Group Members:
- Adam Lint
- Chris Cockrell
- Dan Hubbard

Sponsors:
- Dr. Herb Hess
- Dr. Brian Johnson

**HydroFly: Fuel Cell Project**

**Final Design Review Outline**

- Project Objectives
- Project Introduction
- Project Status
- Design Description and Functionality
  - DC/DC Converter
  - Inverter
  - Transformer
  - Control
  - Software
  - Zero Crossing Detection
- Schedule
- Budgeting
- Questions

**Primary Objectives**

- Interface a fuel cell to the AMPS.
- Provide power to the AMPS

**Secondary Objectives**

- Produce an operation manual
- Protect the fuel cell and interface
- User safety
Introduction

Why are we interfacing the fuel cell to the analog model power system?

- Alternative energy source
- Flexibility for the AMPS

Overview: Last Spring

• Characterized fuel cell
• Established a basic interface design
• Chose system components
• Generated schematics and simulations
• Set overall specifications
• Presented results

Overview: This Fall

• Accomplished Goals:
  – Enhanced design description
  – Refined specifications
  – Chose final system components (and ordered)
  – Obtained transformer: configured ∆-Y; determined turns ratio
  – Added humidification to fuel cell
  – Built and tested zero-detection circuitry
  – Generated a system control scheme
• Future Goals
  – Characterize DC/DC converter and inverter
  – Find transformer inductance
  – Finish zero-detection PCB design
  – Implement system control scheme (interface)
  – Test if system meets required specifications
  – Present results

Functional Specifications

Overall interface design specifications:

• AC signal MUST BE present on the AMPS
• 18-36V DC input from the fuel cell
• Output 208 +/- 2% V AC (L-L 3-phase)
• Output frequency at 60Hz +/- 0.05Hz
• Max power flow of 200W through the interface
• Dimensions: fit on cart with dimensions 32” x 27” x 18” (2 shelves)*

*not including fuel cell and transformers
**Overall System Layout**

- DC/DC Converter
- Inverter
- Transformer
- Control
- Software
- Zero Crossing Detection

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**DC/DC Converter**

- **ABSOLPULSE BAP265 - Customized**
  - Input: 18 – 36 VDC
  - Protection: Current limiting, thermal fuse, reverse polarity protection, 500VDC isolation from output/chassis
  - Output: 120VDC ±1%
  - Protection: Current limiting, thermal shutdown
  - Power capability: 200W
  - Efficiency: ~80% (within 0º – 50ºC)
  - Cost: ~$318.00

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**DC/AC Inverter**

- **Tier Electronics – Custom Package**
  - Input: 75-200VDC
  - Output: variable 3 phase AC (depends on programming)
  - Switching circuitry: 600V IGBT devices
  - Rated current: 3A RMS at 5kHz
  - TI 2401 DSP: fully programmable
  - I/O plug
    - +15V output, receive and transmit outputs, auxiliary inputs and outputs (digital and analog)
  - Cost: $500
  - Other specifications: to be determined upon receipt
    - Input/Output protection
    - Max output voltage
    - Previous programming

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**Transformer**

- **Nameplate Specifications:**
  - 3 single phase SORGEL transformers
  - 8.5kVA rating
  - Type: INS. Class H-115
  - HV: 208/460 LV: 120/20

- **Experimental Data (∆ - Y connected):**
  - Turns Ratio: \((X_{LL}:H_{LL})\) 1:3
**Transformer**

- **Purpose**
  - Steps up voltage to 208V_{LL} (RMS)
  - Filters PWM output
  - Provides known inductance (power flow control)
- **Delta – Wye Configuration (3 single phase)**
  - System protection

![Transformer Diagram](image)

**Overall System Layout**

- DC/DC Converter
- Inverter
- Transformer
- Control
- Software
- Zero Crossing Detection

![System Layout Diagram](image)

**Control**

Why do we need system control?

