**Design of Experiments**

**Energy Management System**

A modular solution for power monitoring and management for homes and small businesses

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# Design of Experiments

## Testing Schedule

The initial testing schedule is provided in Table 1. Adjustments to the schedule may be made depending upon other aspects of the project. Unit testing will be done first, to ensure that individual components of the Energy Management System are working correctly. The integration testing follows the unit testing, and is responsible for ensuring that the components work together with one another. Finally, acceptance testing is performed to ensure the system as a whole is working correctly to meet the engineering and marketing requirements.

Table . Preliminary Testing Schedule

|  |  |
| --- | --- |
| Unit Testing | June 2015 |
| Integration Testing | September - October 2015 |
| Acceptance Testing | October - November 2015 |

## Unit Tests

Unit tests verify that individual components are operating as expected. Unit tests are critical to properly debugging a project, as they significantly reduce the scope of variables to be tested. Unit tests validate individual components, ensuring that higher level tests will not fail due to unexpected operation of the subcomponents. The unit tests for this project are shown below.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Test Name: | Electrical - Power Supply DC Output Voltage – Test 1 | | | | |
| Setup: | Apply 120 VAC to terminals 1 and 2 of Recom power supply module | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | Measure the output voltage at pin 3 with respect to pin 4 | DC voltage of 3.3V is measured +/- 5% |  |  |  |
| 2 | Apply load resistors ranging from 1k to 4.8k across pins 3 and 4 | Verify DC voltage of 3.3V is measured +/- 5% |  |  |  |

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| --- | --- | --- | --- | --- | --- |
| Test Name: | Electrical - Voltage Sense Output Voltage – Test 2 | | | | |
| Setup: | Apply voltage of 0V to the input of the voltage sense circuitry | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | Measure the output voltage | The measured output voltage should correspond to the scale factor \* input +/- 10% |  |  |  |
| 2 | Increase input voltage by steps of 5V until 170V (120V RMS) is achieved and repeat step 1 | The measured output voltage should correspond to the scale factor \* input +/- 10% |  |  |  |

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| --- | --- | --- | --- | --- | --- |
| Test Name: | Electrical - Voltage Sense Output Voltage Frequency Response – Test 3 | | | | |
| Setup: | Set a function generator to a sinusoidal signal of a fixed amplitude at a frequency of 10 Hz | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | Measure the output amplitude Voltage | Results should match dc test. |  |  |  |
| 2 | Repeat step 1 at frequencies of 100, 200, 500, 1000 Hz | As frequency increases the output amplitude will decrease with frequency |  |  |  |
| 3 | Plot the output voltage amplitude vs frequency |  |  |  |  |
| 4 | Verify that output frequency response is acceptable for application | 3dB bandwidth of at least 1000 Hz |  |  |  |

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| --- | --- | --- | --- | --- | --- |
| Test Name: | Electrical - Voltage Sense Circuit Power Supply Draw – Test 4 | | | | |
| Setup: | Install an ammeter in the power supply input to the voltage sense circuitry. | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | Measure the current draw at rated supply voltage. | The current draw should be less than TBD ma. |  |  |  |

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| --- | --- | --- | --- | --- | --- |
| Test Name: | Electrical - Current Sense Circuit Power Supply Draw – Test 5 | | | | |
| Setup: | Install an ammeter in the power supply input to the current sense circuitry. | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | Measure the current draw at rated supply voltage. | The current draw should be less than TBD ma. |  |  |  |

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| --- | --- | --- | --- | --- | --- |
| Test Name: | Electrical - Load Switch - Switching Control – Test 6 | | | | |
| Setup: | Connect a power rheostat between the high side triac output and the ac neutral. Connect an ammeter in series with the load. | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | Set the Triac to the OFF position | Verify no current flow through the load |  |  |  |
| 2 | Set the Triac to the ON position and adjust the rheostat for 5 amps load current. | 5 amp current flow through the load |  |  |  |
| 3 | Repeat steps 1 and 2 with the rheostat adjusted for 10, 15 and 20 amps. | 10, 15 and 20 amps current flow through the load |  |  |  |

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| --- | --- | --- | --- | --- | --- |
| Test Name: | Electrical - Load Switch - Switching Control – Test 7 | | | | |
| Setup: | Modify triac load circuit to monitor load voltage with an oscilloscope. | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | Set the Triac to the OFF position | No current flow through the load |  |  |  |
| 2 | Set the Triac to the ON position | Current flow through the load |  |  |  |
| 3 | Turn triac to the OFF position | Verify with oscilloscope that triac shuts off at next zero crossing of ac waveform |  |  |  |

