Energy Management System

SYSTEM ELECTRONICS HIGH RISK INVESTIGATION

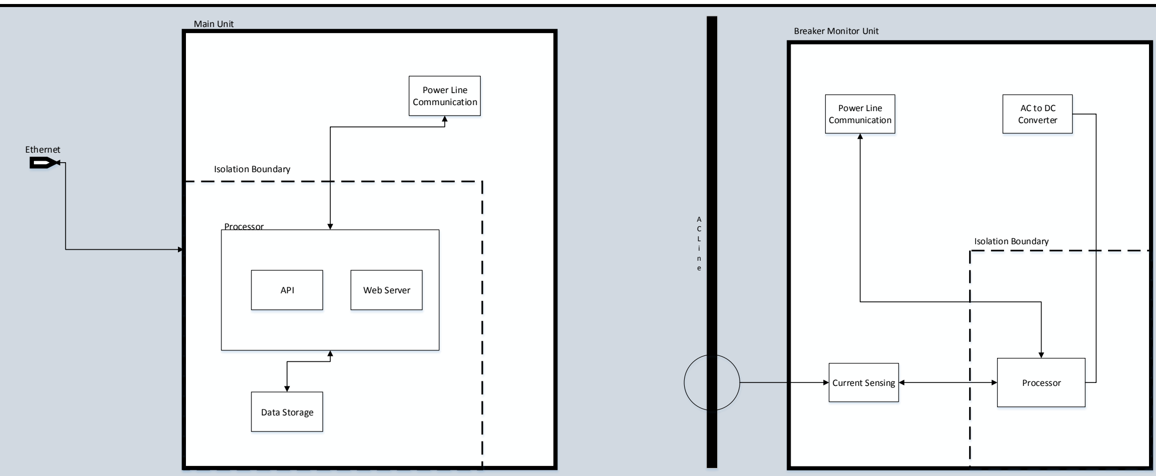
Donald MacIntyre – April 14, 2015

Presentation Overview

- Energy Management System Overview
- System Electronics Overview
  - Risk Specification
  - Risk Investigation – Solutions Considered – Pugh Tables
- Risk Mitigation Design Details
- Parts List
- Testing Strategy
- Uncertainties
- Questions

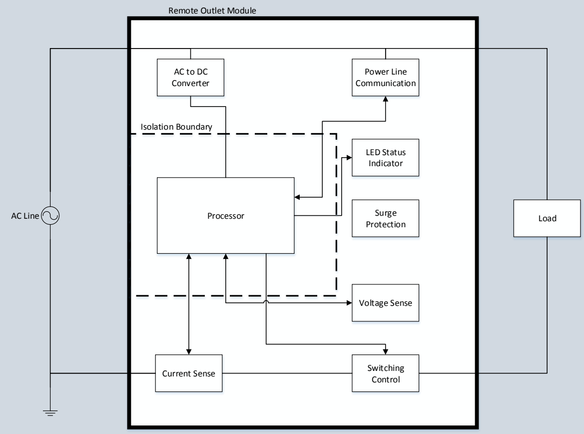
Energy Management System Overview

- The Energy Management system is being developed to provide a modular power control and monitoring solution for homes and small business allowing for improved energy management.
- The Energy Management System allows users to:
  - Monitor total power consumption
  - Control and schedule power consumption remotely
- The Energy Management will consist of two principal hardware components:
  - Main Unit – Contains master controller, data storage and hosts web application
  - Remote Units – Contains all necessary hardware electronics to perform:
    - Load switching
    - Power measurements
    - Power line communication



Main Unit

Functional Block Diagram



Remote Outlet Modules

Functional Block Diagram

Remote Outlet Modules

- To simplify the system electronics risk investigation, the remote outlet modules were focused on and the investigation was broken into the following parts:
  - Power Supply – AC to DC Power Conversion
  - Surge Protection
  - Switching Control
  - Power Sensing
    - Current Sensing
    - Voltage Sensing
  - Controller

Module	AC to DC Power Supply
Inputs	AC Voltage: 120 VRMS 60 Hz
Outputs	DC Voltage: Low voltage DC Supply and references voltages
Power	2 watts or less expected (will depend on final circuit design needs)
Functionality	Convert AC line voltages to necessary voltages to power all other modules. Each module powered by this block will have current and voltage power requirements which this block shall meet.

