Design of Experiments

Energy Management System

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

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2 DESIGN OF EXPERIMENTS

2.1 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 1. Preliminary Testing Schedule

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

2.2 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%			

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%			

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			

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.			

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.			

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			

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			

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.			

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			

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			

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			

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

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				

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			

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			

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			

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			

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			

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			

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			

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			

2.3 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.

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			

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			

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			

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				

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			

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			

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			

2.4 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.

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			

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			

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			

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			

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			

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			

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			

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			

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			

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.				

3 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.

Marketing requirements	Engineering Requirements	Justification
6	A. 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	B. 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	C. 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	D. 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	E. 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	F. 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	G. 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	H. 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	I. The system shall use only UL recognized components.	Safety agency approvals will be required to sell product commercially.
9	J. 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	K. 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	L. 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	M. 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.

4 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	
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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										