Ultra-High Temperature (250°C+) and Wide Operating Temperature Range Ultracapacitor Enabling Downhole Power Source for Geothermal Exploration

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Keywords

250°C Ultracapacitor, ultra-high temperature energy storage, wide temperature range ultracapacitor, geothermal exploration, downhole energy storage, extreme environment ultracapacitor, nanotechnology, lithium-free energy storage, sub-zero ultracapacitor, low temperature ultracapacitor

ABSTRACT

FastCAP developed a novel and innovative ultra-high temperature ultracapacitor ("ultracap") energy storage device showing outstanding performance suitable for geothermal exploration applications. This proposed ultracap is an upgraded version of the previous 200°C presented at GRC Summit 2014. The ultracap performs reliably at ultra-high operating temperatures of 250°C and beyond and operates over an extremely wide operating temperature range, -5°C to 250°C+. The rechargeable ultracap has significantly higher power density than lithium thionyl chloride batteries, a non-rechargeable incumbent used in oil and gas drilling today. Several hermetically sealed, commercial ready prototype devices were tested in our laboratories at constant temperatures of 250°C+ showing no significant degradation over 1000 hours of operation (See Figure 1). Six similar prototypes will be tested at Sandia National Lab in the month of April, 2015 for an overall performance third party validation. We expect these devices to show very good performance over 1000 hours of operation at three rated temperatures, 200°C, 225°C and 250°C+, with negligible capacitance retention and minimal equivalent series resistance (ESR) increase. Deployment of these novel ultra-high temperature ultracapacitors in geothermal drilling and exploration applications could have an immediate and significant impact on the effectiveness and efficiency of drilling processes, particularly with regard to use of advanced logging and monitoring techniques in the geothermal context.

Ultracapacitor Technologies Developed at Fastcap Systems

FastCAP Systems is a technology company, spun out of MIT, which specializes in the development and commercialization of high performance ultracapacitors [1]. The work leading to the development of this new ultracapacitor was completed under two Department of Energy grants; a multi-year ARPA-E program that was completed in the 1st quarter of 2014, and a Geothermal Technologies Office ("GTO") program that has just been completed in the 1st quarter of 2015 [2]. Under its ARPA-E program, FastCAP's ultracaps were validated by Crane National Laboratories as having the highest energy density and highest power density of any commercially available ultracapacitor device, achieving a groundbreaking 10X in high power density cells, and up to 6X in high energy density cells over commercial incumbents.[3, 4]

Building on this device performance, our team pursued a parallel line of research in a new generation of high temperature ultracapacitors. By 2012, FastCAP had developed an ultracapacitor capable of reliable operation at 150°C. The team leveraged this technology in the development of high temperature devices under its second DOE grant with the Geothermal Technologies Office [5]. The project, which aimed to develop a cutting-edge downhole power system incorporating high temperature ultracapacitors (capable of 250°C operation for up to 200 hrs.) and a cutting edge downhole energy generator, kicked off in summer of 2012. Under this program, the team has developed and validated at Sandia National Lab, a high temperature rechargeable energy storage device, capable of operating at 200°C [6, 7]. By the end of the GTO program, in the 1st quarter of 2015, the team was able to obtain outstanding results (See Figure 1 below); a novel energy storage technology able to operate at a very wide spectrum of temperatures from as low as -5°C all the way up to +250°C and beyond. Table 1, below, summarizes the GTO program performance outcomes, compared with program milestones.

FastCAP plans to validate the optimized technology at Sandia National Laboratories, where lifetime tests will be performed on hermetically sealed, fully functional and commercial ready ultracapacitor cells. Related results will be ready by GRC's 39th Annual Meeting 2015. Based on in-house testing FastCAP expects the cells to perform safely, reliably, and without failure or significant performance degradation at selected temperatures of 200°C, 225°C and 250°C through 1000 hours of constant voltage.

Table 1. GTO performance milestones. No incumbent are available on the current market for comparison.

