Battery Storage Systems - Group Project Presentation

Full electric small transporter vehicle

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Application Analysis

- **Problem Statement :**
  - Full electric small transporter with a daily mileage of approximately 70 km and a machine with 40kW motor power.

- **Assumed Application :**
  - Courier delivery vehicle for E-Commerce / Parcel services (Amazon, DHL etc.)
  - Goods transport vehicle between Manufacturing companies

- **Application Requirements :**
  - Fixed operating time (7 am to 7 pm)
  - Most of the times daily mileage of 70km would be reached
  - Vehicle will have a minimum of 50 % load

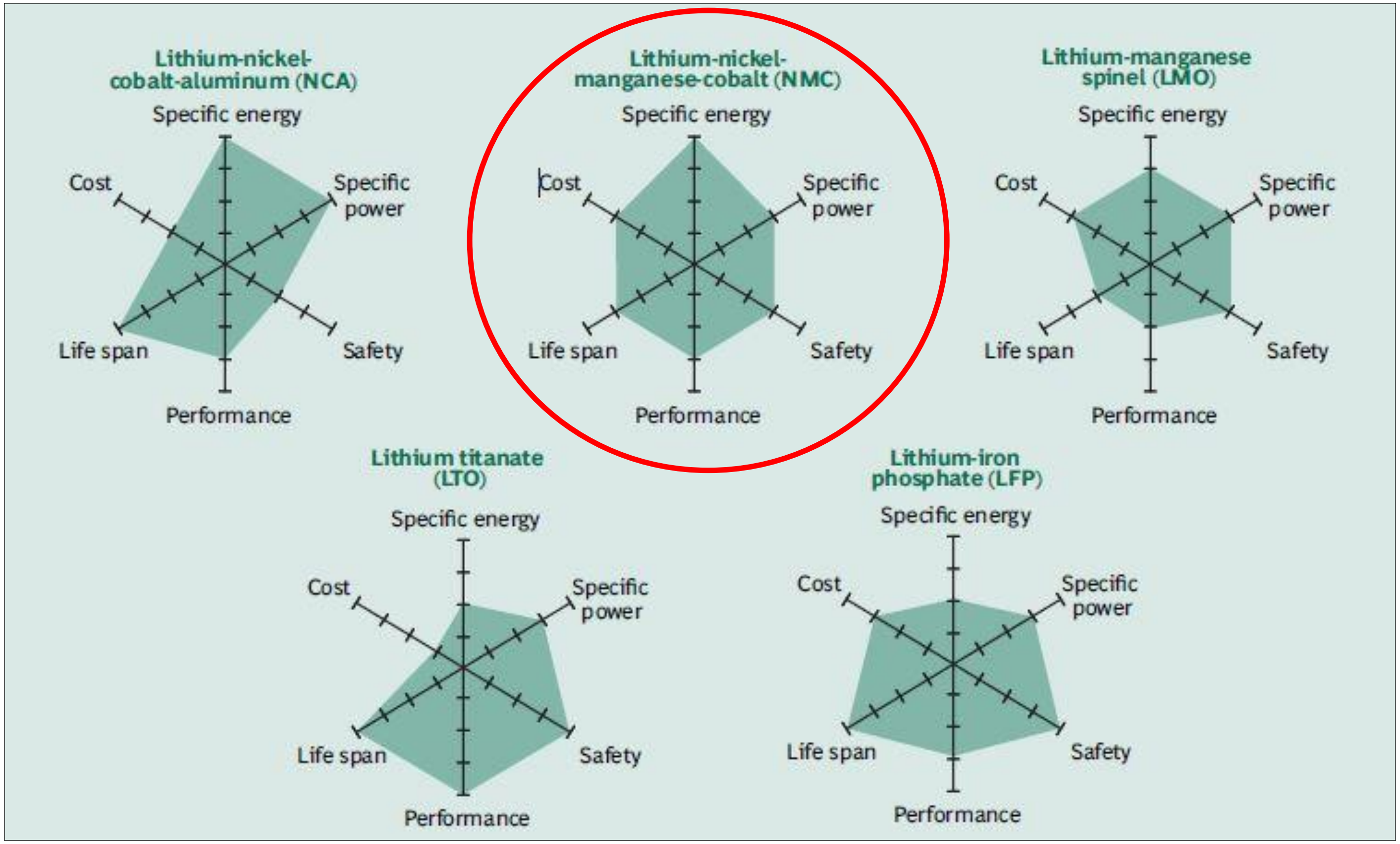
Storage System Selection

PUGH Matrix

Parameters	Super-capacitors	Fuel Cells	Battery
Specific Energy	-1	1	0
Specific Power	1	1	1
Technology	-1	0	1
Initial Cost	0	-1	1
Market Availability	0	-1	1
Running Cost	1	-1	1
Energy Efficiency	1	-1	0
Safety	0	-1	1
Life Time	1	0	-1
No. of positives (+)	4	2	6
No. of negatives (-)	2	5	1
Total	**2**	**-3**	**5**

