Building effective electric bus systems

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Anders Grauers

Swedish Electric & Hybrid Vehicle Centre

Chalmers University of technology, anders.grauers@chalmers.se

Gunnar Ohlin, Lindholmen Science Park

Oscar Olsson, Viktoria Swedish ICT

… and many more

Summary

Analysis method must include many system interdependencies to find the best bus system

Cost effective charging system can be explained using Battery State Of Charge curves.

Several factors make end-stop charging attractive.

Planning of bus schedules must be included when searching for cost effective charger systems

Conclusions may change – System understanding will be relevant

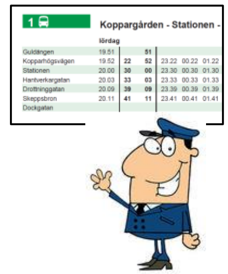
It is the total cost which shall be minimized!

Charger

+

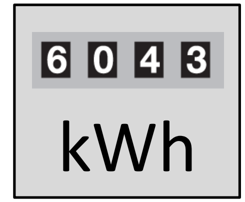
Buses

+



Bus operation

+



Electricity

+

Other costs influenced by charger system

Must include how changes in one part influence the cost of other parts

Charger power

Battery Size

Charging time

Energy tariff

No of Chargers

Bus weight

Time table

Power tariff

Depot cost

Max No of passengers

Bus schedules

Charger placing

Traveller time

Grid connection

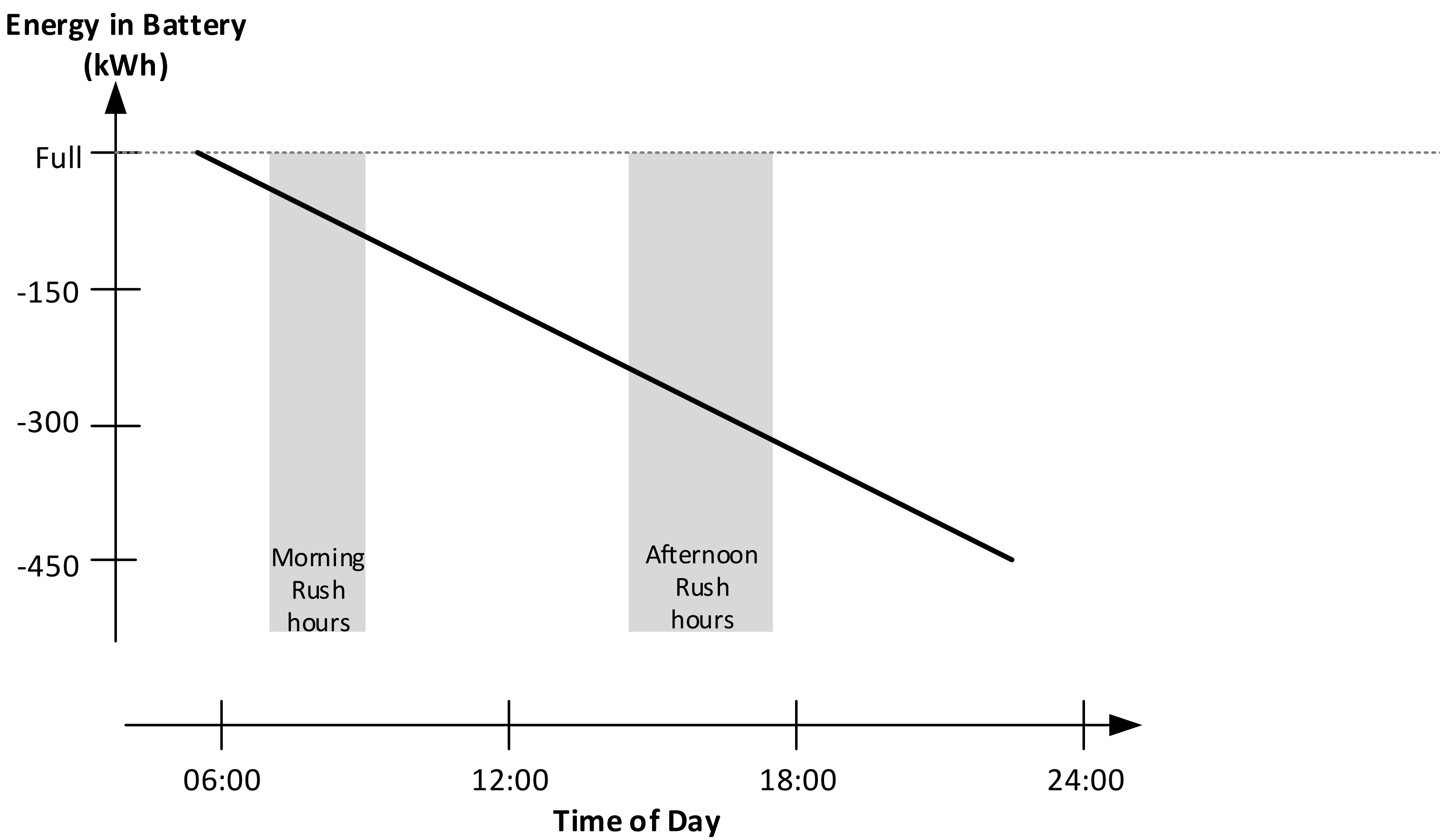
No of buses

Driver hours

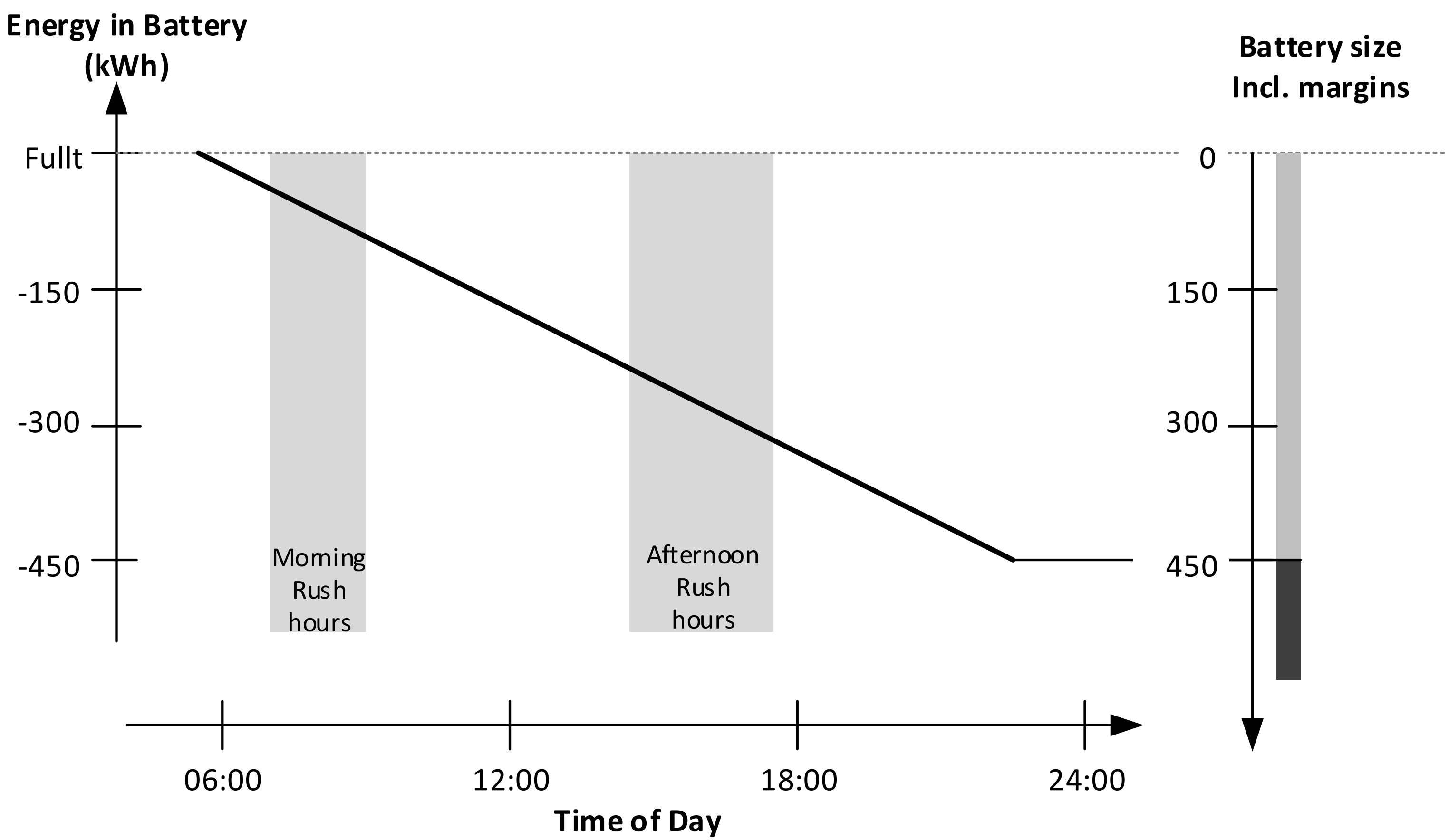
Charger cost + Bus cost + Operating cost + Elec. cost + Other costs

