Starting an engine at -43 °C with hybrid power capacitor batteries? **Yes, we can!**

Introduction

Most of us have experienced the frustration when having to start their car the first time it has been freezing during the night. The battery (a lead-acid accu) is dead. At very cold temperatures like -20°C even a new battery will not have enough energy left to crank an unwilling engine. The oil will be sticky and the fuel is cold. Note that even electric cars will have a hard time starting to move. At -20 °C Lithium-ion batteries have no energy left and they need to heat themselves during the night to avoid this situation.
But how do you crank an engine at -40 °C? This white paper explains it and shows test results using a 70 Ah power capacitor battery based on our 18650 cells. It turns out that it is not a battery problem but one of pre-heating the air and the fuel. And yes at -43°C, some self-heating of the battery is needed as well.

The test set-up

As it is not feasible to do this test at different temperatures on the real vehicle, the test is performed in a laboratory whereby the different loads are simulated using heavy power resistors. The whole is put in a cooling chamber for 24 hours at -30, -35, and -43°C doing the tests in the morning.

The simulated test vehicle:

- An off-road vehicle with a starter motor of peak 8 kW and 71 Nm at 1064 rpm. The main engine is a diesel of 220 kW.
- The starter motor has a variable load profile depending on the rotational speed. This translates in a variable internal resistance changing between 14 to 70 mOhm.

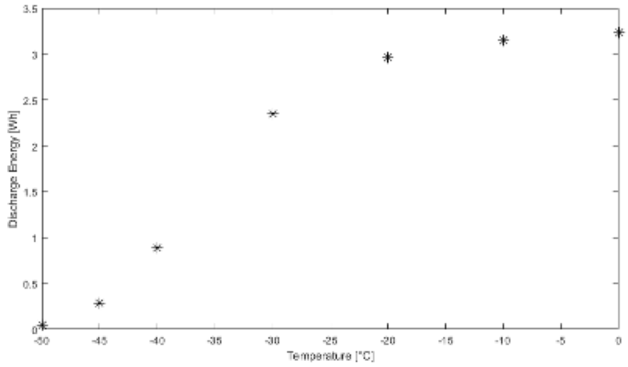
The power capacitor test battery:

- 18650 based 24V / 68 Ah / battery pack.
- Internal resistance around 2.5 mOhm.
- Peak current capability: 1200 A (200 ms),
- Sustained current capability: 900 A.
- Specified to operate from -40°C to +80°C.
- Lifetime: 20000 to 50000 cycles depending on the load profile and temperature.
- For the tests at -43°C a preheating pad is used (internal resistance 0.9 Ohm).

Simulated battery loads:

① Preheating pad: 25 minutes at 25A, requiring 10.42 Ah
② Fuel preheating: 20 minutes at 10A, requiring 3.33 Ah
③ Inlet air preheating: 45 seconds at 100 A, requiring 1.25 Ah
④ Control system: 30 minutes at 10 A, requiring 5 Ah.
⑤ Motor: simulated with resistors. Requires pulses of 1000A during 2 seconds and 600A during 5 seconds. About 1.5 Ah for each start.
⑥ Total load for the one start sequence: 21.50 Ah.
⑦ One extra start needs ③ + ⑤, i.e. 1.25 + 1.5 = 2.75 Ah.

The 18650 cell has been tested by T.U. Munich, Institute of Astronautics till -50°C. The graph clearly shows that even at -20°C there is very little capacity loss, whereby one must keep in mind that the energy is not lost but will be recovered as the cell slightly heats up when drawing current. This allows even to start engines at -40°C by pulsing the batteries until they reach -30 °C, at which point enough energy is available. At -40°C about 25% energy is available, which is sufficient to preheat itself.



Cold start test at -30 °C

For starting a diesel engine at -30°C, it is sufficient to preheat the air at the engine inlet for 30 seconds. This also acts as an internal pre-heating of the battery pack. The engine is then started.