Pugh Matrix clearly shows "Battery Technology" is the optimum solution

Li-ion cell chemistry selection



- Chosen Battery : **Li-ion** - High energy density and technology proven for this application
- Chosen Chemistry : **Li-ion NMC** - High Specific Energy and Power

Capacity Estimation

Parameters	Value
Average Energy Consumption	200 Wh/km
Daily Mileage	70 km
Minimum Storage Capacity	14 kWh
Power loss in Motor (η-95%) and Inverter (η-98%)	~ 7 %
Power for BMS, cooling and other electrical and electronics components	~ 3 %
Assumed Depth of Discharge (DOD)	80 %
Required Storage Capacity	**~ 20 kWh**

Model : Streetscooter WORK

- The assumed vehicle and its specifications closely matches with Screetscooter WORK

Cell Type

- Cell Name : **Sanyo NCR18650GA**
  - Why Cylindrical Cell ? - Proven cell-type for EV and easily procureable
  - Why NCR18650GA ? - High Energy density and power drain capability
  - Why Sanyo ? - High Capacity at high C-rates [1]

Parameters	Values
Nominal Capacity	3300 mAh
Capacity (Min / Typ)	3350 / 3450 mAh
Nominal Voltage	3.6 V
Weight	48 g
Charging time	4.5 hrs @ 1475mA
Energy Density Gravimetric : Volumetric :	 224 Wh/kg 693 Wh/l

Source : www.amazon.in

Battery Dimensioning

- Number of Cells :
  - Energy per cell = Voltage x Nominal Capacity = 11.88 Wh
  - No. of cells = Battery Capacity / Energy per cell = **1620 cells**

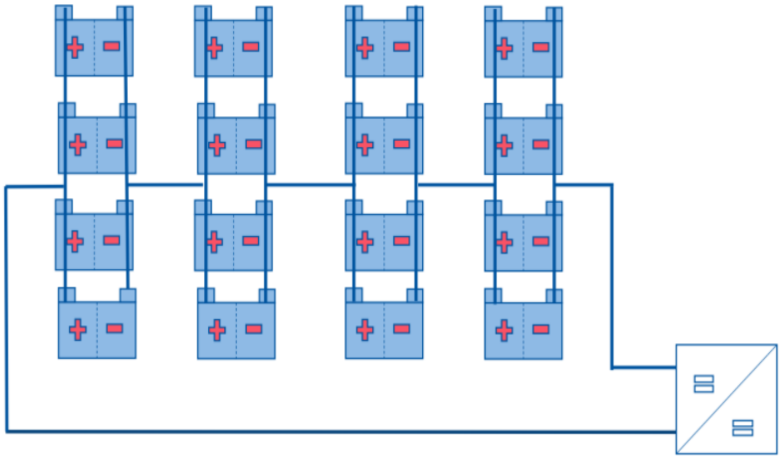
- Total Weight of Cells:
  - Total weight of cells = No. of cells x Weight per cell = **88 kg**

- Total Volume of Cells:
  - Cell dimensions (Height x Diameter) : 65.3 mm x 18.5 mm
  - Total volume of cells = No. of cells x Volume per cell = **0.0284 m^3**

Cell Connection – Parallel Connection on cell level

- From the previous calculation, the total number of cells required = 1620 cells
- To achieve a battery pack voltage of ~400 V, the number of cells that needs to be connected in series is 400/3.6 = ~112 cells
- Battery Pack voltage = 112 * 3.6 = 403.2 V
- Capacity of the pack = 3.3 Ah * 15 = 49.5 Ah
- Maximum Power of 40kW delivered at C_{rate} = 40k / (403.2 * 49.5) ~ 2.0C

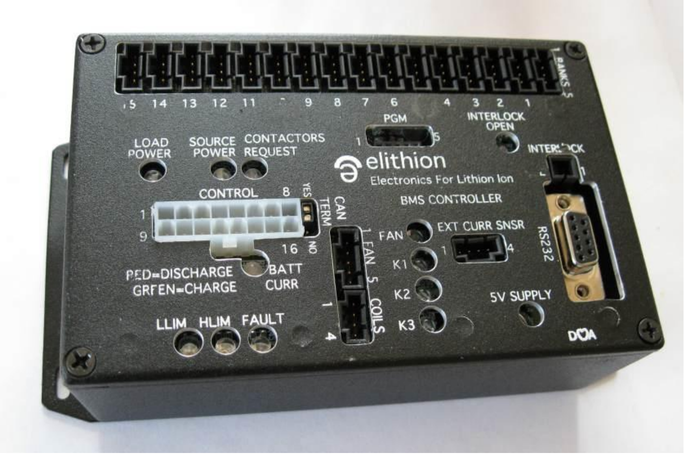
- High Redundancy
- Low BMS Effort
- It consists of 15 cells connected in parallel and 112 such units connected in series.



