Impact of Smart Charging on the Reliability of Charging Infrastructure

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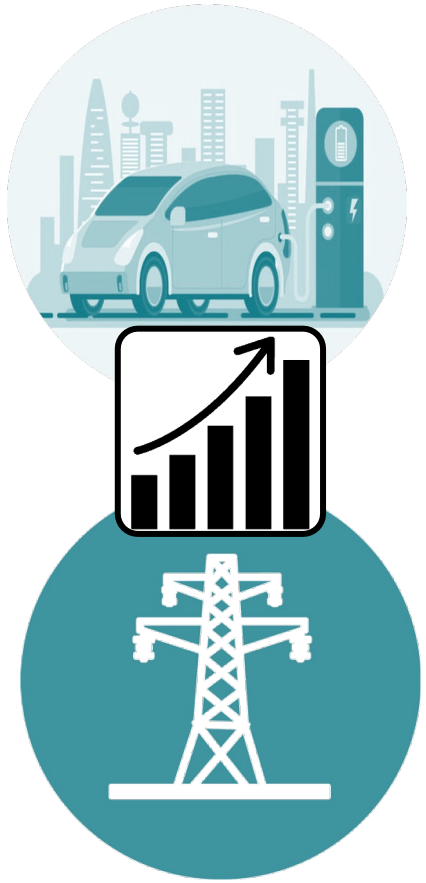
Introduction



Smart charging

Cost reduction

Load shaving

Charger lifetime

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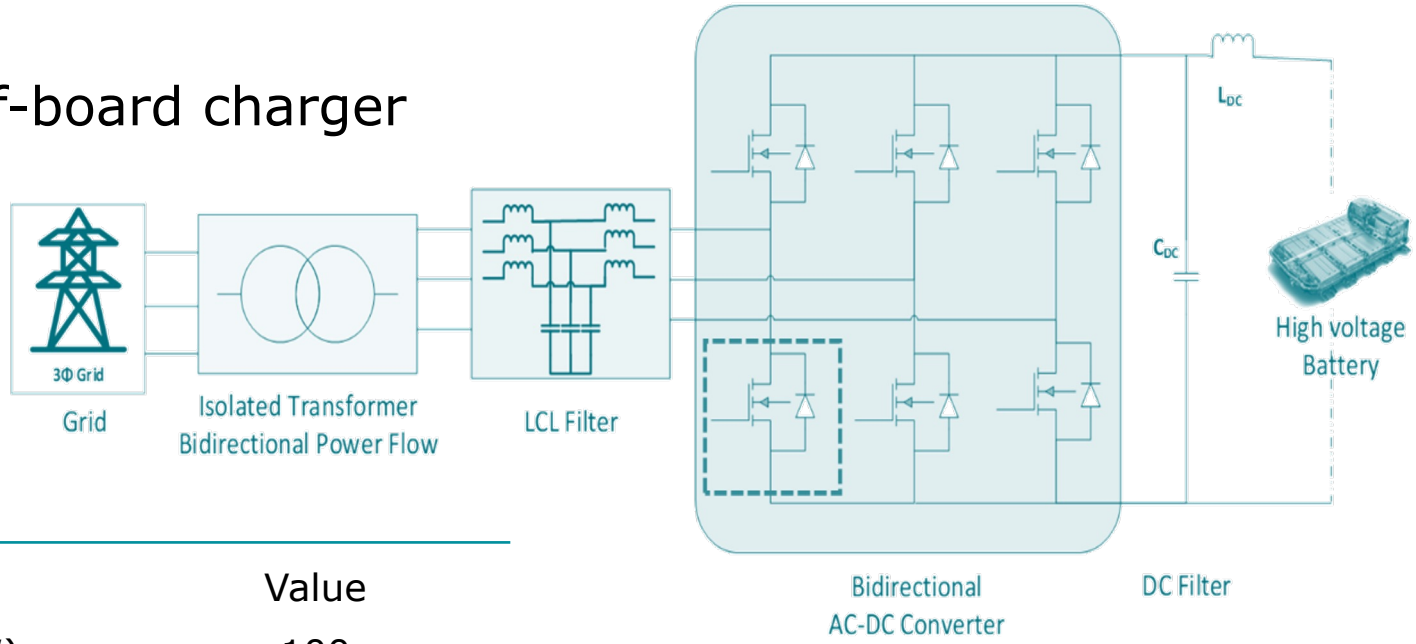
System architecture

