Scheduling Electric Vehicles for Ancillary Services

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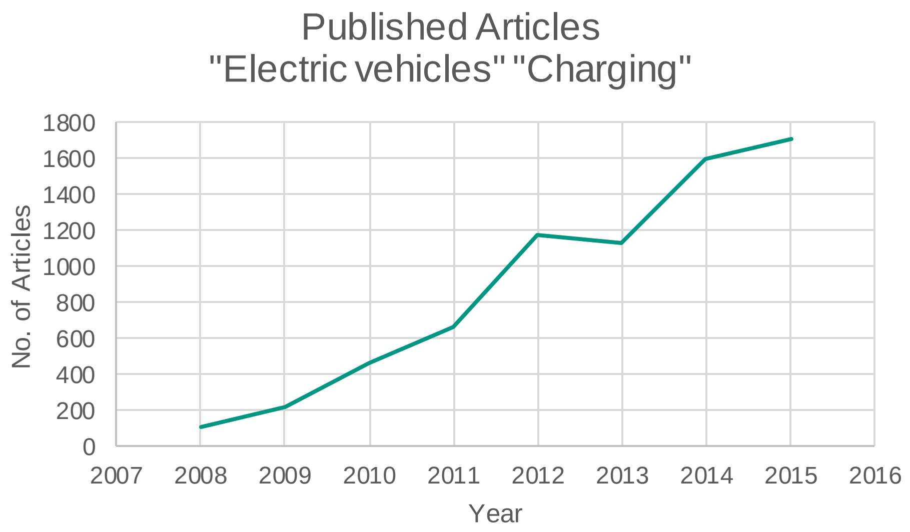
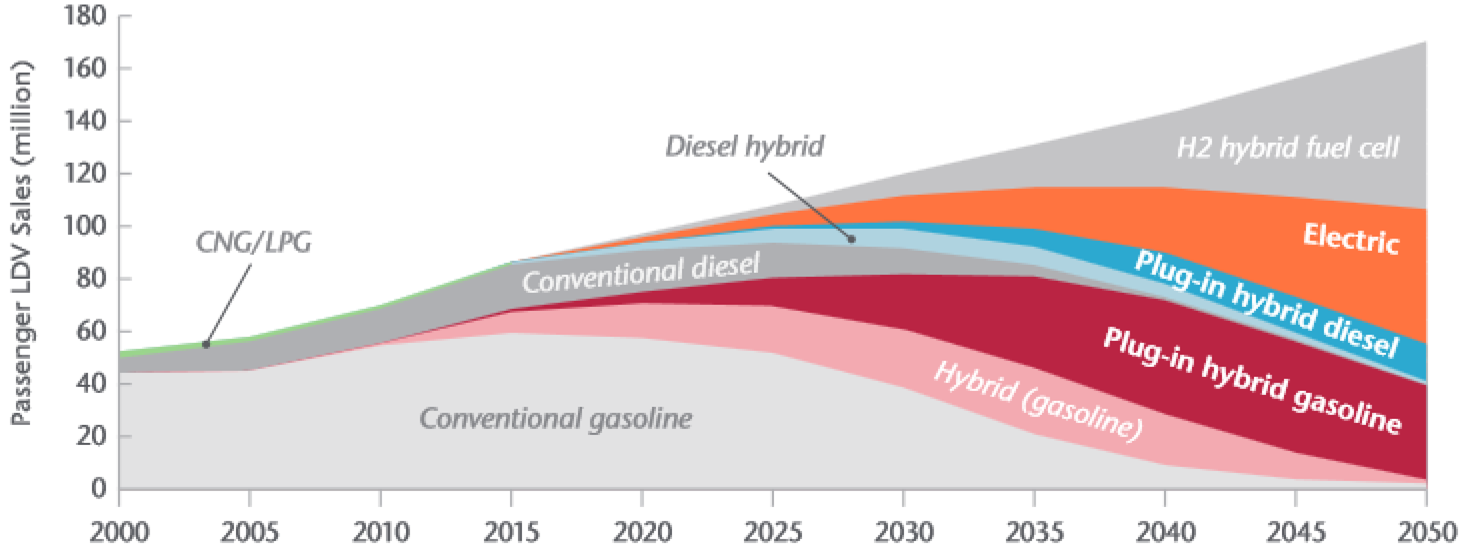
http://www.greenerkirkcaldy.org.uk/wp-content/uploads/Electric-vehicle-charging.jpg [11/5/2016]

The Development of Electric Mobility



Need for incentive to participate!

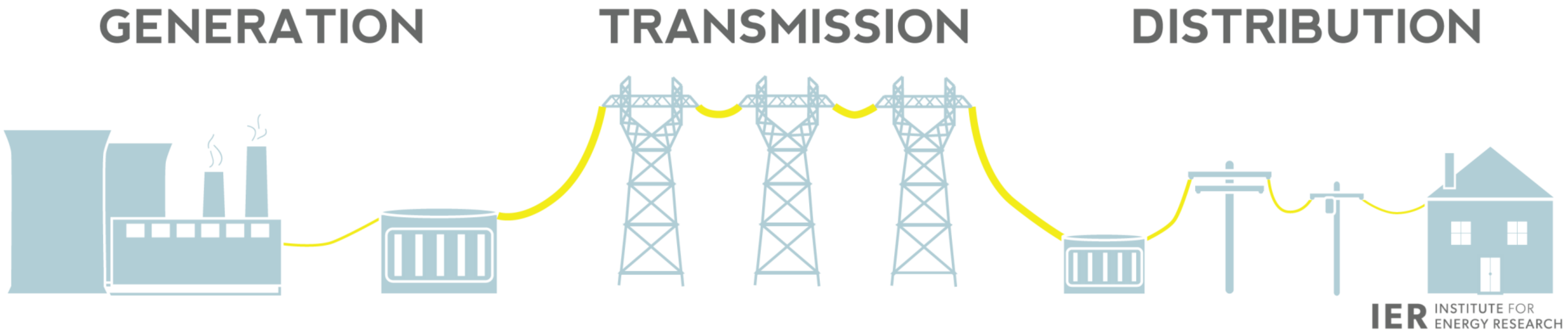


https://www.iea.org/publications/freepublications/publication/EV_PHEV_brochure.pdf [11/5/2016]