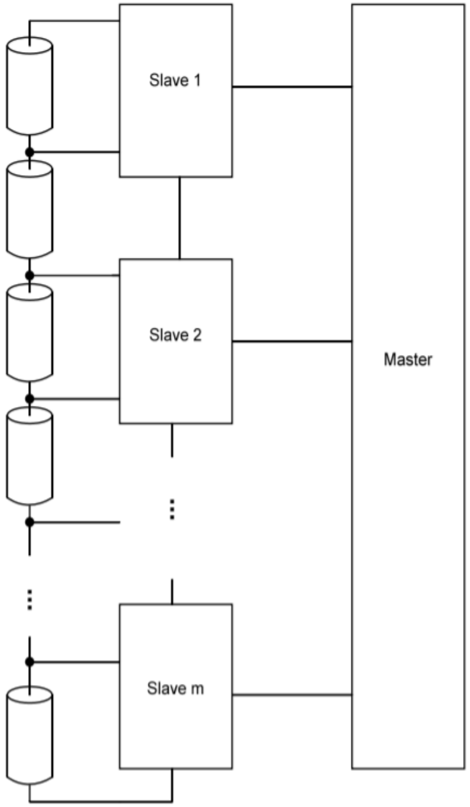
Parallel Connection on cell level

Battery Management System

- Master Slave Configuration
- Slave measures the voltage, temperature of parallel connected blocks
- Slave relays the information to the Master module
- Communication via CAN Bus
- Advantage: Doesn’t require PCB for individual cells
- Cell balancing system used is Passive Controlled



Elithion Battery Management System
(Source: http://elithion.com/lithiumate.php)

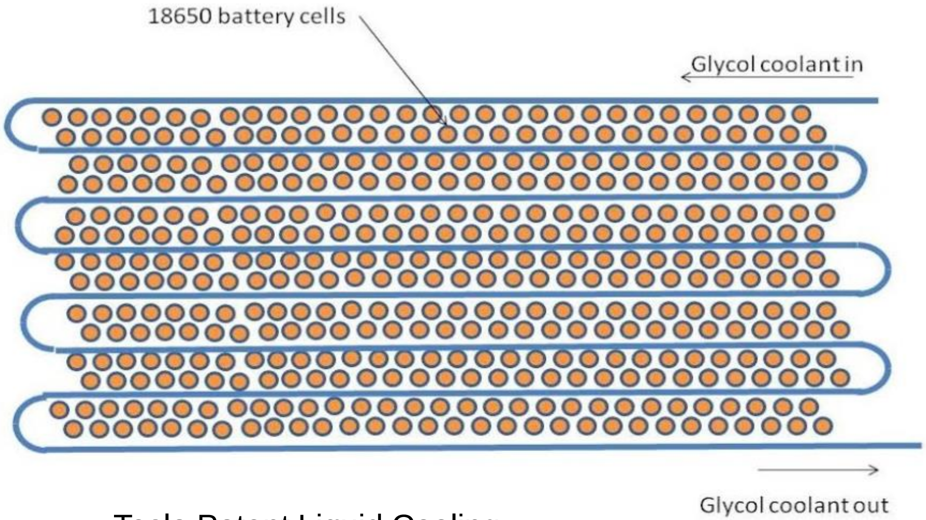


Master-Slave Configuration
(Source: http://robotics.ee.uwa.edu.au/theses/2013-REV-BMS-Scherer.pdf)

Thermal Management System (1/2)

- Battery overheats due to internal short circuit, Overcharging, external heat source
- Cooling necessary for homogenous temperature distribution and avoiding thermal runaway/explosion
- At Low temperatures (Winter climate), the batteries are at a risk of Lithium Plating and hence needs to be heated

- For our application, Liquid Cooling System is chosen
- Liquid Glycol used as coolant
- Simple design



Tesla Patent Liquid Cooling
(Source: https://insideevs.com/tesla-or-gm-who-has-the-best-battery-thermal-management-bower/)

Thermal Management System (2/2)