This ratio influence what is optimal!

Energy Consumption during a day

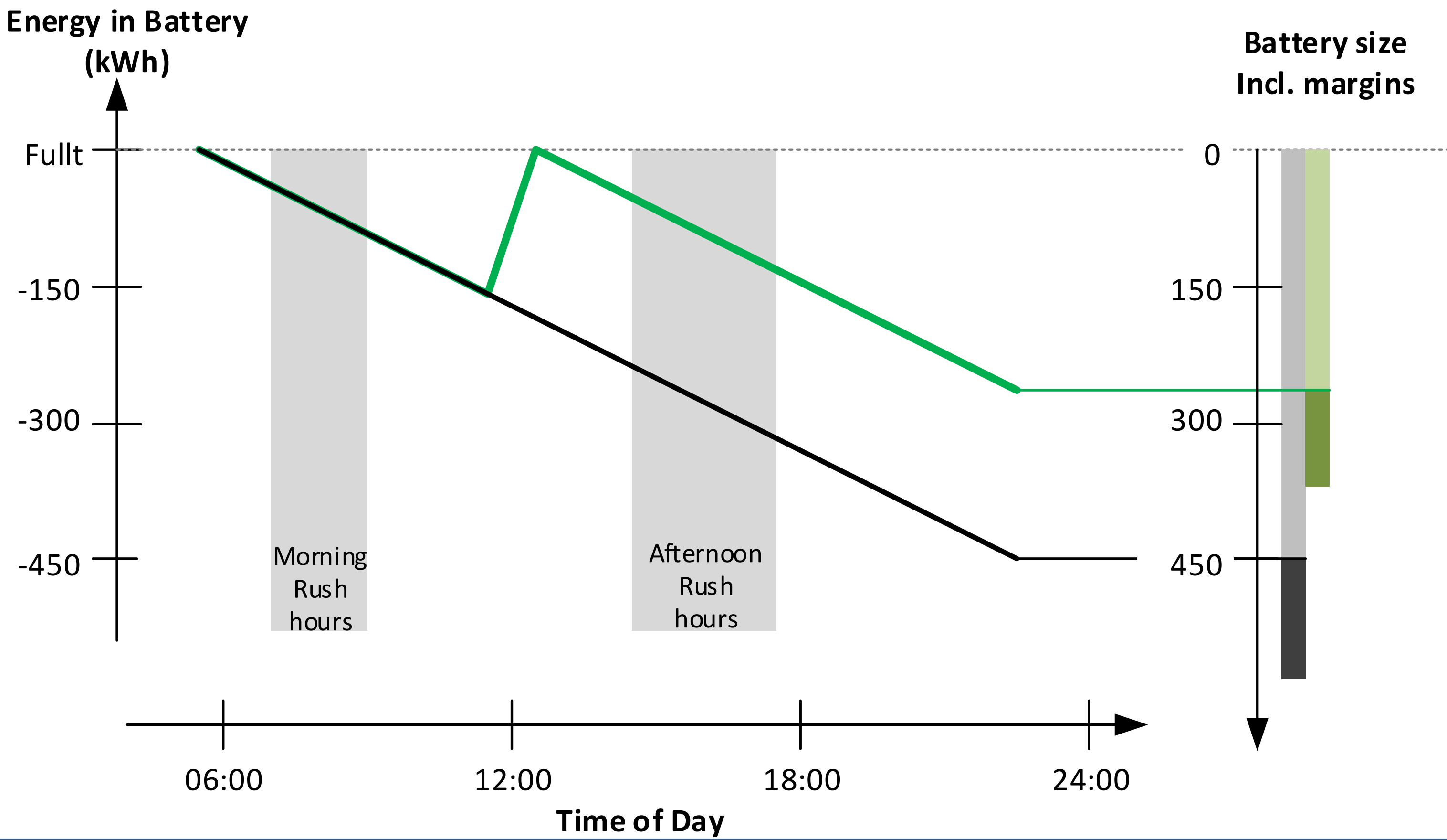


Only night charging



Bus cost	+	Charger cost
~ 600 kWh * No of buses	+	80 kW * No of buses

