Cohyb – Customized Hybrid Powertrains

Technical meeting

- Battery management CLEVER
- Reliability prediction
- Proposed tests
- Cell tester
- Battery tester

EMPA Reliability Center
Marcel Held

EMPA Materials Science & Technology

ccem.ch

LAV

Institute for Dynamic Systems and Control
IDSC
Institut für Dynamische Systeme und Regelungstechnik

swisselectric research

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Bundesamt für Energie BFE

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

sa swissauto WENKO AG

Battery Management CLEVER

Main components

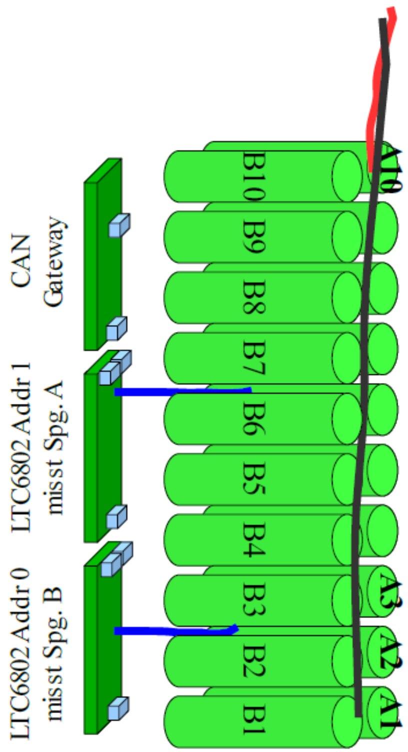
2 Battery boxes

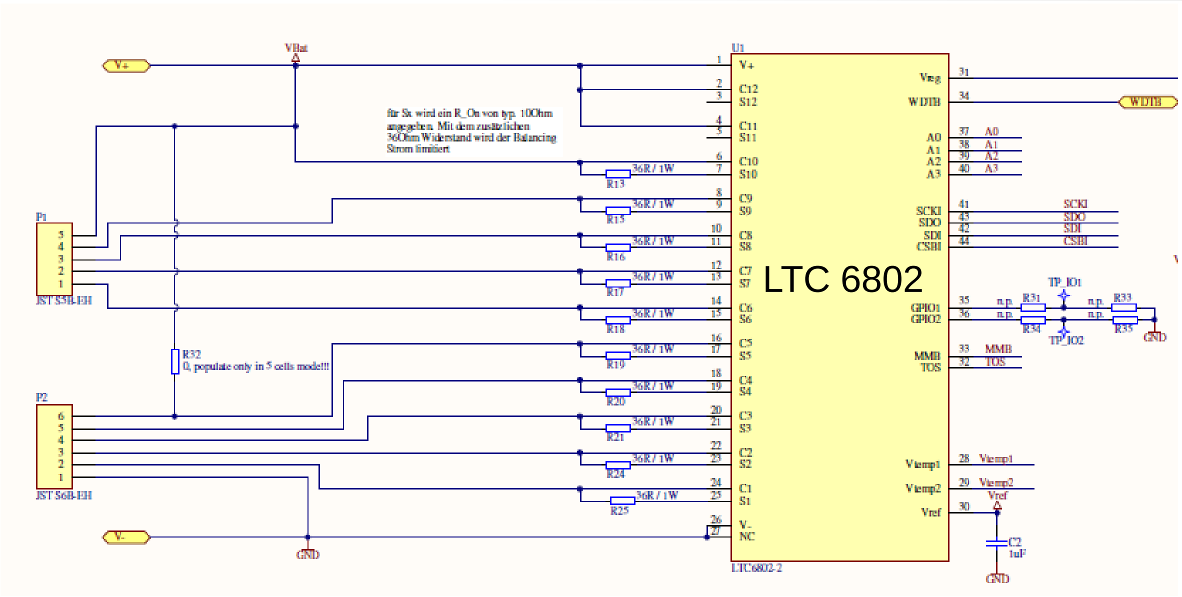
- Cells BMZ18650 BTC1, cylindrical, 3.7V, 1.32Ah @ 0.2C,
- Pakets 2 *10 Cells in Serie (10S2P), 37V, 2.64h, 20 Cells
- Groups 5 Pakets parallel, 37V, 13.2 Ah, 100 Cells
- Box right 4 Groups in series, 148V, 13.2 Ah, 400 Cells
- Box left 5 Groups in series, 185V, 13.2 Ah, 500 Cells
- Total 333V, 13.2Ah ~4.4 kWh, 900 Cells