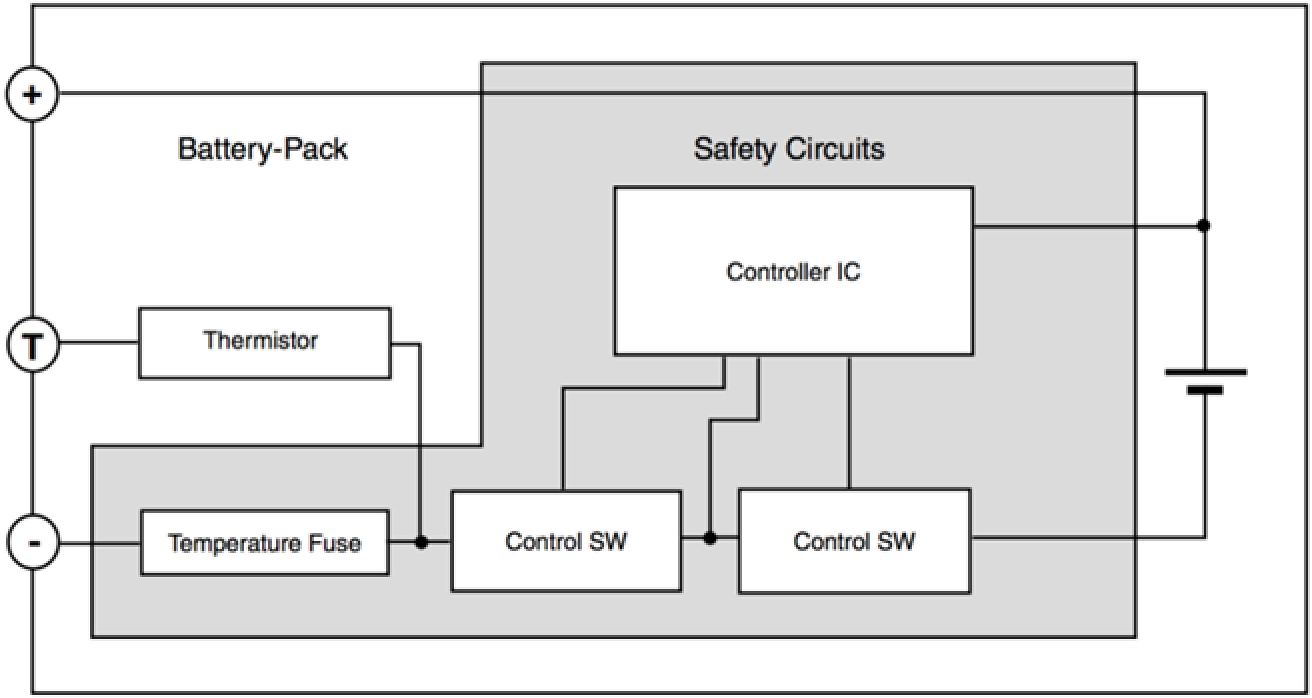
- At low temperatures, the internal resistance of the battery increases
- Heating can be done by passing high frequency AC current
- This method directly heats up the cell and hence more efficient
- The AC source can be taken from the charging station
- Produces uniform heat distribution

Heating of cells by high frequency AC current
(Source: Yan Ji, Chao Yang Wang, “Heating strategies for Li-Ion batteries operated from subzero temperatures”)

