LPRDS-ETS-2009

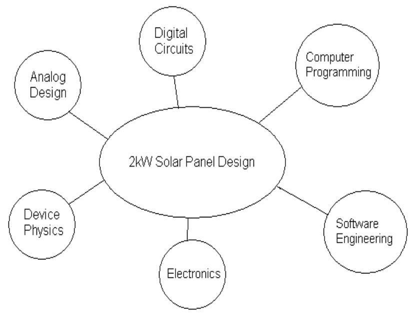
Project Overview

Lafayette Photovoltaic Research and Development System - Energy Transfer System

•Stores and distributes energy from a 2kW solar panel array to a load at 60Hz.

Overview

•One semester team-based capstone senior design project
•22 person team
•$4000 budget (not including array cost and initial battery costs)
•Subject to 55 page requirements document

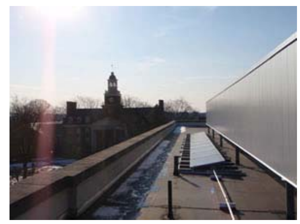


Major Design Constraints:

•Accept DC voltage from PV Array
•Output AC voltage @ 120V, 60Hz +/- 0.05%
•Contain an Energy Storage system
•Contain a SCADA sub-system

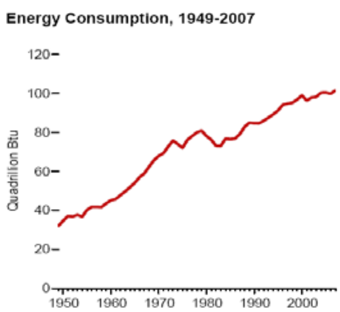
Features:

•Commercial Off the Shelf (COTS)
  •Sensors
  •Relays
  •PIC
  •Microcontroller
  •PC
•Custom Circuit Design
  •7 PCB Boards
  •Software



Inspiration

•Energy Consumption is on the rise due to technological developments and population growth.
•Non-renewable resources account for 85% of US Energy Consumption.

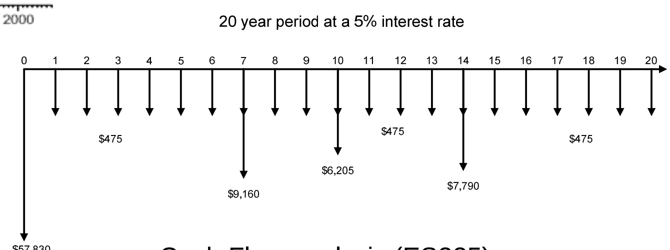


Economic Analysis for Easton PA:

•A 20 year system would cost $72,400
•This is 5.45 times the price of buying energy from the grid
•Replacement costs of critical components is too high to make solar energy viable today.

For the future:

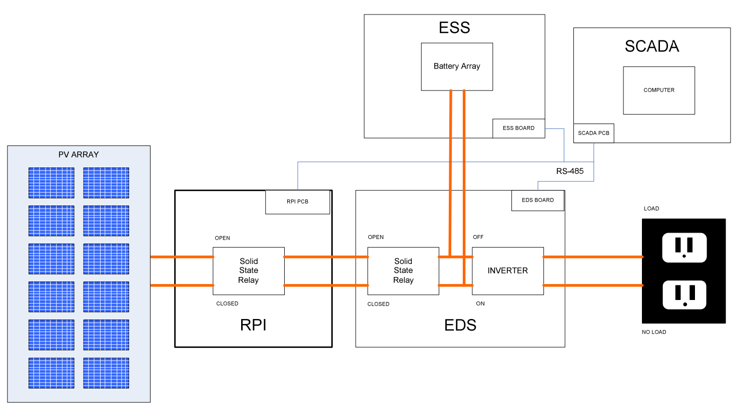
•Solar Energy Technology will continue to improve
•Critical components will become more reliable and cheaper to replace



Cash Flow analysis (ES225)

Our System

•Consists of 4 major subsystems
  •Raw Power Interface (RPI) for ground fault protection
  •Energy Delivery Subsystem (EDS) for DC/AC conversion and to provide proper voltage to batteries
  •Energy Storage Subsystem (ESS) to store energy for the system
  •Supervisory Control and Data Acquisition (SCADA) to monitor key voltages, currents, and temperatures.