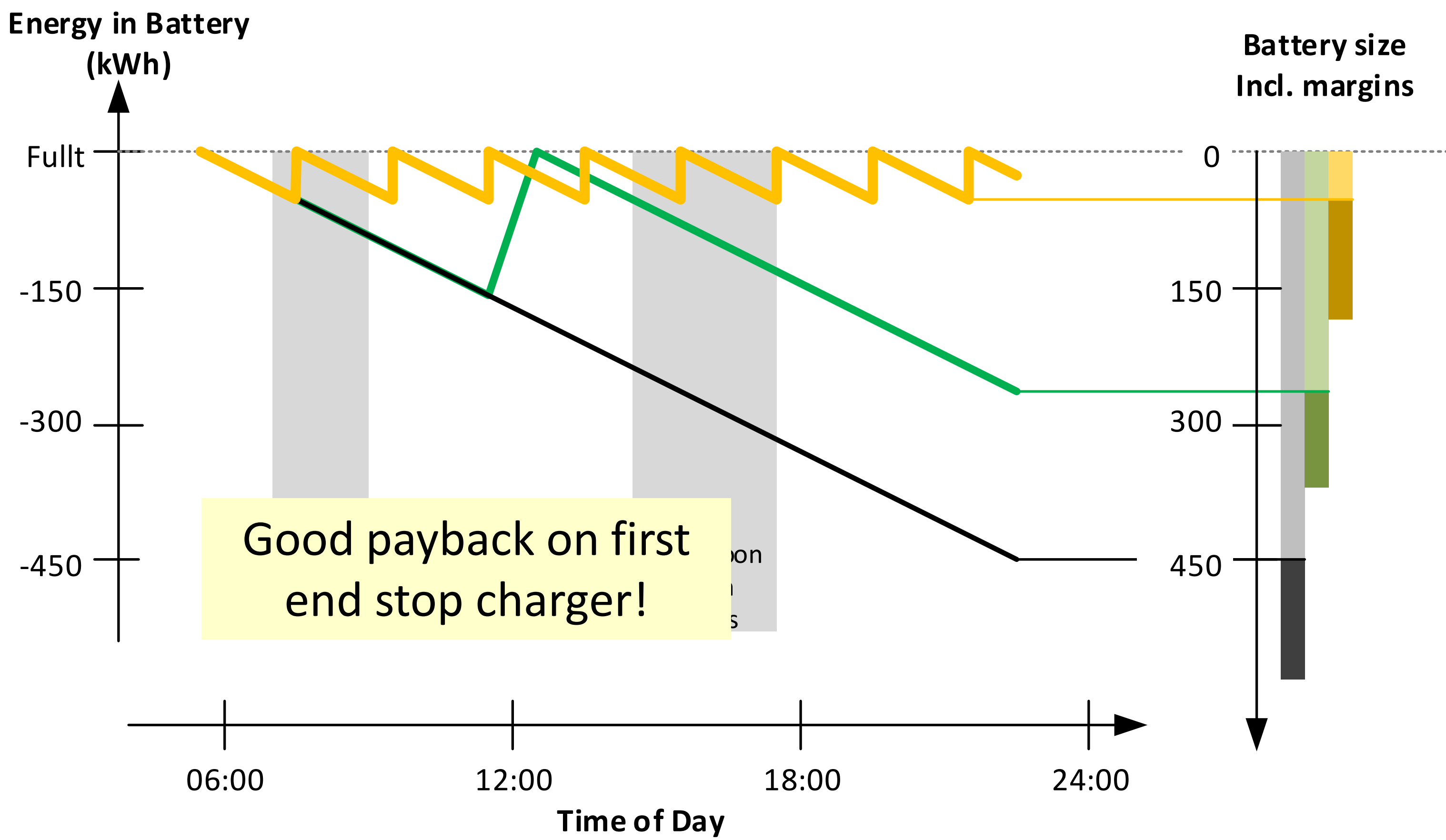
Night charging and charging off-peak



~ 400 kWh * No of buses + 80 kW * No of buses

+ Time to drive to depot + May need more buses!

