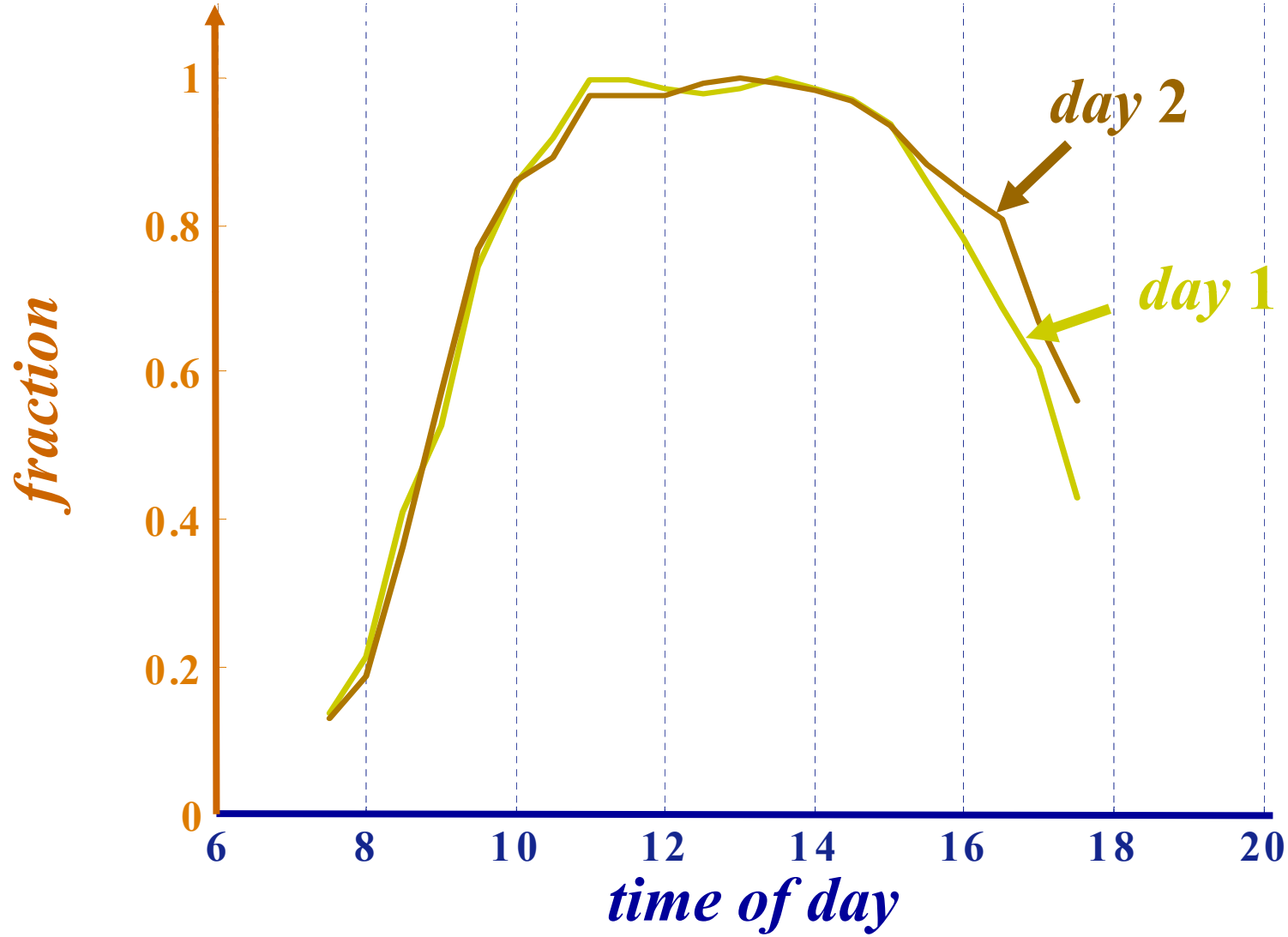
PARKING LOT UTILIZATION AS A FRACTION OF ITS CAPACITY



PARKING LOT UTILIZATION AS A FRACTION OF ITS CAPACITY



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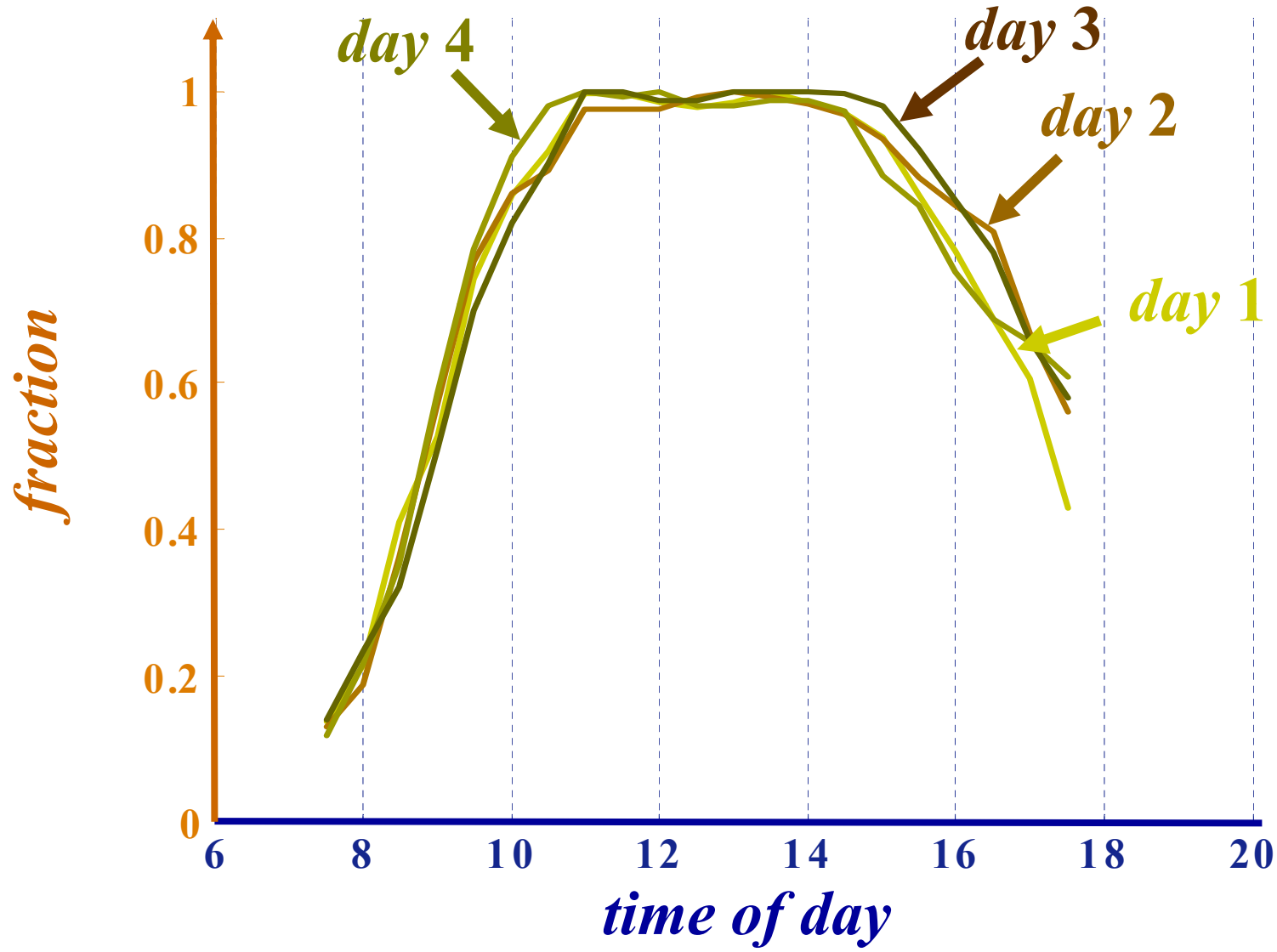
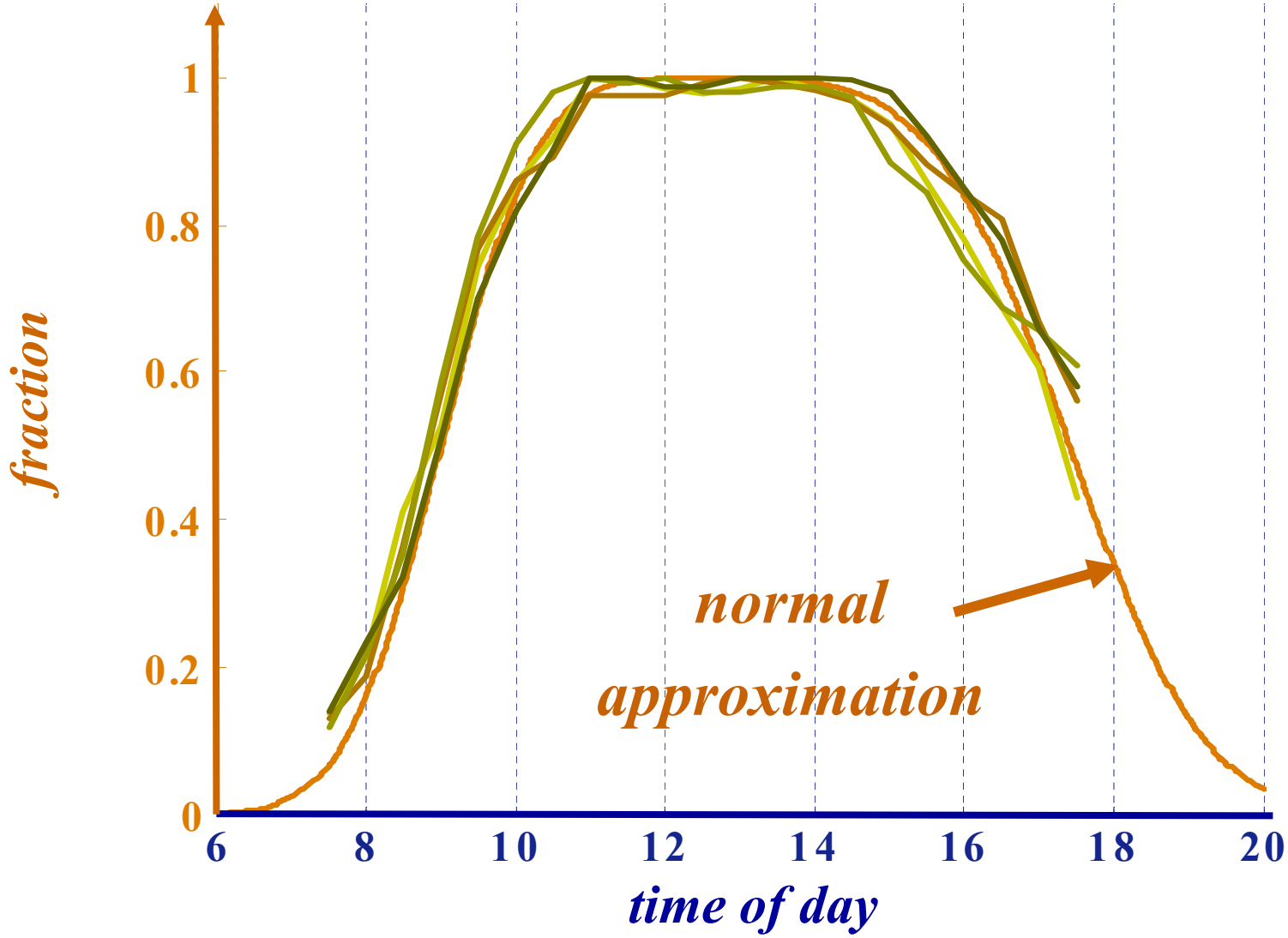
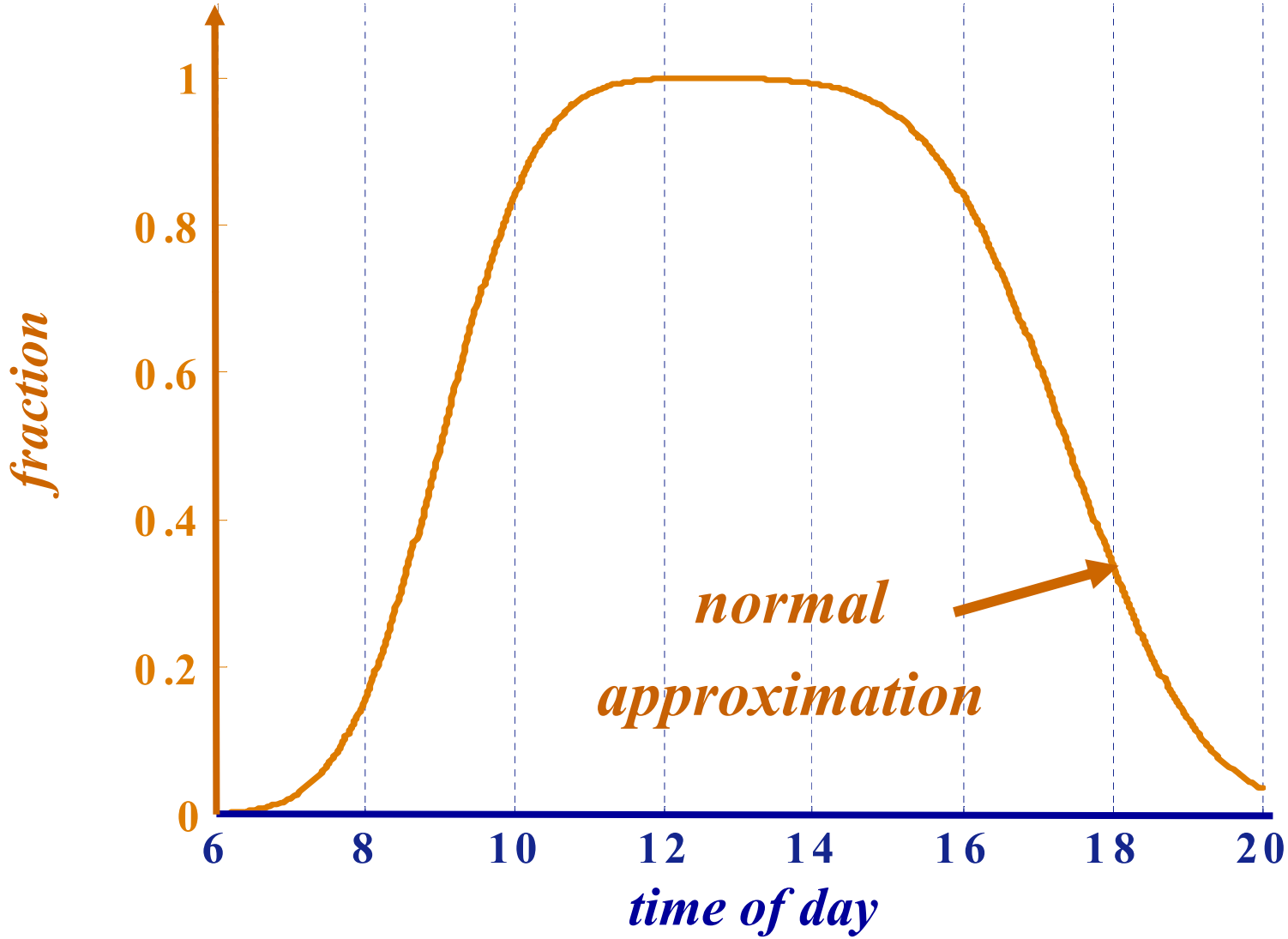