Agenda

- Motivation
  - Actors in the Grid
  - Frequency Control
- Related Work
- Model by Sortomme and El-Sharkawi [4]
- Conclusion

Actors in the Grid 1/2

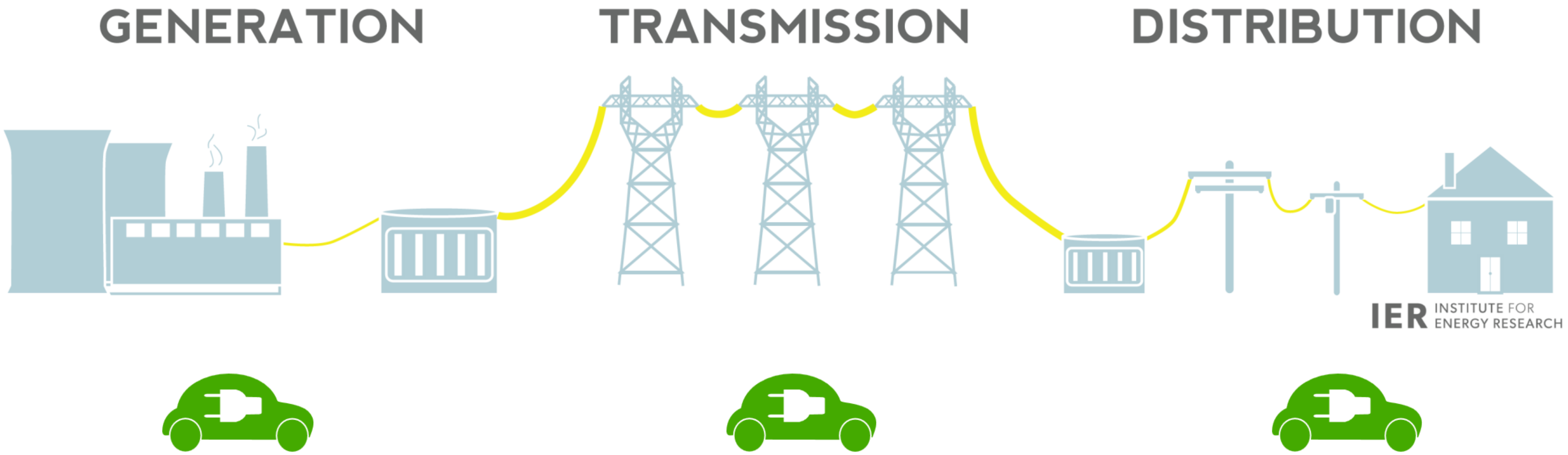


- **Electric Utility Companies** (EnBW, Vattenfall…)
- **Transmission System Operator** (TransnetBW, Amprion…)
- **Distribution System Operator** (NetzeBW, Stadtwerke…)

http://instituteforenergyresearch.org/wp-content/uploads/2014/09/schematic.png [11/5/2016]

Actors in the Grid 2/2

- Where do Electric Vehicles fit?



- Store excess power by renewable energy sources
- Smart charging to increase use of renewable energies

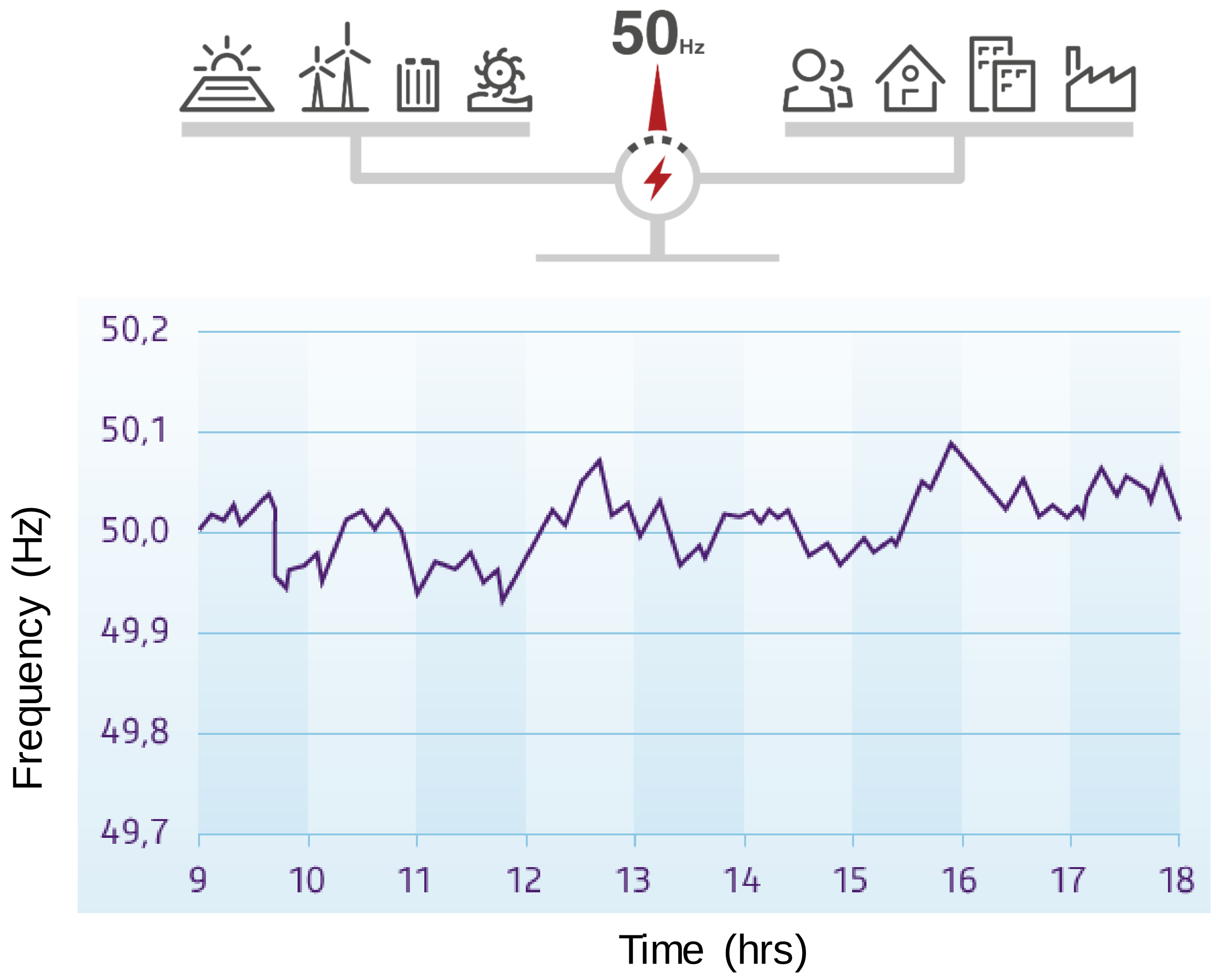
- Frequency control
  - Regulation up and down
  - Spinning reserve
- Peak Shaving