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| --- | --- | --- | --- | --- | --- |
| Test Name: | Electrical - Load Switch - Temperature Measurements – Test 8 | | | | |
| Setup: | Same setup as for Triac Load Switching | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | Apply loads ranging from 0A to 20A (maximum) |  |  |  |  |
| 2 | Measure temperature for all applied currents | Allow sufficient time for temperature to stabilize |  |  |  |
| 3 | Generate a temperature vs current plot | Temperature will increase with load current |  |  |  |
| 4 | Verify if measured temperatures are acceptable for application | A maximum temperature rise of 20 C. |  |  |  |

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| --- | --- | --- | --- | --- | --- |
| Test Name: | Web App - Signing In – Test 9 | | | | |
| Setup: | The web application is running | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | Load into the web application |  |  |  |  |
| 2 | Enter Invalid username/password | Invalid username/password message |  |  |  |
| 3 | Enter valid username/password | Application loads |  |  |  |

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| --- | --- | --- | --- | --- | --- |
| Test Name: | Web App - Viewing Charts – Test 10 | | | | |
| Setup: | Logged into web application | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | Go to the 'charts' tab | Chart interface appears |  |  |  |
| 2 | Select a single outlet | Default' chart appears for that outlet |  |  |  |
| 3 | Cycle through all time scales | Chart should display the appropriate time scale |  |  |  |
| 4 | Cycle through all time divisions | Chart should display the appropriate time divisions |  |  |  |
| 5 | Select a group of outlets | Default' chart appears for that outlet |  |  |  |
| 6 | Cycle through all time scales | Chart should display the appropriate time scale |  |  |  |
| 7 | Cycle through all time divisions | Chart should display the appropriate time divisions |  |  |  |

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| Test Name: | Web App - Naming Outlets – Test 11 | | | | |
| Setup: | Logged into web application | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | Select an outlet in the table |  |  |  |  |
| 2 | Click rename/double click | Naming window appears |  |  |  |
| 3 | Enter a new name | Screen reflects entry |  |  |  |
| 4 | Save the name | Window closes and table updates, reflecting the new name |  |  |  |

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| --- | --- | --- | --- | --- | --- |
| Test Name: | Web App - Grouping Outlets – Test 12 | | | | |
| Setup: | Logged into web application | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | Navigate to the 'groups' tab | Grouping interface appears |  |  |  |
| 2 | Test grouping multiple outlets | The outlets become grouped |  |  | Details Unknown |

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| --- | --- | --- | --- | --- | --- |
| Test Name: | Web App - Scheduling Interface – Test 13 | | | | |
| Setup: | Logged into web application | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | Navigate to the 'scheduling' tab | The scheduling interface appears |  |  |  |
| 2 | Create a single (one-time) event | The event appears on the calendar |  |  |  |
| 3 | Edit the event | The event changes on the calendar |  |  |  |
| 4 | Create another event |  |  |  |  |
| 5 | Set this event to recurring on Wednesdays | The same event appears on every Wednesday |  |  |  |
| 6 | Delete a single instance of this event | That one instance is removed |  |  |  |
| 7 | Create multiple events of different types | The schedule handles all of the events |  |  |  |
| 8 | Multiple events on a single day |  |  |  |  |

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| Test Name: | Web App - Scheduling Job – Test 14 | | | | |
| Setup: | The web application is running (this is a background process) | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | Create a simple schedule using the web interface |  |  |  |  |
| 2 | Close the application |  |  |  |  |
| 3 | Using text output in a log file, verify that events are happening at scheduled times | The scheduled events are being fired on time |  |  |  |

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| Test Name: | Web App - Toggle outlet state – Test 15 | | | | |
| Setup: | Logged into web application | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | Navigate to the 'main' tab |  |  |  |  |
| 2 | Select an outlet in the table | Outlet highlighted |  |  |  |
| 3 | Click 'state' button | State' window appears |  |  |  |
| 4 | Observe current state | Should either be on or off |  |  |  |
| 5 | Toggle the state and save | Window disappears and table is updated |  |  |  |

