Lafayette Formula Electric Vehicle

Preliminary Design Review
30 November 2012
Introduction

- Design of an Energy Storage, Control, and Monitoring (ESCM) system for use in the Formula Hybrid Competition
  - To include all electrical systems used on the car
  - Our design requirements are based on the most recent Formula Hybrid rules
Goals

**Fall Semester**

- To choose battery cells and a configuration of these cells for an accumulator segment
- To design a prototype battery pack with per-cell management
- To design a SCADA that will communicate with the BMS, output data to a GUI, and control the states of the ESCM system
- To understand mechanical requirements of the EV and determine whether our design meets these requirements

**Spring Semester**

- To complete the designs of the BMS, SCADA, and safety loop from the fall
- To assemble four accumulator segments
- To thoroughly test the system components, both separately and as an integrated whole
- To recommend an electric motor and motor controller to integrate with the accumulator, BMS, and SCADA
- To present the complete system to the Mechanical Engineering department for use in the 2014 Formula SAE Electric Vehicle (EV) competition
Overview

- High-Level Design
- Simulation
- Design safety features
- Motor and Motor Controller
- Accumulator & Battery Management System (BMS)
- System Control And Data Acquisition (SCADA)
- Safety Plan
- Scheduling
- Budget
High-Level Design – Requirements

- Course requirements:
  - Listed in LFEV-ESCM Statement of Work
  - Includes Ethics Debate, PDR, CDR, ATP, etc.

- Competition requirements:
  - Separate high-voltage and low-voltage systems
  - Monitor cells’ voltages and temperatures
  - Include a safety loop to control the AIRs (Accumulator Isolation Relays)
  - Documentation: Electrical System Form (ESF), Failure Modes and Effects Analysis (FMEA)
High-Level Design – Deliverables

- ESCM system for integration with FSAE EV
  - 4 accumulator packs with BMS, charging & discharging connections, packaging, cable connectors for each pack
  - SCADA with touchscreen display, processor, bus connections to BMS and motor controller, and pit station software
  - Motor and motor controller
  - Placement recommendation on the EV itself
  - Charger for accumulator
  - Acceptance test results

- Deliverables do not include:
  - Chassis
  - Brakes, suspension
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Major deliverables:

- Software CDR and display demo: February 6
- SCADA OVS demo (motor controller simulated): March 8
- SCADA Pit station software demo: March 8
- Pack demo: March 13
- Hardware Purchase Deadline: March 14
- CDR: March 8
- Final presentation: May 9
High-Level Design – Block Diagram

- BMS, Pack1
- BMS, Pack2
- BMS, Pack3
- BMS, Pack4
- Cells, Pack1
- Cells, Pack2
- Cells, Pack3
- Cells, Pack4

- Motor Controller
- Motor
- Temperature Sensor
- Tachometer/Encoder

- SCADA
- Insulation Monitoring Device (IMD)

- Mechanical connection
- Three-phase power
- RPM

- Switching Connection
- Isolation

- Start
- Safety loop control signal
- Motor RPM, temperature
- Insulation control signal

- Touchscreen display
- PLC station
High-Level Design – Test Configuration
Safety – Safety Loop

- Insulation Monitoring Device (IMD)
- SCADA control
- (BMS) Tractive System
- Master Switch
- Emergency Shutoff Switches (ESS)
- Brake Over-Travel Switch
- + SCADA, Sensors, Brake Lights
- "GLV Master Switch"
- Low Voltage Batteries
- IR1-8 Accumulator Isolation Relays
- IR1-8 Tractive System
- IR5 Manual Reset Switch
- *Not accessible by driver
Safety – Safety Loop

Addresses Requirements
○ Article EV5 Shutdown Circuit and Systems

Tests
○ Insulation Monitor Device Test
  • Fault resistance between tractive system ground and Chassis
○ BMS Failure Test
  • IR Gun to Temperature Sensors
○ Physical Switch Tests
  • Master Switches, Emergency Button Switches, Brake Over–Travel Switch, Manual Reset Switch
Goals
- Determine reasonable expectations for the performance of the car: speed, position, acceleration
- Determine requirements for current and voltage outputs

Design Components
- Battery
- Transformer
- Motor
- Gear Box
- Wheels
- Environmental Factors
Based on the differential equations of a Permanent Magnet DC Motor
Parameters found to mirror performance of a Netgain WarP 7 DC Motor
Notable results (GR = 4):

- Current spike and settles
- Car runs for 47 minutes at a continuous current demand of 70 amps.
- Car travels approximately 38 miles
- Run through entire battery
  - 28 cells, 3.2 V per cell
  - 60 Ah per cell
  - Yields 5.376 KwHr
- Mileage: 7.09 Mi/KWHr
Simulink Model – Endurance

Course Description:
- Each lap is about 1 mile, run for 13 laps
- Straightaways => 50mph
- Turns => 25mph
- Mileage: 8.06 Mi/KWHr for (GR = 4)
Simulink Model – Autocross