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Raw Power Interface

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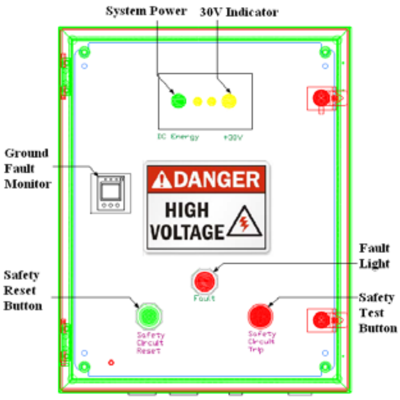
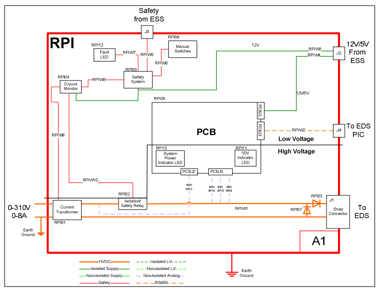
Functionality

- Disconnect the system from photovoltaic array
- Ground fault detection
- Provide sensor data for PV array

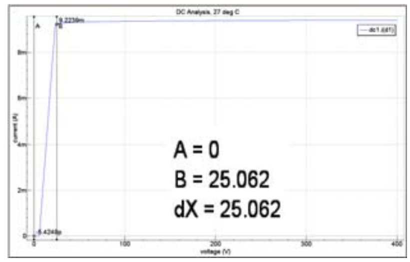
Design



- PV power disconnected from LPRDS-ETS through manual disconnect or solid state relay
- Ground fault monitor trips the safety circuit at 10mA of ground fault current



30V Indicator LED Current VS Vin



- Safety test and reset buttons located on RPI door
- 30V indicator runs off of PV power, works without supply power from ESS

Implementation

Manual Disconnect

Components:

- Student designed Printed Circuit Board (PCB) with sensors, Programmable Integrated Circuit (PIC), and indicator lights (made off-site by 4pcb.com)
- Purchased ground fault monitor (from Bender) that trips safety circuit at 10mA of fault current
- Solid state relay
- Manual disconnect switch

Conclusion

Successes:

- Successfully provided power to the system
- Ground fault monitor opened the safety relay on ground fault
- Safety test button opened safety relay
- All indicators worked as designed
- Permanent part of LPRDS-ETS

Problems:

- Inductive load from test power supply causes a current spike and destroys the solid state relay when it opens
- Never fully integrated into the system

Next Steps:

- Integrate RPI with the rest of LPRDS-ETS
- Improve surge protection on solid state relay

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Energy Storage System

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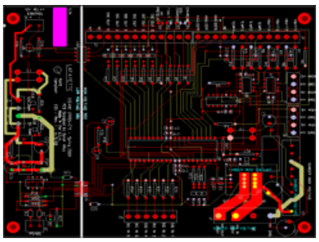
Functionality

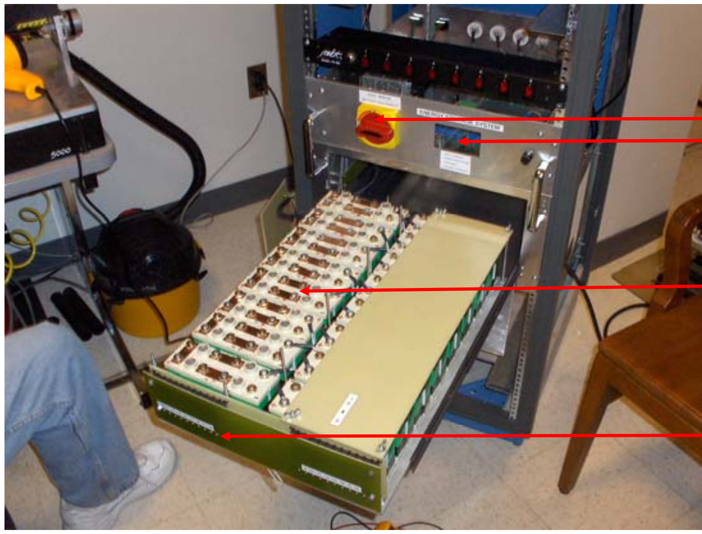
- •Stores 2KWh of power
- •Supply inverter with HV DC power
- •Supply system power (12V and 5V) to LPRDS-ETS