One end-stop Charger



~ 175 kWh * No of buses + 300 kW * 1

Much Smaller Battery Bigger but only one Charger!

Charger power versus Stop time

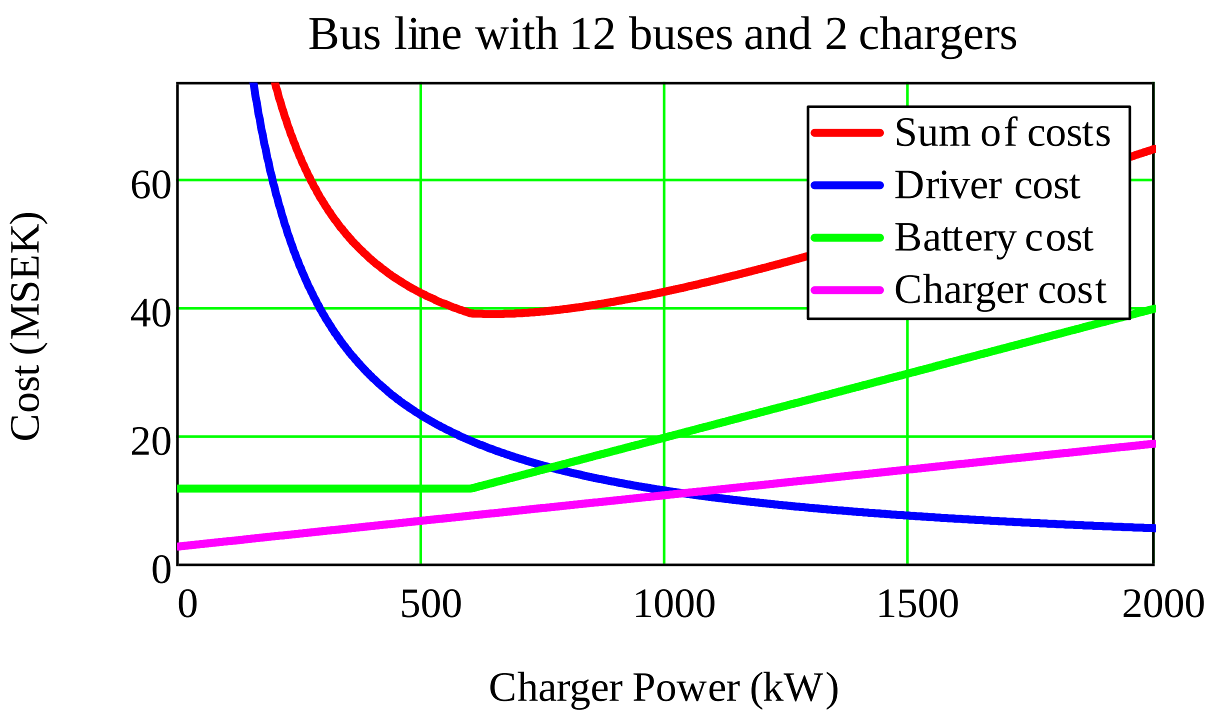
(showing the complex relation between <u>some</u> costs)

Increased charger power leads to:

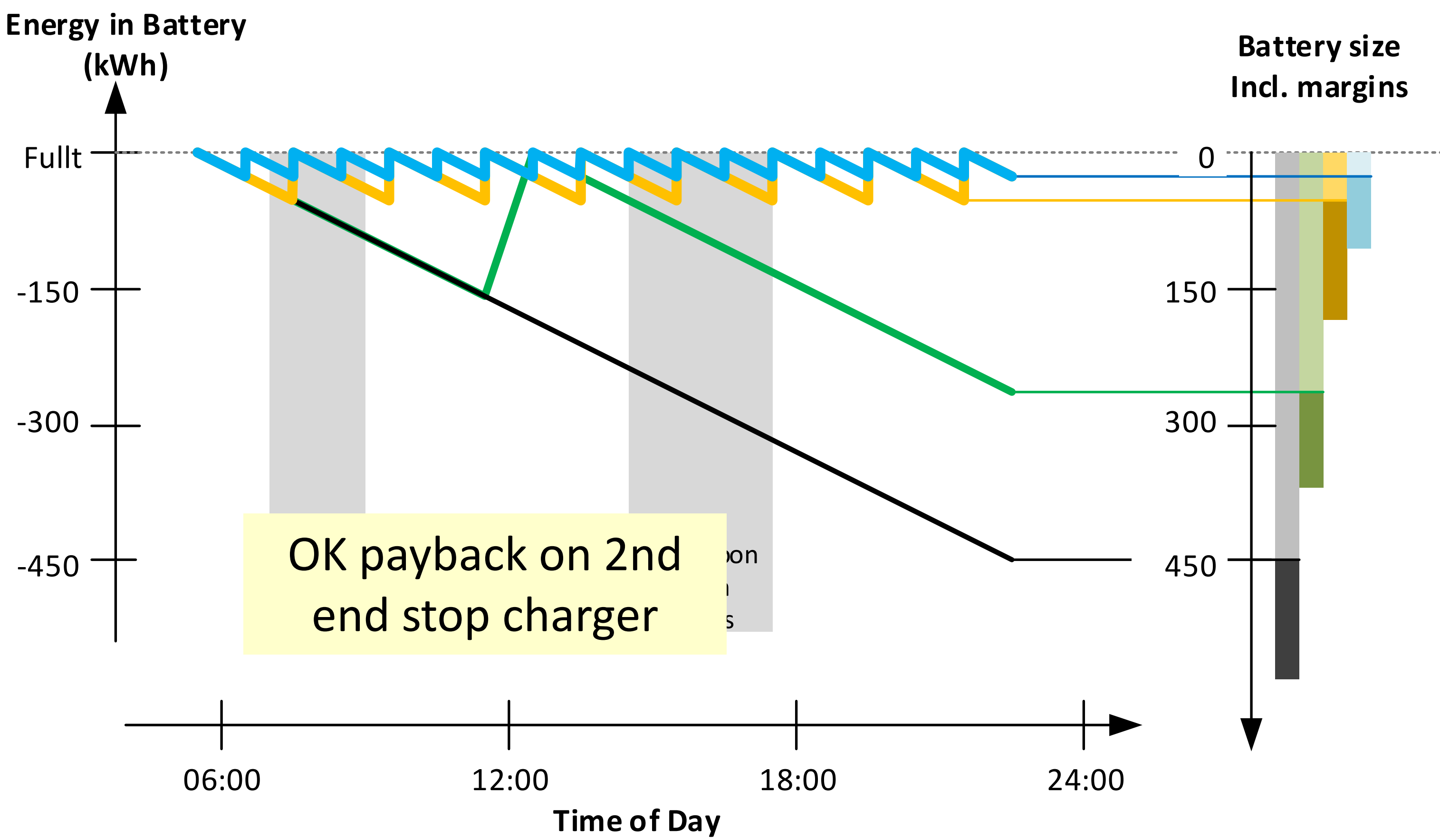
– More expensive charger

+ Shorter stop time for bus and driver

– May require bigger battery to handle power.



Two end-stop Chargers



~ 100 kWh * No of buses + 300 kW * **2**

Even Smaller Battery

2 chargers ⇒ more robust

Marginal effect of adding one more charger

Goal
With a minimum of charger investment
save as much as possible on other costs

Simplified analysis - only battery saving :

1 additional 300 kW charger **Costs** ~ 3 MSEK

Each battery about 75 kWh smaller **Saves** ~ 0.5 MSEK/bus

5 buses or less $\Rightarrow$ Do not build second charger
6 buses or more $\Rightarrow$ build charger

(Assuming time is available for charging)

Build chargers at many bus stops?

Energy charged proportional to dwell time:

End stop:	3 minutes	$\Rightarrow$	15 kWh
Bus stops:	20 sec	$\Rightarrow$	1.67 kWh

Need <u>many</u> more buses for pay back!