APPROXIMATION OF PARKING UTILIZATION

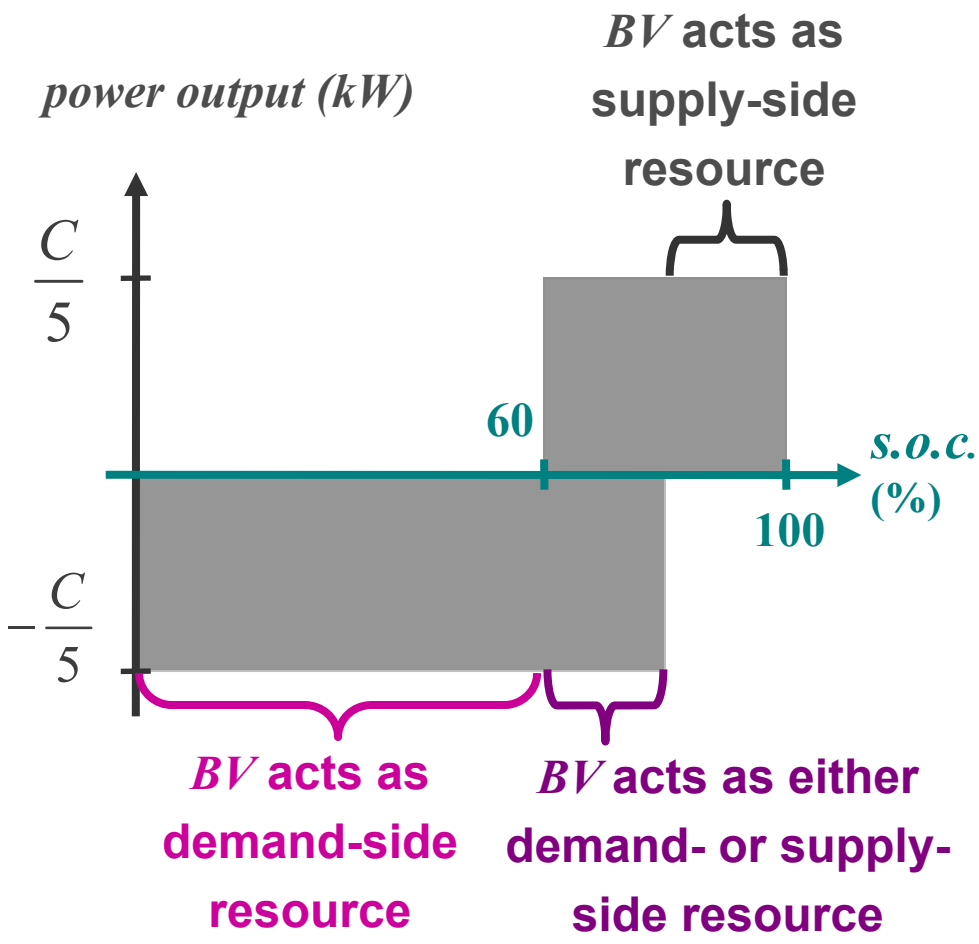


MODEL OF PARKING UTILIZATION



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

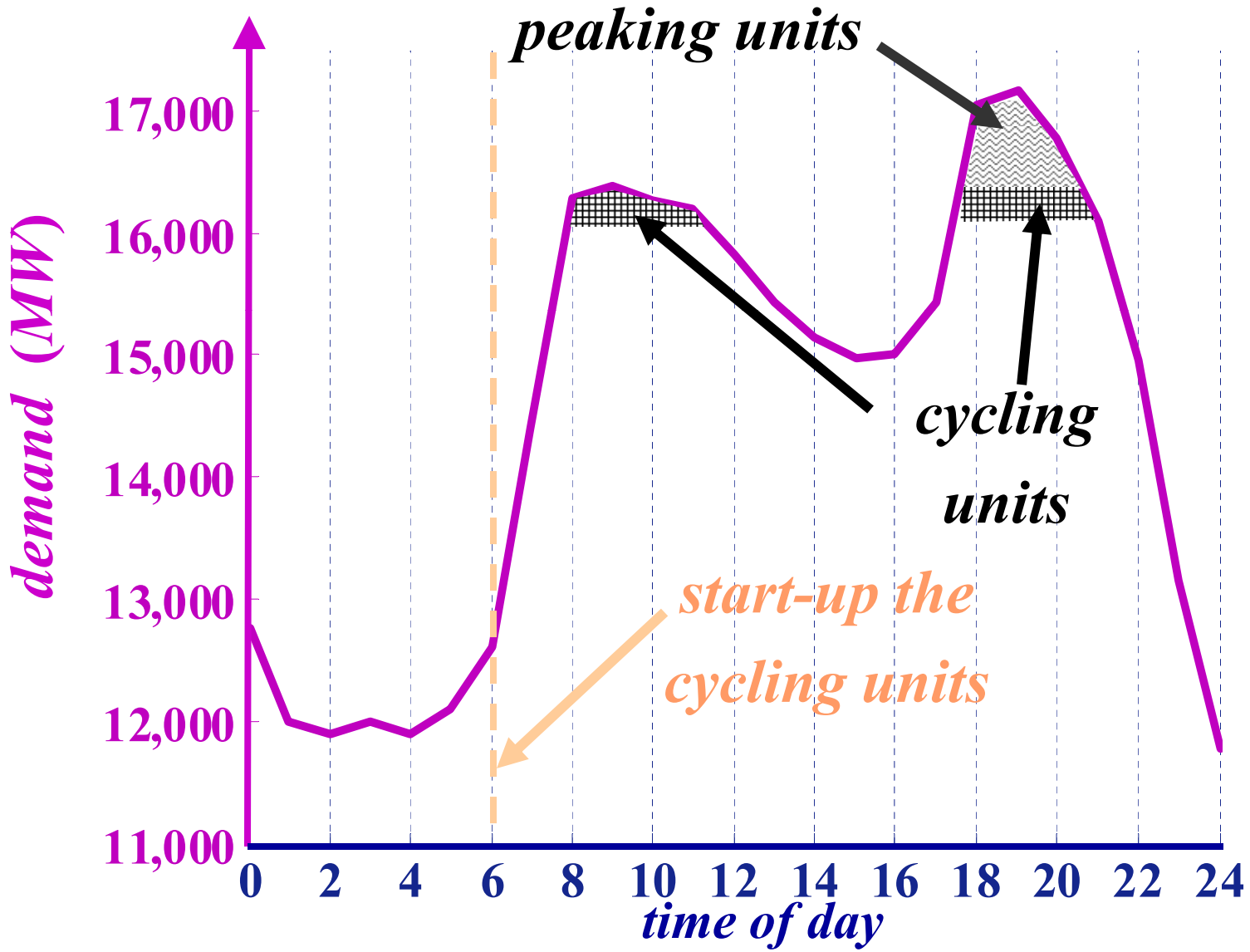
- The role of the *s.o.c.* is key to the effective management of the aggregated *BV* integration into the grid
- The output of a battery is a function of its storage capability