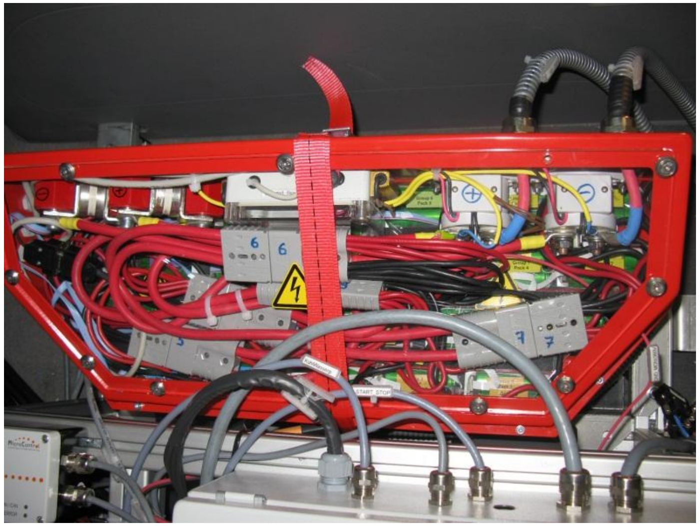
Per Paket two Battery Stack Monitors LTC 6802, measuring 20 Cells, total 90 LTC 6802, Total 900 Cells
Per Group one CAN Gateway, total 9 CAN Gateways

Transmission and processing of data with CAN Gateways / Microcontroller AT90CAN32 + MATLAB Simulink Software / MicroAutoBox

Battery Management CLEVER







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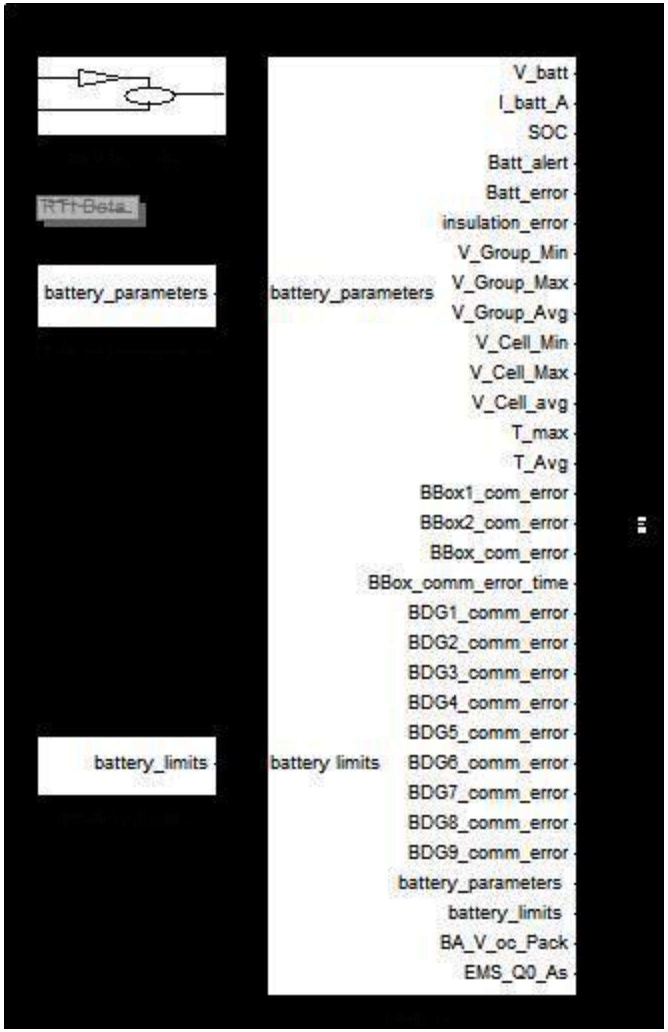
Battery Management CLEVER