Parameter	Milestone	Measurement	Milestone Outcome
Max reliable operating temperature: ultracapacitor cell	250°C	≥250°C	Met
Max reliable operating vibration: ultracapacitor cell	$10g_{rms}$	$\geq 10g_{rms}$	Met
Max Energy stored in a 70″ Length 1.5″ OD Pack: ultracapacitor pack	0.75Wh	≥0.75Wh	Met
Max reliable operating temperature: ultracapacitor pack	200°C	≥200°C	Met
Max reliable operating vibration: ultracapacitor pack	$5g_{rms}$	$\geq 5g_{rms}$	Met
Lifetime @ Max reliable temperature	200 hours	≥1000 hours	Exceeded
Equivalent Series Resistance increase @ 200 hours	50%	<5%	Exceeded
Capacitance degradation @ 200 hours	50%	0%	Exceeded

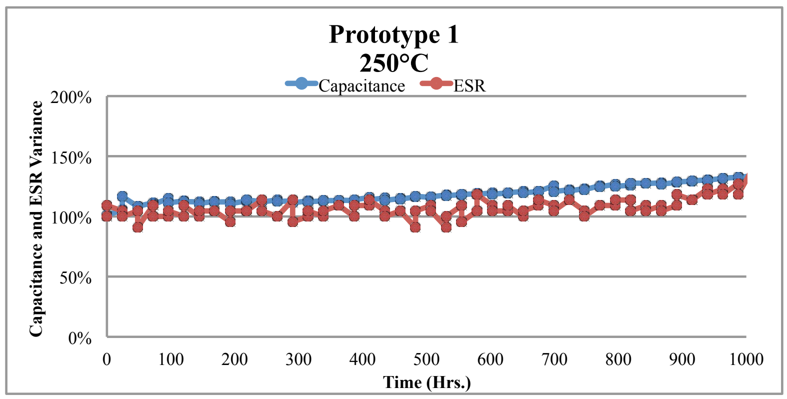

Figure 1. Ultra-High Temperature Ultracapacitor performance over 1000 hours of lifetime.

Enabling the Next Generation of Geothermal Energy

FastCAP's ultra-high temperature ultracaps may be used to provide energy storage devices that enable the intelligent drilling and smart well techniques that are currently ubiquitous in the oil and gas industry to be widely deployed in the geothermal context, allowing geothermal energy to become a major contender to meet global energy demand [8, 9, 10, 11].

One of the most significant obstacles that currently stands in the way of the deployment of advanced drilling and production techniques in the geothermal context are limitations related to the maximum operating temperatures of downhole batteries used to provide power for downhole sensors, steering tools, telemetry equipment and other MWD/LWD technologies. In the oil and gas context, FastCAP's high temperature energy storage technology has been used to provide power for advanced downhole systems at temperatures of 150° and above without the drawbacks associated with conventional battery technology — volatility, thermal runaway explosion risk, inability to be recharged, and low power not suitable for powering increasingly power hungry downhole tools.

FastCAP's higher temperature ultracapacitor technology will provide power solutions for similar advanced drilling and production techniques, even in the harsher environments associated with geothermal energy production [4]. This ultracapacitor will provide downhole power solutions for the geothermal industry capable of the same reliable and safe operation our team has demonstrated in the oil and gas context.

In-House Test and the Sandia National Laboratory Validation

Development of this new ultracapacitor started by redesigning the novel ultracap based on the technology developed for the previous 200°C rated version. In particular each component of the internal architecture of this device has been studied and developed separately by different teams. Then, these optimized components have been coupled together, obtaining a completely novel architecture able to reach and stand at a continuous temperature of 250°C. In the last twelve months, several prototypes have been tested at different temperatures, including 200°C, 225°C and 250°C for a complete characterization and final optimization of the ultra-high temperature device. A target of 200 hours of operation given by the GTO was surpassed by 5 times, reaching 1,000 hours. Representative results of an optimized version of the 200°C rated energy storage device, now rated at 250°C+, are reported in Figures 2 and 3.

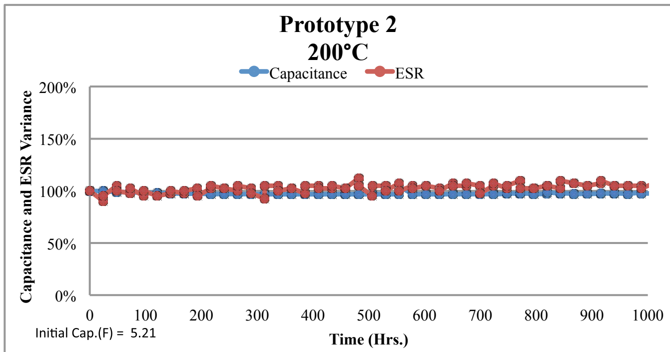

Figure 2. Capacitance and Equivalent Internal Resistance over time during extreme high temperature test at 200°C+. No sign of degradation is showed.