- Reduce regional congestion
- Stabilize voltage level

http://instituteforenergyresearch.org/wp-content/uploads/2014/09/schematic.png [11/5/2016]
http://www.clker.com/cliparts/W/H/S/A/B/5/green-car-icon.svg [11/5/2016]

Frequency Control

- Grid has to be balanced
  - Production = Consumption
- Imbalance can lead to power losses
- Different mechanisms
  - Regulation up and down
  - Spinning reserves
  - Non-spinning reserves



http://fokusenergie.com/wp-content/uploads/sites/91/2015/12/Regelenergie.png [11/5/2016]
http://www.amprion.net/netzfrequenz [11/10/2016]

Related Work

- Ev suitable for ancillary services
  - Brooks, Gage et al. (2001)
  - Kempton, Tomić (2005)
- Dynamic Programming
  - Rotering, Ilic (2011)
- Metaheuristics
  - Particle Swarm Optimization: Hutson, Venayagamoorthy, Corzine (2008)
  - Simulated Annealing: Sousa, Tiago et al. (2012)

- Focus on „Optimal Scheduling of Vehcile-to-Grid Energy and Ancillary Services“, Sortomme, El-Sharkawi (2012)

Agenda

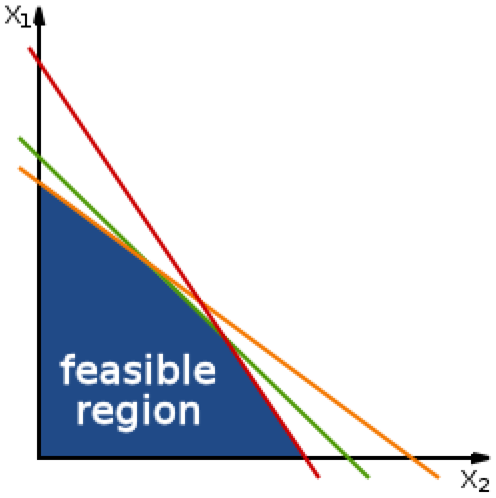
- Motivation
- Related Work
- Model by Sortomme and El-Sharkawi [4]
  - Model Structure
  - Parameters
  - Bidding Problem
  - Dispatch Algorithm
  - Simulation Results
- Conclusion

Model Structure 1/2

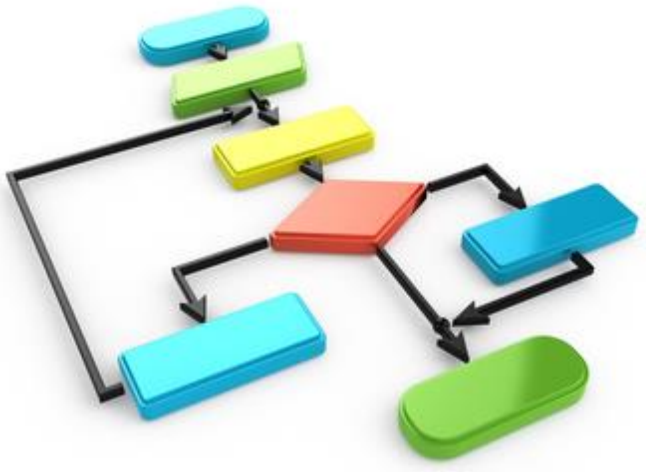
- Aggregator manages Electric Vehicles (EVs) with bidirectional V2G technology
- Objective: Maximize profit
- Revenues
  - Provide EVs with energy
  - Sell ancillary services
  - Sell energy
- Costs
  - Cost for energy for EVs
  - Battery degradation from discharging
- Compute optimal, feasible charging schedule

Model Structure 2/2

- Linear Program
  - Determine bidding strategy



- Dispatch Algorithm
  - Find dispatch schedule
  - React to regulation signal quickly



https://en.wikipedia.org/wiki/Linear_programming [11/12/2016]
http://www.bobology.com/public/What-is-an-Algorithm.cfm [11/12/2016]

Parameters

- Technical parameters
  - Battery capacity
  - Charging limits
- Customer-based parameters
  - Driving pattern
  - State of charge for each EV
- Market-based parameters
  - Forecasted prices for regulation up and down and spinning reserve
  - Forecasted regulation signals and amounts