	Concepts		
Selection Criteria	Capacitive Coupled Circuit	Linear Supply	Switch Mode Supply
Power Delivered	0	+	+
Isolation	-	+	0
Size	+	-	+
Cost	+	-	-
Positive	2	2	2
Neutral	1	0	1
Negative	1	2	1
Net Score	1	0	1
Rank	1	2	1
Continue	Yes	No	Yes

Power Supply

Block Requirements and Concept Selection

Module	Surge Protection
Inputs	Voltage: 120 VRMS 60 Hz
Outputs	Voltage: Surge protected output voltage
Surge Energy	Investigate recommendations for typical household branch circuit
Functionality	This module shall provide protection from voltage spikes and/or surges which is typically seen in the home due to lightning strikes. In the event of a power surge/spike all devices shall be protected such that they are functional after a power event.

	Concepts			
Selection Criteria	GDT	TVS	MOV	TSPD
Cost	-	0	+	0
Energy Dissipated	+	-	0	+
Response Time	-	+	0	0
Clamping Voltage	0	0	0	+
Length of Life	-	-	+	0
Positive	1	1	2	2
Neutral	1	2	3	3
Negative	3	2	0	0
Net Score	-2	-1	2	2
Rank	4	3	1	1
Continue	No	No	Yes	No

Surge Protection

Block Requirements and Concept Selection

Module	Switching Control
Inputs	Voltage: 120 VRMS 60 Hz Digital: Enable Signal with the desired status of the switch control unit encoded.
Outputs	Current: Ability to conduct 20 ARMS with minimal power loss
Functionality	Capable of switching a load on or off based on an input signal. A system stretch goal also includes being able to modify the power delivered to a load thus producing a dimming functionality which would provide a method for saving power for purely resistive loads.

	Concepts		
Selection Criteria	Triac	Relay	Transistor
Cost	0	0	0
Switching Speed	+	0	+
Isolation	0	+	-
Interfacing	0	0	-
Power Dissipated	+	-	0
Phase Control	+	0	0
Positive	3	1	1
Neutral	3	4	3
Negative	0	1	2
Net Score	3	0	-1
Rank	1	2	3
Continue	Yes	No	No

Load Switching

Block Requirements and Concept Selection

Module	Power Sensing
Inputs	Voltage: 120 VRMS 60 Hz Current: 0.5 ARMS min, 20 ARMS max
Outputs	Digital: Digital value representing the amount of current sensed. Digital: Digital value representing the amount of voltage sensed.
Functionality	Measure current through and voltage across a load, at a sample rate high enough to calculate RMS values of non-sinusoidal waveforms.

Power Sensing Requirements

Block Requirements

Current Sense			
	Concepts		
	Sampling Resistor	Hall Effect Sensor	Integrated Circuit
Effect on circuit	-	+	+
Accuracy	-	0	+
Cost	+	0	0
Positive	1	1	2
Neutral	0	2	1
Negative	2	0	0
Net Score	-1	1	2
Rank	3	2	1
Continue	No	No	Yes

Power – Current Sensing

Concept Selection – Pugh Table

	Concepts	
Selection Criteria	Differential Amplifier	Optical Isolator
Accuracy	0	0
Cost	+	-
Interfacing	0	0
Isolation	0	+
Linearity	+	0
Positive	2	1
Neutral	3	3
Negative	0	1
Net Score	2	0
Rank	1	2
Continue	Yes	No

Power – Voltage Sensing

Concept Selection – Pugh Table

Module	Controller
Inputs	Voltage: DC Input Voltage Digital: Control Signals From Main Unit Analog: Current Measurement data Analog: Voltage Measurement data
Outputs	Digital: Control information to main unit Digital: Load Switching Control Enable
Functionality	Control current and voltage sampling hardware, control switching circuitry and transmit/receive data to/from main unit.