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| --- | --- | --- | --- | --- | --- |
| Test Name: | Web App - Scheduling Job – Test 16 | | | | |
| Setup: | The web application is running (this is a background process) | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | Create a simple schedule using the web interface |  |  |  |  |
| 2 | Close the application |  |  |  |  |
| 3 | Using text output in a log file, verify that events are happening at scheduled times | The scheduled events are being fired on time |  |  |  |

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| Test Name: | Web App – Settings – Test 17 | | | | |
| Setup: | Logged into web application | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | Navigate to the 'settings' tab | Settings interface appears |  |  |  |
| 2 | Change each setting | Verify the settings update on screen |  |  |  |
| 3 |  | Verify settings are reflected in other locations |  |  |  |
| 4 |  | Verify settings are reflected in database |  |  |  |

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| Test Name: | Database - Load Test – Test 18 | | | | |
| Setup: |  | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | Insert 1000 rows per second for 10 seconds | 10,000 rows are in the database |  |  |  |
| 2 | Read all of the rows from the database | All 10,000 rows are correctly read from the database |  |  |  |

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| Test Name: | Database - Insert Outlet Module Data – Test 19 | | | | |
| Setup: |  | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | Insert data for one outlet module | 1 outlet module has been added to the database |  |  |  |
| 2 | Read the data for the inserted outlet module | The correct data is read from the database |  |  |  |

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| Test Name: | Database – Insert Outlet Reading Data – Test 20 | | | | |
| Setup: |  | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | Insert data for one outlet reading | One outlet reading has been added to the database |  |  |  |
| 2 | Read the data for the inserted outlet reading | The correct data is read from the database |  |  |  |

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| --- | --- | --- | --- | --- | --- |
| Test Name: | Database – Compression of Data – Test 21 | | | | |
| Setup: | Outlet readings that are 30 days old | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | Set (or wait for) data to be 31 days old. | Data from 30 days ago is now 31 days ago |  |  |  |
| 2 | Validate averaged data | The averaged data should be correct from averaging 4 outlet readings |  |  |  |

## Integration Tests

Once the Unit tests have been passed, it is critical that the boundary between the subsystems are thoroughly tested. This boundary is known as the interface between components, and is the primary location for errors when endeavoring to utilize integration tests. In addition, it is only upon integration that some components can be tested, as they lack a usable interface for reasonable tests. Thus the Integration tests for the EMS is shown here.

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| --- | --- | --- | --- | --- | --- |
| Test Name: | Electrical - Voltage Sense with Controller – Test 22 | | | | |
| Setup: |  | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | Read a static voltage from the voltage sense circuitry | Valid voltage measurement computed in processor |  |  |  |
| 2 | Read in a dynamic voltage at frequencies up to 10kHz | Valid voltage measurement computed in processor |  |  |  |
| 3 | Verify processor average voltage calculation | Valid average voltage calculated |  |  |  |
| 4 | Calculate frequency of voltage waveform | Valid voltage waveform frequency determined |  |  |  |

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| --- | --- | --- | --- | --- | --- |
| Test Name: | Electrical - Current Sense with Controller – Test 23 | | | | |
| Setup: |  | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | Read a static current from the current sense circuitry | Valid voltage measurement computed in processor |  |  |  |
| 2 | Read in a dynamic current at frequencies up to 10kHz | Valid voltage measurement computed in processor |  |  |  |
| 3 | Verify processor average current calculation | Valid average voltage calculated |  |  |  |
| 4 | Calculate frequency of current waveform | Valid voltage waveform frequency determined |  |  |  |

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| --- | --- | --- | --- | --- | --- |
| Test Name: | Electrical - Load Switch with Controller – Test 24 | | | | |
| Setup: |  | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | Processor Request to turn load switch ON | Verify load switch is in ON state |  |  |  |
| 2 | Processor Request to turn load switch OFF | Verify load switch is in OFF state |  |  |  |

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| --- | --- | --- | --- | --- | --- |
| Test Name: | Electrical - PCB Testing – Test 25 | | | | |
| Setup: |  | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | Visually inspect for obvious mechanical flaws |  |  |  |  |
| 2 | Verify that power and ground planes are not shorted together (use ohmmeter) |  |  |  |  |
| 3 | Verify electrical continuity of individual traces |  |  |  |  |
| 4 | Verify all ICs have been installed properly with correct pin orientation |  |  |  |  |
| 5 | Verify all ICs have been installed properly with correct pin orientation |  |  |  |  |
| 6 | Apply Power to Board And Verify all DC voltages are as expected |  |  |  |  |