Bidding Problem - Constraints 1/2

- Battery capacity constraints
  - Each vehicle's charge needs to stay between 0 and the max. capacity at all time
- Consumer preferences
  - Ability to perform one trip each day
  - End period with at least 99% charge
- Charging station charge rate

MP_i = max. available power draw

$POP_i(t)$ = preferred point of operation

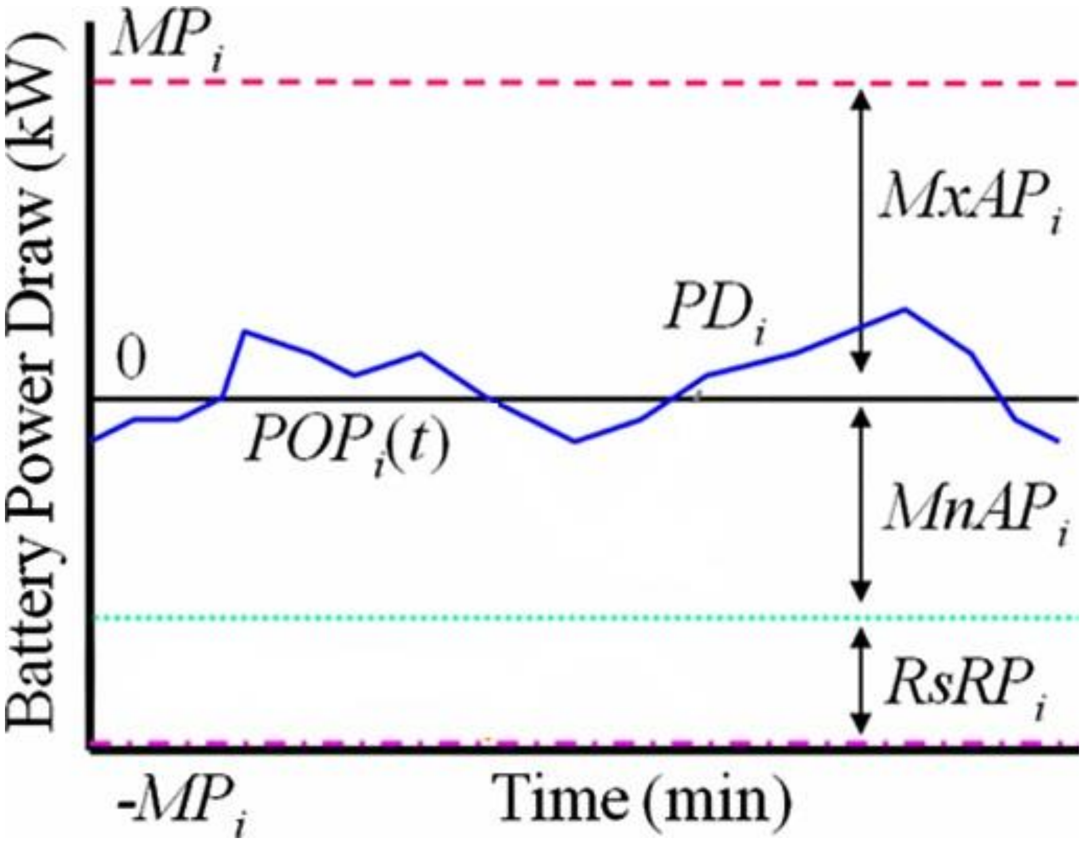
$MxAP_i$ = reg. down capacity

$MnAP_i$ = reg. up capacity

$RsRP_i$ = spinning reserve capacity

$RsRP_i(t)+MnAP_i(t)-POP_i(t) \leq MP_i$

$MxAP_i+POP_i(t) \leq MP_i$



Sortomme, El-Sharkawi (2012)

Bidding Problem - Constraints 2/2

- Minimize peak load charging

$$\sum_{i}^{cars} POP_i(t) \leq \frac{Mx_L - L(t)}{Mx_L - Mn_L} \sum_{i}^{cars} MP_i(t) \; \forall t$$

  - Load greater than Mn_L
    - → Less power available
    - → Lower charging profile
  - Not restricting for $L(t) \leq Mn_L$