Course Description:
- Used meters instead of feet
- Very Sharp Turn => 5 mph
- Sharp Turn => 13 mph
- Gradual Turn => 20 mph
- Short Straightaway => 30 mph
- Long Straightaway => 45 mph
- Mileage: 6.69 Mi/KWHr (KG = 4)
Simulink Model – Acceleration

- Course Description:
  - Accelerate at full speed for 75m
  - Previous times range from 4–9s
  - Mileage: .436 Mi/KWHr

![Graph showing 75m Performance vs. Gear Ratio](image)
Results and Recommendations

- Performance highly dependent on gear ratio
  - Optimal ratio: 3:1 to 5:1
  - If a proper gear ratio is used, we should not run into energy issues on the Endurance test
- Expect ~750 max, ~20–135 continuous
- Next steps:
  - Find optimal speed
  - Gather results with braking system applied
  - Explore different motors (different models)
Motor and Motor Controller
Using AC–50 motor (AC electric motor) with Curtis 1238 motor controller
- AC motors more efficient than DC
- Allows for regenerative braking capability without added circuitry
- Comparable cost
- Curtis controller is pre-programmed and tuned for the AC–50 by the manufacturer
Motor and Motor Controller – Connections

- Connections provided for accumulator terminals, three-phase power, speed encoder, serial transmission and other areas of concern.
Motor and Motor Controller – Test Configuration
Accumulator System and BMS
Accumulator System – Cell Choice

- **Cell Selection constraints:**
  - Accumulator energy no greater than 5400Wh
  - Segment’s energy no greater than 12MJ (1.39kWh)
  - ~100 Amps nominal, ~650 Amps peak
  - Controller operational voltage range of 72–120V
- **Cell voltage × Cell Capacity × Number of cells < 5400**
- 60 Ah cells at 3.2V nominal voltage
  - 3C discharge with 10C discharge for < 10s
  - Draw 200A nominal with 600A peak for drag race
- **Accumulator**
  - 28 Cells, 5376 Wh, 89.6 V, 4 packs
Accumulator System – Cell Choice

- Cells chosen: AA Portable Power Corp
  LiFePO4 3.2 V, 60 Ah prismatic cells

Charging Curve

Discharge Curve

Note: Red = 0.5C rate, Black = 1.0C rate, Blue = 3.0C rate
Accumulator System – Cell Verification Plan

Cell Test Unit

- Vsource
- Resistor
- Oscilloscope
- Relay
- Vref
- Comparator

120 VAC

Cell Under Test

+ -
Accumulator System – Cell Verification Plan

- Charging of one cell
  - Charges cell until it nears full charge (3.8V)
  - Draft of a charging base for production to come

- Discharging of one cell
  - Discharges cell until it nears depletion (2.5V)
  - Draft of a discharging base for production to come

- Cell Testing
  - Discharge at different rates using large resistors to simulate different races
  - Discharge at 20 – 125 Amps for endurance
  - Discharge at 600 Amps for drag
  - Use oscilloscope to analyze performance of cell
BMS – Purpose

- Addresses Requirements
  - EV 3.6 AMS System
- Monitor cell voltages, temperatures, and pack currents
  - Extend cells’ lifetimes
  - Avoid overcharging and overheating
BMS – Block Diagram
Control algorithm from 2011 project will be extended but otherwise unchanged

Implemented with C code in microprocessor (PIC) on the BMS board
BMS – Proposed Changes

- Design based on project from Class of 2011
- Our design will use:
  - New current sensor (Hall effect)
    - Suitable for higher currents
    - Means of galvanic isolation
  - New PIC processor
    - More A/D pins to support more cells per pack
  - New I2C isolator
    - Fewer pins = lower profile on the PCB; saves space
  - No high–current path through the PCB
    - High–current path will instead travel through inter–cell straps and be wired to connectors not attached to the PCB
  - Modified PCB layout
    - Configured for inter–cell taps for taking voltage measurements
    - Fit parts for 7 cells rather than 4
Addresses Requirements
- EV3.6.6 Thermal operation range must be maintained
- EV3.3 Electrical Configuration
- EV3.4 Mechanical Configuration

Energy limit (5400 Wh) divided among four packs

Each pack must contain:
- Seven battery cells
- BMS
- High-current connections
Accumulator System – Pack Design
Accumulator System – Pack Design

- Requirements:
  - Nominal Current: ~120Amps
  - Impulse Current: 650 Amps for < 10 seconds
  - Maximum 40 degrees C increase above ambient
- Cell balancing cells with unequal SOCs
Accumulator System and BMS – Test Configuration

Diagram showing the integration of components such as the Processor (PIC), I2C isolator, I2C interface board, Realterm, Voltage sensor, Current sensor, Temperature sensor, Battery, Ammeter, Voltmeter, and IR gun.
Accumulator System and BMS – Test Strategy

- Charging a pack
- Discharging a pack
- Tests run on the packs
  - Check charge stop
  - Check discharge stop
  - Discharge at 4/3 C (80 Amps nominal)
  - Discharge at 10C (600 Amps)
  - Drain one cell, check balancing algorithm and shutoff
- Cell balancing cells with unequal SOCs
SCADA
SCADA – Purpose

