SKELETON TECHNOLOGIES

GLOBAL LEADER IN ULTRACAPACITOR-BASED ENERGY STORAGE

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COMPARATIVE ESR TEST RESULTS OF THE CURRENT STATE-OF-THE ART SUPERCAPACITORS.

AGENDA

SKELE+ON TECHNOLOGIES

- Skeleton Introduction
- Case for the IEC standard
- Comparative ESR test results
- ESR Impact

COMPANY OVERVIEW
Skeleton Technologies Group

SKELETON TECHNOLOGIES

ULTRACAPACITORS

- Ultracapacitors are an energy storage technology that offers high power density, almost instant recharging and very long lifetimes.

PRODUCTS

- Our patented “curved graphene” delivers 60% higher energy storage capacity and double the power performance
- Ultracapacitor-based energy storage solutions:
  - Full energy storage systems
  - Industrial modules
  - Ultracapacitor cells

PEOPLE

- 100 employees, 7 phDs

FUNDING

- 41,7 M EUR invested by UP Invest, Harju Elekter, KIC InnoEnergy, FirstFloor Capital and European Investment Bank

FIRSTFLOOR CAPITAL

eit InnoEnergy

European Investment Bank The EU bank

up invest

HARJU ELEKTER

CUSTOMERS

- Tier 1 automotives, OEMs,
- Bus and truck
- Industrial equipment
- Grid
- European Space Agency

PROUDLY EUROPEAN
Skeleton Technologies Group

Skeleton Technologies GMBH
Großröhrsdorf, Germany

+ Industrial scale manufacturing facility

Skeleton Technologies OÜ
Viimsi, Estonia

+ R&D Laboratory
+ Assembly facility and module development

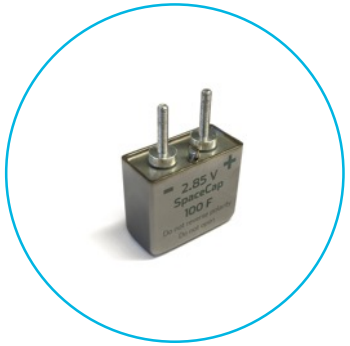
ONLY ULTRACAP MANUFACTURER WITH A COMPLETE VALUE CHAIN

MATERIALS

Curved Graphene
OUR PATENTED
RAW MATERIAL

SINGLE CELLS

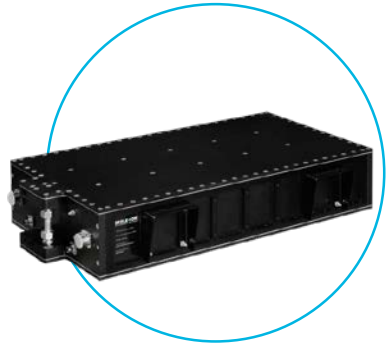
SkelCap SCA series
INDUSTRIAL ULTRACAPACITORS



SpaceCap
CUSTOM ULTRACAPACITORS

SOLUTIONS

SkelMod 51V
ULTRACAPACITOR MODULE



SkelMod 170V
ULTRACAPACITOR MODULE

SkelStart Engine Module
ULTRACAPACITOR MODULE

SkelGrid
ULTRACAPACITOR-BASED
ENERGY STORAGE SYSTEM

PROBLEM: LACK OF STANDARDIZED MEASUREMENT OF ULTRACAPACITOR POWER PERFORMANCE

SKELE+ON TECHNOLOGIES

- **Maxwell:** six step DC charge-discharge method with 5 s current-cut.
- **LS Mtron:** DC charge-discharge curve analysis, defining the voltage drop as the change in voltage during the first 10 ms of discharge.
- **Ioxus:** DC charge-discharge curve analysis, similar to IEC 62391-1A (class 3) method, also the so-called 10 ms method. Additionally, Ioxus uses a 1 kHz AC impedance test.
- **Nesscap:** used DC charge-discharge curve analysis, defining the voltage drop as the change in voltage during the first 10 ms of discharge.

