Lafayette Photovoltaic Research and Development System - Energy Transfer System

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.

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

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

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.
**Raw Power Interface**

**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

**Implementation**
- 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

**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

**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
## Energy Storage System

**LPRDS-ETS 2009**

### 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 LiFePO4 Battery Cells
- 205V nominal operating voltage @ 10Ah
- Safer and more robust than other battery technologies

### Implementation
- Supply system power (12V and 5V) to LPRDS-ETS
- Array of 64 series connected LiFePO4 Battery Cells
- 205V nominal operating voltage @ 10Ah
- Safer and more robust than other battery technologies
- 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
**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

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

**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

**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

**Custom Parts Designed:**

<table>
<thead>
<tr>
<th>Parts designed</th>
<th>Parts purchased</th>
</tr>
</thead>
<tbody>
<tr>
<td>H-Bridge/Inverter</td>
<td>Isolation Transformer</td>
</tr>
<tr>
<td>Differential Voltage measurement</td>
<td>12v DC-to-DC converter (hi-lo voltage isolation)</td>
</tr>
<tr>
<td>Filter</td>
<td>microcontroller</td>
</tr>
</tbody>
</table>

**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

**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

**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

**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
**Supervisory Control And Data Acquisition**

## 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

## 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

## 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

### Custom Parts Designed:

<table>
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</thead>
<tbody>
<tr>
<td>PIC Board</td>
<td>LPC</td>
</tr>
<tr>
<td>Demo Display</td>
<td>pixLCD Display</td>
</tr>
</tbody>
</table>

## Software

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

## 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

## 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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LAFAYETTE

Department of Electrical and Computer Engineering

D2464 Spring 2009

LPRDS-ETS-ETS
Conclusion
LPRDS-ETS 2009

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

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

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