Measured / calculated Battery Parameters

Paket Temperatures	90	Max Avg
Cell Voltages	900	Min Max Avg
Group Voltages	9	Min Max Avg
Battery Voltage	1	
Battery Current	1	
Battery Power	1	
Battery OC Voltage	1	
Battery SOC	1	
Comm. Error	12	
Isolation Error	1	

Battery Limits

Battery Temperature max.	60° C
Battery Temperature Alert	52° C
Battery Voltage max.	410V
Battery Voltage min.	300V
Cell Voltage max.	4.3V
Cell Voltage min.	3.4V
Current discharge max.	150A
Current charge max.	100A
SOC max.	1.1
SOC min.	0.2
Batt. Comm. Timeout max.	2s

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Failure rate prediction IEC TR 62380

$$\lambda = \left(\left(\lambda_1 \times \mathbf{N} \times \mathbf{e}^{-0.35\times\mathbf{a}} + \lambda_2\right) \times \left(\frac{\sum_{\mathbf{i}=1}^{\mathbf{y}} (\Pi_{\mathbf{t}})_{\mathbf{i}} \times \tau_{\mathbf{i}}}{\tau_{\mathbf{on}} + \tau_{\mathbf{off}}} \right) + \left(2.75 \times 10^{-3} \times \Pi_\alpha \times \left(\sum_{\mathbf{i}=1}^{\mathbf{z}} (\Pi_{\mathbf{n}})_{\mathbf{i}} \times (\Delta \mathbf{T_i})^{0.68} \right) \times \lambda_3 \right) + \{\Pi_{\mathbf{I}} \times \lambda_{\mathbf{EOS}}\} \right) \times 10^{-9} \ / \mathbf{h}$$

λ_1	Basisausfallrate pro Transistor der integrierten Schaltung, pro Familie, nach Tabelle
N	Anzahl Transistoren der integrierten Schaltung
a	Produktionsjahr minus 1998
λ_2	Ausfallrate bezogen auf Technologiebeherrschung, pro Familie, nach Tabelle
$(\pi_t)_i$	i-ter Temperaturfaktor bezogen auf die i-te Junctiontemperatur des Missionsprofils z.B für MOS/BiCMOS: $\pi_t = e^{(A(1/328-1/(Tj+273))}$, mit Tj= Junctiontemperatur, A=3480 (E_a=0.3eV)
τ_i	i-ter *Zeitanteil im Betrieb* des Missionsprofils
τ_{on}	totaler Zeitanteil im Betrieb. Mit $\tau_{on} = \sum \tau_i$
τ_{off}	Zeitanteil nicht im Betrieb. Mit $\tau_{on} + \tau_{off} = 1$
Π_α	Faktor bezogen auf die Differenz der Ausdehnungskoeffizienten von Komponentenmaterial α_C und Substrat α_S: $\Pi_\alpha = 0.06x(\lvert\alpha_S - \alpha_C\rvert)^{1.68}$
$(\pi_n)_i$	i-ter Einflussfaktor bezogen auf die jährliche Anzahl von Temperaturzyklen des Gehäuses, mit Amplitude ΔT_i. $(\pi_n)_i = n_i^{0.76}$ für $n_i \le 8760$
n_i	Jährliche Anzahl Zyklen mit Amplitude ΔT_i
ΔT_i	i-te Temperaturamplitude des Missionsprofils, $\Delta T_i = (\Delta T_J/3 + (T_{ac})_i) - (T_{ae})_i$
$(T_{ae})_i$	durchschnittliche Umgebungstemperatur ausserhalb des Gerätes, während der i-ten Phase des Missionsprofils
$(T_{ac})_i$	durchschnittliche Umgebungstemperatur auf der Leiterplatte in der Nähe der Komponenten, während der i-ten Phase des Missionsprofils
λ_3	Basisausfallrate des IC-Package, nach Tabelle
π_I	Faktor bezogen auf Anwendung (Interface oder nicht)
λ_{EOS}	Ausfallrate bezogen auf den elektrischen Überstress der Anwendung