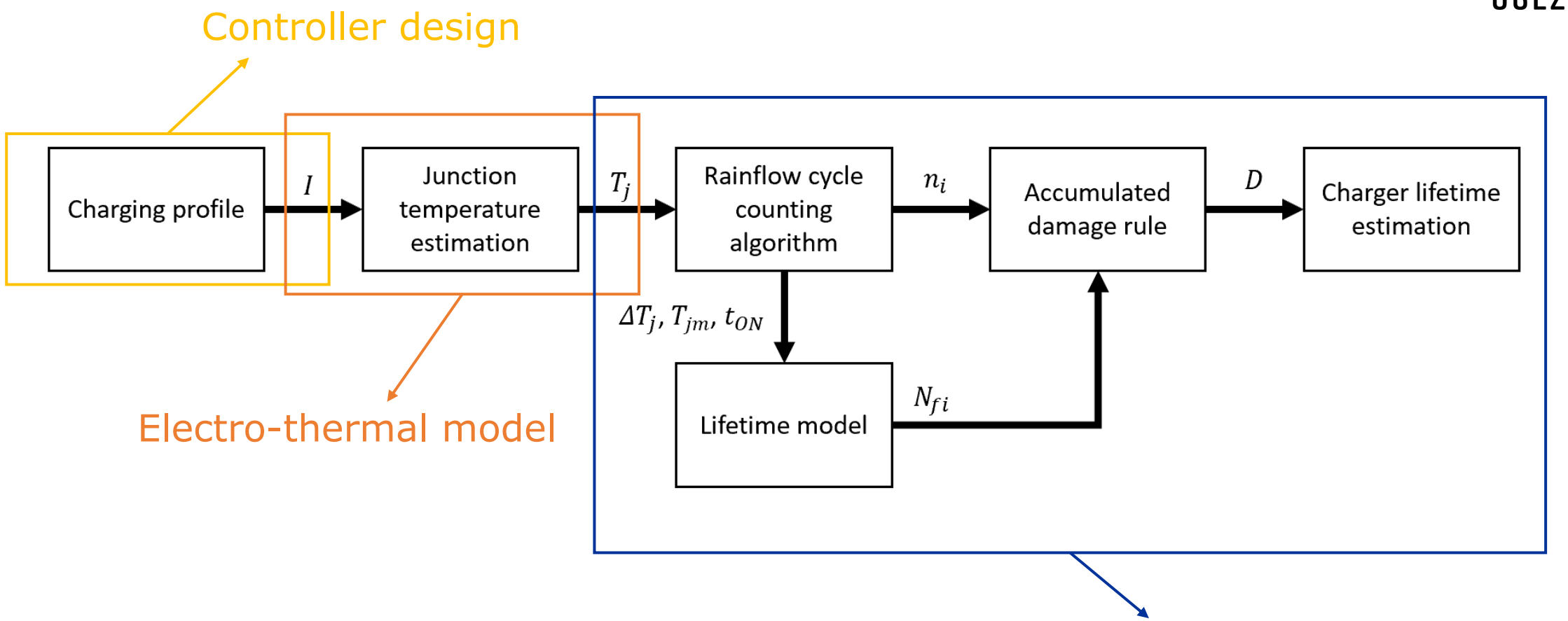
High-power off-board charger



Parameter	Value
Maximum power (kW)	100
Switching frequency (kHz)	40
AC voltage (V)	400
DC bus voltage (V)	750
Power Electronic Module	SiC half bridge module