① Air admission pre-heating for 30 sec.
② Start the simulated motor with a resistor load of 0.014 Ohm for 2 sec, and then switch to a resistor load of 0.023 Ohm for 5 sec.
If ICC ⩾ 1000A, and the terminal voltage of pack ⩾ 12V, the start is considered as successful;
If ICC < 1000A, or the terminal voltage of the battery remains below < 12V, keep starting with the 0.023 Ohm for 45 seconds, stop starting.
③ Rest 2 minutes
④ The second start: repeat step ① to ③.
⑤ And then the 3rd Start, the 4th start...

Results: all steps were successful.

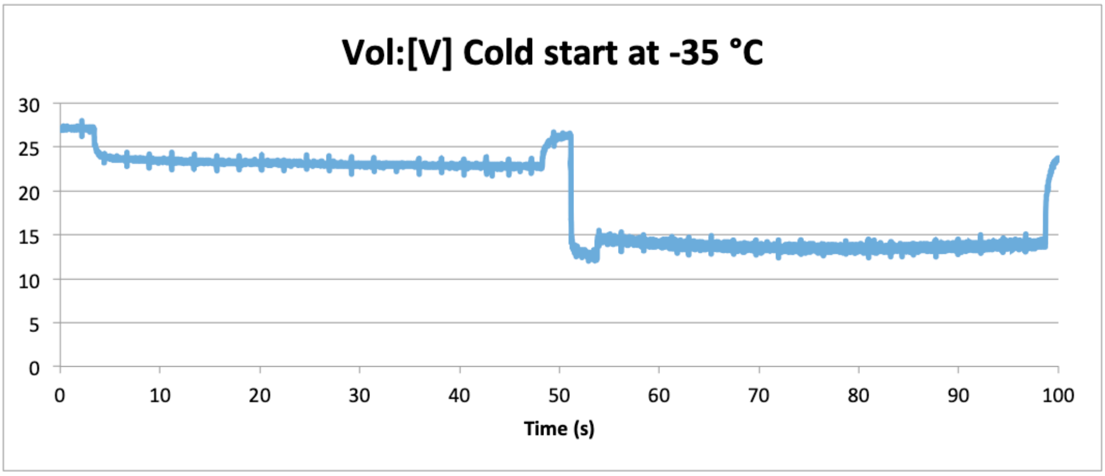
Cold start test at -35 °C

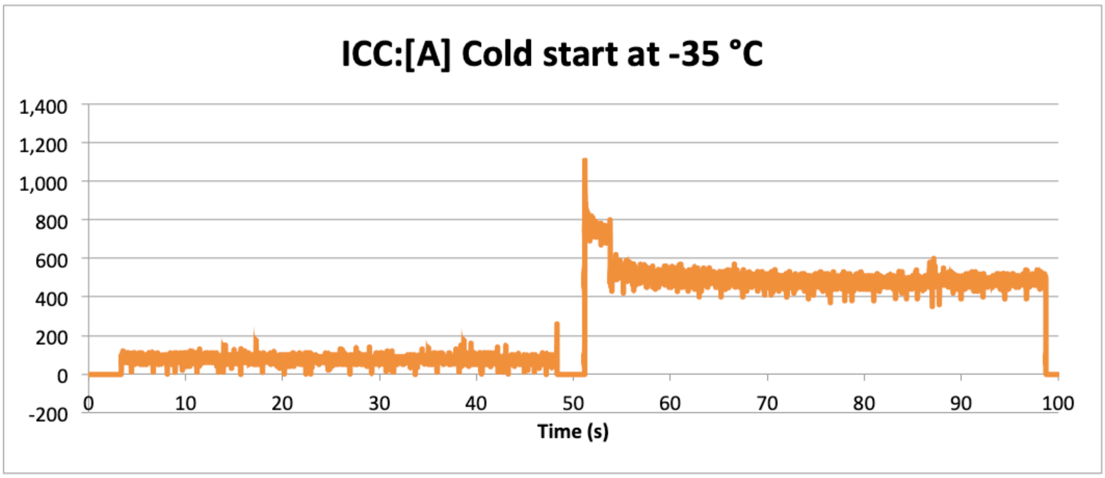
At the -35°C the preheating phase is increased to 45 seconds.