Failure rate prediction IEC TR 62380

Paket Sensor Prints		
Component	**#**	Failure rate, predicted [FIT]
U1 LTC6802-2	1	211.9
D1 BAR43C	2	80.1
D2 BAV70	2	20.1
NTC1	1	2.6
R Balance	10	9.7
R22, R23	2	0.1
R	23	0.3
C1, C2	1	0.1
P1	1	6.7
P2	1	7.3
P3, P4, P5	3	58.8
Sum	**47**	**398**

Number of Battery Sensor Prints: 90

Total failure rate: 90 x 398 = 35820 FIT

Failure rate λ in FIT (Failure in Time)

1 FIT = 1 failure in 10^9 hours

Mean Time Between Failures MTBF = $1/\lambda$

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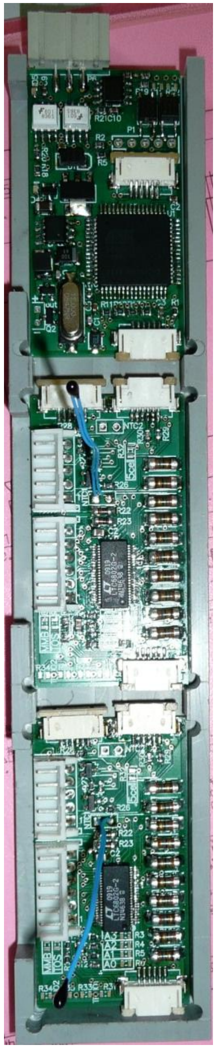
Failure rate prediction IEC TR 62380

CAN Gateway Prints		
Component	#	Failure rate, predicted [FIT]
U1 AT90CAN32	1	40.6
U2 LM2594HVM	1	41.3
U3, U7 PC357N1	2	82.1
U4, U6 HCPL-0601	2	82.1
U5 PCA82C250	1	46.9
X1 Quarz	1	5
Q1 IRLF9014	1	40.1
Q2 BCR108	1	40.0
D1 Z1SMA39	1	40.2
D2 BAV70	2	80.1
D3 BAR43C	1	40.8
D4, D5 HSMG-C190	2	64.3
L1 10microH	1	0.2
L2 330microH	1	0.2
C1-C6,C9-C11	9	0.5
C7 Tantal	1	0.3
R1-R22	22	0.3
P4, P5, P6	3	9.7
Sum	**52**	**615**



Number of CAN-Gateway Prints: 9

Total failure rate: 9 x 615 = 5535 FIT

Total failure rate of Battery Sensor Prints and CAN Gateway Prints: 41355 FIT

Car duty cycle ≈ 5% → 2068 FIT

MTBF = 55.2 years

Failure rate of Lithium-Ion cells

IEC TR 62380: Fixed failure rate of secondary Li-Ion cells: 150 FIT

"The estimated failure rate of lithium-ion batteries is one failure per 10 million manufactured"
Dr. Kerry Lanza, Marketing Manager
Palladium Energy

~ 0.1 ppm

"It is estimated that today's 18650 Li ion cells have an internal short failure rate of 1 in 5-10 million."
Pesaran et al. , Integration Issues of Cells into Battery Packs for Plug-In and Hybrid Electric Vehicles, *Conference Paper,* NREL/CP-540-45779, May 2009