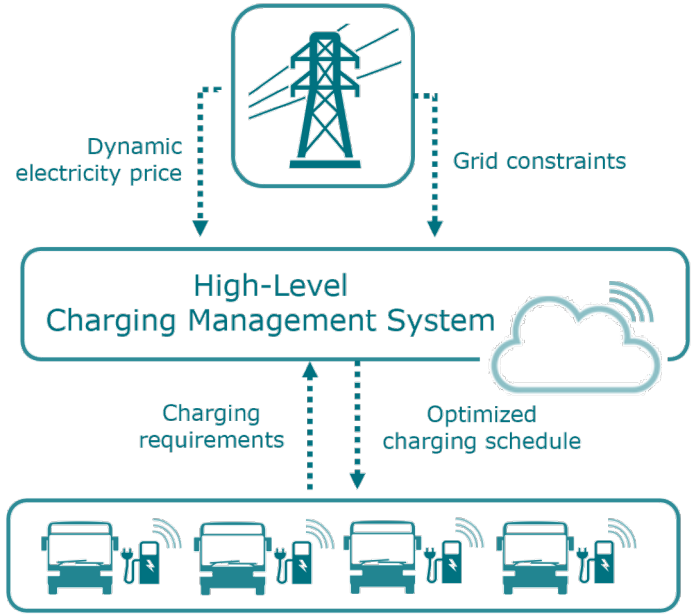
Exposed to repetitive thermal stress
- Temperature swings
- Load power variations

Methodology

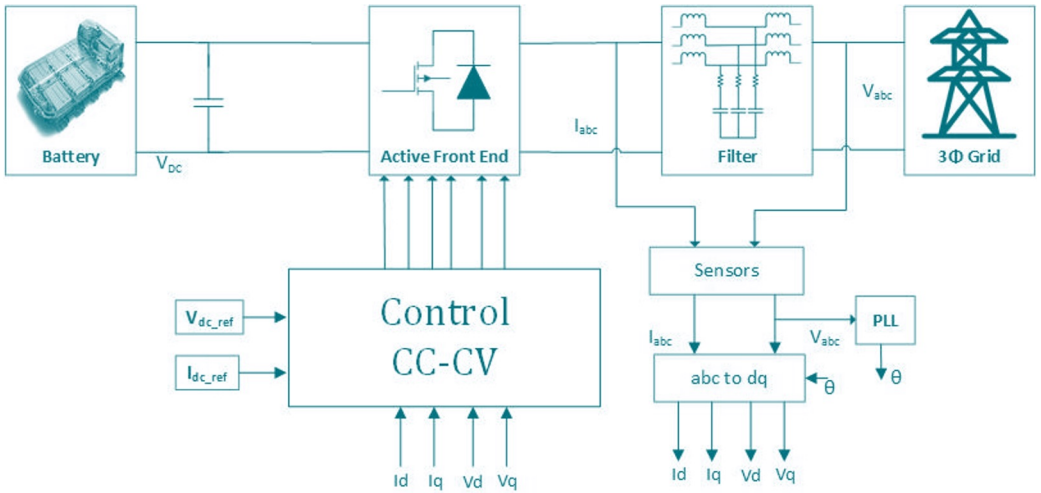


Controller design

High-level charging management



Low-level control



Electro-thermal model

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Universal semiconductor loss model

Conduction losses: $P_{cond} = \underbrace{V_d(I, T_j)}_{\text{Voltage drop}} \cdot I$

Switching losses: $P_{sw} = P_{sw,on} + P_{sw,off} \approx f_{sw} \cdot \underbrace{\left(E_{sw,on}(I, V, T_j) + E_{sw,off}(I, V, T_{si})\right)}_{\text{Energy losses}}$

Thermal model

Junction temperature: $T_j = T_a + \Delta T_{sa} + \Delta T_{js}$

(s = heatsink; a = ambient)

$\Delta T_{sa} = \underbrace{Z_{th(sa)}}_{\text{Thermal resistance}} \cdot \sum P_n$

$\Delta T_{js} = \underbrace{P_n}_{P_{cond} + P_{sw} \text{ for n}^{th} \text{ MOSFET}} \cdot Z_{th(js)n}$

