Acceptance Test T001:

This test verifies the following requirements:

R002-2: The LPRDS-CMS-2011 shall re-engineer the design of a new ESS to permit per-cell battery management.

R002-3: The new system shall charge every cell in the ESS in the 4-cell pack to its maximum recommended capacity. Should some cells charge faster than others, a means shall be provided to bypass the cells that become full first, allowing complete charge to be delivered to cells that charge more slowly.

R002-4: On discharge, every cell shall be monitored and over-discharge of any individual cell must be avoided.

R002-5: The ESS shall be capable of standalone operation. It shall be possible to properly charge and discharge the ESS without needing an outside computer system for control or monitoring. Indicators shall be provided that give a basic display operational state (charge/discharge rate) and charge state (fuel gauge). Controls shall be provided, if needed, to permit standalone management.

SWR001-3: Surface temperatures, supply current drains per GPR005 must be analytically predicted at CDR and physically measured (less than 70°F over ambient (30°C) ) and verified as compliant during ATP.

GPR005-8: Components must be cooled such that the surface temperature is no greater than 40 degrees C above ambient.

Required Materials:

- MPJA 9604PS Power Supply
- Cell Management System (CMS)
- 4-cell pack with OBPP (partially charged)
- (2) Gold SDP4040D DC Solid State Relay
- (4) 120 Watt 1-Ohm resistors
- IR Thermometer
- PC running Simulink
- National Instruments BNC2110 Data Acquisition Board
- Test Power Cables 1, 2, 3
- Test Data Cables 1, 2, 3
- Test Voltage Cables 1, 2, 3, 4
- Test Bypass Cables 1, 2, 3, 4
Test Procedure:

- Take 4 LiFePO4 cells and fully charge them individually using MPJA 9604PS Power Supply until each cell voltage reaches 3.8 V.
- Discharge all the cells to the following SOCs: 80%, 50%, 25%, 10% by attaching the resistor network in figure 1 to the two terminals of the battery cell for the specified amount of time. This distribution of SOCs represents a 12% SOC standard deviation.

<table>
<thead>
<tr>
<th>Cell</th>
<th>SOC (%)</th>
<th>Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>80</td>
<td>9</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td>23</td>
</tr>
<tr>
<td>3</td>
<td>25</td>
<td>34</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>41</td>
</tr>
</tbody>
</table>

- Connect the OBPP to the test system shown in figure 2:
  - Connect wire 1 of Test Power Cable 1 to the positive (+) terminal of the source (MPJA 9604PS Power Supply).
  - Connect wire 2 of Test Power Cable 1 to the negative (-) terminal of the 'Source Relay'.
  - Connect wire 3 of Test Power Cable 1 to the 'Load Relay'.
  - Connect wire 4 of Test Power Cable 1 to the negative (-) terminal of the load ('Transistor Devices RBL-400-600-4000 Variable Load') resistor network in figure 1.
  - Connect the negative terminal of the source to terminal '1' of the 'Source Relay' using Test Power Cable 2.
  - Connect the positive terminal of the load to terminal '2' of the 'Source Relay' using Test Power Cable 3.
  - Connect the common ground from the National Instruments DAQ board to terminal '4-' of the 'Source Relay' and 'Load Relay' using wires '2' of Test Data Cable 2 and Test Data Cable 3, respectively.
  - Connect wire '1' of Test Data Cable 2 from an output port of the DAQ to terminal '4-' of the 'Source Relay' and wire '1' of Test Data Cable 3 from an output port of the DAQ to terminal '4-' of the 'Load Relay'.
  - Connect wire '1' of the data connector on the OBPP to an input port on the DAQ with a 1Ω resistive load using Test Data Cable 1. Then connect the 5V ground on the DAQ to the same input port.
  - Connect the positive terminals of each of the cells to analog inputs 0-3 of the DAQ using Test Voltage Cables 1-4.
  - Connect the positive leads of each of the bypass TFRs to analog inputs 4-7 of the DAQ using Test Bypass Cables 1-4.

- Using Simulink and the previous setup, the test will run for 5 charge/discharge cycles and record the voltage of the individual cells, demonstrating per-cell balancing within one pack. The Simulink file is named 'test.mdl' and is located on the project website under the tab "Resources" -> "Test Software" -> 'test_setup.mdl' in the zip file "test_software.zip".
- Set the MPJA 9604PS Power Supply to supply a 10A current to the CMS.
- Connect the 1Ω Resistors in a 2S-2P configuration as shown in figure 1 as the 'Load'.
First Charge/Discharge Cycle

- The OBPP will initially charge the cells.
- Observe that the yellow LED blinks to indicate that the OBPP is on.