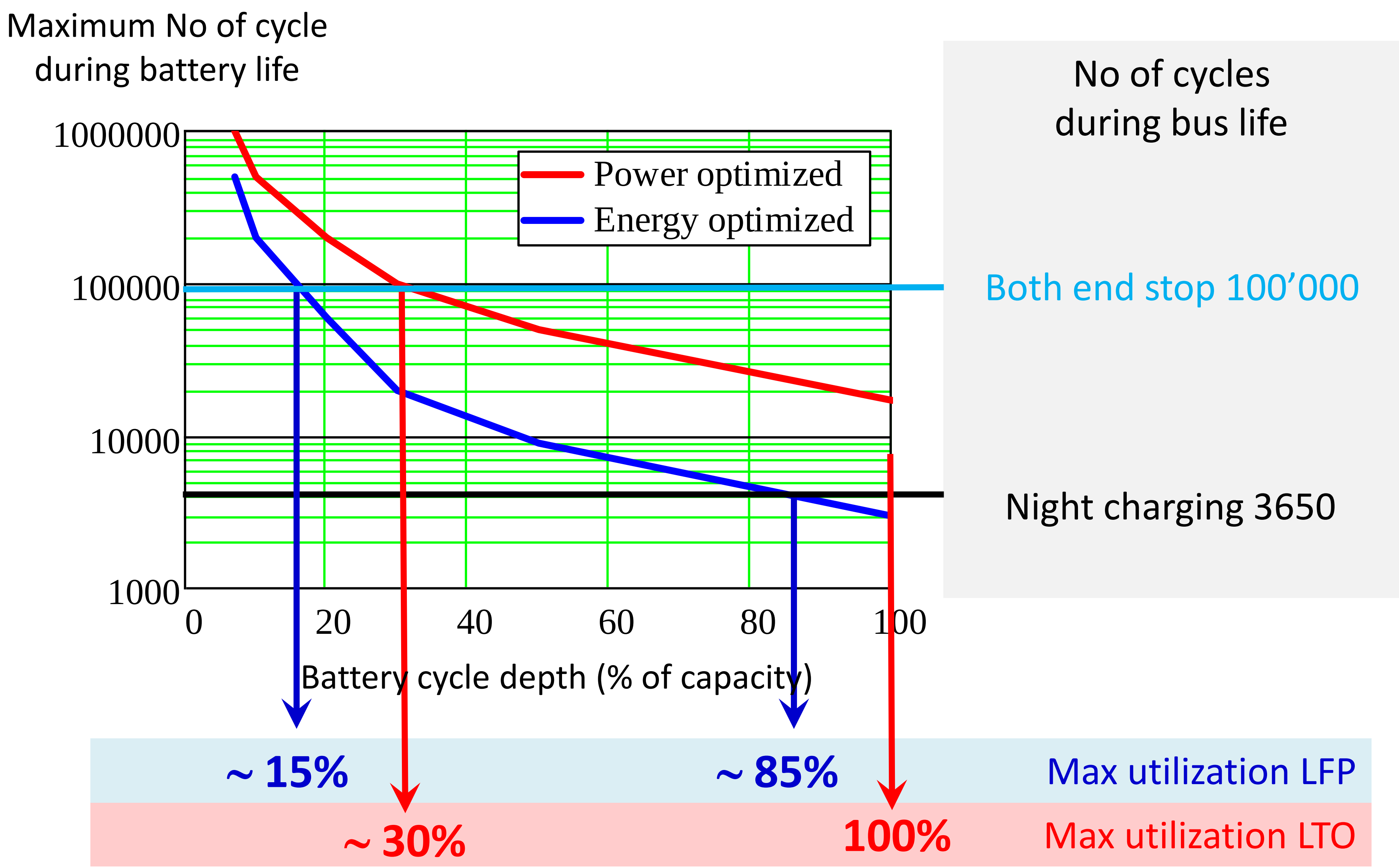
Poor payback on chargers
for normal bus stops

Why so much margin in the battery sizing?

Battery size depends on several requirements:

- Largest energy cycle
  - Normal cycle + missed charging + loss of capacity +…
- Peak power:
  - Charging +200 to +600 kW (?)
  - Acceleration -200 kW, deceleration +200 kW
- No of Cycles

Max battery cycle depth for different charging



Why so much margin in the battery sizing?