*BV*s PROVIDE IMPORTANT SERVICE

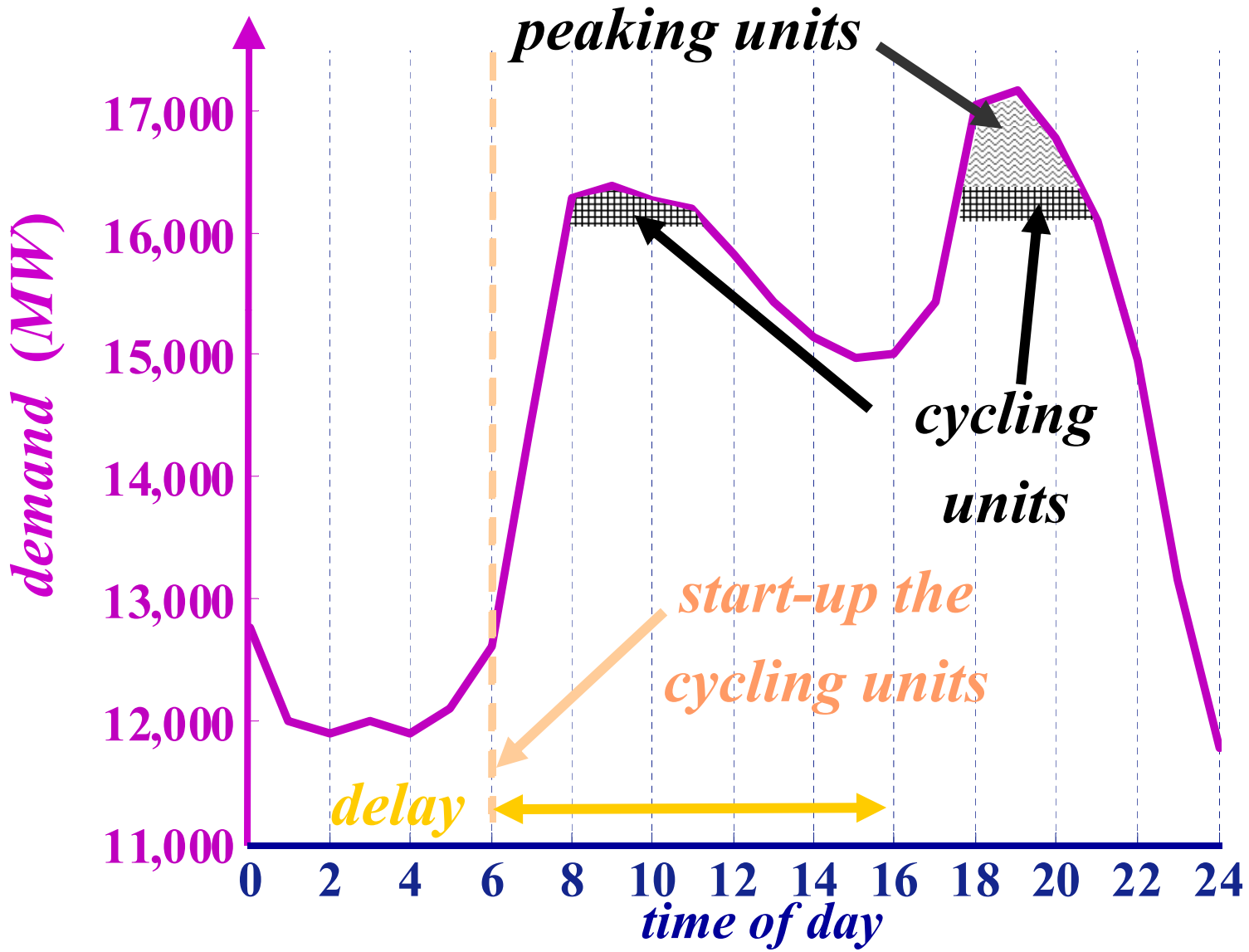
- The aggregated *BV*s constitute a very important supply-side resource to the grid
- The presence of the *BV*s provide the *ISO*/*RTO* with considerable flexibility in the scheduling of units
- As a result, the start-up of cycling and peaking units may be delayed or avoided; the availability of reserves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