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| Test Name: | Web App - Receive Database Information – Test 26 | | | | |
| Setup: | Logged into web application and database is running and connected | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | View the list of outlets | All current outlets should be displayed |  |  |  |
| 2 | View the list of groups | All groups are shown with appropriate outlets |  |  |  |
| 3 | View many charts | Calculate and verify that the charts are displaying the correct information |  |  |  |
| 4 | View the settings | Verify settings match database settings |  |  |  |
| 5 | Manually add outlet to database and refresh data | Outlet should appear in list |  |  |  |
| 6 | Manually change settings and refresh | New settings should appear in app |  |  |  |

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| --- | --- | --- | --- | --- | --- |
| Test Name: | Web App - Send Database Information – Test 27 | | | | |
| Setup: | Logged into web application and database is running and connected | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | Rename an outlet | Verify data in database |  |  |  |
| 2 | Create/edit groups | Verify data in database |  |  |  |
| 3 | Change settings | Verify data in database |  |  |  |
| 4 | Create new user account | Verify data in database |  |  |  |
| 5 | Toggle status of outlet or group | Verify data in database |  |  |  |

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| --- | --- | --- | --- | --- | --- |
| Test Name: | Web App / Database – Requesting Real Time Readings – Test 28 | | | | |
| Setup: | Logged into web application and database is running and connected | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | Go to the 'charts' tab | Chart interface appears |  |  |  |
| 2 | Select a single outlet | Default' chart appears for that outlet |  |  |  |
| 3 | Select real time update | Chart displays real time information, readings in database have real time flag set to 1 |  |  |  |
| 4 | End user session | User session ends, real time readings are removed from the database |  |  |  |

## Acceptance Tests

Acceptance tests are the tests conducted to verify that the requirements of a project have been met. Acceptance tests validate the product, and verify that it works as expected upon completion. As such, the acceptance tests of the EMS are closely coupled to the engineering requirements. Passing all acceptance tests will guarantee that all marketing and engineering requirements have been satisfied. In order to release a finished product fulfilling the engineering specifications, the project must pass the following tests.

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| Test Name: | Module Costs – Test 29 | | | | |
| Setup: |  | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | Calculate component, shipping, and fabrication costs for Outlet Module | Cost should not exceed $50 |  |  |  |
| 2 | Calculate component, shipping, and fabrication costs for Main Module | Cost should not exceed $200 |  |  |  |

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| --- | --- | --- | --- | --- | --- |
| Test Name: | Short Installation Time – Test 30 | | | | |
| Setup: | Obtain Main Module, Outlet Module(s) | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | Have certified Electrician Replace/Install each Outlet Module | Installation of each module should not exceed 30 minutes |  |  |  |
| 2 | Have certified Electrician Replace/Install the Main Module | Installation and configuration of main module should not exceed 2 hours |  |  |  |

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| --- | --- | --- | --- | --- | --- |
| Test Name: | Power Measurement Accuracy Test – Test 31 | | | | |
| Setup: | Apply AC mains to system, provide various resistances | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | Apply various resistors (fixing the current), and obtain the power consumption results | For each resistor, verify that the measured power is within 10% of the fixed power usage |  |  |  |

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| --- | --- | --- | --- | --- | --- |
| Test Name: | Usability Test – Test 32 | | | | |
| Setup: | Professionally installed modules, Provided an hour of familiarization with application | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | User navigates to application or web interface | Page opens to login screen, unless otherwise configured |  |  |  |
| 2 | User enters login credentials (existing user or default credentials) | Success within 3 minutes |  |  |  |
| 3 | Name an outlet module | Success within 5 minutes |  |  |  |
| 4 | View usage statistics of a single module | Success within 5 minutes |  |  |  |
| 5 | Turn an outlet module on/off | Success within 5 minutes |  |  |  |
| 6 | remove an outlet module | Success within 5 minutes |  |  |  |
| 7 | reach and configure schedule | Success within 5 minutes |  |  |  |