	Concepts		
Selection Criteria	TI MSP430	STMicro	PIC
Cost	+	0	+
Size	+	+	+
Development Tools	+	-	0
Development Time	0	0	0
Interface	0	0	0
Positive	3	1	2
Neutral	2	3	3
Negative	0	1	0
Net Score	3	0	2
Rank	1	3	2
Continue	Yes	Yes	Yes

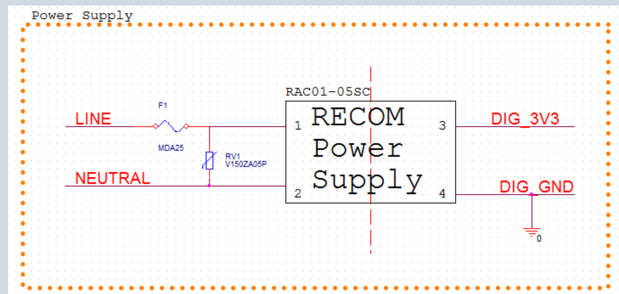
Controller

Power Supply – Design Risk Mitigation

- Based on analysis completed, the power supply design was broken up into an iterative process with two solutions.

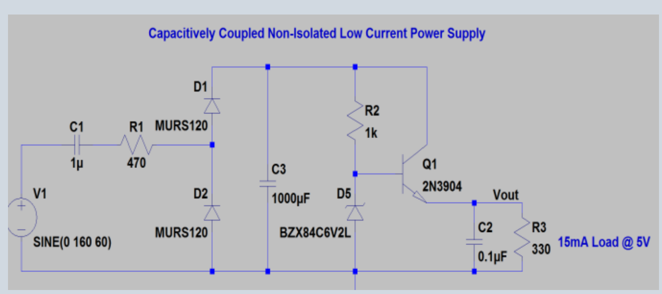
Power Supply – Generation 1

- Recom Switch Mode Supply
  - Will provide electrical isolation during testing and debugging process
  - Provide a proven and working solution thus allowing for debugging and troubleshooting efforts to be spent working on more serious unknowns
- Shortcomings of Generation 1 Power Supply
  - Recom power supplies are expensive ($12.34 dollars a unit) and would not be feasible for a production environment



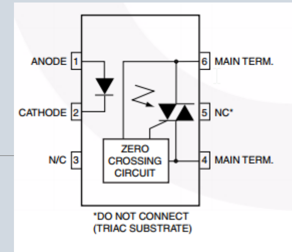
Power Supply – Generation 2

- Capacitively Coupled Power Supply
  - Will provide a cheap solution allowing the project to meet cost goals.
  - Will provide a smaller implementation thus taking up less board space
- Shortcomings of Generation 2 Power Supply
  - Dependent on low power demands
  - All electronics will be running at line potential (no isolation), which is common in competing products such as the Kill-a-Watt meter

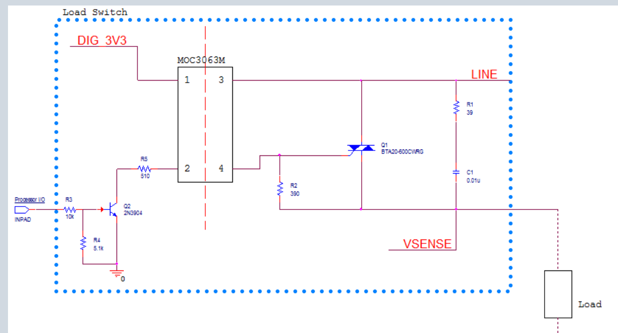


Load Switch – Design Risk Mitigation

- Triac – bidirectional device, commonly used as switches in AC circuits
- MOC3063M – optically coupled triac driver, allows isolated source (processor) to drive the load
- Contains zero crossing circuitry thus mitigating need to develop software to fire the triac
- Mitigates Design:
  - Inexpensive proven solution
  - Provides isolation between processor and AC line electronics
  - Meets all design requirements
  - Provides ability to meet stretch goal of phase control