CYCLING UNITS WITHOUT *V2G*



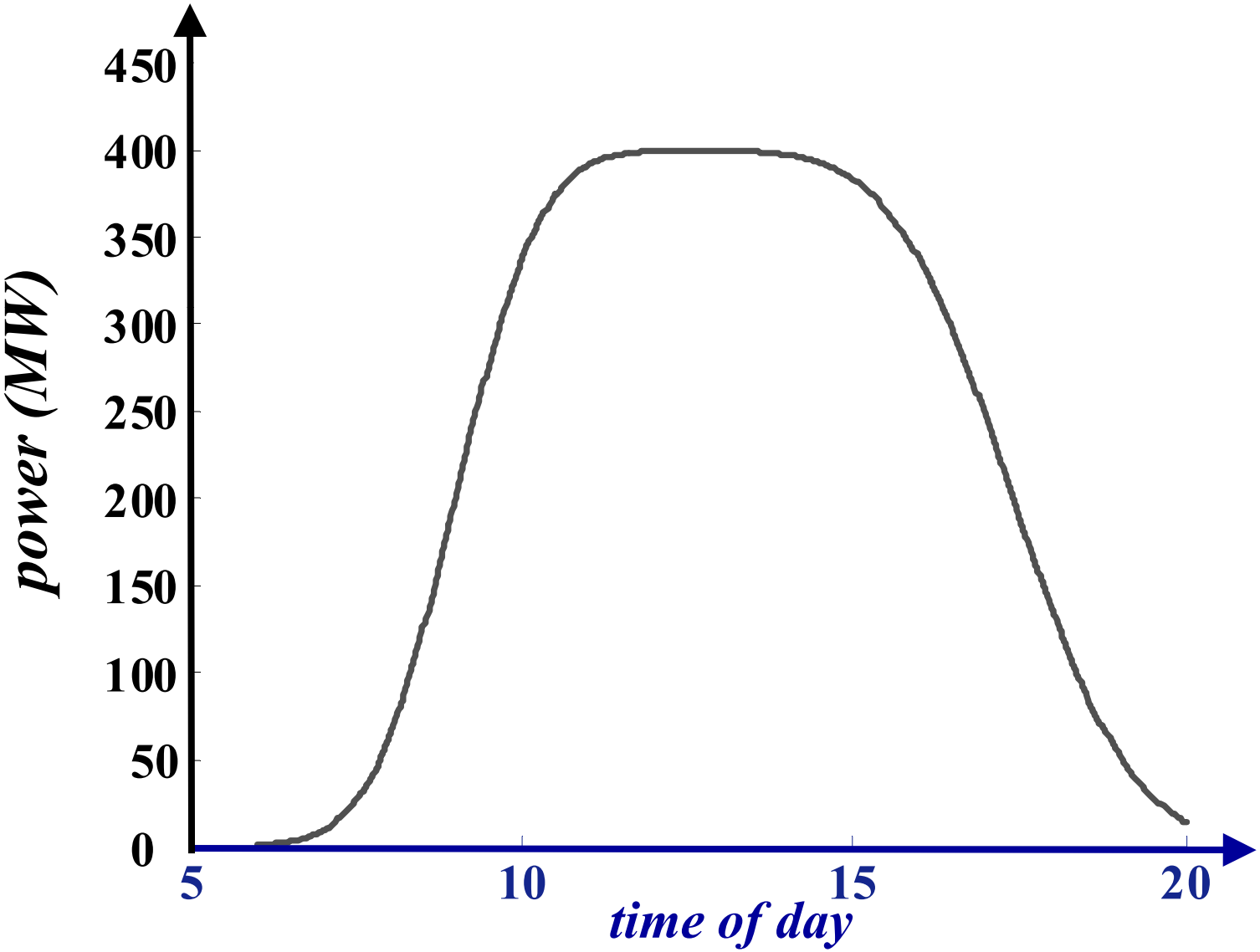
Source: NE ISO

CYCLING UNITS WITH *V2G*

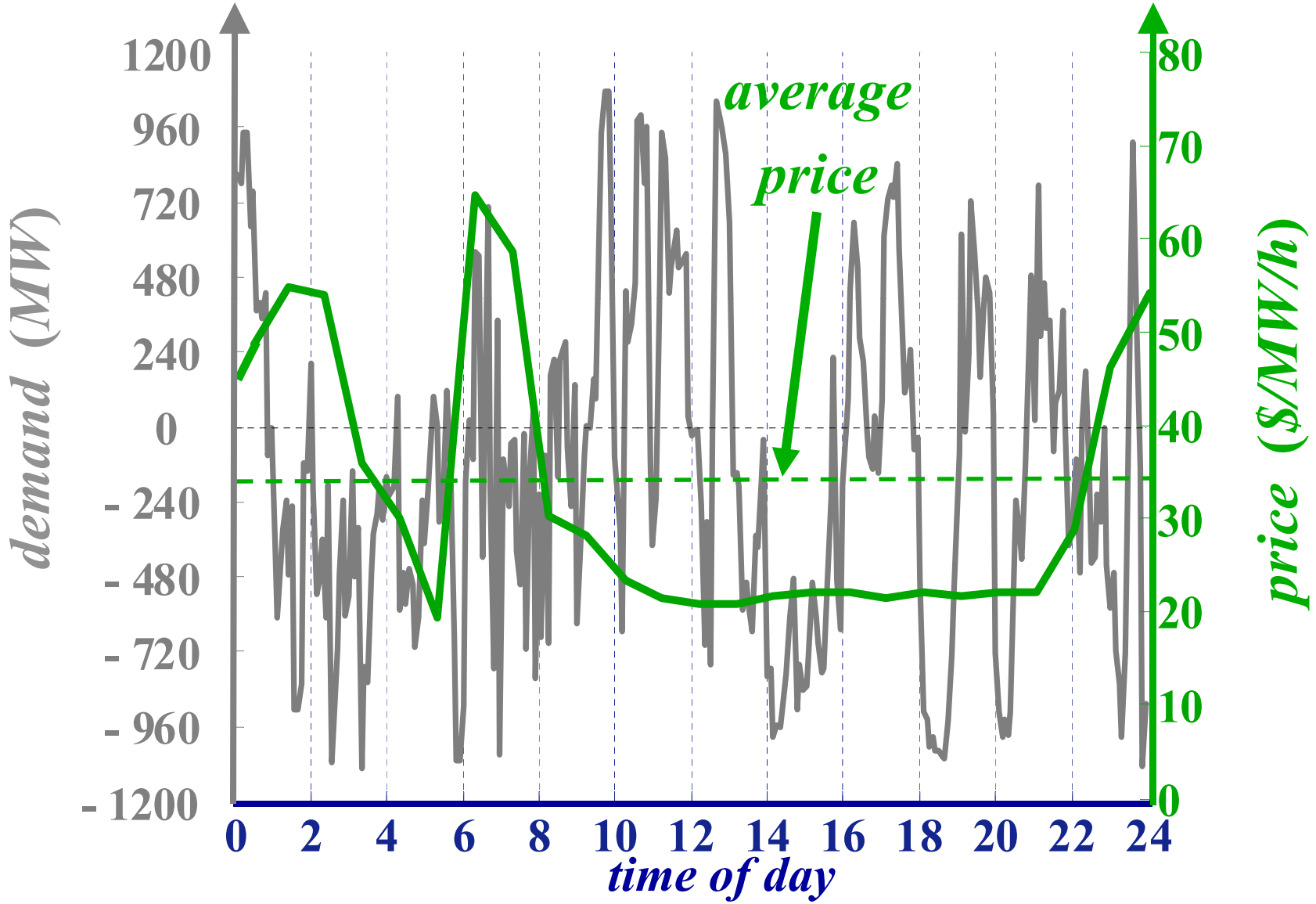


Source: NE ISO

AGGREGATED *BV* POWER/CAPACITY

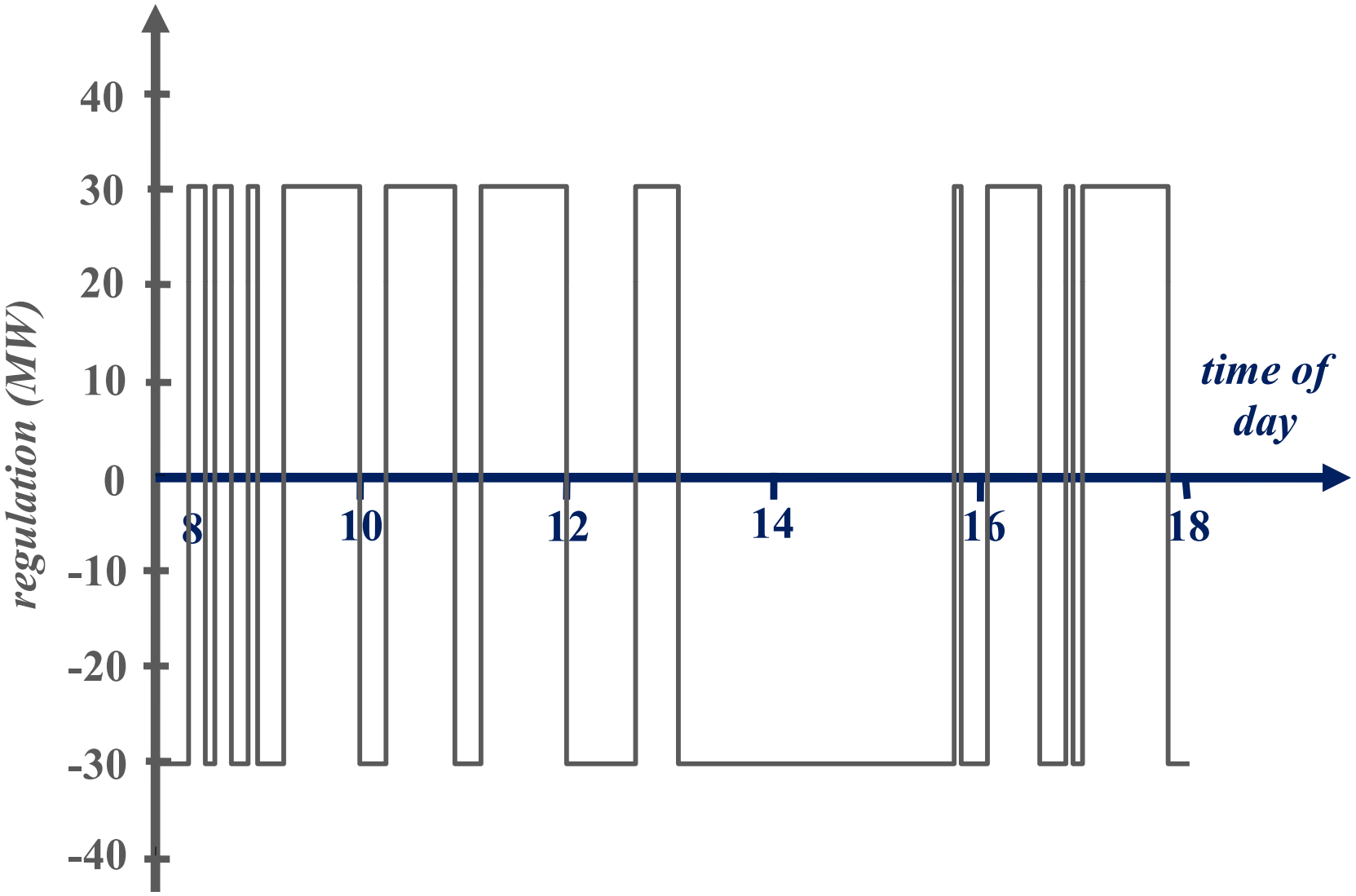


REGULATION SERVICE AND PRICING

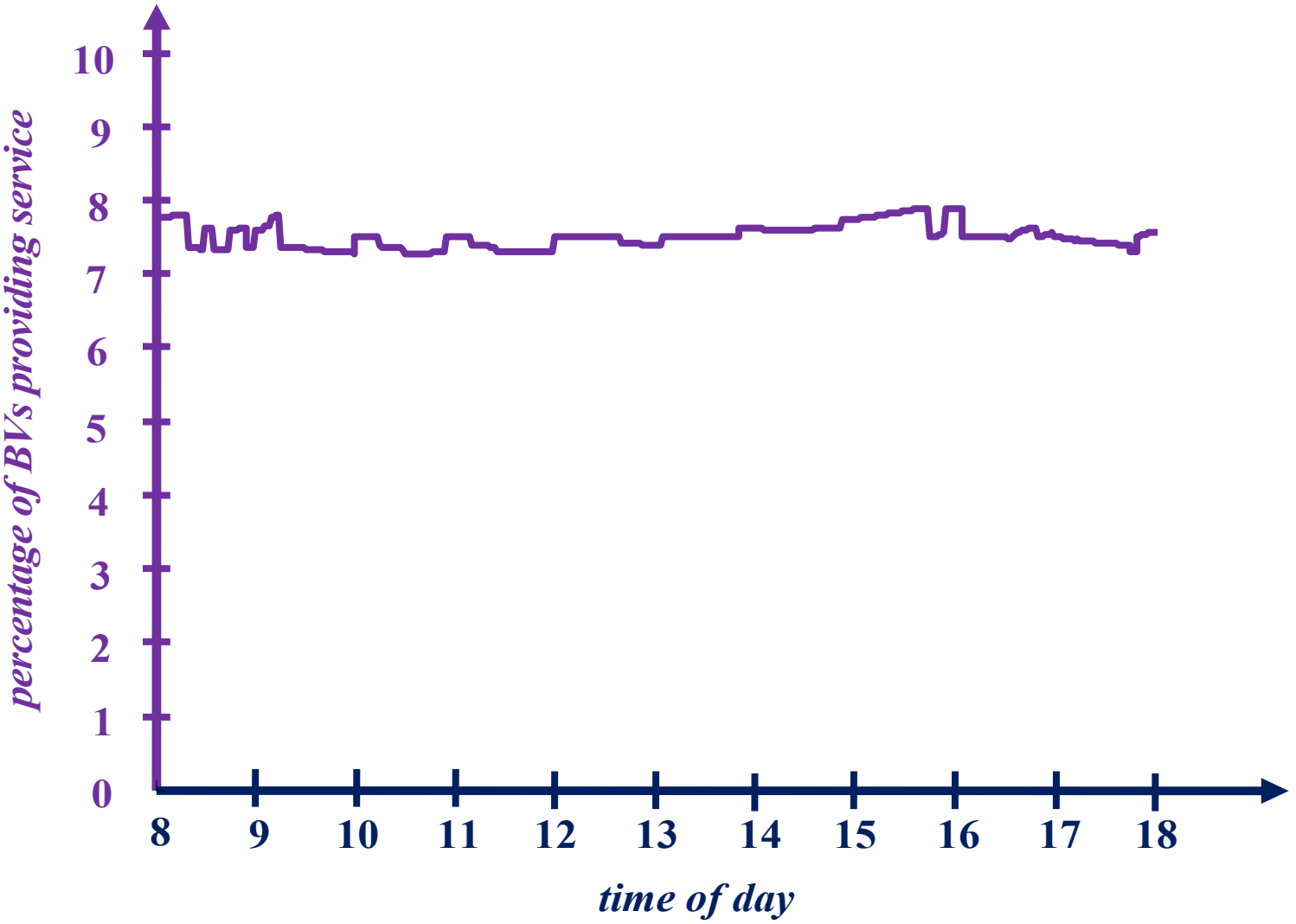


Source: PJM

DAY – TIME REGULATION SERVICE PROVISION BY 100,000 *BVs*



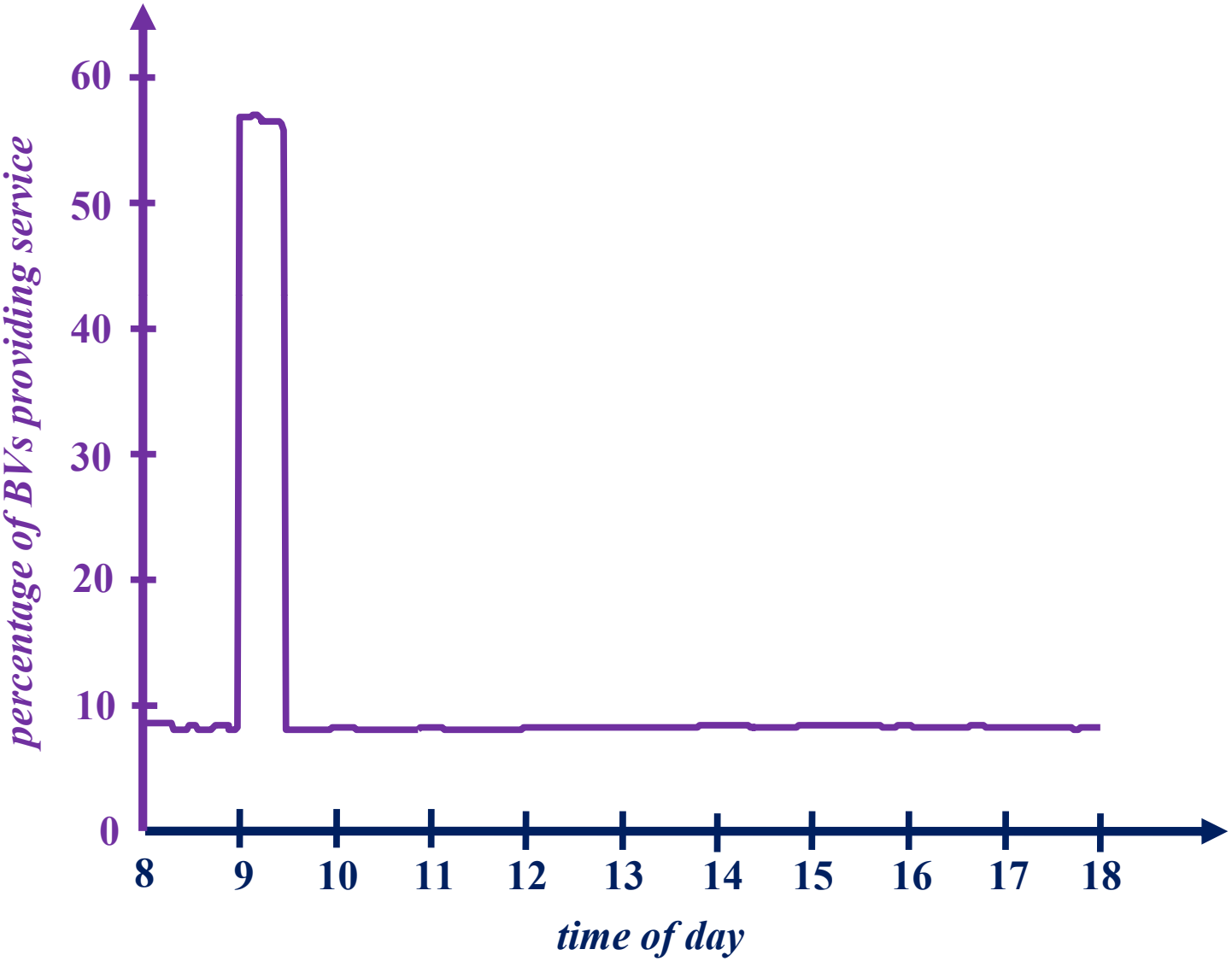
PERCENTAGE OF BVS PROVIDING THE REGULATION SERVICE