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| --- | --- | --- | --- | --- | --- |
| Test Name: | Outlet Module Sizing – Test 33 | | | | |
| Setup: | Outlet Module is fabricated and constructed | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | Place outlet module in (at the maximum size) a 22 cubic inch electrical box. | Should sit flat with faceplate, without bulging out of the box |  |  |  |
| 2 | Wire the electrical box and module with mains cabling | Should sit flat with faceplate, without bulging out of the box |  |  |  |

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| Test Name: | Load Testing – Test 34 | | | | |
| Setup: |  | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | Connect a single module, with default communication rate | Data communication sufficiently low that data is received without issue |  |  |  |
| 2 | Connect a single module, with real time communication rate | Data communication sufficiently low that data is received without issue |  |  |  |
| 3 | Connect up to 10 modules, with real time communication rate | Data communication sufficiently low that data is received without issue |  |  |  |
| 4 | Connect 100 Modules, with default communication rate | Data communication sufficiently low that data is received without issue |  |  |  |
| 5 | Connect 100 Modules, with 5 in real time communication mode | Data communication sufficiently low that data is received without issue |  |  |  |

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| Test Name: | Schedule testing – Test 35 | | | | |
| Setup: |  | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | Navigate to the 'scheduling' tab | The scheduling interface appears |  |  |  |
| 2 | Create a single (one-time) event | The event appears on the calendar |  |  |  |
| 3 | Observe outlet before/after scheduled time | Outlet should turn On/Off according to schedule |  |  |  |
| 4 | Create another event |  |  |  |  |
| 5 | Set this event to recurring on Wednesdays | The same event appears on every Wednesday |  |  |  |
| 6 | Observe outlet before/after scheduled time multiple days | Outlet should turn On/Off according to the schedule |  |  |  |
| 7 | Delete a single instance of this event | That one instance is removed |  |  |  |
| 8 | Observe outlet before/after the previous scheduled time | The outlet should no longer be controlled by this scheduled event |  |  |  |

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| Test Name: | Remote Tests – Test 36 | | | | |
| Setup: |  | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | Navigate to the 'outlet' tab | The outlet interface appears |  |  |  |
| 2 | Select a target outlet |  |  |  |  |
| 3 | Turn outlet on | The outlet should now be on, without affecting other outlets |  |  |  |
| 4 | Turn outlet off | The outlet should now be off, without affecting other outlets |  |  |  |

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| Test Name: | High Pot Testing – Test 37 | | | | |
| Setup: | Short all control terminals together and all power terminals together | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | Apply a 1500VAC using a high pot tester between the control and power circuits | No indication of breakdown |  |  |  |

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| --- | --- | --- | --- | --- | --- |
| Test Name: | Power Line Transient Survival – Test 38 | | | | |
| Setup: | Connect a transient pulse generator to the power line input | | | | |
| Steps | Action | Expected Results | Pass | Fail | Comments |
| 1 | Apply a impulse voltage per IEC-60664-1 | No indication of component failure |  |  |  |
| 2 | Perform a functional test of the unit, post-impulse test | Functional test results as expected |  |  |  |
| NOTE | If an impulse tester is not available this test will be verified through analysis. | | | | |

# Requirements

Requirements are provided for reference such that each test case can be traced to particular requirements and to verify that all requirements are tested. Since engineering requirements are already mapped to marketing requirements only engineering requirements are used for test case coverage.

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| --- | --- | --- |
| Marketing requirements | Engineering Requirements | Justification |
| 6 | 1. Production cost shall not exceed $200 for the main unit and $50 for the outlet modules. | This is based upon analysis of a competitive market and current design requirements. |
| 7 | 1. Installation time of an outlet module within an electrical box shall not exceed 30 minutes during typical installation. | Using a professional electrician, the outlets can be installed within this time frame. |
| 4 | 1. The system shall survive a 2500V impulse voltage per IEC-60664-1. | This will prevent devices from being damaged due to transient spikes on the power line. |
| 4 | 1. Control circuits shall be isolated from power line by 1250V RMS minimum. | Electrical isolation is required by safety agencies for equipment connected to the AC power line. |
| 1 | 1. The control unit shall be capable of varying the load power from 0 to full power for resistive loads. | Dimming function allows reducing load power consumed for energy savings. This is only applicable for purely resistive loads (i.e. lightbulbs, heaters, etc.). |
| 1 | 1. The system shall measure power consumption with an accuracy of ± 10 % | This will allow for the system to measure usage accurately enough for the typical user. |
| 1,2,3,5,8 | 1. A web interface or web application shall allow the monitoring and management of the system. | This will allow for user to be able to manage the system and perform various tasks associated with the system. |
| 8 | 1. The user shall be able to understand complete system functionality within an hour. | Analysis shows that an intuitive interface should require minimal time to operate. |
| 4 | 1. The system shall use only UL recognized components. | Safety agency approvals will be required to sell product commercially. |
| 9 | 1. The system shall be able to fit into current standard electrical outlets. | To be fully integrated and competitive, the system must be able to replace current outlets. |
| 10 | 1. The system shall have greater than 95% efficiency at maximum rated load. | To achieve energy savings and to avoid excessive heating of the wall units. |
| 2,3 | 1. Wall units shall be identifiable. | This allows the system to know what information is coming from what wall unit and to provide individual control. |
| 11 | 1. All modules shall transmit at a BPS rate sufficient to relay commands and usage data at the chosen sampling frequency. | In order to have reliable communication, the modules must have an adequate minimum communication rate. |