Yellow LED Flashes: [Circle] Pass / [Circle] Fail
Initials: [signature]

- Set up scopes in Simulink to monitor the voltages from the four cells, the bypass LEDs, and the 'done' signal. These seven scopes will be used to analyze the operation of the pack.

Following completion of the test, analysis of the data from the first charge/discharge cycle will be completed in ATR to demonstrate the operation of the bypass circuits.

Criteria for demonstrating operation of bypass is to show that if a cell is greater than 50mV from the lowest cell, the scope of the bypassed cell will show a jump in voltage for a 20 min period. Full analysis for all cells for the full charge cycle will be completed in the ATR.

Second Charge/Discharge Cycle

- Observe when the cells are charging when a bypass LED is turned on, indicating partial resistive bypass. Using the IR heat gun & laser crosshairs, aim as close as possible towards the underside of the board where the power resistors are located and find the maximum temperature.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Within 70°C above 30°C ambient: [Circle] Pass / [Circle] Fail</td>
<td>Initials: [signature]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Wait 15 minutes and repeat previous step again.

<table>
<thead>
<tr>
<th>Temp 1: 33.5 °C</th>
<th>Temp 2: 35.2 °C</th>
<th>Temp 3: 30 °C</th>
<th>Temp 4: 31 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Within 70°C above 30°C ambient: [Circle] Pass / [Circle] Fail</td>
<td>Initials: [signature]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Wait 15 minutes and repeat step a third time.

<table>
<thead>
<tr>
<th>Temp 1: 34.7 °C</th>
<th>Temp 2: 36.9 °C</th>
<th>Temp 3: 33.5 °C</th>
<th>Temp 4: 32.6 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Within 70°C above 30°C ambient: [Circle] Pass / [Circle] Fail</td>
<td>Initials: [signature]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Once the second charge/discharge cycle has completed, stop the Simulink file and save the information collected. Restart the file once the previous data has been saved. Following every two (2) charge/discharge cycles, stop the Simulink file and save a backup of the information collected during that time.
Third, Tenth Charge/Discharge Cycles

- Monitor temperature of board once at end of every charging cycle to make sure that board does not exceed temperature requirements:

  Cycle 3: 50 °C  
  Cycle 4: 43 °C  
  Cycle 5: 42 °C 

  Within 70°C above 30°C ambient: Pass  
  Fail  
  Initials:  

- Following the completion of all five (5) charge/discharge cycles, look at the voltage curve data which the Simulink test collected.

- Identify that the standard deviation of the states of charge over the period of 5 charge/discharge cycles decreased by the following analysis:

  Once the cells have finished the 5 charge/discharge cycles, remove cells from pack and individually charge them to capacity (Vmax being set at 3.8V) by attaching each individual cell to the MPJA 9604PS Power Supply and setting the current to 10A. Record the time required to charge each cell to its maximum voltage:

  Cell 1: 0.1844 hrs  
  Cell 2: 0.2261 hrs  
  Cell 3: 0.2625 hrs  
  Cell 4: 0.0128 hrs

- Multiply the time to top-off by the current used to charge the cells to get the amount of SOC still uncharged in each of the cells. Subtract each of these numbers from the capacity of the cell (10 A-hr) and divide by the cell capacity and multiply by 100 to get the SOC of each cell at the end of the five (5) charge/discharge cycles:

  Uncharged Capacity:

  Cell 1: 1.844 A-hr  
  Cell 2: 2.261 A-hr  
  Cell 3: 3.625 A-hr  
  Cell 4: 0.128 A-hr

  Ending State of Charge:

  \[
  \frac{10 \text{ Amp} \cdot \text{hrs} - x}{10 \text{ Amp} \cdot \text{hrs}} \times 100 = \text{SOC}
  \]

  Cell 1: \( x_1 = 81.56 \% \)  
  Cell 2: \( x_2 = 77.39 \% \)  
  Cell 3: \( x_3 = 73.75 \% \)  
  Cell 4: \( x_4 = 98.72 \% \)

  Compute the average SOCs of the four cells: \( \bar{x} = 82.86 \% \)

- Compute the standard deviation of the cells in the pack by the following formula:

  \[
  \sigma = \sqrt{\frac{(x_1 - \bar{x})^2 + (x_2 - \bar{x})^2 + (x_3 - \bar{x})^2 + (x_4 - \bar{x})^2}{4}} = 9.57 \% \text{SOC}
  \]

  Is the final standard deviation of the cells within the pack less than the standard deviation at the beginning of the test (27%)?