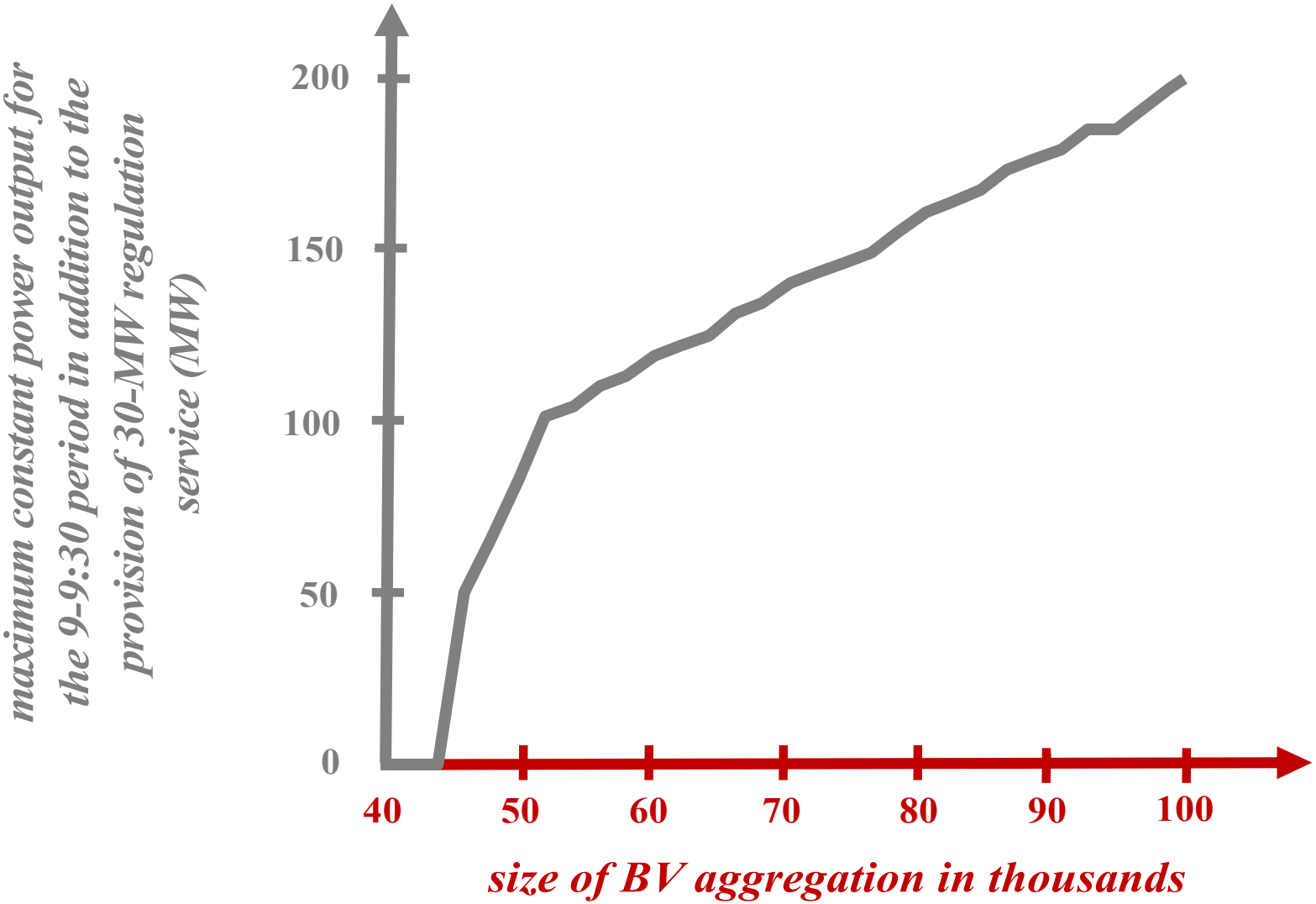
PROVISION OF LOAD SHAVING SERVICE IN ADDITION TO REGULATION

- The number of BVs providing regulation service remains rather low, with fewer than 10% of the BVs in the aggregation providing service at each point in time
- We consider the provision of load shaving service in addition to the regulation service
- We show that the Aggregator can provide 100 MWh of load shaving service at a constant power output between $9{:}00$ and $9{:}30$ a.m for an aggregation of $100{,}000$ BVs

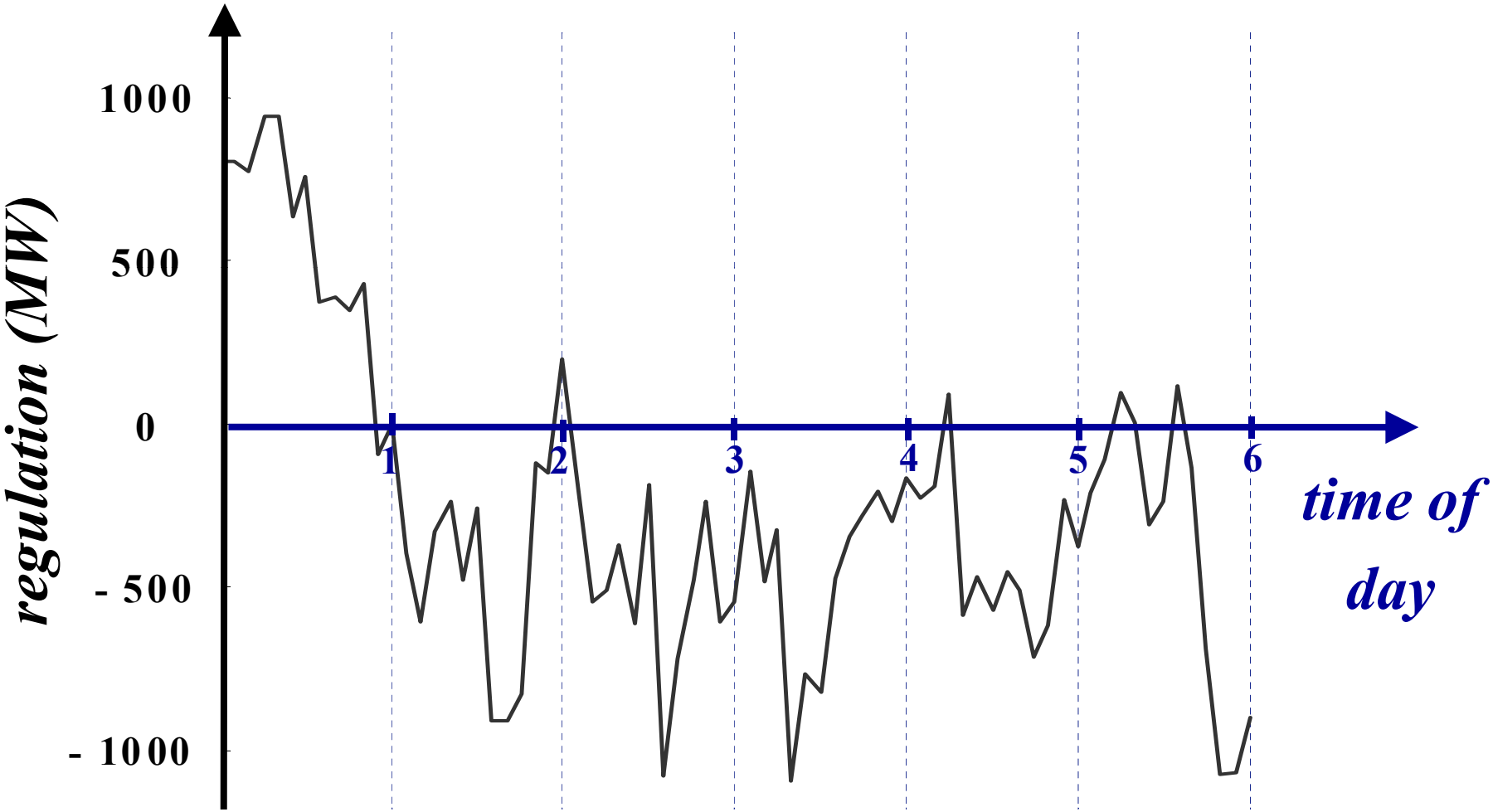
PERCENTAGE OF BVS PROVIDING LOAD SHAVING AND REGULATION SERVICE



ENERGY PROVIDED IN ADDITION TO THE REGULATION SERVICE



REGULATION FOR OFF-PEAK CONDITIONS



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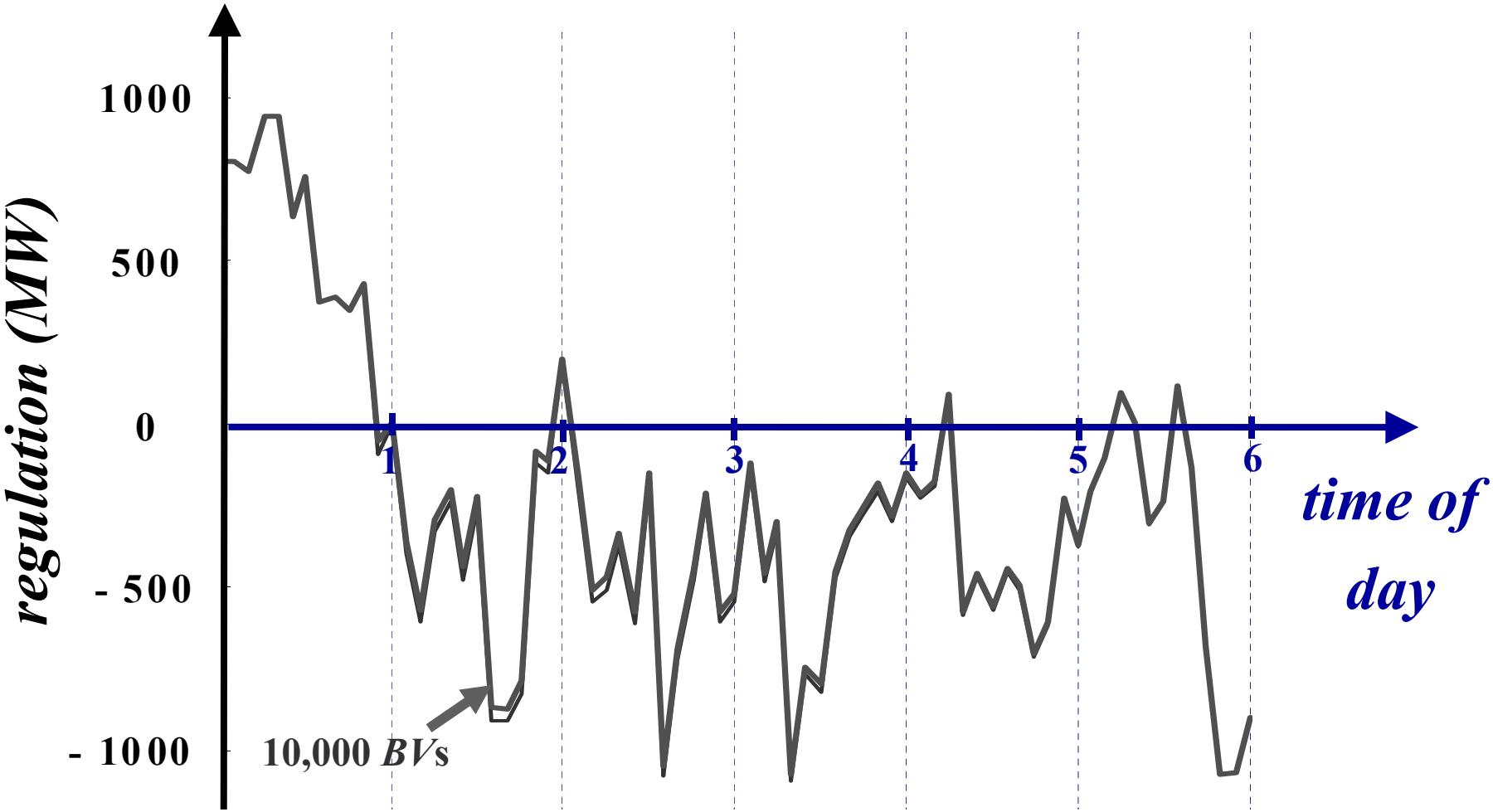