Battery size depends on several requirements:

- Largest energy cycle
  - Normal cycle + missed charging + loss of capacity +…
- Peak power
  - Charging +200 to +600 kW (?)
  - Acceleration -200 kW, deceleration +200 kW
- No of Cycles
  - use 15-30 % for end stop charging
  - use 55-100 % for night charging

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Continued research:
Systems of bus lines – Improve method – Charge when driving – …

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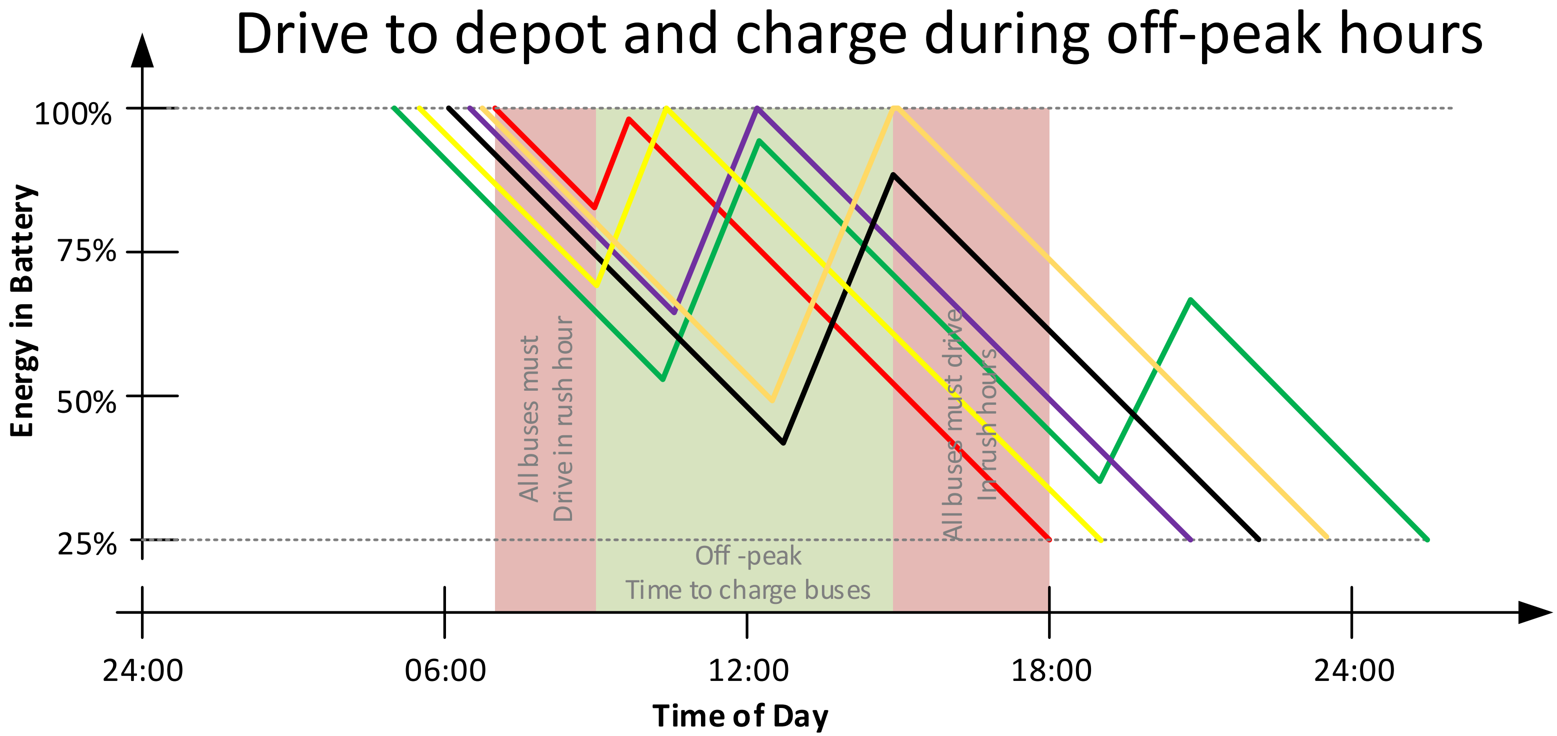
Night charging and charging off-peak



Buses charge before using 50% of energy ⇒ Battery reduced ~30 %

Only ~30% of buses can charge at same time ⇒ may req. extra bus

Bus scheduling necessary in system analysis!