Safety

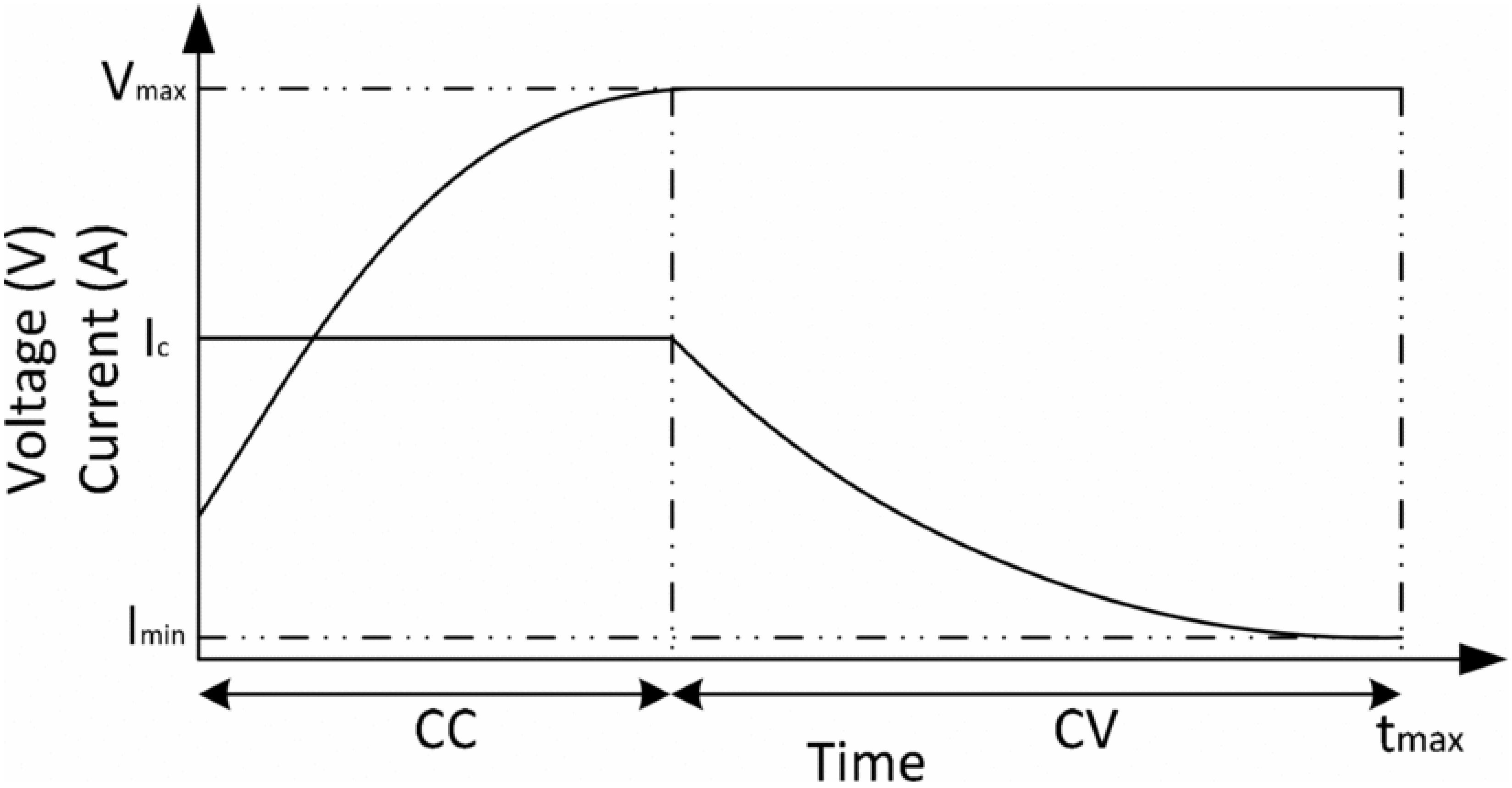
- 18650 cells are intrinsically safe

- Safety Electric circuits (embedded in the BMS)



Safety Circuitry
(Source: Panasonic)

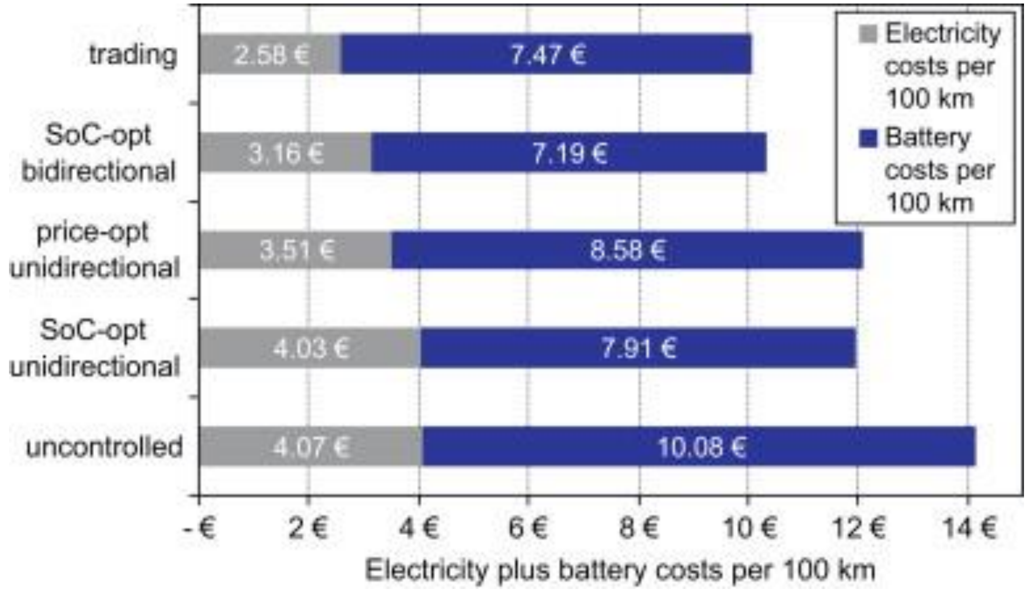
Charging Strategy



- Constant Current-Constant Voltage (CC-CV) charging.
  - CC with 0.6 C-rate, then CV

Operational Management Strategy

- SoC-Optimal Bidirectional or Unidirectional Charging?
  - Trade off between battery aging and charging cost reducing.
- A simulation study by Benedikt Lunz[2] from PGS, RWTH shows that SoC-Optimal Bidirectional charging is more profitable, considering battery aging as additional battery cost.