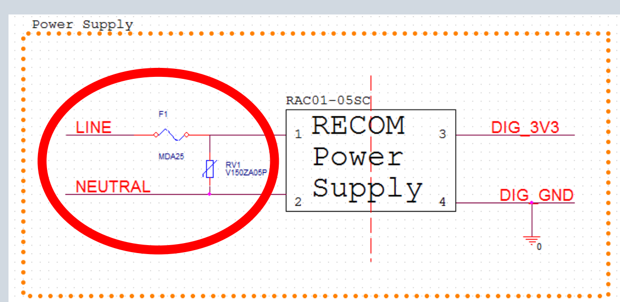


MOC3063M - Schematic

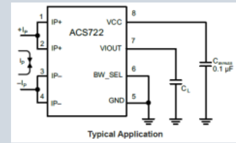


Surge Protection – Design Risk Mitigation

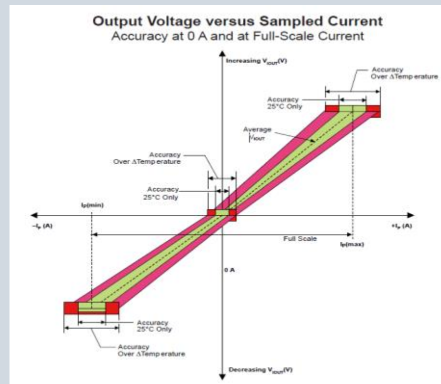
- Surge Protection easily mitigated as it is addressed by all electronics currently manufactured
- Surge protection circuitry:
  - No effect on circuit during normal operation
  - MOV will dissipate excess energy in event of a surge
  - Slow blow fuse will further protect circuitry by blowing if MOV fails as a short circuit

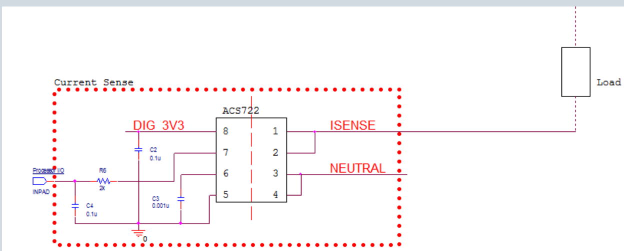


Current Sensing – Design Risk Mitigation

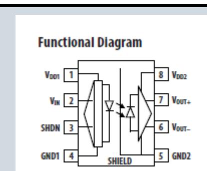


- Hall Effect Current Sensor – Provides a DC voltage that can be sampled by controller which corresponds to measured current.
- Mitigates Design:
  - Inexpensive proven solution
  - Isolation between digital and AC line electronics
  - Due to Hall Effect, no effect on the load