① Air admission pre-heating for 45 sec
② Start the simulated motor with a resistor load of 0.014 Ohm for 2 sec, and then switch to a resistor load of 0.023 Ohm for 5 sec.
If ICC ⩾ 1000A, and the terminal voltage of pack ⩾ 12V, the start is considered ad successful;
If ICC < 1000A, or the terminal voltage of the battery remains below < 12V, keep starting with the 0.023 Ohm for 45 seconds, stop starting.
③ Rest 2 minutes
④ The second start: Repeat step ① to ③.
⑤ And then the 3rd Start...

Results: all steps were successful.

The graphs below are a recording of voltage and current of above test set-up.

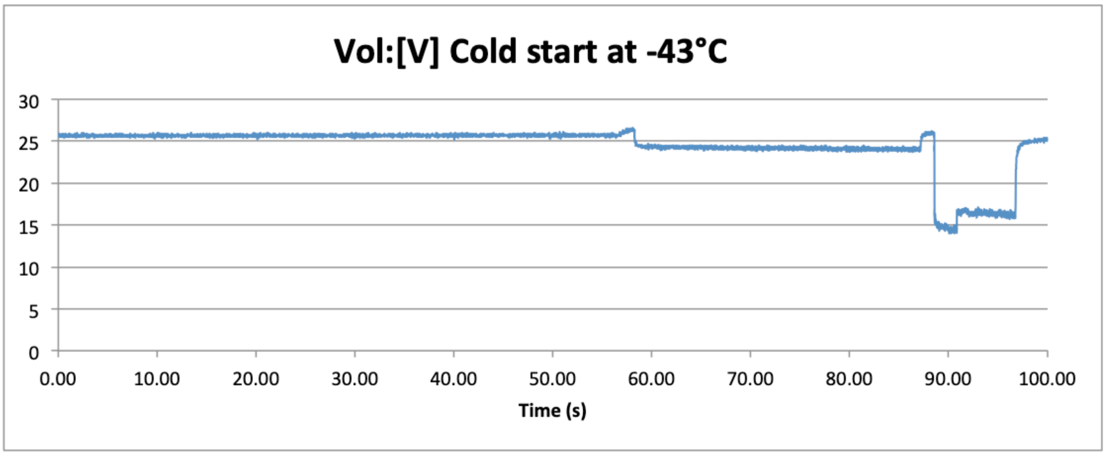


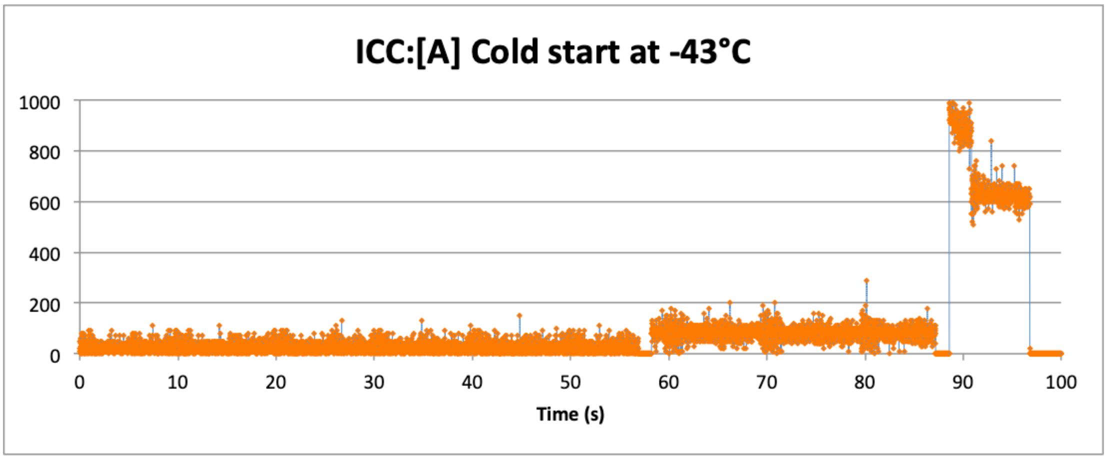


Cold start test at -43°C with internal pre-heating.

The test sequence is the same as at -35°C but as the voltage drops too much on the first attempt, it is repeated a 2 to 3 times. The initial attempts warm up the battery increasing the available energy and reducing the voltage drop. This allows to close the motor contactor and the motor can be started.