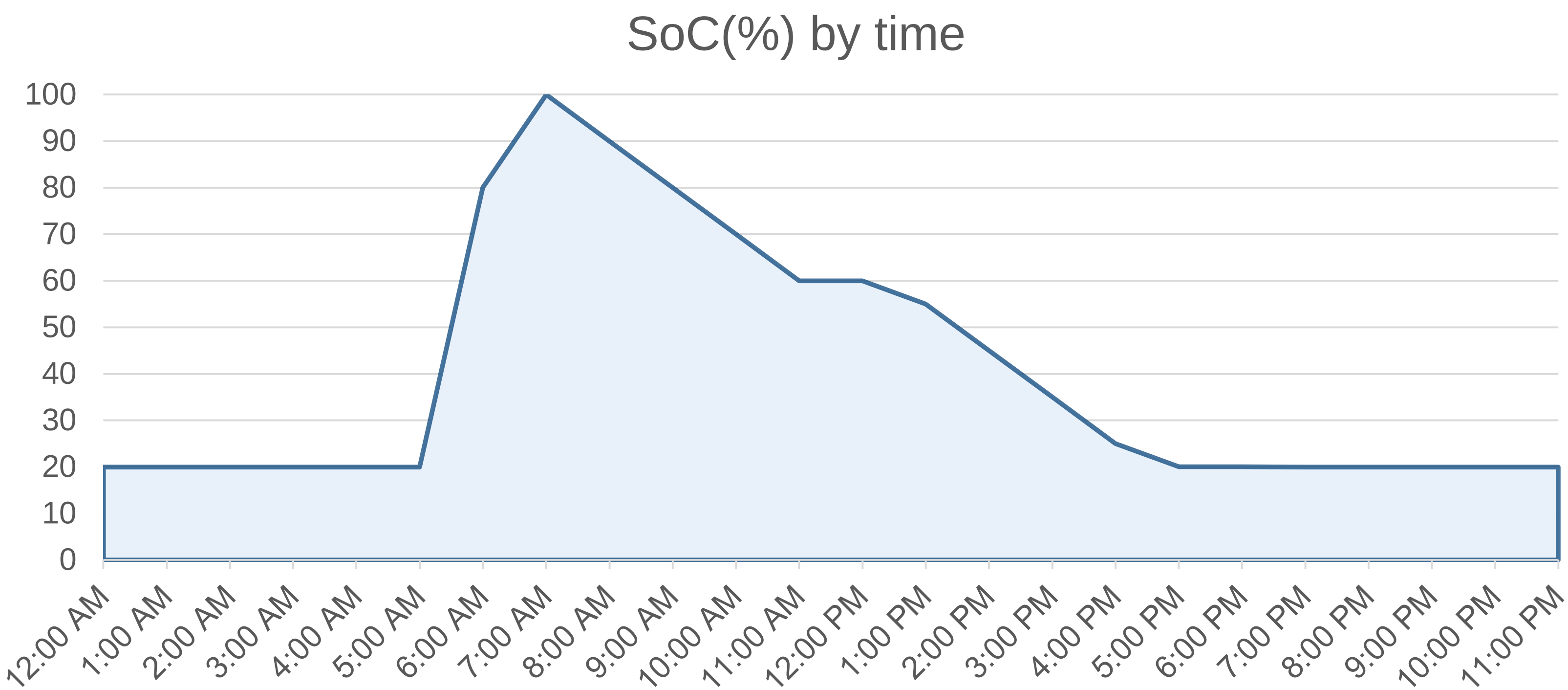
Quelle: B. Lunz et al, "Influence of plug-in hybrid electric vehicle charging strategies on charging and battery degradation costs," Energy Policy, 2012.

Operational Management Strategy

- SoC-Optimal Bidirectional Charging
  - Vehicle to Grid (V2G)
    - Electricity trading under restricted SoC
    - Frequency regulation [3]
  - Deciding when to do Electricity Trading and when to frequency modulation[4]
- Considering the simulation studies may not fully applicable to our scenario, user can decide whether Unidirectional or Bidirectional charging

	Profitability	Risk of increasing cost
Bidirectional	yes	exist
Unidirectional	no	no

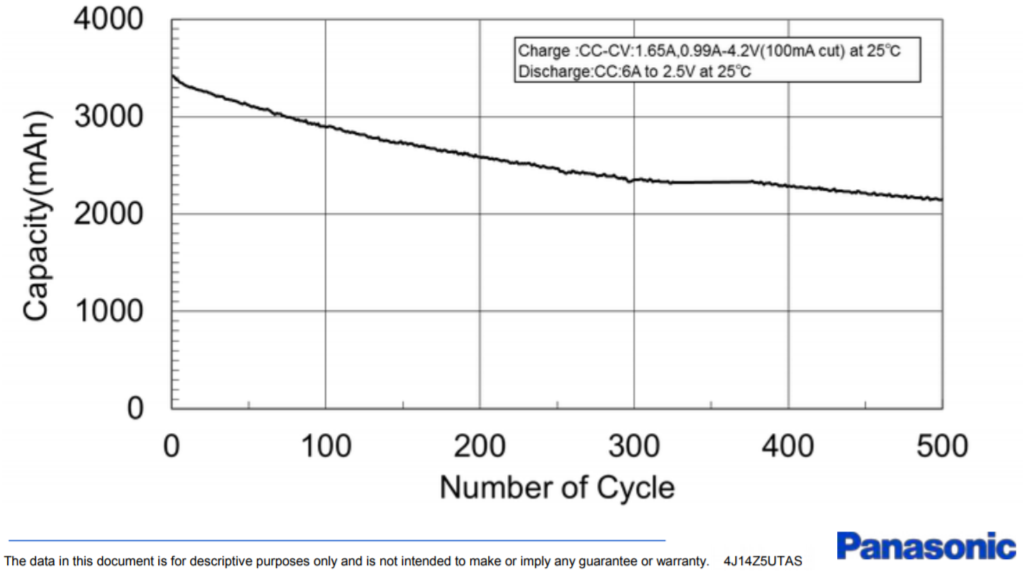
Operational Management Strategy



- In SoC-Optimal Unidirectional Charging, we start charging the battery 2 hours before departure.
  - CC-CV charging strategy[5]

