Peak Load Shaving in a Fuel Cell Powered Industrial Servo System

Since original publication of this document, further enhancements have been made to ultracapacitor technology enabling improved performance over that listed within this application example. The product referenced is no longer available and has been upgraded. The methodologies cited within this document are unaffected.

Challenge

Replace a battery and power supply with a fuel cell and ultracapacitors in a mobile industrial servo system.

A company has developed a mobile industrial robotic system. The original version of the robot was powered with a combination of batteries and off board power supplied through a tether. This limited the range of mobility of the system to the length of the tether. The off-board power was required because batteries alone would have been prohibitively large to sustain the combination of continuous power and peak power required for extended operation. The system was upgraded for increased mobility by integrating a fuel cell and an ultracapacitor to eliminate the need for the tethered link to an off-board power source.

Solution

Size the fuel cell for the continuous average requirement, and the ultracapacitor for the peak requirement.

In this application, the ultracapacitor was sized to shave the peak loads off of the fuel cell. Since the fuel cell itself is sized for power, we want to size it for the lowest continuous average power requirement which will serve the application (the fuel cell's energy capability is a function of the fuel storage, not the fuel cell itself). The ultracapacitor system is sized to deliver the required power within the system's voltage range.

Using the ultracapacitor provides two benefits. First, the fuel cell is sized for continuous power rather than peak power. This enables a smaller, lighter, and less expensive fuel cell. Secondly, the ultracapacitor provides a response time which cannot be practically achieved by the fuel cell, regardless of size.

The continuous average current is (2 A + 30A*0.05 sec/1 sec) = 3.5 amps. This assumes the worst case duty cycle for the servo at one actuation per second. The fuel cell is sized to deliver a minimum of 3.5 amps continuously at 150 VDC. This will provide the 2 amps required to support the baseline system, as well as an additional 1.5 amps to recharge the ultracapacitor in between pulses.

The ultracapacitor must be able to deliver 30 amps for 50 milliseconds with a voltage drop no greater than 25 volts. Since this is a short pulse for an ultracapacitor, the ultracapacitor's resistance and capacitance will be different from its performance

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under DC conditions. Based on test data, we can scale the ultracapacitor's performance from its DC ratings to determine its performance during a 50 millisecond pulse.

For a 50 millisecond pulse, Maxwell Technologies has test data showing that an ultracapacitor will behave as if it has approximately 30% of its DC capacitance, and 60% of its DC equivalent series resistance (ESR). We also know that the approximate RC time constant under DC conditions for Maxwell's BOOSTCAP ultracapacitors is 1.5 seconds. The relatively low current (30A) and short duration (50 msec) designates the use of a smaller BOOSTCAP product. Since at 50msec we have 30% capacitance and 60% resistance, the device will function as a 0.27 second time constant for purposes of these calculations.

The total voltage drop permitted in this application is 25 V. For margin, we size this system for a 20 V voltage drop. Two factors contribute to the total voltage drop during discharge; voltage drop due to resistance (dV = I*ESR), and voltage drop due to discharge of the capacitor (dV = I*dt/C). Therefore, the total resistance drop during a pulse is:

dV = I*ESR + I*dt/C   Factor out I

dV = I * (ESR + dt/C)   ESR*C = RC time constant = 0.27; C = 0.27/ESR

dV = I * (ESR + dt*ESR/0.27)

dV = I * ESR * (1 + dt/0.27)

ESR = dV/(I*(1+dt/0.27));   dV = 20 V; I = 30 A, dt = 0.05 sec

ESR @ 50msec = **0.56 ohms**

This is the value of ESR in ohms for 50msec, which is 60% of the DC ESR

ESR @ DC = **0.94 ohms**

Since RC time constant at DC = 1.5 seconds,

Capacitance, C = 1/ESR = 1.5/0.94 = 1.6 farads

We now know that we need a 1.6 F capacitor operating at 150 VDC. Since BOOSTCAP ultracapacitors have a recommended maximum continuous operating voltage of 2.3 V, and this is basically a continuous voltage profile, we need 150 V/2.3 V = 66 cells in series to meet this requirement.

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The total capacitance of a series of capacitor cells (of equal value) is equal to the individual capacitor value divided by the number of cells in series; $C_{total} = C_{cell}$ / (# of cells in series). Therefore, $C_{cell} = C_{total}$ * (# of cells in series). This indicates we require cells that are ideally 105 F for this application. We now need to find a product solution.

Maxwell Technologies' BOOSTCAP ultracapacitors are available in 100 F cells, Model PC100. These cells have a typical ESR of 0.015 ohms. 66 cells in series will serve as a 1.52F capacitor with 1 ohm resistance at DC. This assembly's performance for a 50 millisecond pulse will be 0.455 F and 0.6 ohms (based on 60% of ESR and 30% of capacitance for this short pulse width). The total voltage drop for a 30A pulse of 50 msec duration will be:

$$dV = I * (ESR + dt/C)$$

where;

I = 30 A; ESR = 0.6 ohm; dt = 0.05 sec; C = 0.455 F

Therefore;

dV = 21.3 volts

The original system requirements stated a voltage drop of no more than 25 volts during the pulse. Using PC100 cells (100 F/0.015 ohm) in a series assembly of 66 cells satisfies the requirements.

(Maxwell Technologies staff regularly works with customers to evaluate their specific performance requirements as shown in this example.)

Summary

66 cells of PC100 were integrated into the industrial servo system, which is now in operation with the fuel cell system. The final weight of the ultracapacitor solution, including enclosure, was 4.2 kg. The robot system is now mobile, and no longer requires a tether to a fixed power source.

Using ultracapacitors in concert with a fuel cell allows system performance which previously required a battery supplemented with an off-board power supply. The ultracapacitors allow the fuel cell to be used in an application with pulse loads that would be impractical with the fuel cell alone. The same design strategy can be used with any power source having excellent energy capabilities but poor power performance, poor response time, or both.

The system can now operate with complete mobility, for longer periods, and requires less weight and volume than an equivalent battery pack.

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