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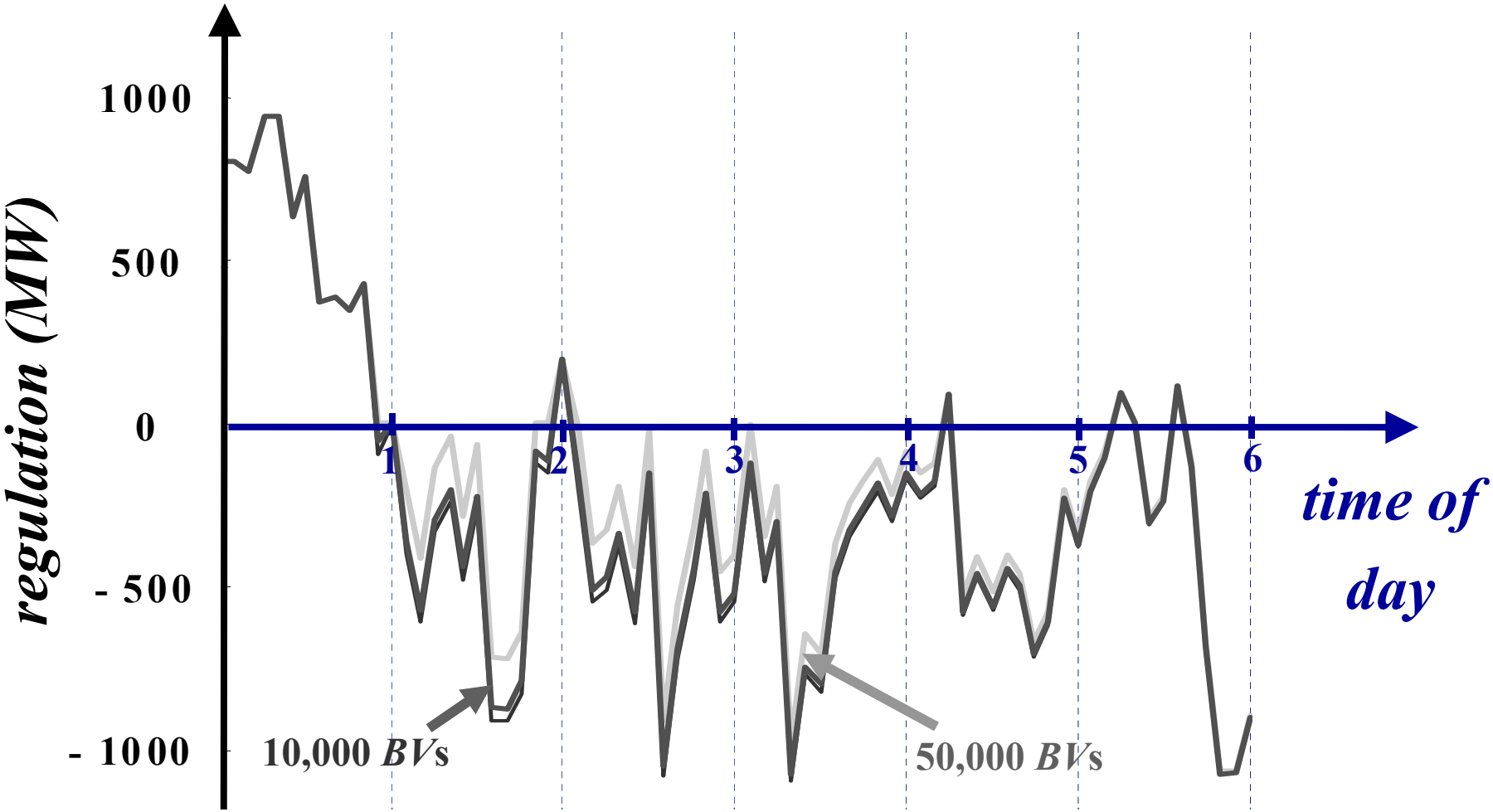

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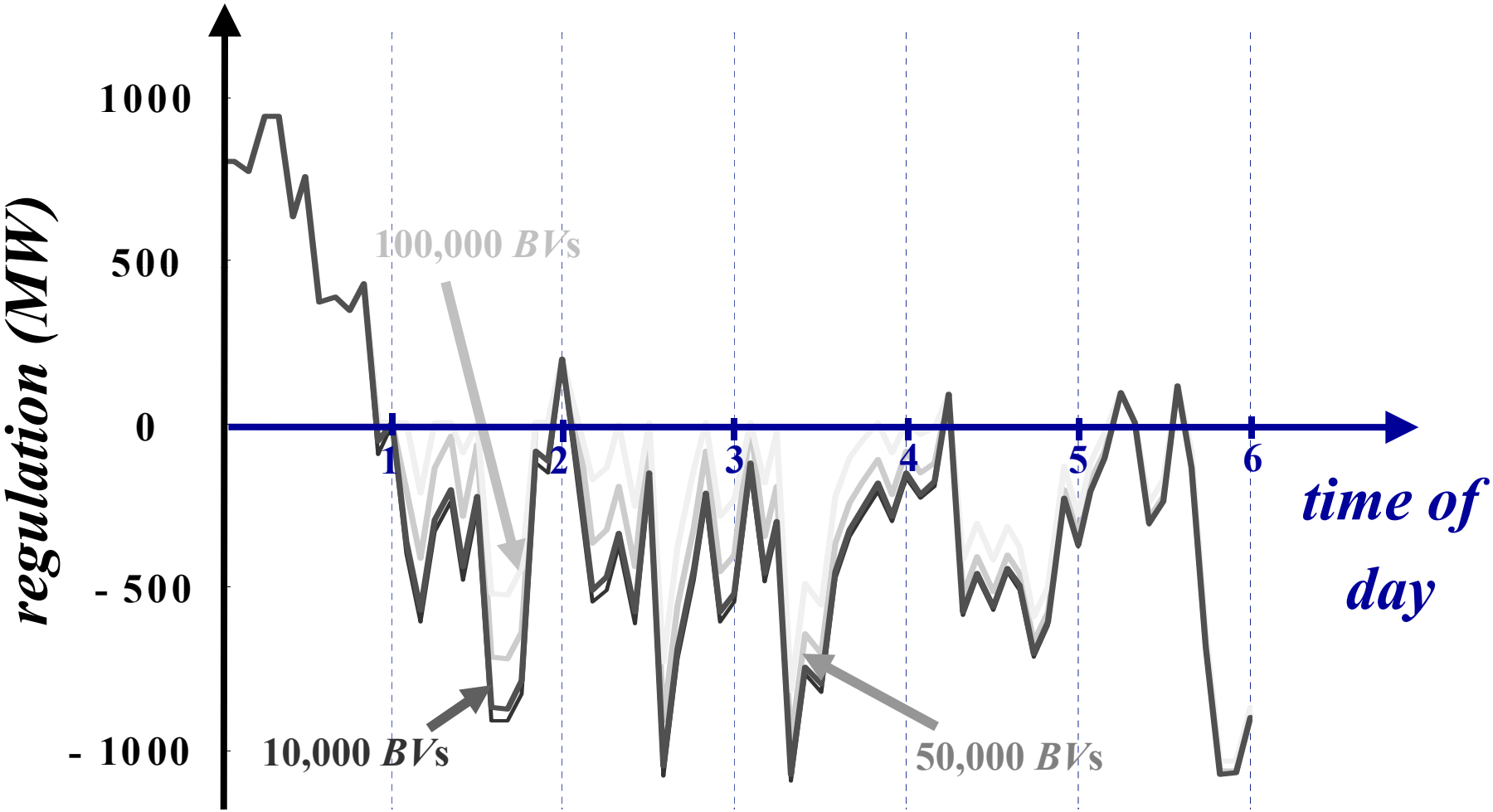