The graphs below show the recorded voltage and current of the test:





Cold start test at -43°C with internal and engine pre-heating

As such a cold start is also a serious stress operation on the engine, it is better to pre-heat not only the battery itself but also the air at the inlet and the fuel.

The complete test sequence is as follows:

① Preheating battery for 5 minutes. 00:00 – 05:00
For testing at -43°C, the battery is equipped with a heating pad. The battery itself supplies a 20A current for 5 minutes whereby the voltage initially drops from 28V to 20V. As the battery heats up, its voltage as well as the current increases because the heating liberates more energy.

② Preheating battery + fuel for 20 minutes. 05.00 – 25:00
As the capacity of the battery is now higher, the fuel heating is enabled in conjunction with the heating pad.

③ Preheating inlet air for 45 seconds. 25:00 – 25:45
The battery and fuel preheating is stopped and the inlet air heating enabled.

④ Start engine for 2 seconds at 0.014 Ohm. 25:45 – 25:47

⑤ Start engine for 5 seconds at 0.023 Ohm. 25:47 – 25:52
If ICC ⩾ 1000A, and the terminal voltage of pack ⩾ 12V , start successfully;
If ICC ＜ 1000A, or the terminal voltage of pack ＜ 12V, keep 0.023Ω continuous drag operation until 45 seconds.

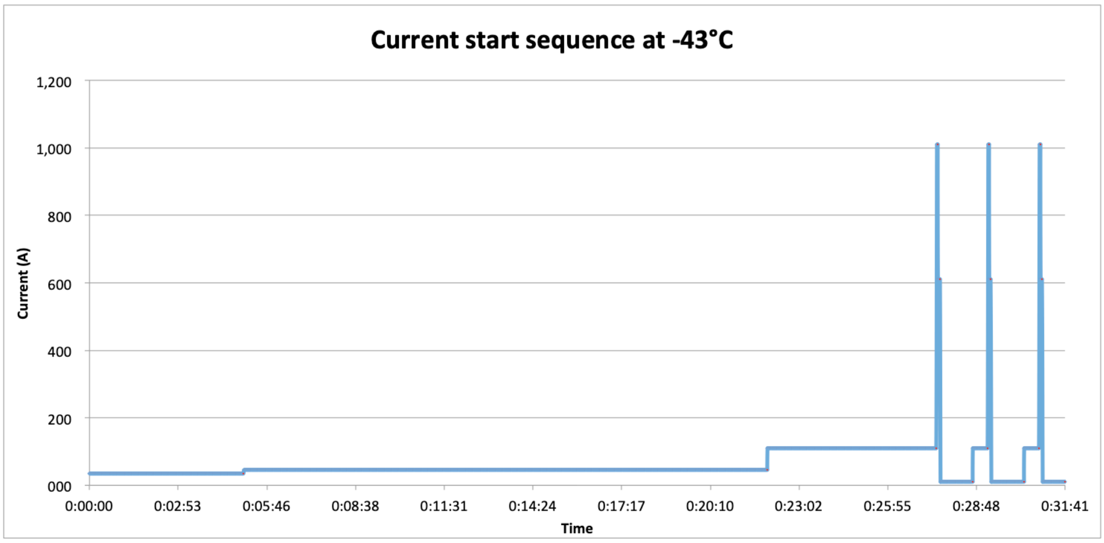
⑥ Engine is assumed started and stopped. Rest period of 2 minute. 25:52 – 27:52

⑦ Preheating air inlet for 45 seconds. 27:52 – 28:37

⑧ Second start 28:37 – 28:44

⑨ Repeat

This is illustrated on the time sequence below.



Results: all steps were successful.

Conclusions

The 18650 hybrid powercapacitor offers a decent energy density in conjunction with a high power capability and can be operated at very low temperatures. Configured in a battery pack it has enough energy available at -43°C to start a self-heating process and provide heating capability to warm up the inlet air and fuel of the heavy diesel engine. In principle it can start the motor in less than 100 seconds while a complete heating up of the engine air and fuel for a safe engine start can take up to 30 minutes. At that moment only about 21.5 Ah (at 24V) will have been used with an additional cold start only requiring 2.75 Ah.

For more information on the hybrid power capacitors, visit:

www.kurt.energy
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