  Pass  
  Fail  
  Initials:  

  RO02-2
• After the last charge/discharge cycle, allow the pack to sit without balancing overnight. If there is more time left in the 24-hour period of the test, continue to observe the board and look for failure conditions.

Does system runs without failure*:

Pass  Fail

Initials: [Signature]

*Failure is defined as the following conditions for board and software:

Board failure: overheating beyond specified threshold temperature, discoloration, combustion or other obvious component failure.

Software failure: relays cease to function and charging/discharging indicators fail to update over the expected duration of a cycle. Further software failure can occur in I2C communication, which will be tested in T002.
Acceptance Test T002:

This test verifies the following requirements:

R002-6: In addition to local controls and indicators, a remote SCADA I^2C system shall be able to monitor in detail the voltage, and current of, and state of charge of the aggregate ESS battery and every individual cell in the CMS ESS, as well as the overall state of charge of the pack ESS parameters.

R002-5: The ESS shall be capable of standalone operation. It shall be possible to properly charge and discharge the ESS without needing an outside computer system for control or monitoring. Indicators shall be provided that give a basic display operational state (charge/discharge rate) and charge state (fuel gauge). Controls shall be provided, if needed, to permit standalone management.

Required Materials:

- MPJA 9604PS Power Supply
- Cell Management System (CMS)
  - 4-cell pack with OBPP (partially charged)
- (2) Gold SDP4040D DC Solid State Relay
- (4) 120 Watt 1-Ohm resistors
- PC running Simulink & RealTerm
- National Instruments BNC2110 Data Acquisition Board
- Test Power Cables 1,2,3
- Test Data Cables 1,2,3
- Test Voltage Cables 1,2,3,4
- Test Bypass Cables 1,2,3,4
- PC to I2C Adaptor (utilizing USB)
- Agilent Digital Multimeter 34401A
- 16710 TE Infrared Thermometer

![Figure 3](image-url)
Test Procedure:

- Maintain the same connection configuration as shown in figure 2 with the following exception:
  - Connect the red connector of ‘Test Data Cable 1’ to the ‘PC to I2C’ Adaptor as displayed in
    Figure 3 to enable I2C communication

- Begin the program RealTerm on the PC, click on the tab which says I2C in order to test the
  functionality of the communication.

- The OBPP will begin charging the pack of cells as an initialization cycle

- I2C commands are formed by three bytes of information:

### I2C Command Format

<table>
<thead>
<tr>
<th>Board Address</th>
<th>Command Byte</th>
<th>Argument 1</th>
<th>Argument 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>7-bits</td>
<td>8-bits</td>
<td>8-bits</td>
<td>8-bits</td>
</tr>
</tbody>
</table>

Initial tests:

- Change the I2C address of the board currently connected to the I2C interface to be board 0x00
  with the following command in RealTerm:
  - Write I2C Address: 00000000-00000000-00010000 0h54100008

- Query the I2C for the Board Number and Firmware Version ID with the following command in
  RealTerm to confirm that the change of I2C address was successful
  - Read Board Number: 00010000-00000001-00011001 0h081B0000
  - Read Version ID: 00010000-00000001-00011000 0h081A0000

Voltages Tests:

- Query via I2C for the voltages of the 4 cells by typing in the following commands into RealTerm:
  - Read Voltage 1: 00010000-00000001-00000001 0h0801F000
  - Read Voltage 2: 00010000-00000001-00000010 0h0802F000
  - Read Voltage 3: 00010000-01000001-00001100 0h0803F000
  - Read Voltage 4: 00010000-00000001-00001100 0h0804F000

<table>
<thead>
<tr>
<th>I2C V1: 3.34 V</th>
<th>I2C V2: 3.36 V</th>
<th>I2C V3: 3.38 V</th>
<th>I2C V4: 3.36 V</th>
</tr>
</thead>
<tbody>
<tr>
<td>A B 2</td>
<td>A C 1</td>
<td>A C F</td>
<td>A B F</td>
</tr>
</tbody>
</table>
• Manually measure the voltages across the terminals of each cell in the CMS
  DMM V1: 3.33 V  DMM V2: 3.34 V  DMM V3: 3.34 V  DMM V4: 3.34 V

SOC & Current Tests
• Query I2C for the integrated current of the pack and time step by entering the following
  commands into RealTerm.

  o Because the system was originally designed for the master device to do the calculations for aggregate battery
    pack SOC, the number which is returned by this query is not the actual SOC of the pack. The number returned is
    the average current which passed through the cell for the duration of the charge/discharge cycle.

  o Read I<sub>INT</sub>:  

  \[
  I_{\text{INT}} \times T = \frac{340 \text{ A} \times \frac{1}{60 \text{ hr}}}{10 \text{ A} \cdot \text{h}} \times 100 = 56.6\% 
  \]