$POP_i(t)$ = preferred point of operation

Mx_L = forecasted max. load

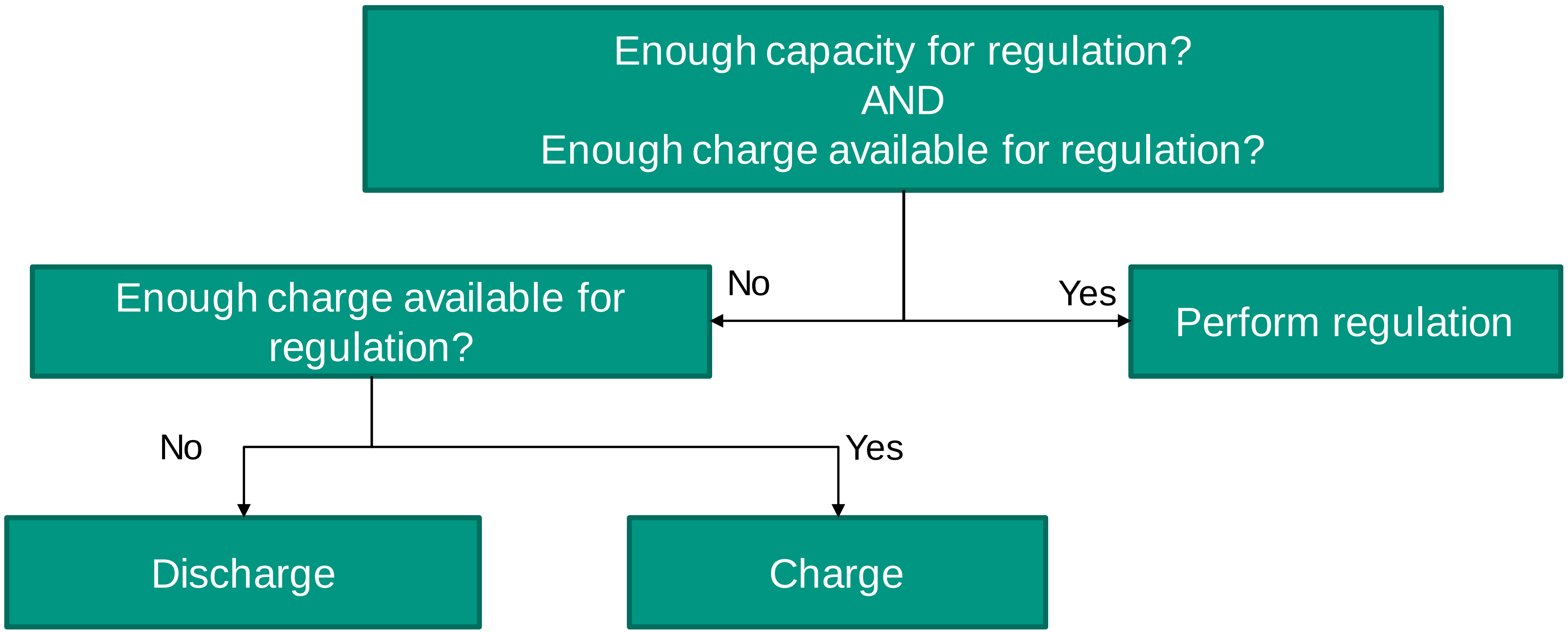
Mn_L = forecasted min. load

$L(t)$ = load ad time t

MP_i = max. available power draw

Sortomme, El-Sharkawi (2012)

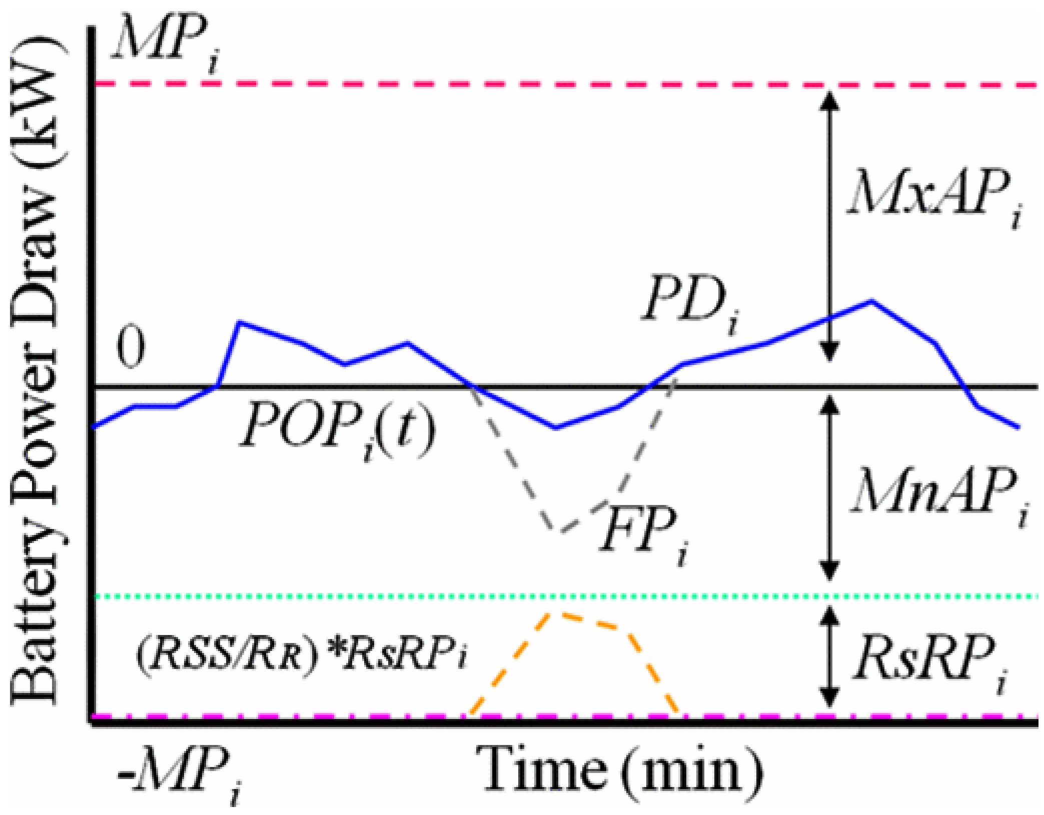
Dispatch Schedule Algorithm 1/2



Sortomme, El-Sharkawi (2012)

Dispatch Schedule Algorithm 2/2

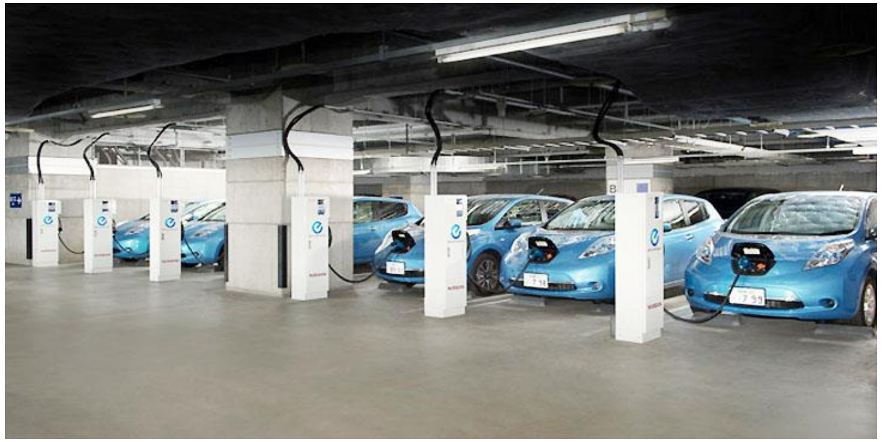
- Compute power draw for each vehicle considering
  - Regulation up
  - Regulation down
  - Spinning reserve
- Sum = final power draw for each vehicle