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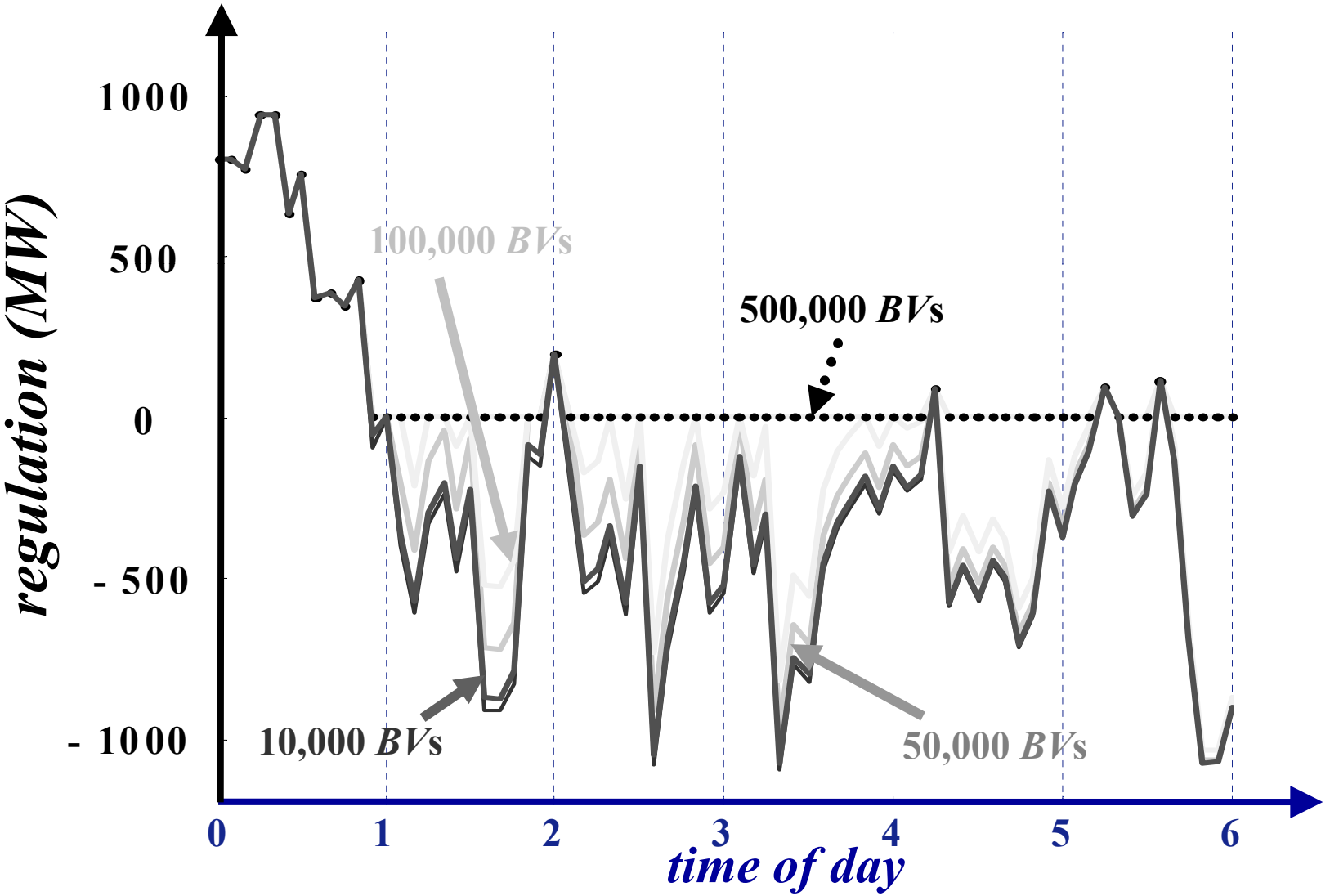
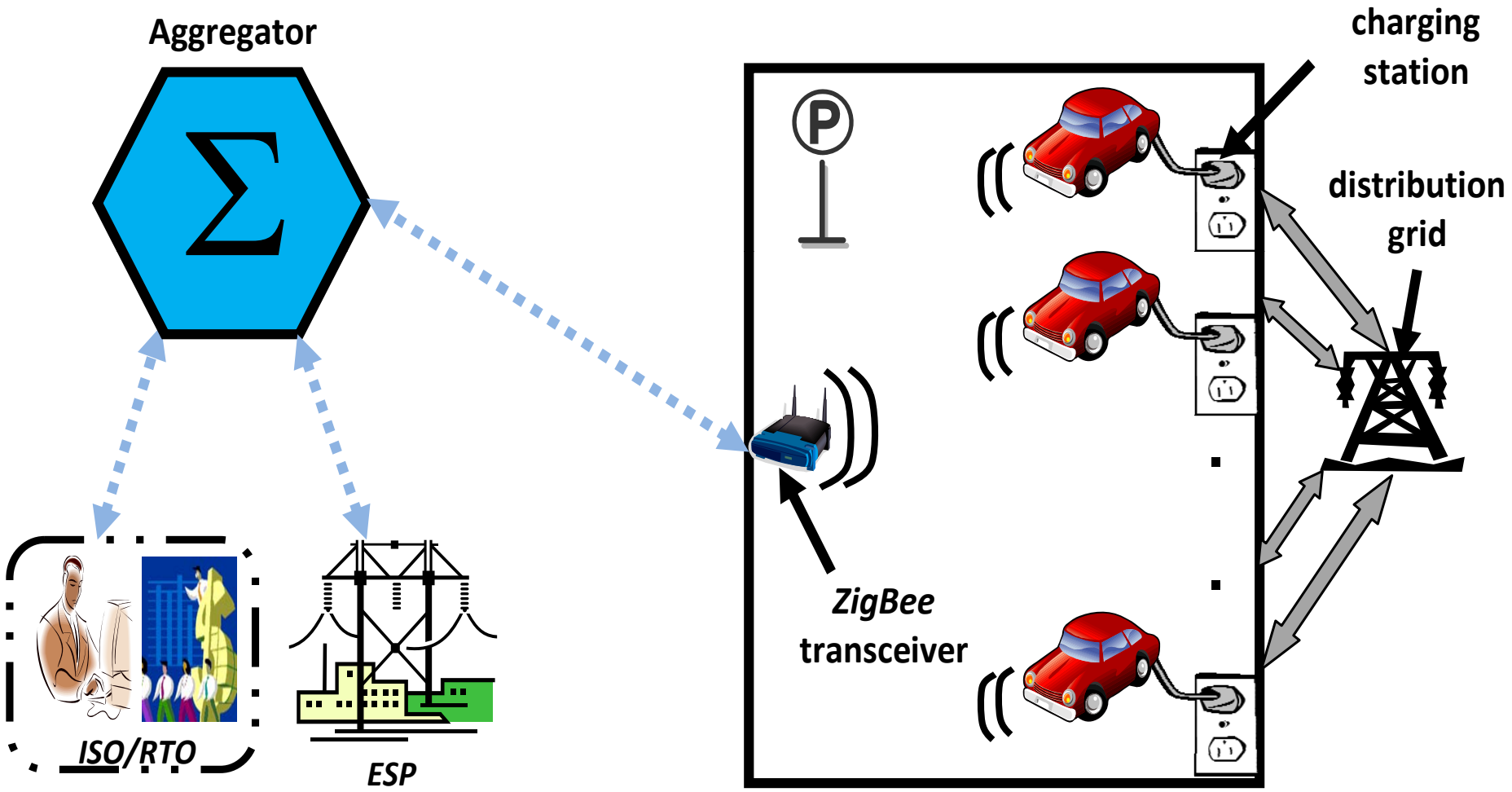


KEY IMPLEMENTATIONAL ISSUES

- Aggregation implementation
- 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 may be used to hack the network