SOLUTION: CONSTANT CURRENT ESR MEASUREMENT METHODS IEC 62391

Method 1A

+ Storage at 20+/- 2ºC, uniform temperature.
+ Held at rated voltage for 30 min.
+ Current according to capacitor class

Method 1B

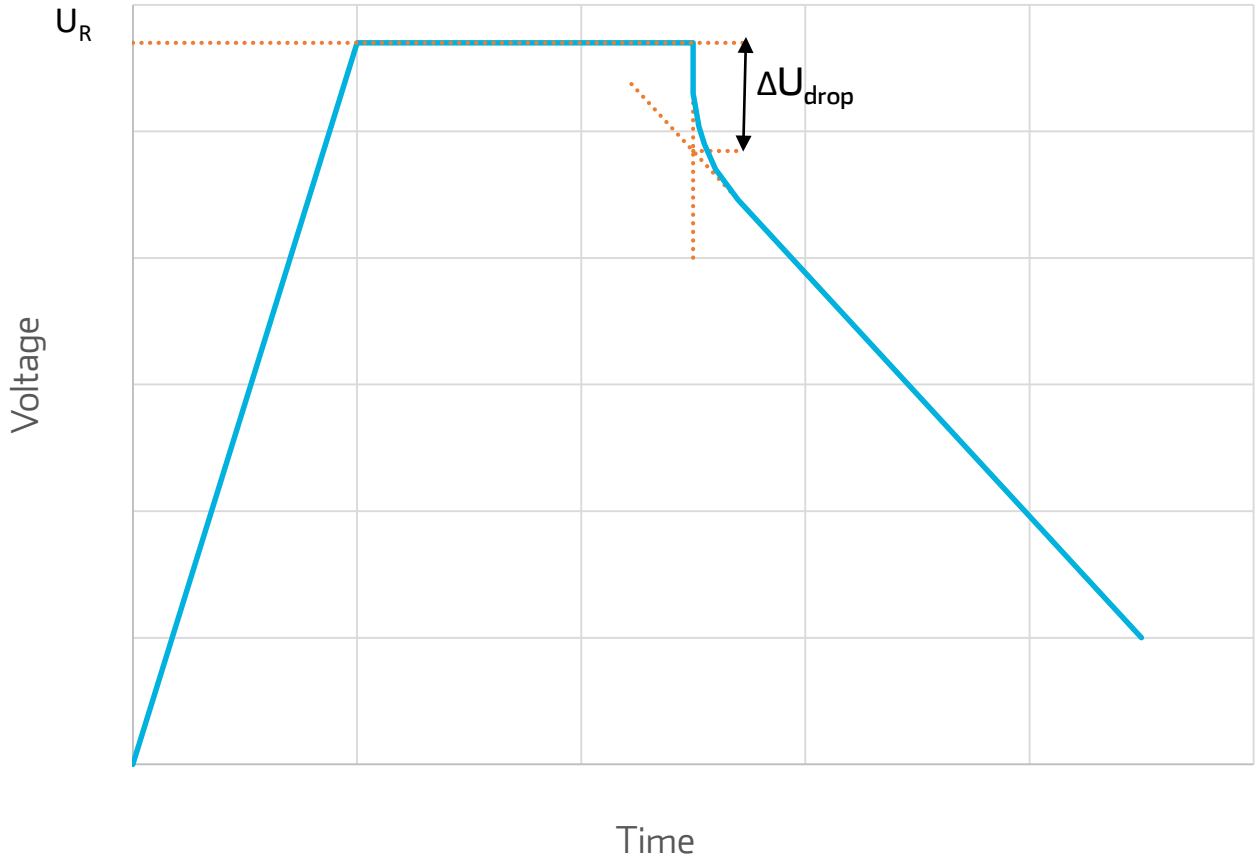
+ Constant current charging at 95% efficiency,
+ Constant voltage charging time is 5 min,
+ Discharge current at 95% efficiency.

Testing current for methods IEC 62391 1A and 1B

CLASS	TYPE	CHARACTERISTICS	METHOD 1A	METHOD 1B
Class 2	Energy storage	High capacitance, ESR not a priority	$4 \times C_N U_R$	
Class 3	Power	Relatively high capacitance, low ESR	$40 \times C_N U_R$	@95% efficiency
Class 4	Instantaneous power	Large current, short discharge, lower ESR	$400 \times C_N U_R$	@95% efficiency
Class 5	High power cycling	Lowest ESR		@95% efficiency