~ 0.1 - 0.2 ppm

Failure rate of Lithium-Ion cells

Failure rate λ = 150 FIT → MTBF = 761 years

900 cells with 150 FIT → MTBF = 0.85 years

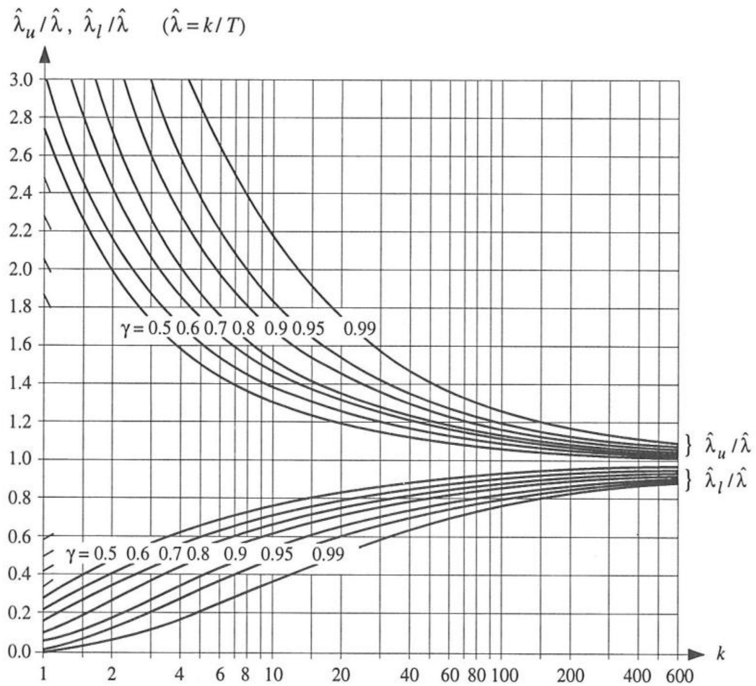


Bild 6.6 Vertrauensgrenzen $\hat{\lambda}_l$ und $\hat{\lambda}_u$ für eine unbekannte konstante Ausfallrate λ oder von $MTBF = 1/\lambda$ (T = kumulative Betriebszeit, k = Anzahl Ausfälle während T, γ = Aussagewahrscheinlichkeit; es gilt $\hat{MTBF}_l = 1/\hat{\lambda}_u$ und $\hat{MTBF}_u = 1/\hat{\lambda}_l$)

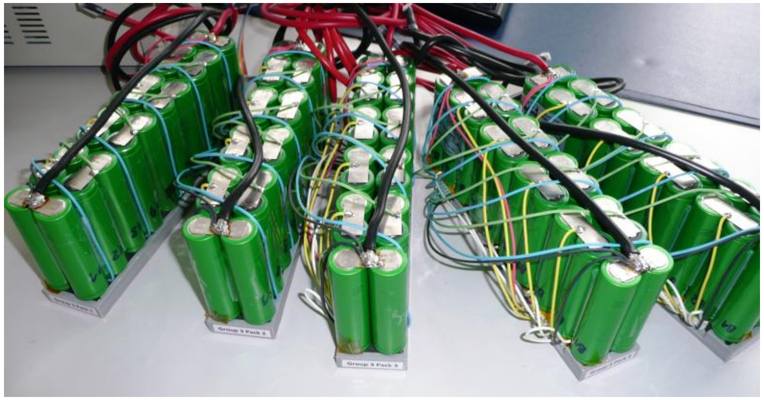
Estimation and demonstration of failure rate λ

$\hat{\lambda} = k/T$

k = number of failures
T = cumulative operating time

But: what is operating time for a cell?

Proposed Tests



Paket Reliability and Degradation

- Run large number of standard charge / discharge cycles on cell paket (10s2p)
- Run large number of real drive cycles on cell paket
- Comparison of standard and drive cycles
- Observation of single cell voltages and effect of non-balancing

