“EMC System Engineering of the Hybrid Vehicle Electric Motor and Battery Pack”

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FR-AM-5 EMC Issues in Hybrid & Electric-Propulsion Vehicles
Description

Before discussing the process for developing good requirements, some important definitions must be established:

**System**: a set of components acting together to achieve a set of common objectives via the accomplishment of a set of tasks.

**System Behavior**: a sequence of functions or tasks, with inputs and outputs, that must be performed to achieve a specific objective.

**Requirement**: mandates that something must be accomplished, transformed, produced, or provided. The attributes of a good requirement are that it is unambiguous, understandable, traceable, correct, concise, unique and verifiable.

**Traceable**: in reference to requirements; a requirement is said to be traceable if one can identify its source. The source may be a higher level requirement or a source document defining its existence. An example would be if a component level requirement (weight, reliability) is traceable back to a vehicle level requirement.

**Operational Concept**: an operational concept is a shared vision from the perspective of the users and development participants of how the system will be developed, produced, deployed, trained, operated, maintained, refined and retired to meet the operational needs and objectives.
Honda Civic Hybrid System

Electric Motor  High Voltage Cables  Fuel Tank

Gasoline Engine

Transmission  12 V Battery

Under-hood Fuse Box  Fuel Lines  IPU Compartment With High-Voltage Battery

12 V Battery

Under-hood Fuse Box

Gasoline Engine, Electric Motor, and Transmission  High Voltage Cables  Fuel Tank

IPU Compartment With High-Voltage Battery
Systems Engineering Approach to EMC

Coordinate and Iterate as Required

1. Bound System for EMC
2. Identify Source of Requirements
3. Discover & Understand Requirements
4. Create Alternatives
5. Select Best Solution
6. Validate Best Solution
Step 1 - Bound System For EMC
- Identify All External Items
- Establish Interactions
- Create System Context Diagram

Step 2 - Identify Source of Reqts
- Collect Requirements
- Sort Requirements by Classification

Step 3 - Discover & Understand Reqts
- Discover System, Subsystem, and Component Level Requirements
- Brainstorm Scenarios
- Benchmark Competition
- Use Behavior Models to:
  - Discover “Hidden” Interface Requirements
  - Resolve Conflicts between Models and Scenarios

Step 4 - Create Alternatives
- List Performance and Operational Objectives
- Prioritize Requirements with Weighting Factors
- Synthesize Physical Architecture to Support Each Alternative

Step 5 - Select Best Solution
- Compare Proposed Systems Implementation
- Select Best Solution

Step 6 - Validate Best Solution
- Define Validation Plan
- Linkage to Design Requirements at each Level (vehicle, system, component)
Step 1 - Bound System For EMC

From: Hybrid www.gov
Step 1 - Bound System For EMC

Typical Hybrid Electric Powertrain With Inverter

Note: EMC08 EMC08-WS FR WS FR-AM AM-5-6 IEEE EMC 2008 August; “Overview of Component Level EMC Characteristics Overview of Component Level EMC Characteristics for HEV application”
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Step 2 - Identify Source of Requirements

Source Requirements

• Requirements can come from a variety of sources.
• Look for implied requirements from the interfaces between your “system” and the others that you must function with.
• Next chart shows other sources of requirements.
Step 2 - Identify Source of Requirements

Requirements Come From ...
Step 2 - Identify Source of Requirements

- EMI - Electromagnetic Interference is any electric or magnetic emission from a device or system that interferes with the normal operation of another device or system.

- EMC - Electromagnetic Compatibility is the ability of a device or system to function without error (susceptibility) in its intended electromagnetic environment.
Step 2 - Identify Source of Requirements

**Differential Mode noise**
- Differential Mode noise goes out one wire and comes back on another
- Usually caused by Inverter or Power Supply pulse current drawn from source
- Block with Differential Mode Choke followed by adequate bulk capacitance

**Common Mode noise**
- Common Mode noise goes out both wires and comes back on the chassis
- Usually caused by high frequency power switches coupling to the heatsink
- Block with Common Mode Choke and high frequency capacitors to chassis
Step 2 - Identify Source of Requirements

- **EMC requirements:**
  - OEM vehicle level EMC tests
  - OEM module level EMC tests
  - Government EMC tests