Third party testing by EGGO Space s.r.o

VOLTAGE DROP POINT IS EXTRAPOLATED

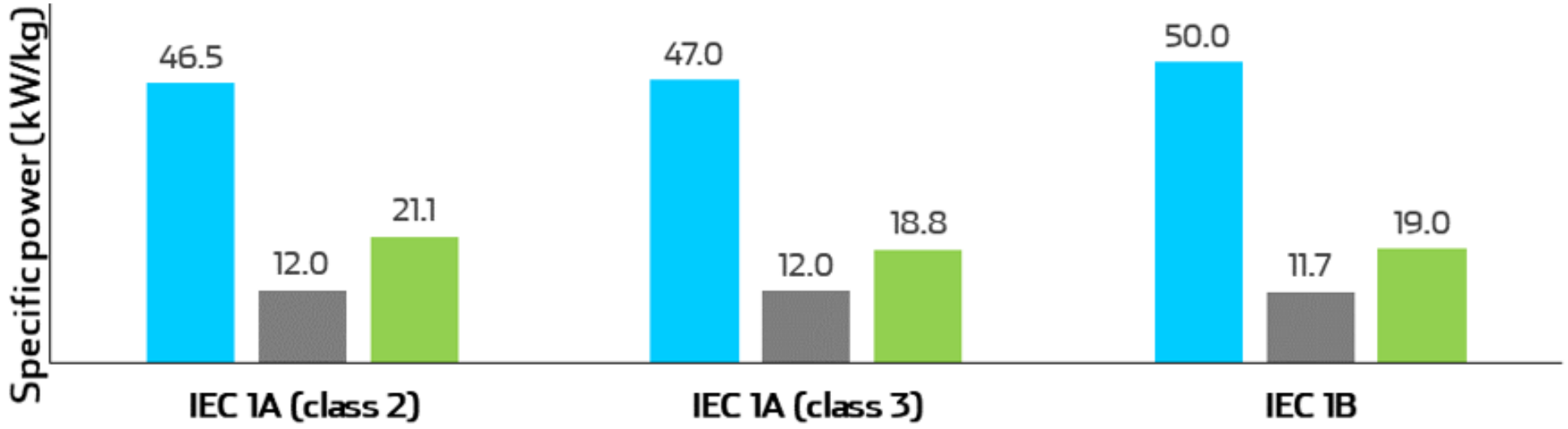


$$ESR\ (\Omega) = \frac{\Delta U_{drop}}{I_d}$$

RESULTS:
1200F capacitors

Method	Skeleton					
	Internal resistance (mΩ)	**Specific power (kW/kg)**	Internal resistance (mΩ)	**Specific power (kW/kg)**	Internal resistance (mΩ)	**Specific power (kW/kg)**
1A: class 2	0.17	**46.5**	0.58	**12.0**	0.31	**21.1**
1A: class 3	0.17	**47.0**	0.59	**12.0**	0.35	**18.8**
1B: classes 3, 4 and 5	0.16	**50.0**	0.60	**11.7**	0.34	**19.0**