Observe the current indicator on the MPJA 9604PS Power Supply. Record the value, this will be
used as average current to calculate SOC. Record the amount of time that this charge cycle took
to complete, enter values into the following formula and calculate:

\[
I_{\text{AVG}} \times \frac{\text{Time}}{\text{capacity}} \times 100 = \frac{A \times \text{hr}}{10 \text{ A} \cdot \text{h}} \times 100 = \text{___} \%
\]

SOC from I2C and observation differ by less than 10%  Pass / Fail Initials: ___

• Query I2C for the current of the pack by entering the following command into RealTerm:
  o Read current:  

  I2C Current: 4.75 A

• Observe the current indicator on the MPJA 9604PS Power Supply. Test whether the I2C current
  is within 10% C (2A) of the Power Supply current.

  PS Current: 5 A  I2C ± 1A = PS (Pass) / Fail Initials: ___

Temperature Test 1
• Query I2C for the temperatures of the 4 cells by entering the following commands into RealTerm:
  o Read Temp 1:  
  o Read Temp 2:  
  o Read Temp 3:  
  o Read Temp 4:  

  I2C T1: 26.1°C  I2C T2: 22.3°C  I2C T3: 24.2°C  I2C T4: 25.2°C

• Manually measure the temperatures of areas near each of the temp sensors on the OBPP using
  the 16710 TE Infrared Thermometer

  IR T1: 25.9°C  IR T2: 22.2°C  IR T3: 22.2°C  IR T4: 22.8°C
Master Device Test 1
- Query I2C and set all power resistors in bypass for 5 minutes with the following commands in RealTerm:
  - Bypass Switch 1: 00010000 00000000 00001010 00001011 00008000 00008000 00008000 00008000
  - Bypass Switch 2: 00010000 00000000 00001011 00001011 00008000 00008000 00008000 00008000
  - Bypass Switch 3: 00010000 00000000 00001100 00001111 00008000 00008000 00008000 00008000
  - Bypass Switch 4: 00010000 00000000 00001101 00001011 00008000 00008000 00008000 00008000

Red Bypass LEDs turned on for 5 min ± 30 sec: Pass / Fail  
Initials: 

- Setting the resistors in bypass causes the board to go into “non-automatic” mode. Observe that the yellow “status” LED no longer pulses, but remains solid, indicating “non-automatic” mode.

Yellow LED solid: Pass / Fail  
Initials: 

Temperature Test 2
- Query I2C for the temperatures of the 4 cells and manually measure temperatures of areas near each of the temp sensors on the OBPP as in Temperature Test 1:

<table>
<thead>
<tr>
<th>Device</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>I2C</td>
<td>31.4°C</td>
</tr>
<tr>
<td>I2C</td>
<td>33.7°C</td>
</tr>
<tr>
<td>I2C</td>
<td>35.3°C</td>
</tr>
<tr>
<td>I2C</td>
<td>35.7°C</td>
</tr>
<tr>
<td>IR</td>
<td>27.4°C</td>
</tr>
<tr>
<td>IR</td>
<td>24.5°C</td>
</tr>
<tr>
<td>IR</td>
<td>24.0°C</td>
</tr>
<tr>
<td>IR</td>
<td>35.9°C</td>
</tr>
</tbody>
</table>

Subtract temperatures from Temperatures Test 1 from Temperature Test 2 for both I2C and IR:

**I2C:**
- Diff 1: 4.7°C
- Diff 2: 11.4°C
- Diff 3: 11.1°C
- Diff 4: 10.2°C

**IR:**
- Diff 1: 3.5°C
- Diff 2: 2.3°C
- Diff 3: 1.8°C
- Diff 4: 3.1°C

Differences between I2C & IR are no greater than 10% of highest of the two values:

Diff 1: Pass / Fail  Diff 2: Pass / Fail  Diff 3: Pass / Fail  Diff 4: Pass / Fail
Initials: 

Master Device Test 2
- Query I2C and set board back to ‘automatic mode’ with the following command with RealTerm
  - Enter Automatic Mode: 00010000 00000000 00008120 00008000

- Query I2C and determine which mode the system is in (automatic/not) with the following command in RealTerm:
  - Get Mode: 00010000 00000000 00001001 00001001

Does RealTerm return 0x0F? Pass / Fail  
Initials: 

Yellow LED solid blinking: Pass / Fail  
Initials: 

Does system runs without failure*:  Pass / Fail  

Initials: 

*Board failure criteria are the same as in T001

*Software failure: I2C commands remain responsive throughout test.