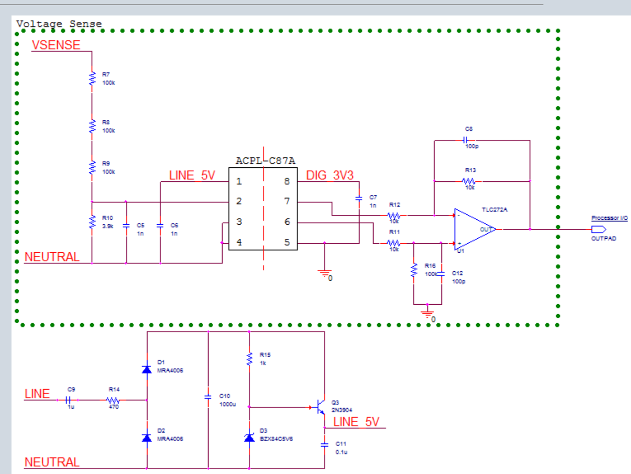




Voltage Sensing – Design Risk Mitigation

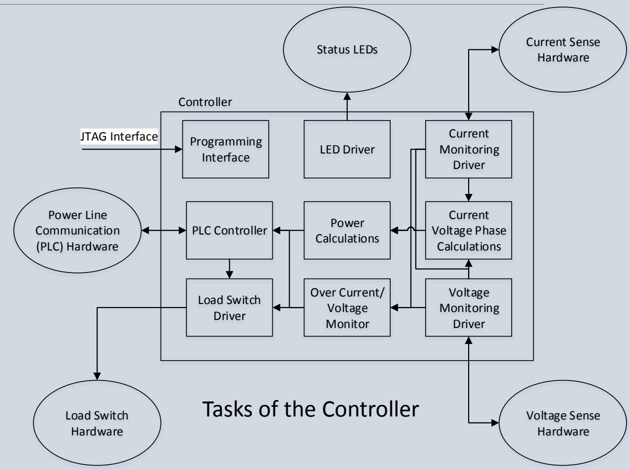


- Optically Isolated Amplifier designed for voltage sensing
  - 2V input range, high input impedance minimizing loading effects
  - Provides differential output voltage proportional to input voltage
  - Uses sigma delta modulation to transmit across isolation barrier
  - ACPL-C87A, requires reference voltage with respect to neutral
    - Simply DC power supply needed to provide 5V reference
- Mitigates Design:
  - Inexpensive proven solution
  - Isolation
  - Little effect on load



Controller – Design Risk Mitigation

- Mitigates Design:
  - Extensive application notes and source code available, can be used as a basis for this project
  - Excellent development tools
  - Has analog to digital hardware built in thus eliminating need for custom ADC hardware



Tasks of the Controller

Part Number	Description	Vendor	Cost per Unit	Qty	Ext Cost	Lead Time	Functional Block
RAC01-05SC	AC/DC switching power supply	Recom	$ 12.34	1	$ 12.34	stock	Power Supply
V150ZA05P	Varistor	Littelfuse	$ 0.56	1	$ 0.56	stock	Power Supply
MOC3063M	Optoisolator	Fairchild Semi	$ 0.95	1	$ 0.95	stock	Load Switch
MMBT3904	NPN Transistor	Fairchild Semi	$ 0.15	1	$ 0.15	stock	Load Switch
BTA20-600CWRG	Triac	STMicroelectronics	$ 1.97	1	$ 1.97	stock	Load Switch
ACS722	Hall Effect Current IC	Allegro	$ 5.27	1	$ 5.27	stock	Current Sense
ACPL-C87A	Isolated Voltage Sense	Avago	$ 6.42	1	$ 6.42	stock	Voltage Sense
TLC272A	dual op-amp	TI	$ 1.35	1	$ 1.35	stock	Voltage Sense
MMBT3904	NPN Transistor	Fairchild Semi	$ 0.15	1	$ 0.15	stock	Voltage Sense
MSP430F672	Embedded Microcontroller	TI	$ 7.31	1	$ 7.31	stock	Controller
BZX84C5V6	5.6 Zener Diode	Fairchild Semi	$ 0.19	1	$ 0.19	stock	Voltage Sense
MRA4006	1A, 800V diode	On semi	$ 0.31	2	$ 0.62	stock	Voltage Sense

Module	Cost
Power Supply Cost	$ 12.90
Load Switch Cost	$ 3.07
Current Sense Cost	$ 5.27
Voltage Sense Cost	$ 8.73
Controller	$ 7.31
Total Material Cost	$ 37.28

Parts List

Testing Strategy

- Four Phase Testing Plan
  - Phase 1 – Breadboard Testing of Functional Blocks
  - Phase 2 – Initial Firmware Development with Evaluation Board
  - Phase 3 – Interface Processor Evaluation Board to Functional Blocks
  - Phase 4 – Prototype Evaluation

Phase 1 – Breadboard Testing	April 2015
Phase 2 – Controller Eval / Firmware Testing	May 2015
Phase 3 – Controller Eval Integration with Functions	September - October 2015
Phase 4 – Prototype Testing	October – November 2015

Uncertainties

- Power Supply
  - Effect of Power Line Communication (PLC) on power supply currently is an unknown.
- Power Sensing
  - Rate at which we want to sample
- Controller
  - Number of I/O needed for PLC interface
  - Communication protocol between PLC interface
  - Data transmission speeds
  - Required power calculations
  - Sampling Rate

Questions?

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