Reliability assessment

Modified rainflow cycle counting algorithm: ΔT_j, t_{ON}, T_{jm}, n_i

Temperature swing, pulse duration, mean junction temperature, number of cycles

Lifetime model (number of cycles to failure)

$$N_f = A \cdot (\Delta T_j)^{\alpha} \cdot (ar)^{\beta_1 \Delta T_j + \beta_0} \cdot \left[\frac{C + (t_{ON})^{\gamma}}{C+1}\right] \cdot e^{\left(\frac{E_a}{k_b \times T_{jm}}\right)} \cdot f_{diode}$$

Miner linear damage rule

$$D = \sum_{i=1}^{k} \frac{n_i}{N_{fi}}$$

Thermal stress levels

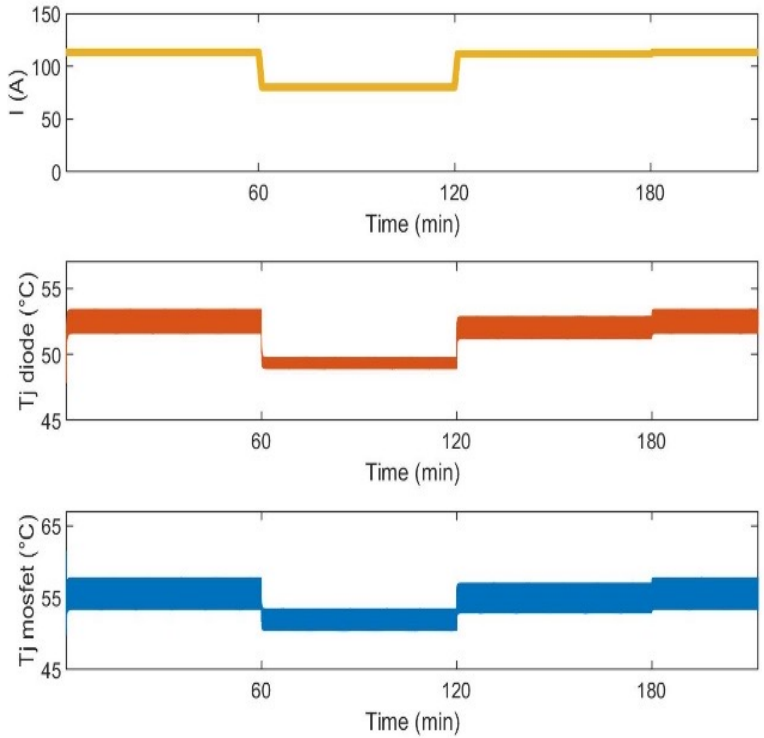
Total system-level reliability

$$R_{charger} = D_{MOSFET}^{6} \cdot D_{Diode}^{6}$$

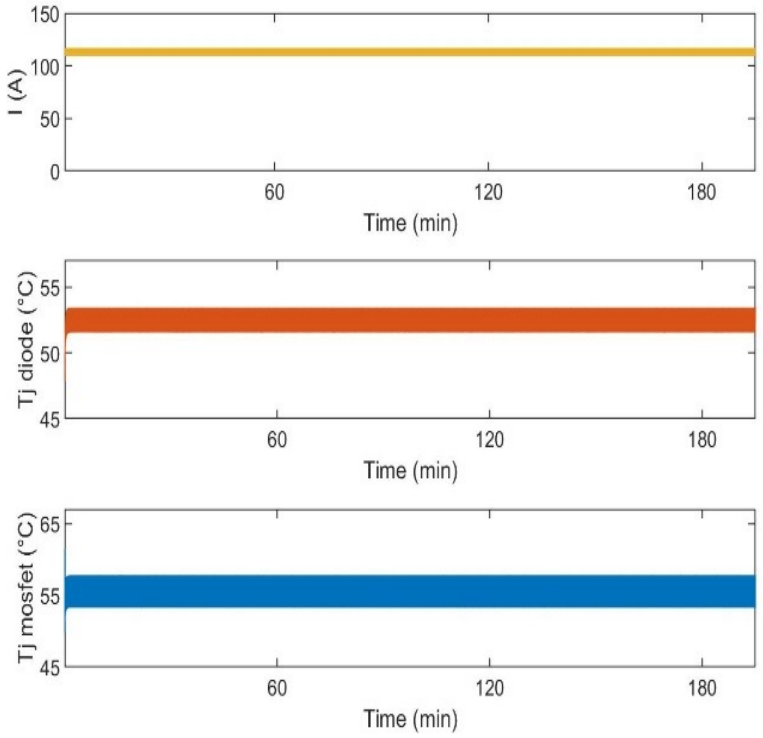
Results

Charging profiles and the corresponding junction temperature profiles

Smart charging



Conventional charging



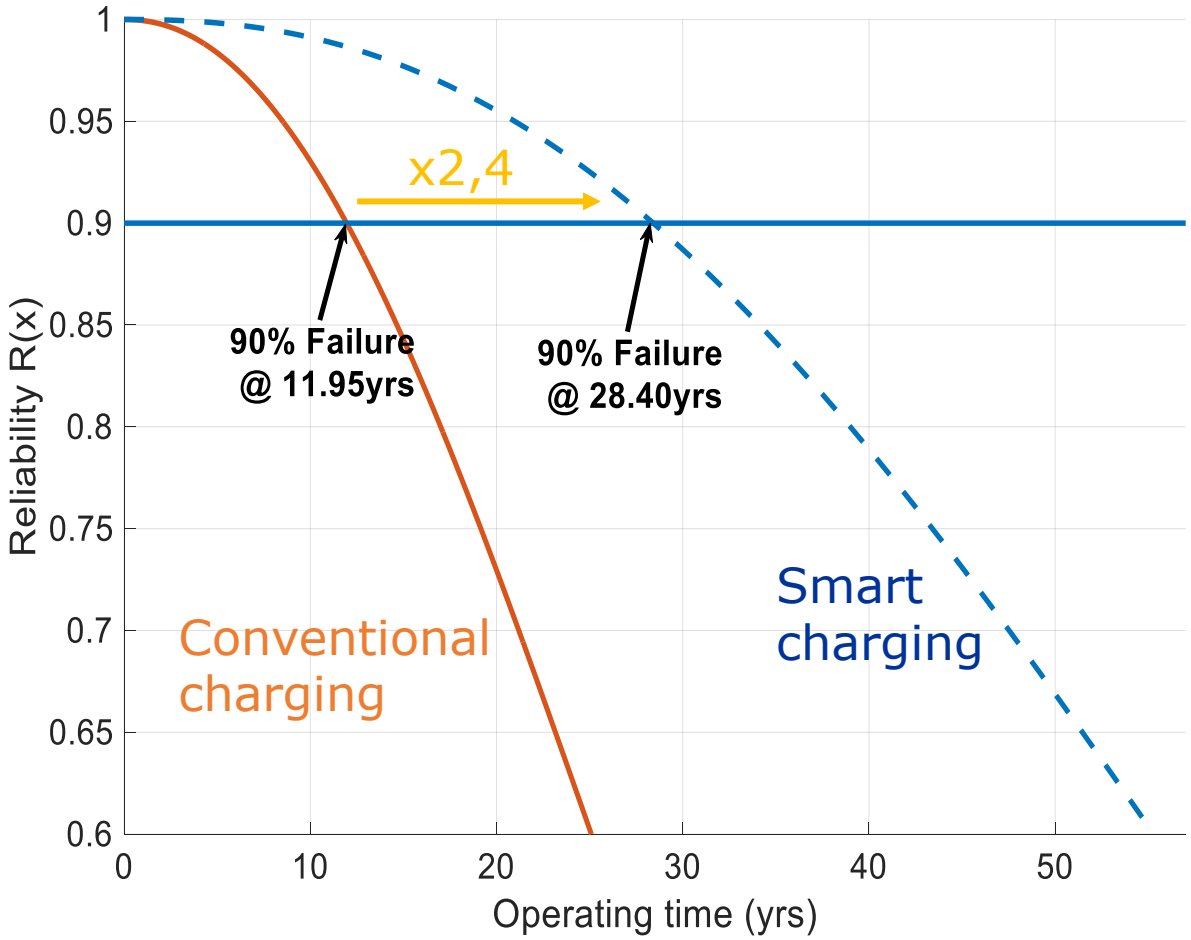
Current (~ 110 A)