Design

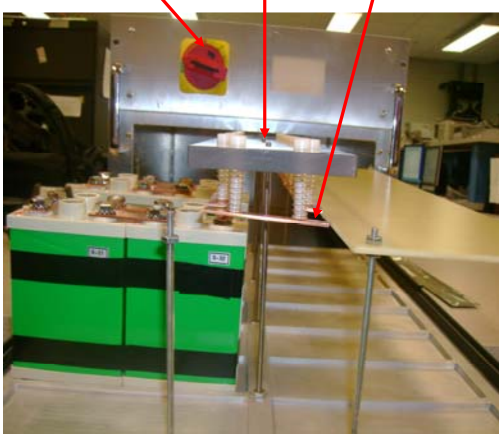
- •Array of 64 series connected $LiFePO_4$ Battery Cells
- •205V nominal operating voltage @ 10Ah
- •Safer and more robust than other battery technologies

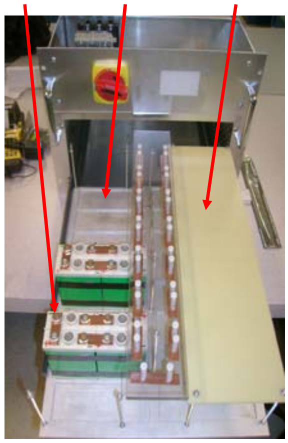


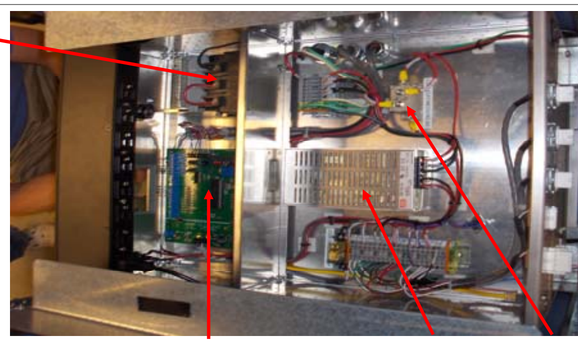
PCB Board in PADS



Implementation







- •One PCB board designed in PADS
- •Made off-site by 4pcb.com
- •Clever Battery mounting mechanism prevents any voltage over 14.8V being exposed when working on battery packs

Conclusion

- •ESS successfully supplied over 15A of current at 205V to a load.
- •ESS also successfully supplied the LPRDS-ETS with system wide 12V and 5V to power for powering PCBs, safety circuit, and other low voltage circuits.

Next Steps:

- •Implement Battery Management System (BMS) to increase charging and discharging efficiency and to improve lifespan of batteries.
- •Redesign the voltage sensors to accommodate a wide voltage rage to avoid mis-wiring.
- •Need a voltage ramping circuit to protect EDS from a current surge from batteries when the disconnect switch is turned on

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Energy Delivery System

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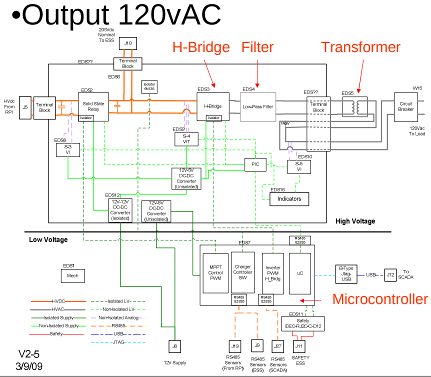
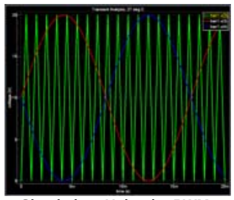
Functionality

- •Convert DC voltage to 120vAC
- •Output is at 60.25Hz
- •Interface with RPI and ESS
- •Handle variable loads

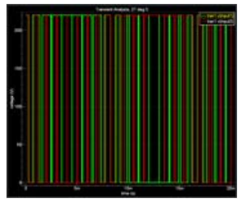
Design

- •Input voltage is determined by the battery voltage ranging from 160v to 235v (205v nominal)
- •Output 120vAC