# Test Coverage Matrix

This test coverage matrix verifies that all engineering requirements are fully tested. The requirement number corresponds to requirements listed in section 3, whereas the test number corresponds to the tests listed in section 2.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Engineering Requirement | | | | | | | | | | | | |
| Test Number | A | B | C | D | E | F | G | H | I | J | K | L | M |
| 1 |  |  |  |  | X | X |  |  |  |  |  |  |  |
| 2 |  |  |  |  |  | X |  |  |  |  |  |  |  |
| 3 |  |  |  |  |  | X |  |  |  |  |  |  |  |
| 4 |  |  |  |  |  |  |  |  |  |  | X |  |  |
| 5 |  |  |  |  |  |  |  |  |  |  | X |  |  |
| 6 |  |  |  |  | X |  |  |  |  |  |  |  |  |
| 7 |  |  |  |  | X |  |  |  |  |  |  |  |  |
| 8 |  |  |  |  |  |  |  |  | X |  | X |  |  |
| 9 |  |  |  |  |  |  | X |  |  |  |  |  |  |
| 10 |  |  |  |  |  |  | X |  |  |  |  |  |  |
| 11 |  |  |  |  |  |  | X |  |  |  |  | X |  |
| 12 |  |  |  |  |  |  |  |  |  |  |  | X |  |
| 13 |  |  |  |  |  |  | X |  |  |  |  |  |  |
| 14 |  |  |  |  |  |  | X |  |  |  |  |  |  |
| 15 |  |  |  |  | X |  |  |  |  |  |  | X |  |
| 16 |  |  |  |  | X |  |  |  |  |  |  |  |  |
| 17 |  |  |  |  |  |  |  | X |  |  |  |  |  |
| 18 |  |  |  |  |  |  | X |  |  |  |  |  |  |
| 19 |  |  |  |  |  |  |  |  |  |  |  | X |  |
| 20 |  |  |  |  |  |  | X |  |  |  |  |  |  |
| 21 |  |  |  |  |  |  | X | X |  |  |  |  |  |
| 22 |  |  |  |  |  | X |  |  |  |  |  |  |  |
| 23 |  |  |  |  |  | X |  |  |  |  |  |  |  |
| 24 |  |  |  |  | X |  |  |  |  |  |  |  |  |
| 25 |  |  |  |  |  |  |  |  | X |  |  |  |  |
| 26 |  |  |  |  |  |  | X |  |  |  |  |  |  |
| 27 |  |  |  |  |  |  | X |  |  |  |  |  |  |
| 28 |  |  |  |  |  |  | X | X |  |  |  |  |  |
| 29 | X |  |  |  |  |  |  |  |  |  |  |  |  |
| 30 |  | X |  |  |  |  |  |  |  |  |  |  |  |
| 31 |  |  |  |  |  | X |  |  |  |  |  |  |  |
| 32 |  |  |  |  |  |  |  | X |  |  |  |  |  |
| 33 |  |  |  |  |  |  |  |  |  | X |  |  |  |
| 34 |  |  |  |  |  |  | X |  |  |  |  |  |  |
| 35 |  |  |  |  |  |  |  |  |  |  |  |  | X |
| 36 |  |  |  |  |  |  | X |  |  |  |  |  |  |
| 37 |  |  |  | X |  |  |  |  |  |  |  |  |  |
| 38 |  |  | X |  |  |  |  |  |  |  |  |  |  |