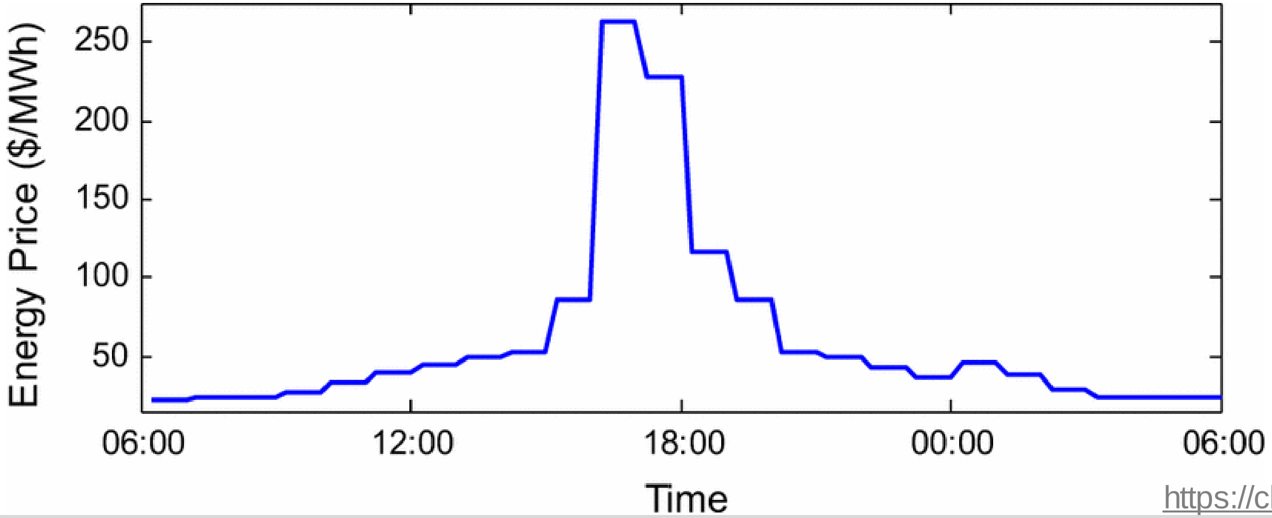


Sortomme, El-Sharkawi (2012)

Simulation Results

- Simulation parameters
  - 10 000 EVs, 5 types of cars
  - 100 driving patterns for weekday and weekend
  - Price for EV consumer = 0.01 $/kWh
  - Market parameters according to Houston, TX market
  - 3 Scenarios for battery cost ($200, $400, $800/kWh)