- **Electrical requirements:**
  - Electric motor voltage specification
  - OEM vehicle electrical specification
  - High voltage safety requirement
  - Government voltage safety standards
• All of the activity above has been for the purpose of performing enough analysis and a variety of analyses to insure you identify and/or discover all of the requirements of your system.
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Step 3 - Discover & Understand Requirements

From: Hybrid www.gov
Step 3 - Discover & Understand Requirements

High Voltage Runs From The High-voltage Battery To The Electric Motor

IMA system

From: Hybrid www.gov
Step 3 - Discover & Understand Requirements

A Small Gasoline Engine & An Electric Motor

From: Hybrid www.gov
Step 3 - Discover & Understand Requirements

From: Hybrid www.gov
Photo of the integrated power electronics and electric machines
EMI Considerations for Military Hybrid Electric

**Power Electronics**
- Use laminated buss bars
- Provide good high frequency DC-Link capacitors
- Snub high power switches to reduce ringing
- Common mode and differential mode filtering
- Separate digital and power circuits
- CPU and bias power supply *COULD* be the noisiest part of your inverter

**Energy Storage System**
- Battery management circuits can contain noisy elements such as processors

**Electric Machines**
- Use brushless types (AC Induction, Permanent Magnet, Switched Reluctance)
- Enclose high power terminals
- Common mode inverter noise
- Magnetic field radiation

**Vehicle Wiring**
- Overbraid high power bundles
- Shield digital data buses
- Provide proper shield terminations

“EMI in a Hybrid Electric World”; Tactical Wheeled Vehicles Conference; February 2, 2004
Brainstorm Scenarios

Scenario 1: Shield cable between battery pack, DC to 3-phase convertor, and electric motor.

Scenario 2: Shield cable between battery pack and shield DC to 3-phase electric motor unit.

Scenario 3: Shield cable between battery pack 3-phase convertor and electric motor.

Scenario 4: No shield cable, filter between battery pack, DC to 3-phase convertor and electric motor.

Scenario 5: No shield cable, filter between battery pack and shield DC to 3-phase electric motor unit.

Scenario 6: No shield cable, filter between battery pack 3-phase convertor and electric motor.

Scenario 7: Etc.
Step 3 - Discover & Understand Requirements

Use Behavior Models to:
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Step 4 - Create Alternatives

• Perform trade-off between candidate architectural solutions that satisfy the requirements.
• Results in a derived set of requirements based on the chosen solution.
• Compare the various alternatives, rank them, and select the best approach.
• Evaluate candidate architectures using measures of effectiveness.
Filter Requirement for Hybrid Electric Motor

- Operating voltage DC 300 to 600 volts
- Operating current 100 to 300 amps
- No DC loss due to filter elements
- Transient Voltage DC less than 1000 V\(_{\text{DC}}\)
- Filter common mode noise
- Filter differential mode noise
- Operating temperature range between -40° to 105° C
Step 4 - Create Alternatives

Different Types of High Voltage DC Filters with No DC Loss

Current Probe Test

NOTE: XZT has not been optimized for maximum filter performance.

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Step 4 - Create Alternatives

Prioritize Requirements with Weighting Factors

- Potential issue for emission

Note: EMC08 EMC08-WS FR WS FR-AM AM-5-6 IEEE EMC 2008 August; “Overview of Component Level EMC Characteristics Overview of Component Level EMC Characteristics for HEV application”
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Synthesize Physical Architecture to Support Each Alternative
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Requirements

Alternatives

Perform Tradeoffs

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<tr>
<td>Quality</td>
<td>.75</td>
<td>.9</td>
<td>.8</td>
</tr>
</tbody>
</table>

Decision → Preferred Solution
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Step 6 - Validate Best Solution

• All requirements must be verified.
• Planning for verification should start early at the system level and be continuous.
• Requirements trace forward to verification. Verification links back to the requirements at all levels.
• Verification methods are:
  – Inspection
  – Test
  – Demonstration
  – Analysis, which may include simulation
Summary

• The EMC Systems Engineering Process methodology integrates all requirements and objectives and facilitates the identification and specification of unknown or hidden requirements.

• It leaves behind a traceable, repeatable, documented path of engineering effort and decisions.
Questions?

For more information and technical papers go to: http://www.Jastech-emc.com