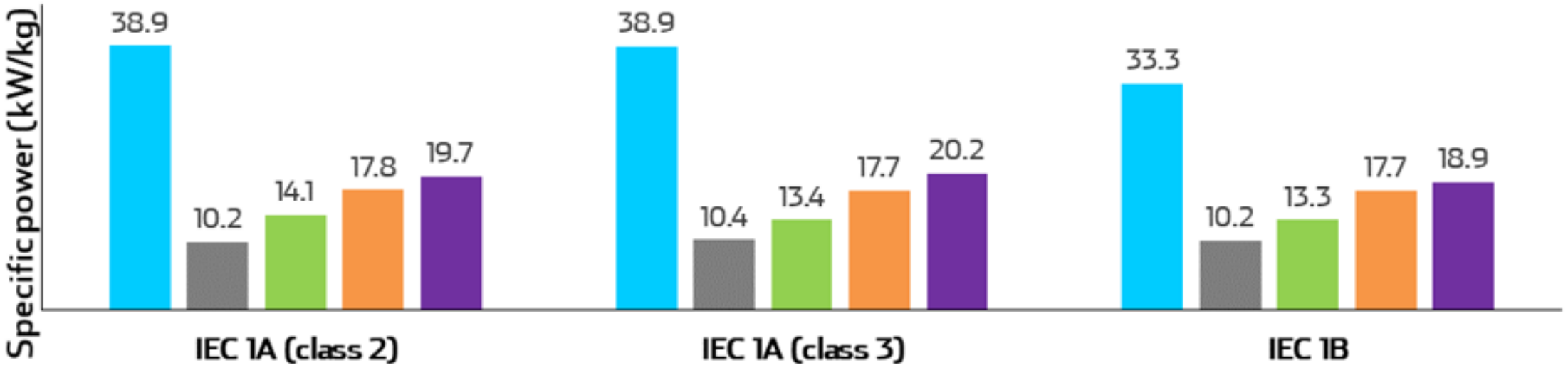
RESULTS:
1200F capacitors



RESULTS:
3000F+ capacitors

Method	Skeleton							
	Internal resistance (mΩ)	Specific power (kW/kg)	Internal resistance (mΩ)	Specific power (kW/kg)	Internal resistance (mΩ)	Specific power (kW/kg)	Internal resistance (mΩ)	Specific power (kW/kg)
1A: class 2	0.098	38.9	0.38	10.2	0.28	14.1	0.20	19.7
1A: class 3	0.098	38.9	0.38	10.4	0.295	13.4	0.20	20.2
1B: classes 3, 4 and 5	0.114	33.3	0.38	10.2	0.296	13.3	0.20	18.9

RESULTS:
3000F+ capacitors



Competitive advantage of superior power
56 MW PULSE POWER SUPPLY

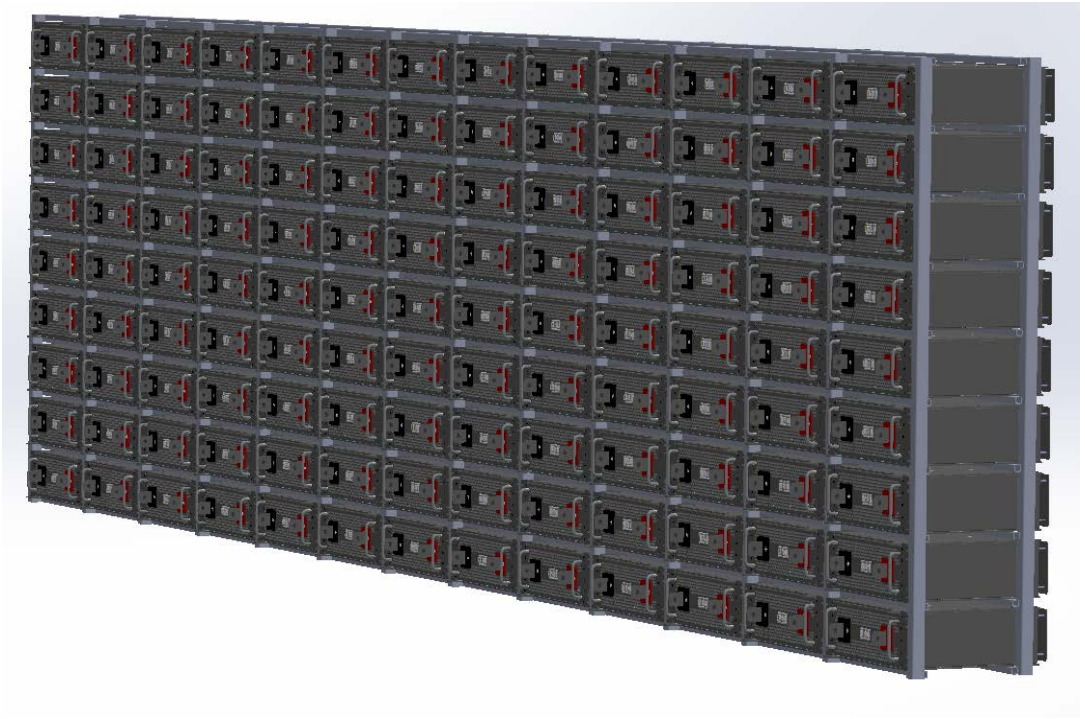
SKELETON TECHNOLOGIES

High-Power Medium Voltage Pulse Power Supply

+ Current: 21 000 A
+ Voltage: 2 700 Vdc
+ Power: 56 MW
+ Application time: 2 x 150 ms
+ ~ 460 x SkelRack102V89F Modules

Comparison:

+ Skeleton's solution 460 modules
+ VS competitor's cells 1012 modules



ACTIVE HEAVE COMPENSATION (20 t crane)

SKELETON TECHNOLOGIES

2.6 TIMES LESS CAPACITORS NEEDED

	SKELETON	COMPETITOR
WEIGHT:	252 kg	650 kg
VOLUME:	220 L	570 L
LIFETIME:	>70 000 days	>70 000 days

WE ARE SKELETON TECHNOLOGIES

WE HELP TO SAVE ENERGY

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