Addresses Requirements
- EV 3.6.7 Shutting Down of Tractive System for BMS Error
- EV 4.12 Ready-To-Drive Sound
- EV 4.9 Control of Tractive System/Extra Action for Ready-To-Drive

Acts as “brains” of the system
- Takes input from system’s sensors and controls system state
- Displays information to the driver and for diagnostics
- Logging and Data Analyzing

Controls:
- Main switches of the system (charging state, discharging/driving state)
- Safety loop switch

Data acquisition
- From BMS via I2C interface
- From motor controller via serial interface
- From system sensors: accelerometer, safety loop monitor

Separated into two blocks
- On-vehicle SCADA (OVS)
- Pit station
SCADA – Processor

- **Arduino Due**
  - 32-bit ARM core microcontroller
  - 84 MHz, 512KBytes of flash memory
  - Performance tier – between ATMega microprocessors and small computers (e.g., Raspberry Pi)
  - Extensive software libraries for both implementation and testing
  - Any pin can be used an interrupt
Coded using Arduino IDE

- Serial Libray
- I2C Library
- Use “Arduino Unit” test framework for method testing

Other Components

- Accelerometer
- Safety loop monitor
- OpenLog stores all data on microSD card
- XBee Wireless Pro chips
- 4 Relays for controlling the positive and negative terminals going to charging station and motor controller
- 1 Relay on the safety loop
SCADA – On-Vehicle SCADA (OVS) Display

- 4D Systems µLCD43(GFX) touchscreen

Purpose
- Main interface for user to the OVS
- Dashboard for driver
- Use as diagnostic tool

- 4D Workshop 3 IDE
  - 4DGL Programming Language
  - GUI Designer
SCADA – OVS Sample Screenshots

- Diagnostic Mode Menu
  - BMS
  - Motor Controller
  - Accelerometer
  - Hold for 5 seconds
  - Ready-To-Drive

- Ready-To-Drive Mode
  - Speed: 0.00 mph
  - BMS: 0%
  - Trip: 0
  - RPM: 0
  - TURN OFF

- Charging Mode
  - Voltage: 0
  - Current: 0
  - Cells Charged/Remaining: 0/0

- ERROR!
  - STOP THE VEHICLE!
SCADA – Pit Station

Purpose
- Synthesizes and analyzes data collected by the OVS
- Receives data via XBee wireless receiver or microSD card
- Export data so that it can be graphed and further analyzed

Visual Studio IDE
- Code in C#
- GUI Designer
- Excel export for graphing and analysis
SCADA – Pit Station States and Control

Pit Station Control Loop

1. Read in Serial Data (if necessary)
2. Update Variables
3. Update GUI
4. Analyze Data
SCADA – Test Configuration

On-Vehicle SCADA (OVS)

- BMS (VCC/GND/SDA/SCL)
- Switch control (Safety loop) (HIGH/LOW)
- Safety Loop Monitor (HIGH/LOW)
- Motor controller (VCC/GND/TX/RX)
- GLV battery (12 V)
- Processor (Arduino Due)
- Display (touchscreen)
- Sonalert ZA016LDPP1

Connections:
- VCC/GND TX/RX
- CHARGE/READY2DRIVE

Testing Equipment:
- Xbee Pro wireless receiver
- Open Log
- Micro SD card
- Pit computer (USB2UART)
- Micro SD – USB connection

- Oscilloscope (Communication Lines)
- Multimeter (Voltage Measurements)
- Software – ArduinoUnit, Realterm
SCADA – Test Strategy

- Tractive switch (isolation relay) tests
- Display tests
  - Tests for serial and interrupts for changing to Ready–To–Drive and Charging modes
- I2C test
  - For implementation with BMS
- Wireless transmission tests
- Logging test
- Ready–To–Drive Sound Test
- Pit Station tests
  - Wireless receive test
  - Data file read/write tests
  - Analyze/export data test
Safety – Safety Plan

- Following College and SAE Rules
  - Lockout/tagout
- Separation of Low and High Voltage Systems
- Hands-on work with High Voltage Systems
- General Responsibility
- Further details provided in the LFEV Safety Plan
High-Level Design – Deliverables

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</table>

**Area 1**
- Test 1
- Test 2
- Test 3

**Area 2**
- Test 4
- Test 5
- Test 6

**Area 3**
- Test 7
- Test 8
- Test 9
Major deliverables:
- Pack demo: March 13
- SCADA Pit station software demo: March 14
- CDR: March 23
- SCADA OVS demo (without motor controller): April 14
- Hardware Purchase Deadline: April 5
- Final presentation: May 9
Major costs:
- Motor and motor controller
- Battery cells
- Packaging (insulation, casing, connecting cables)
- Isolation relays
- Pit station computer
- Test fixtures
Conclusion

- LFEV–ESCM system, including packs with BMS, SCADA, motor controller, and motor will be compatible with future FSAE electric vehicles

- Hope to establish a foundation for future classes (both MechE and ECE) to continue
Questions?