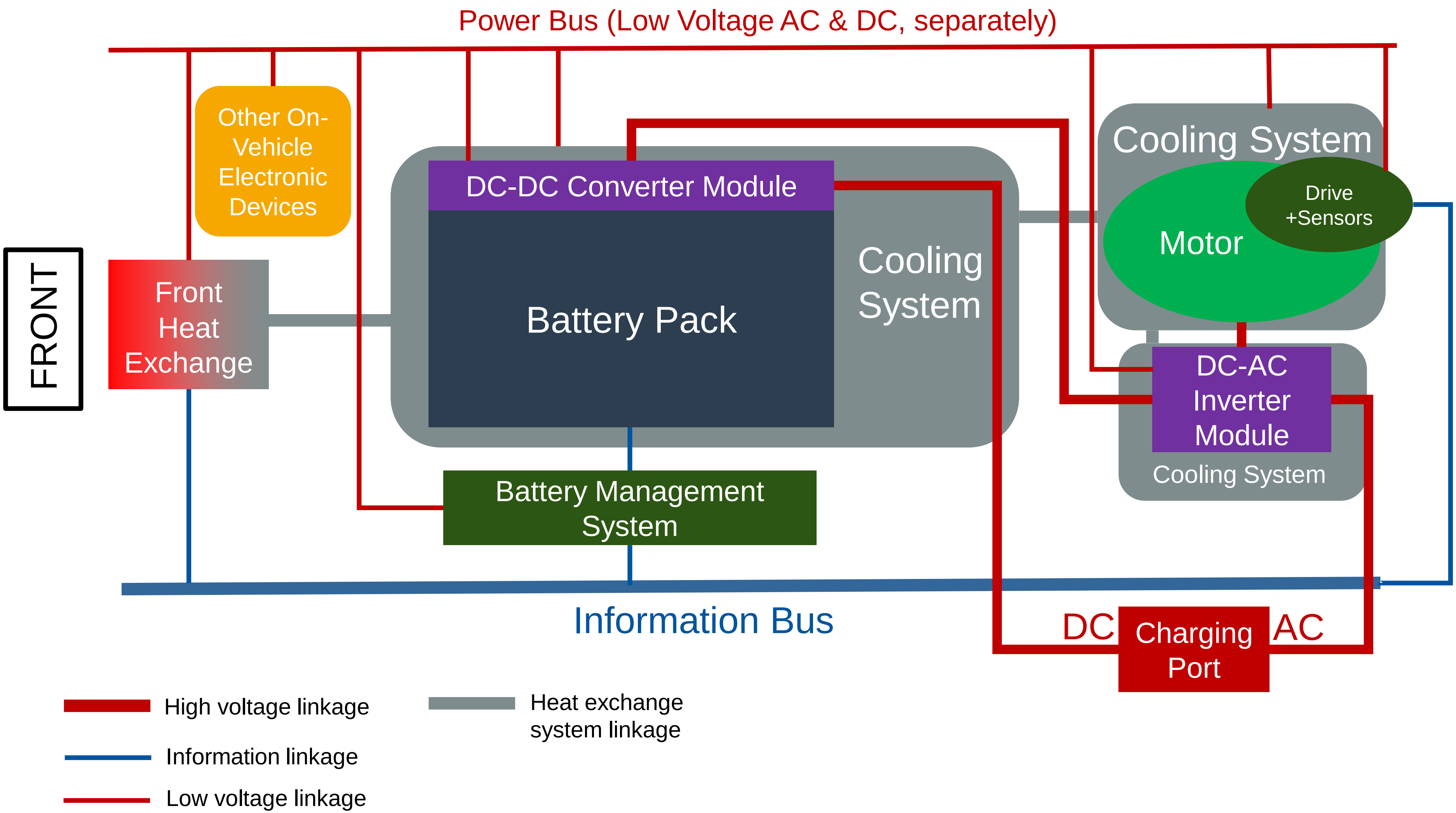
Lifetime Analysis

- Number of full cycles in a year: $80\% \ (DoD) \times 250 = 200 \ cycles/year$
- Cycle-Capacity relationship



- Panasonic provides this relationship with ~1.8 C-rate discharge, whereas our vehicle discharges with ~0.2 C-rate, therefore we consider a factor of 9 to transform these two types of cycles.
- Estimated 20% loss of capacity: 350 cycles (with ~1.8 C-rate discharge)
- End-of-lifetime estimation: $\frac{350}{200} \times 9 = 15.75$ years

Schematic View



Economic Analysis

Parameters	Cost
No of battery cell	1620
Per unit battery cell price	€ 3.55 [6]
Total cell price including shipping cost	€ 5757.52 [6]
40 KW motor with power electronic drive	€ 5900 [7]
Battery management system cost	€ 121 [8]
Charging station cost	€ 300 [8]