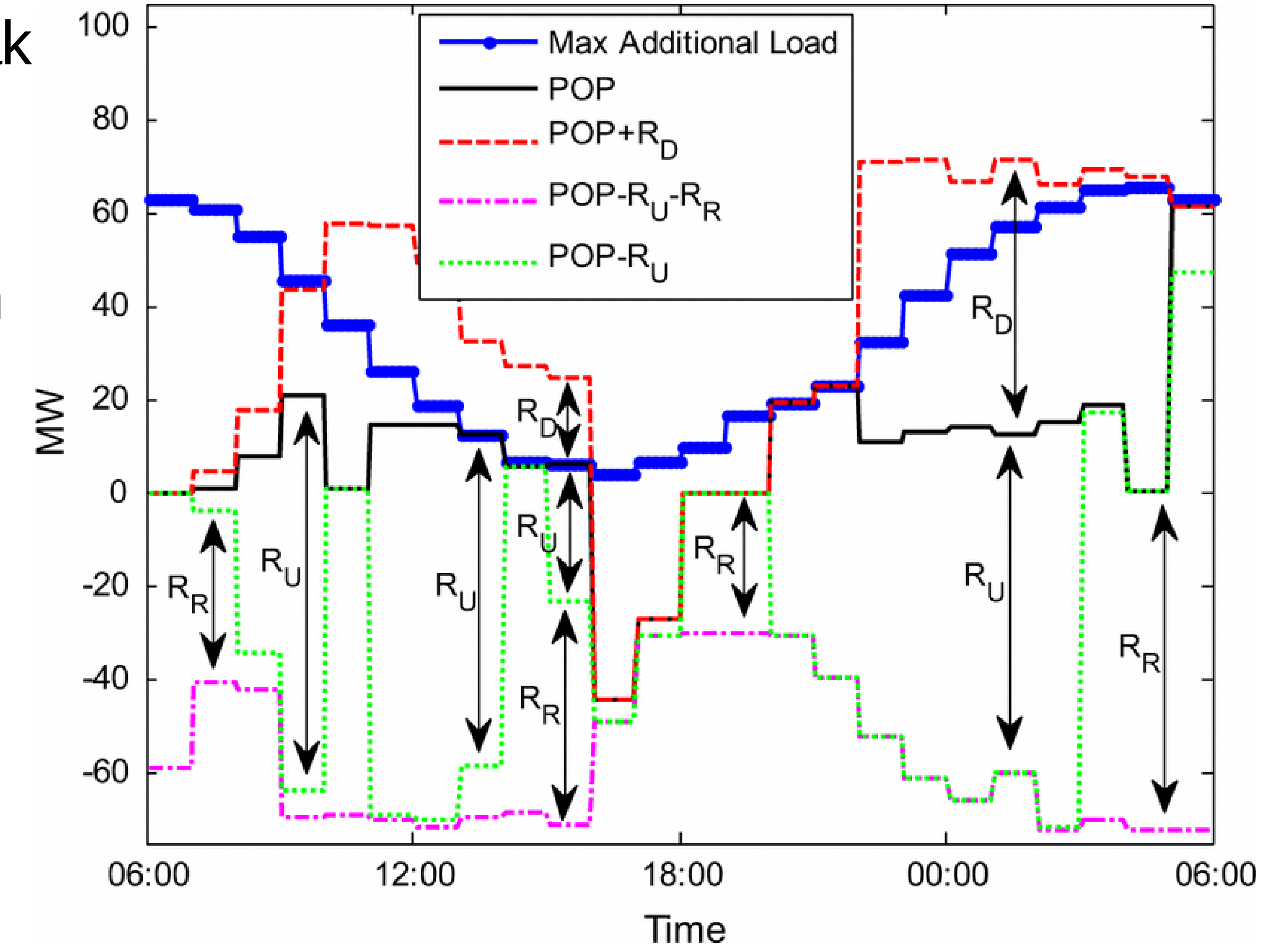




Sortomme, El-Sharkawi (2012)
https://cleantechnica.com/files/2015/03/nissan-leaf-grid-integration.jpg [11/4/2016]

Simulation Results - Charging Profile

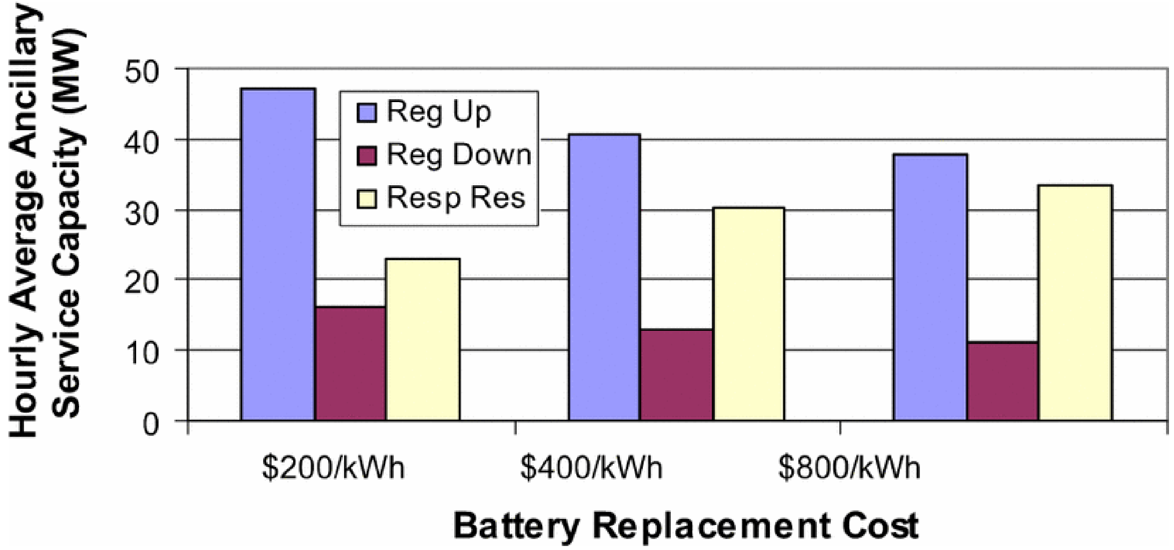
- No additional load during time of peak
- Change of POP to sell ancillary services
- Charging profile highly depending on battery replacement cost



Sortomme, El-Sharkawi (2012)

Simulation Results - System Benefits

- Peak shaving
- Gain of regulation and reserves
- Only small percentage of needed overall capacity
  - Regulation up and down: 800 MW
  - Spinning reserve: 2,300 MW
- Prices for ancillary services drop 7-8%



Sortomme, El-Sharkawi (2012)

Simulation Results - Cost-Benefit Analysis

- Profits between \$1.2 mio and \$6 mio
- Calculation of net present value $NPV = \sum_{t=0}^{10} \frac{R_t}{(1+i)^t}$

Battery Cost	\$200/kWh	\$400/kWh	\$800/kWh
NPV per car	\$6,082.80	\$4,433.90	\$1,540.78

- Assumption of consistent ancillary prices
- Additional cost not considered
  - Communication soft- and hardware
  - Safety measures

Conclusion

- Benefits from V2G services
- Technical burden
- Consumer willingness to adapt
  - Commercial fleets (delivery trucks etc.)
- Integrate regional aspects
- Adjustment for european market

References

[1] Brooks, Alec, Tom Gage, and A. C. Propulsion. "Integration of electric drive vehicles with the electric power grid—a new value stream." *18th International Electric Vehicle Symposium and Exhibition, Berlin, Germany*. 2001.

[2] Hutson, Chris, Ganesh Kumar Venayagamoorthy, and Keith A. Corzine. "Intelligent scheduling of hybrid and electric vehicle storage capacity in a parking lot for profit maximization in grid power transactions." *Energy 2030 Conference, 2008. ENERGY 2008. IEEE*. IEEE, 2008.

[3] Kempton, Willett, and Jasna Tomić. "Vehicle-to-grid power fundamentals: Calculating capacity and net revenue." *Journal of power sources* 144.1 (2005): 268-279.

[4] Rotering, Niklas, and Marija Ilic. "Optimal charge control of plug-in hybrid electric vehicles in deregulated electricity markets." *IEEE Transactions on Power Systems* 26.3 (2011): 1021-1029.

[5] Sortomme, Eric, and Mohamed A. El-Sharkawi. "Optimal scheduling of vehicle-to-grid energy and ancillary services." *IEEE Transactions on Smart Grid* 3.1 (2012): 351-359.

[6] Sousa, Tiago, et al. "Intelligent energy resource management considering vehicle-to-grid: A simulated annealing approach." *IEEE Transactions on Smart Grid* 3.1 (2012): 535-542.