Simulation: Uni-polar PWM Scheme



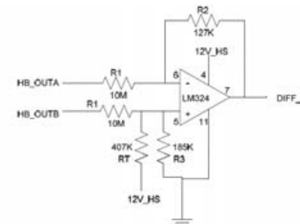
Simulation: Signals going into the gate driver

Design Elements:

- •Voltage inverted using an H-bridge
- • Signals to the H-bridge are driven by an Atmega128 microcontroller using a uni-polar PWM scheme
- •Low and High voltage signals are isolated
- •LC filter is used to filter the output of the H-bridge into a sine wave
- •Transformer isolates the load

PWM Scheme:

- •The uni-polar PWM scheme is created by comparing reference sine waves to a triangle wave
- •This reduces the harmonics



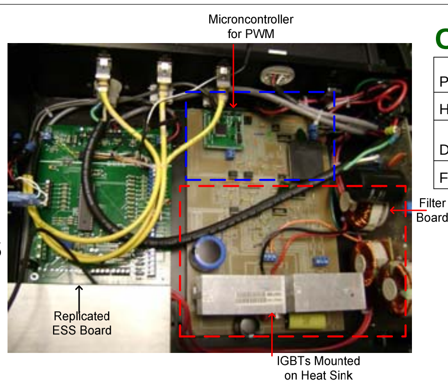
Differential Amplifier Circuit

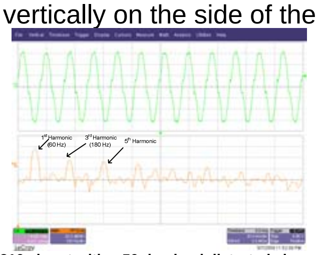
Differential Amplifier:

- •A diff-amp was designed to measure the output voltage after the filter
- •The diff-amp could regulate the output voltage with a closed loop system

Implementation

- •System converts 210vDC (from power supply) to 124Vac
- •Two PCB boards
  - •One fabricated at Lafayette (Right)
  - •One copy-cap board from ESS with sensors (Left)
- •Filter board was mounted vertically on the side of the case





210v input with a 50ohm load distorted sine wave (top), frequency analysis (bottom)

Distortion:

- •At high voltage the sine wave became distorted
- •This may be due to resonance in the filter
- •There may be core saturation in the inductors

Custom Parts Designed:

Parts designed	Parts purchased
H-Bridge/Inverter	Isolation Transformer
Differential Voltage measurement	12v DC-to-DC converter (hi-lo voltage isolation)
Filter	microcontroller

Problems interfacing with ESS:

- •When ESS is connected to EDS it appears an initial current surge occurs
- •This causes damage to the IGBTs
- •The Hi-Lo isolation worked and no low side components were harmed

Board after interfacing with ESS

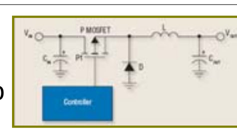
Damage from high current to the heat sink and IGBTs

Conclusion

- •EDS met basic requirements of changing DC voltage into AC voltage
- •Requirements on THD (less than 3%) and frequency accuracy (60 +/-.05% were failed
- •There was not enough time to implement a closed loop system for voltage regulation
- •New inductors may produce better response at high voltage and current
- •A delay circuit could be designed to prevent the problem interfacing EDS with ESS

Next Steps:

- •Implement a buck converter and use a Maximum Power Point Tracking algorithm to increase power intake 12-15%
- •Create a current controller for the current going to ESS to improve efficiency in storing excess voltage in the batteries



Buck Converter controls the ratio of the input to output voltage

George Foreman Grill Cooking Hamburgers

Demonstration:

- •With the EDS board connected to a 210vDC supply we cooked burgers on a George Foreman Grill using the AC voltage out of the EDS board

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Supervisory Control And Data Acquisition

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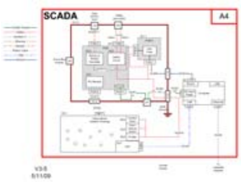
Functionality

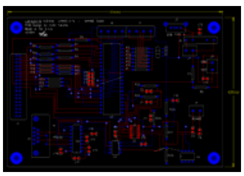
- •Acquire voltage, current and temperature sensor data
- •Monitor sensor data to control system states
- •Display current data on a website
- •Display system state on LCD display and Demonstration board