T_j diode (~ 52 °C)

T_j MOSFET (~ 56 °C)

Results

System-level reliability percentile R90



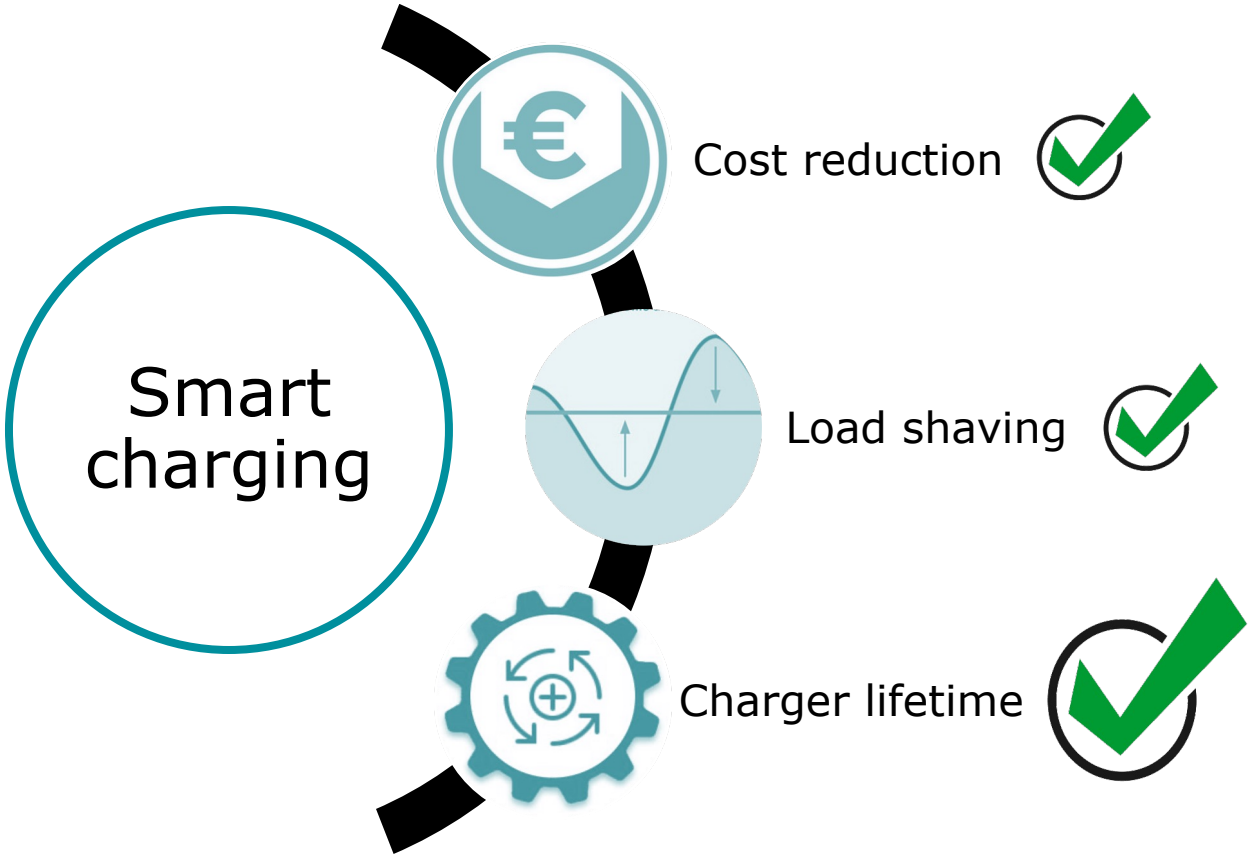
Conclusions

Reliability comparison between smart and conventional charging

Electro-thermal model to estimate T_j from a charging profile

Reliability assessment of semiconductors to predict the lifetime of the charger

Results show an improvement of the lifetime with a factor 2.4



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