1. Produce PWM
2. Synchronize AC systems
3. Control power flow
4. Protect fuel cell and interface components
5. Monitor zero crossings
6. Perform calculations

**How are these tasks accomplished?**

- DSP 
  - TMS320LF2401A 
  - TI

![Control Diagram](image)
1. Produce PWM

Seven 16-bit Pulse-Width Modulation (PWM) channels which enable:
- Three-phase inverter control

2. Synchronize AC Systems

- Magnitude
- Frequency
- Phase/Zero Crossings (30 degrees ahead)

3. Control Power Flow

\[ P = \frac{V_c \cdot I_{AMPS} \cdot \sin(\delta)}{X} \]

\[ Q = \frac{V_c \cdot I_{AMPS} \cdot \cos(\delta) - I_{AMPS}^2}{X} \]

4. Protect Fuel Cell and Interface Components

Checks for undesired operating conditions
- Abnormal pulse width on zero crossings
- Frequency variation
- Voltage differences
5. Monitor Zero Crossings

6. Perform Calculations

Overall System Layout
- DC/DC Converter
- Inverter
- Transformer
- Control
- Software
- Zero Crossing Detection

Software

Interrupt Service Routine:
Overall System Layout

- DC/DC Converter
- Inverter
- Transformer
- Control
- Software
- Zero Cross Detection

Zero Detection

- Gives a timing reference to the TI-2401 DSP on the DC/AC Inverter
- Provides the ability to create a 3-phase signal synchronized with the 3-phase system on the AMPS and, ultimately, control the power flow to the AMPS

Zero Detection

Phase 1 Zero Detection Circuits

Phase 2 Zero Detection Circuits

Phase 3 Zero Detection Circuits
Zero Detection

Pulse Sequence: 1R – 3F – 2R – 1F – 3R – 2F

Vo1(t) = A(p) * B(p)' + A(p)'*B(p)

Vo2(t) = B(1)*A'(1)*A'(2)

A = +0.7 Detection Circuit Output
B = -0.7 Detection Circuit Output
P = Phase (1, 2, 3)

Zero Detection – PCB Board

- 4-layer board – Signal 1, Signal 2, Vcc, GND
- Required external power supply: ±18V
- On-board linear voltage regulator: 3.3V
- Inputs (3): 120VAC (3-phase)
- Outputs (2): serial pulse stream, phase 1 (rising) ref signal
- Software: Eagle

Zero Detection - Prototype

- Test Setup
  - Single phase
  - Voltage: 10Vpp AC
  - Frequency: 50Hz, 60Hz, 70Hz
- Measuring Output of XOR Gate

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<th>Error (µs)</th>
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<td>50</td>
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Original Predicted Budget

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<td>DC/3-Phase AC Converter</td>
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<td>Flyback Converter</td>
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<td>Project Display Costs</td>
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<td>Protection Circuitry</td>
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<td>Filtering</td>
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**Current Budget**

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<td>Project Display Costs</td>
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*Funds received from Power Lab Budget and O’Connor/Curtin Fund.

**Schedule**

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<tbody>
<tr>
<td>Design Review</td>
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<td>Life Cycle Report</td>
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<td>Hardware Reliability</td>
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<td>Functional Test Plan</td>
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<td>DSP Software Development</td>
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<td>System Interfacing</td>
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<td>System Debugging/Finalizing</td>
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<td>Mini-Expo</td>
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<td>Final Report</td>
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**Specific Due Dates:**

- Inverter: scheduled to arrive within the next week.
- DC/DC converter: scheduled to arrive October 13.

**Responsibility Chart**

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<tr>
<th>Project</th>
<th>Adam</th>
<th>Chris</th>
<th>Daniel</th>
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<tr>
<td>Power Transformer Circuit</td>
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<td>Reports</td>
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H = Head of Project  S = Supporting Project
QUESTIONS?

**INPUT**
- 18-36V DC
- ±1%
- 70VLL AC 3-phase
- Synchronous Freq.

**OUTPUT**
- 208V ± 2%
- AC 3-phase
- Synchronous Freq.

**Control**
- Zero-Detection Circuitry
- Max 200W

**Diagram:**
- Fuel Cell
- DC/DC
- DC/AC
- Transformer
- AMPS
- Max 200W
- 3-phase
- Synchronous Freq.
- 18-208
- Δ 5V