Hardware Design

- •fitPC computer
- •PICs placed in EDS, RPI, ESS to collect sensor data
- •SCADA PIC board for controlling display



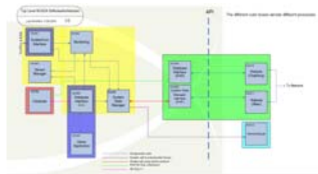
Hardware System Diagram



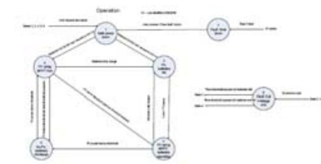
PIC Board Layout

Software Design

- •Used Object Oriented Design techniques
- •Code written in C++
- •LCD4Linux used for LCD
  - •Plugin, coded in C, used for display of data
- •Webpage displays current database data
- •PICs programmed in C



Software System Diagram



System States

Implementation

Hardware

- •Communication through SCADA board
- •Board converts RS232 from fitPC into RS485
- •A/D converters on PIC convert sensor data
- •LCD Display connected to computer by USB
- •Demo Manager connected by ribbon cable to SCADA Board

Final Board in Enclosure

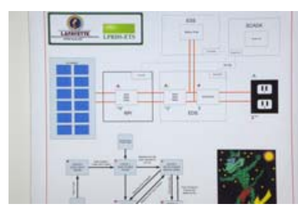
LPRDS Protocol

Custom Parts Designed:

Parts designed	Parts purchased
PIC Board	fitPC
Demo Display	picoLCD Display

Software

- •Website written in PHP
- •Classes for input management, faults, system state management, demo display, data monitoring, and communication



Demo Display

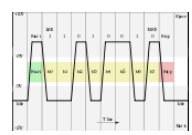
Demo Display showing LCD

Conclusion

- •SCADA met basic requirements of collecting data, monitoring it, and displaying it on a website
- •SCADA met requirement for have a display which shows system in action
- •Requirements for measuring power factor and phase angle were not met
- •Voltage and current data is not displayed on the LCD

Next Steps:

- •Implement graphing of data on website
- •Show these graphs on the LCD display
- •Write software for monitoring of safety circuitry and alarm state
- •Display sensor data on LCD



RS-232 Communication

LPRDS Website

Demonstration:

- •We showed that SCADA can collect and display data on the website
- •The demo board's LEDs, and the LCD state, changed as the state was changed

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Conclusion

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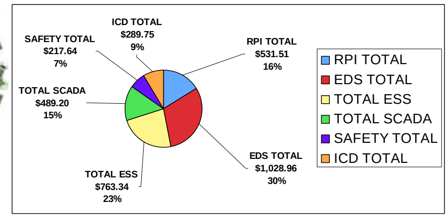
Under Budget

- Current Budget Cost $3400
- Andy Misc. Costs - $400
- $200 under BUDGET!
- ECE Dept absorbed $4400



Results:

- Total of 5735 project hours or $172,059 (at $30/hr)
  - -Developed 7 UNIQUE BOARDS! (RPI, SCADA, SCADA-555, ESS, EDS-ADAPTED-ESS, EDS-PROTO1, EDS- PROTO2). Almost one for every 3 students
  - 66/104 requirements met
- RPI tested and working correctly
- ESS tested and working correctly
  - -Mechanical layout complete
  - -Battery management system needed
- EDS with partial functionality
  - -Proto-type completed with basic functionality
- SCADA with partial functionality

RPI

SCADA

EDS

ESS

For the Future:

- Motor control and electric vehicles

ESS

- Battery management system
- Voltage raming circuit to interface with EDS

SCADA

- correctly log values
- Display graphs on the web page
- Allow user control from the web page

EDS

- Buck Converter- increase power intake 12-15%
- Battery Current Control Algorithm – increase efficiency in storing energy in the batteries (LiFePo4 has a complicated charging curve)
- Grid Tie – allow us to share electricity with the grid

Thanks to:

- Dr. Jemison
- Prof. Nadovich
- Andy Langoussis
- Nicolette Stavrovsky
- Doug Wood
- Chris Lett

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