Comparison between Electric and Diesel Transporter

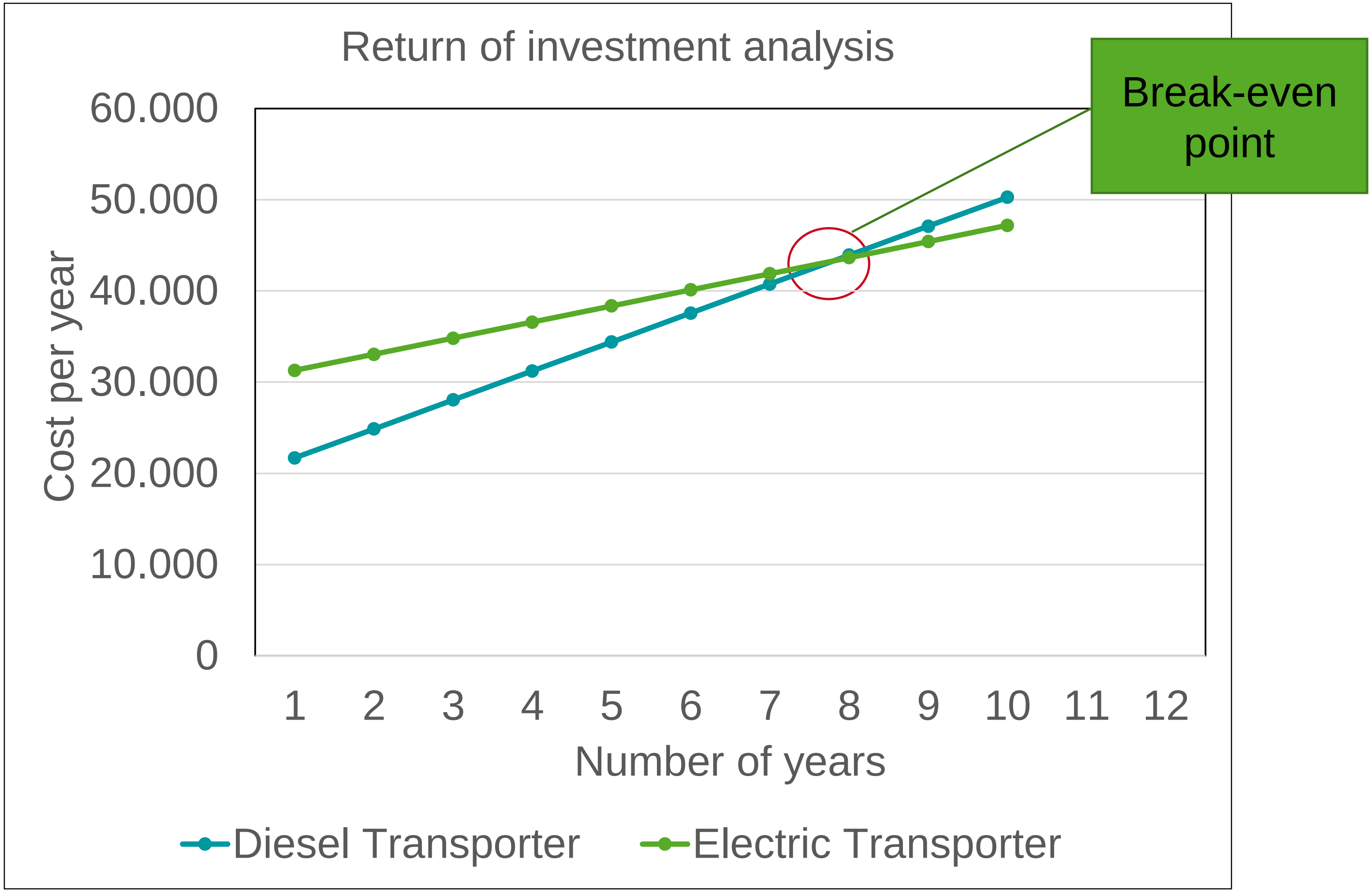
Parameter	Diesel Transporter	Electric Transporter
Cost of ownership	€ 20215 [9]	€ 38020 [10]
Cost after subsidiary	€ 20215	€ 38020 - € 8500 = € 29520 [10] [11]
Considering lifetime of 10 year, cost per year	€ 2021.5	€ 2952
Per km efficiency of a diesel transporter	15 Km/L [12]	-
Energy cost	1.237 €/L [14]	0.27 €/KWh [11]
Operating cost per day	(70 Km/Day) × (0.067 L/Km) × (1.24 €/L) = € 5.8	Considering 80% DOD: (16 KWh) × (0.27 €/KWh) = € 4.3
Operating cost per year	€ 2112	€ 1588
Annual Maintenance (%)	(35 [13] + 10) = 45 %	10 %
Total Annual Operating cost	€ 3062	€ 1747

Profitability

		Diesel Trans. (€)	Electric Trans. (€)	Savings (€)
	Initial Cost	20215	29520	
	Annual running Cost	3062	1747	
Year	1	23277	31267	-7990
	2	26339	33014	-6675
	3	29401	34761	-5360
	4	32463	36508	-4045
	5	35525	38255	-2730
	6	38587	40002	-1415
	7	41649	41749	-100
	8	44711	43496	1215
	9	47773	45243	2530
	10	50835	46990	3845

Break even point

Return of Investment Analysis



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Thank you all

Questions?

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