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

COMPUTER / COMMUNICATION / CONTROL NETWORK: INFORMATION 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

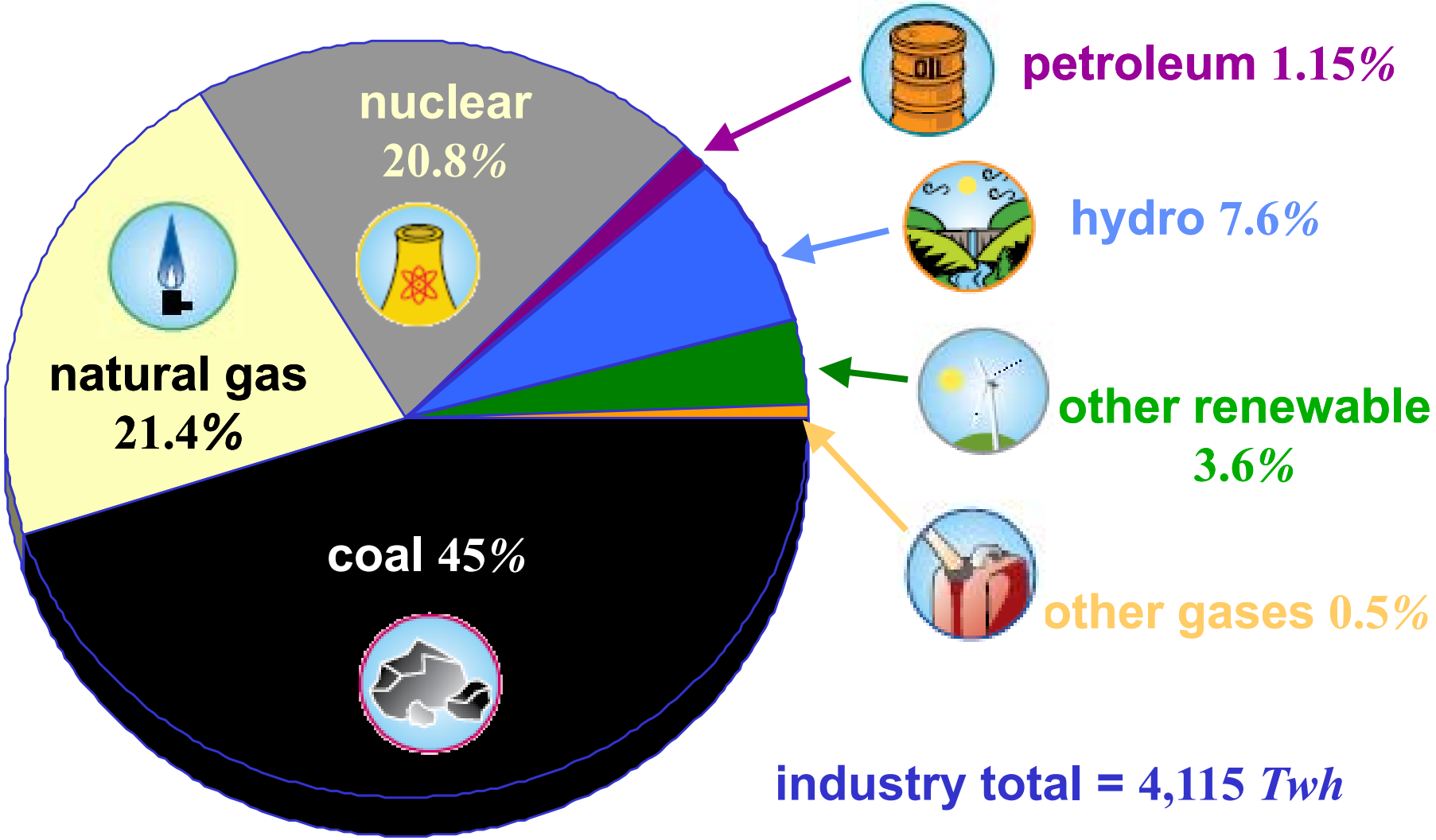
THE ROLES OF THE AGGREGATOR

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

VALUE ADDED BY THE AGGREGATOR

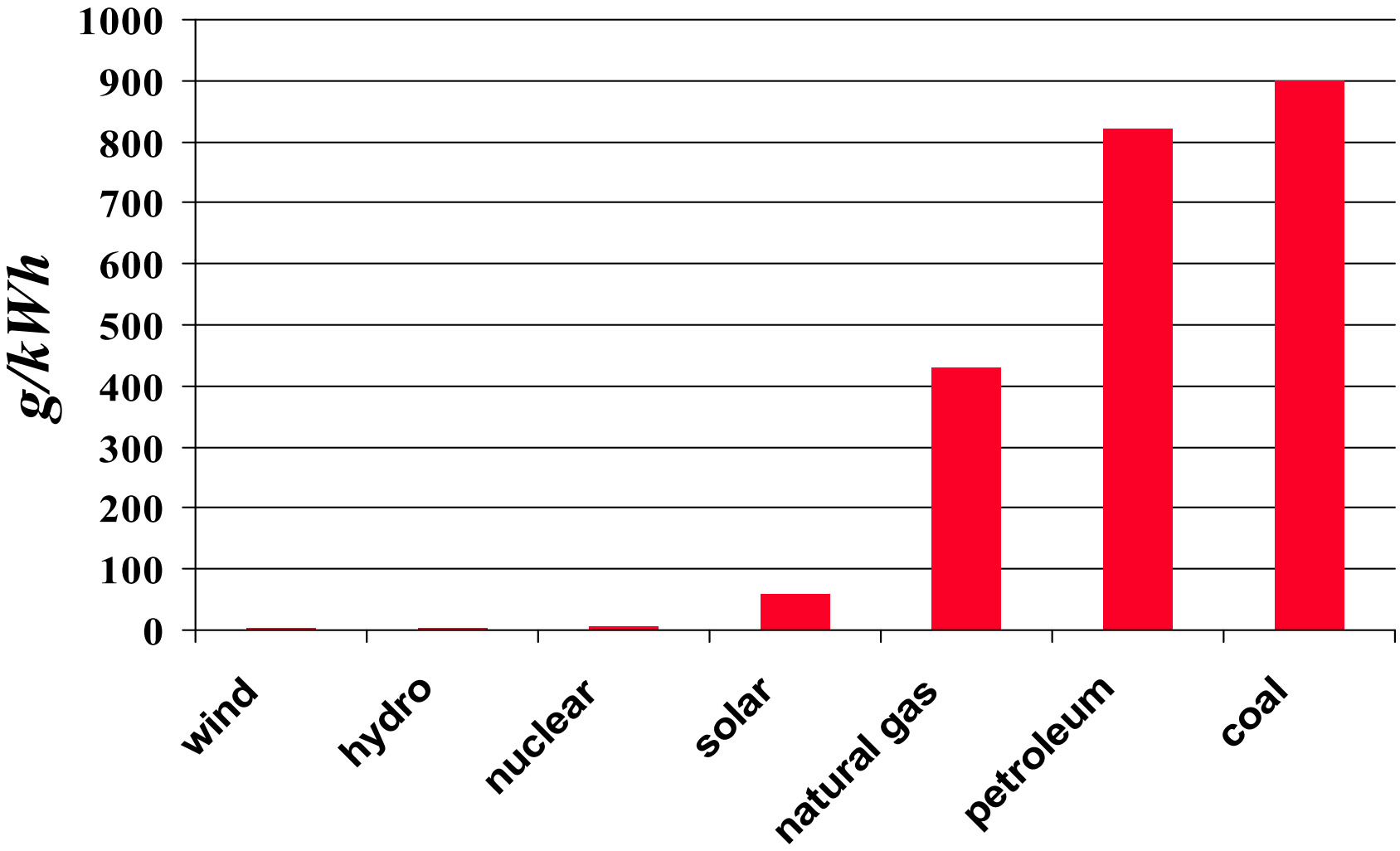
- Provides a "package deal" to the aggregated *BV*s in terms of:
  - parking facilities
  - service acquisition and provision
  - charging of *BV*s
  - battery service
- Allows "one-stop shopping" for potential *BV* participants
- Acts as a provider of environmental benefits for reduced emissions

NET GENERATION BY ENERGY SOURCE UP TO 6/31/2009

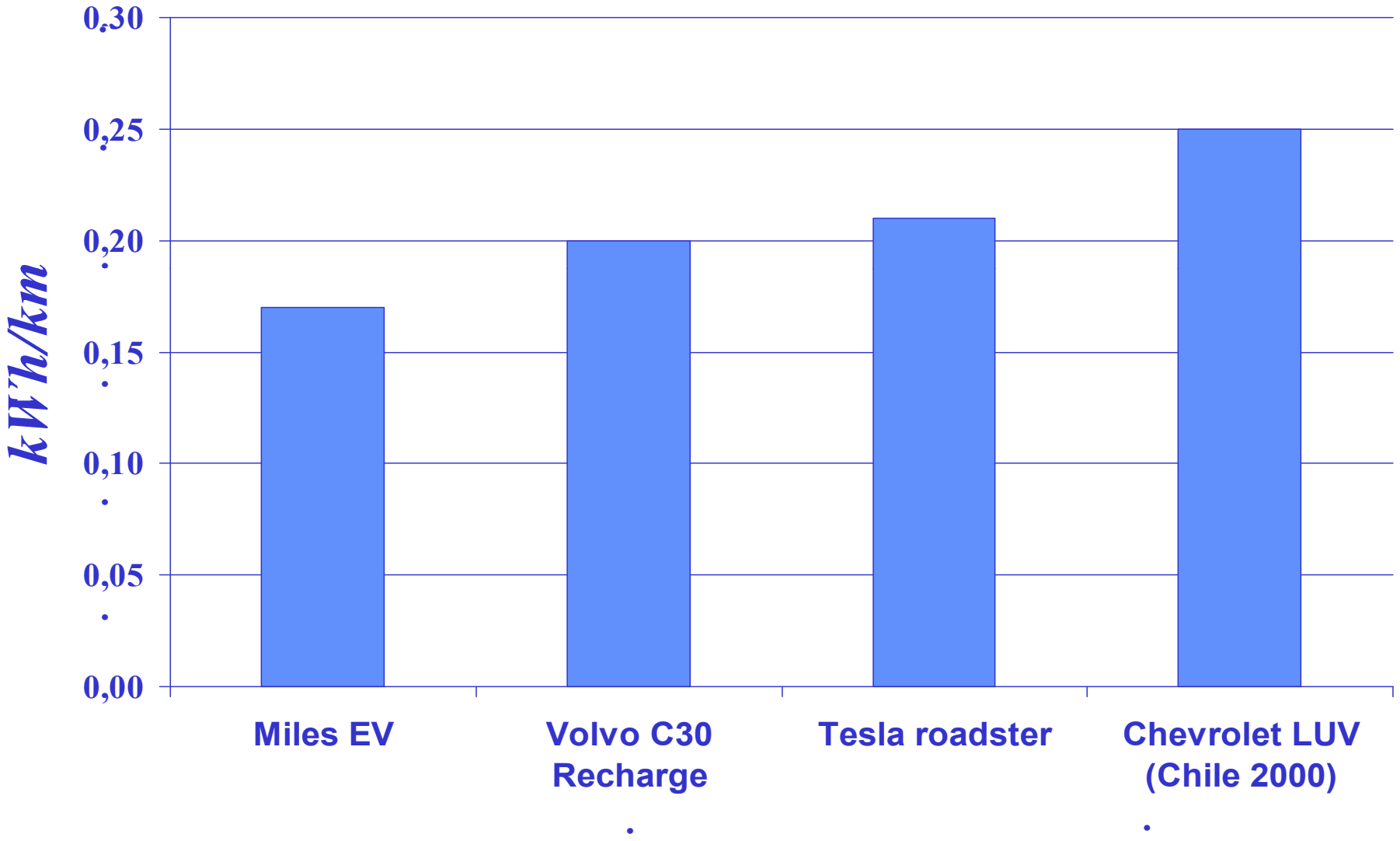


Source : Ameren IP

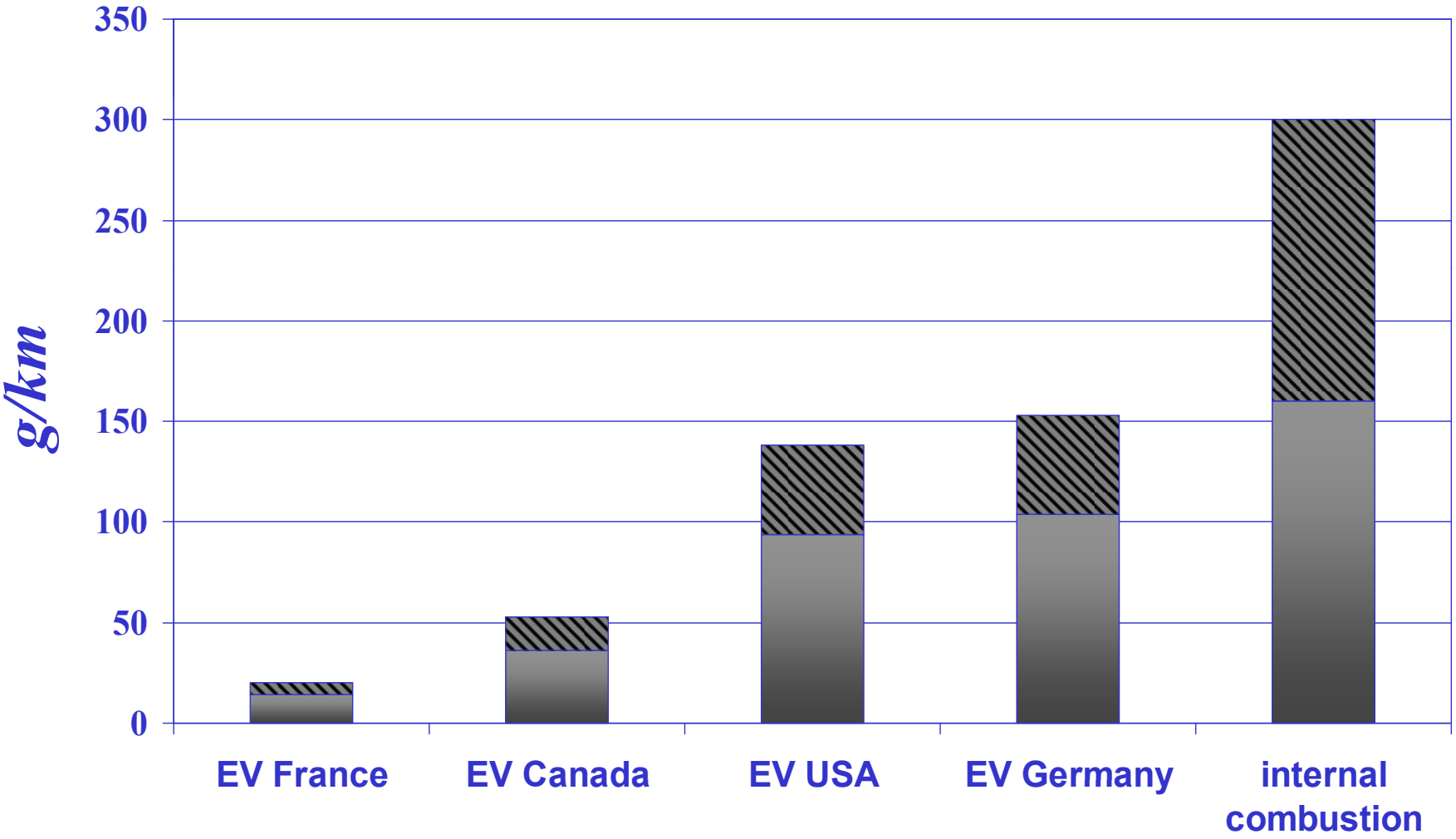
CO_2 EMISSION BY PLANT TYPE



ENERGY CONSUMPTION UNDER MIXED CONDITIONS



VEHICLE CO_2 EMISSIONS



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 and as generation sources
- *ESP*s and *ISO*/*RTO*s will have a new player to do business with
- Aggregators are key for the implementation of *V2G* concept to be successful
- The *BV* aggregator has the potential for making sizeable benefits

REFERENCES

- C. Guille and G. Gross, "A Conceptual Framework for the Vehicle-to-Grid (*V2G*) Implementation," accepted for publication in Energy Policy, 2009