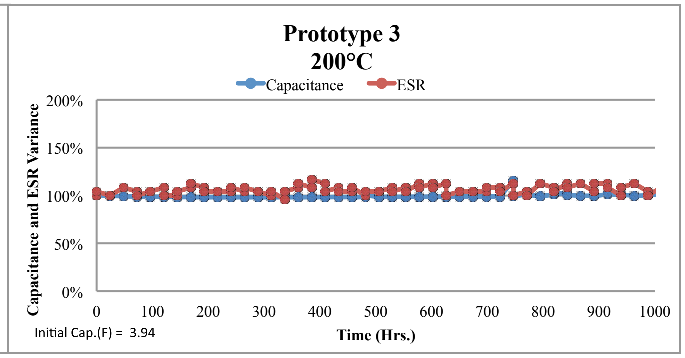

Figure 3. Capacitance and Equivalent Internal Resistance over time during extreme high temperature test at 200°C+. No sign of degradation is showed.

The previous two graphs show the capacitance and internal resistance (ESR) behavior over time. These cells have been tested for nearly 1,000 hours thus far, and testing is ongoing as of the date of publication.

Prototype 1: GT2015022001-01

Equivalent Series Resistance (ESR) variance @ 1,000 hours = +4.9%

Discharge Capacity (C) variance @ 1,000 hours = -3.20%

Prototype 2: GT2015022301-01

Equivalent Series Resistance (ESR) variance @ 1,000 hours = +12.49%

Discharge Capacity (C) variance @ 1,000 hours = -0.001%

On the last week of April 2015, technology validation tests will be run on six 250°C prototypes at Sandia National Laboratories. There will be a preliminary test called *Thermal Characterization*, to demonstrate that the 250°C+ rated prototypes are able to operate reliably in a wide spectrum of temperatures, showing consistent and strong performance at:

- Room Temperature
- 150°C
- 250°C+

The cells will be fully charged and discharged at ±0.01A for 5 cycles at three different temperatures. The cells are expected to perform consistently and reliably at all temperatures tested.

The goal of the second test, titled *Maximum Voltage*, is to show the outstanding performance of these devices even at the maximum rated voltage (in current cases of 0.5V, 0.7V and 1.0V). We expect these prototypes to show excellent performance under this test condition, with negligible degradation over time.

Another novelty related to this technology is represented by the fact that these energy storage devices have good cycling capabilities over a wide spectrum of temperatures as well, from -5°C all the way up to 250°C (See Figure 4).

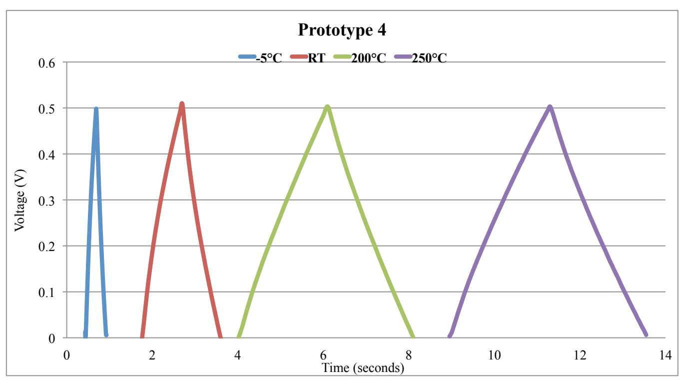

Figure 4. Charge/discharge cycles on the same device at four different temperatures: -5°C, Room Temperature (RT = +25°C), 200°C and 250°C showing cycle ability of the device over a wide operational temperature range.

The Future of Geothermal Drilling and Exploration

The end goal of the GTO program is to incorporate into our novel power system a bank of 250°C ultracapacitors, with a lifetime of 1000 hours. This tool will be transformational in the short term, enabling smart, data driven and efficient geothermal drilling through the use of monitoring while drilling (MWD) and logging while drilling (LWD) instrumentation. In the longer term, and as an area of future development, FastCAP intends to further engineer its 250°C ultracaps to have an operating lifetime 50 times that of the final GTO program target, with the ultimate goal of enabling high powered production monitoring tools in the geothermal context; providing breakthrough monitoring capabilities throughout the lifetime of a geothermal well, such as well optimization, drawdown monitoring, and tracking of fluid boundaries. FastCAP is continuing to develop higher and higher temperature ultracapacitors and a 300°C rated energy storage rechargeable device is expected by the end of 2016.

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