Paket and BMS Safety

- Cell open
- Cell internal short
- Observation of physical reaction and BMS

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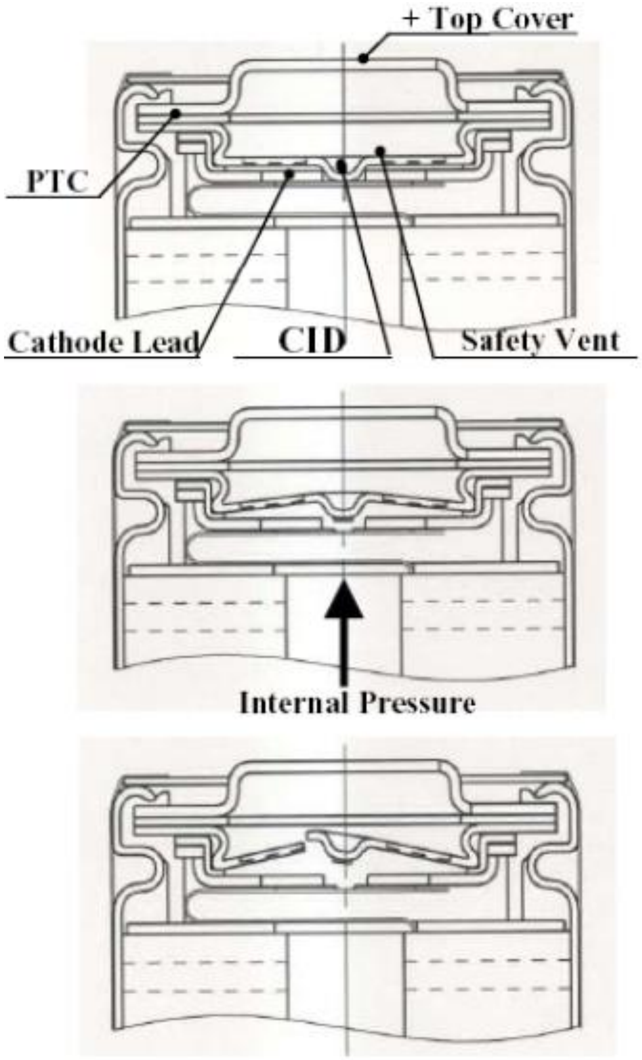
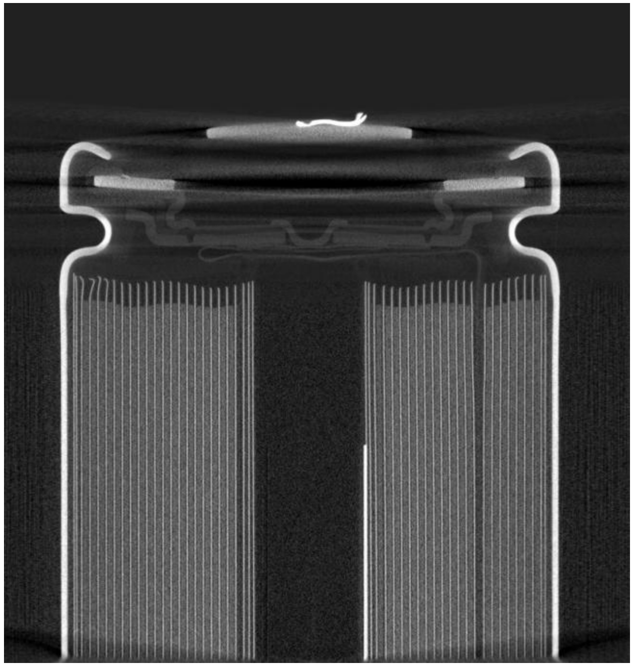
Proposed Tests



PTC Device (Positive Temperature Coefficient)

- Conductive polymer layer in Cathode tab, highly resistive above threshold temperature / current
- Remains conductive within specified current and temperature limits
- Reversible



CT of BMZ/Sony Cell of Hermes/Clever Hybrids by EMPA

CID (Circuit Interrupting Devices)

Mechanically activated by cell internal pressure
Irreversible electrical disconnection from cell intestines

Safety Vent

When the internal pressure suddenly increase, the safety vent would split, and escape the gas**.**

Cell Testers: fully operational!

- Voltage 5V ± 1mV
- Current 100A ± 50mA, 300A ± 150mA
- Minimum step time 10ms
- Control, measurement, adjustment every 10ms
- Waveform: test drive cycles
- Multiplexed Frequency Response Analyzer
  1 mHz to 30 kHz

- Chamber volume 2 X 210 liters
- Temperature range -40° C to +100° C
- N2 Inertisation
- Overpressure exhaust
- Safety locks

Battery Tester: delivered!

Specification

- Voltage 500V ± 2V
- Current 1000A ± 5A; dI/dt = 50ms (25-100%)
- Minimum step time 100ms
- Control, measurement, adjustment every 100ms
- Waveform: test drive cycles
- Total Harmonic Distortion <1.5%
- AC ripple < 2.5%
- Converter efficiency > 91%