Backup - Bidding Problem - Objective

- Income
  - Ancillary services
    $$\sum_t (P_{RU}(t) \cdot R_U(t) + P_{RD}(t) \cdot R_D(t) + P_{RR}(t) \cdot R_R(t))$$
  - Selling energy to the EV owner
    $$+Mk \sum_i \sum_t (E[FP_i(t)])$$
  - Sell excessive energy
    $$+\sum_i \sum_t (E[FP_i(t)] \cdot P(t)) \text{ if } E[FP_i(t)] \leq 0$$
- Cost
  - Opportunity cost of providing energy for EVs
    $$-\sum_i \sum_t (E[FP_i(t)] \cdot P(t))$$
  - Battery degradation through discharge
    $$-\sum_i \sum_t \left(\frac{DC_i \cdot E\left[FP_i^-(t)\right]}{Ef_i} \right)$$

- $P_{RU}(t)$, $P_{RD}(t)$, $P_{RR}(t)$ = price for regulation up, down, responsive reserve
- $R_U(t)$, $R_D(t)$, $R_R(t)$ = capacity for regulation up, down, responsive reserve
- Mk = price charged to EV owner
- $E[FP_i(t)]$ = expected final power draw of vehicle *I*
- $P(t)$ = Market price for energy
- $E[FP^-{}_i(t)]$ = expected “pos.” power draw of vehicle *i*
- DC_i = Degradation cost from discharging
- Ef_i = charging efficiency

Sortomme, El-Sharkawi (2012)

Backup – Computation of expected Final Power Draw

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$$E\left[FP_i(t)\right] = MxAP_i(t) \cdot Ex_D + POP_i(t) - MnAP_i(t) \cdot Ex_U - RsRP_i(t) \cdot Ex_R \quad (2)$$

$$Ex_D = \frac{\int_{RS_{\min}}^{0} RS \cdot \Pr[RS] \cdot dRS}{\int_{RS_{\min}}^{0} RS \cdot dRS} \quad (3)$$

$$Ex_U = \frac{\int_{0}^{RS_{\max}} RS \cdot \Pr[RS] \cdot dRS}{\int_{0}^{RS_{\max}} RS \cdot dRS} \quad (4)$$

$$Ex_R = \frac{\int_{0}^{RRS_{\max}} RRS \cdot \Pr[RRS] \cdot dRRS}{\int_{0}^{RRS_{\max}} RRS \cdot dRRS} \quad (5)$$

Backup - Mathematical Formulation of Dispatch Algorithm

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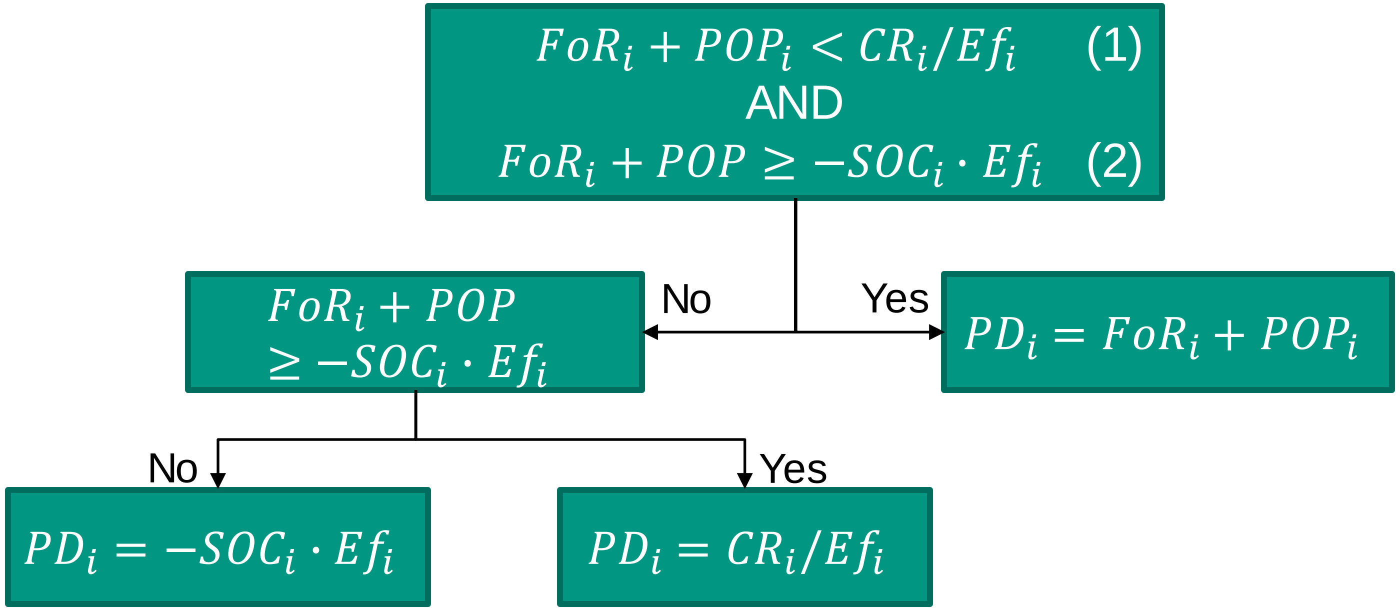

(1) Complete power draw less than remaining capacity

If violated: additional load reduction impossible

$\rightarrow PD_i \leq CR_i/Ef_i$

(2) Complete discharge greater than max. battery discharge

If violated: additional load increase impossible

$\rightarrow PD_i = -SOC_i \cdot Ef_i$

FoR_i = $(RS/R_D)MxAP_i$; $(RS/R_U)MnAP_i$; $(RSS/R_R)RsRP_i$ = fraction of regulation (reduction / increase)

POP_i = scheduled operating point

CR/Ef_i = charge needed for maximum charge

$-SOC_i \cdot Ef_i$ = discharge of battery

PD_i = power draw

Sortomme, El-Sharkawi (2012)