ABSTRACT

FastCAP has studied and developed a novel and innovative high temperature ultracapacitor ("ultracap") energy storage device, showing outstanding performance for geothermal exploration applications. This ultracap performs reliably at operating temperatures of 200°C+, is rechargeable, and has significantly higher power density than lithium thionyl chloride batteries, a non-rechargeable incumbent used in oil and gas drilling today. Five hermetically sealed, commercial ready prototype devices were performance validated by Sandia National Lab in April, 2014. The devices performed successfully and consistently for 500 hours of operation at 200°C+, showing outstanding capacitance retention and negligible Equivalent Series Resistance (ESR) increase. Equivalent prototype devices have been tested for more than 1,500 hours in our lab, with similarly minimal performance degradation (See Fig. 4 & 5). Deployment of these novel 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. Our ultracapacitors hold multiple third-party validated world records across several performance metrics, including highest power density, highest energy density and highest temperature. Many of the breakthroughs that serve as the foundation for these performance results were developed 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 is on track for completion in 2015. 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. The table below summarizes the ARPA-E program performance outcomes, compared with program milestones and the performance of commercially available ultracap incumbents.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>ARPA-E Milestones Review</th>
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<tbody>
<tr>
<td>Number of cycles at max voltage before cell failure</td>
<td>500k</td>
</tr>
<tr>
<td>Volumetric energy density $E_v$ for consumer electronics applications prototype</td>
<td>12.18Wh/L</td>
</tr>
<tr>
<td>Volumetric energy density $E_v$ for automotive applications</td>
<td>22Wh/L</td>
</tr>
<tr>
<td>Gravimetric energy density $E_w$ for consumer electronics applications prototype</td>
<td>9.14Wh/kg</td>
</tr>
<tr>
<td>Gravimetric energy density $E_w$ for automotive applications</td>
<td>18Wh/kg</td>
</tr>
<tr>
<td>Volumetric Power Density $P_v$</td>
<td>38kW/L</td>
</tr>
<tr>
<td>Gravimetric Power Density $P_g$</td>
<td>28.5kW/kg</td>
</tr>
<tr>
<td>Power #90% RTE</td>
<td>4.55kW/L</td>
</tr>
<tr>
<td>Specific leakage current $I_s$</td>
<td>0.02mA/cc</td>
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Building on this track record of breakthrough device performance, our team pursued a parallel line of research in a new generation of high temperature ultracapacitors. By 2012, FastCAP had developed and commercialized the world’s first ultracapacitor capable of reliable operation at 150°C. The team leveraged this success in the development of high temperature devices under its second DOE grant with the Geothermal Technologies Office. The project, which aims 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, the highest temperature rechargeable energy storage device in the world, surpassing its own prior world record of 150°C. The testing showed our devices, which are hermetically sealed, fully functional and commercial ready ultracapacitor cells, performing safely, reliably and without failure at 200°C, through 500 hours of constant voltage, with only minor performance degradation. These results are explored further below.

The Current State of High Temperature Energy Storage Devices

If the intelligent drilling and smart well techniques that are currently ubiquitous in the oil and gas industry were enabled and widely deployed in the geothermal context, geothermal energy would quickly become a major contender to meet global energy demand. One of the most significant obstacles that stands in the way of such deployment are limitations related to the max operating temperatures of downhole batteries used in the oil and gas industry, which currently provide power for downhole sensors, steering tools, telemetry equipment and other MWD/LWD technologies in temperature ranges of 100-200°C. However, even at temperatures at the low end of this range, which are significantly lower than those typically experienced in geothermal wells, these batteries have significant drawbacks, including volatility, thermal runaway explosion risk and inability to be recharged. They are also low power, a significant and limiting drawback when attempting to power increasingly power hungry downhole tools.

To date, with the sole exception of the 150°C ultracap technology developed in our lab, rechargeable energy storage devices capable of reliable and safe operation at the high temperatures encountered during oil, gas and geothermal drilling operations do not exist.

The Sandia National Laboratory Validation

On April 3rd 2014, several characterization tests were performed on five of our 200°C prototypes at Sandia National Laboratories. The goal of the first test, titled Thermal Characterization, was to demonstrate that the 200°C+ prototypes were able to operate reliably in a wide spectrum of temperatures, showing consistent and strong performance at:

- Room Temperature
- 100°C
- 200°C+ (peaks at 201.6°C)

The cells were fully charged and discharged at ±0.01A for 5 cycles at three different temperatures. The cells performed consistently and reliably at all temperatures tested.

The goal of the second test, titled Maximum Voltage, was to show that even at the maximum rated voltage of the cells (in current case 0.5V), there would be only negligible degradation over time. The prototypes showed excellent performance under this test (see Figure 2 & 3). In particular:

Prototype 1: UHT2014032102-01
Equivalent Series Resistance (ESR) @ 512 hours = +8.02%
Discharge Capacity (C) @ 512 hours = -3.82%

Prototype 2: UHT2014032602-01
Equivalent Series Resistance (ESR) @ 512 hours = +15.23%
Discharge Capacity (C) @ 512 hours = -7.08%

Figure 1. Series of FastXAP ultracapacitors for 200°C+ applications.

Figure 2. Equivalent Series Resistance (ESR) over time during extreme high temperature test at 200°C+. Negligible degradation is showed.

Figure 3. Capacitance over time during extreme high temperature test at 200°C+. No sign of degradation is showed.
Figures 4 and 5 show the capacitance and internal resistance (ESR) of 200°C cells currently undergoing testing in our laboratory. These cells have been tested for nearly 1,600 hours thus far, and testing is ongoing as of the date of publication.

Table 2 summarizes the GTO program performance outcomes to date, including the validation results, compared with program milestones.

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 200 hours. This tool will be transformational in the short term in enabling smart, data driven and efficient geothermal drilling through the use of monitoring while drilling and logging while drilling 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.

References


