Performance Requirements and Simulation of Aircraft Power Systems

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About the Speaker …

- Vince Socci – BS EE, MS EE, MBA TM, IEEE
- 18-yr veteran of vehicle-based power control system design
- Principal, On Target Technology Development
- Diverse power technologies
  - Electromechanical actuation
  - Motor controls
  - Vehicle engine and drive systems
  - Robust, safety-critical, pulsed power applications
- Military & defense, commercial aerospace & automotive systems
- Applied these system design considerations in aerospace, automotive, locomotive, and marine applications.
When a vehicle electric power system fails, lives, missions and property are at risk. What can we do to minimize that risk?
Our Roadmap...

- Aircraft platform trends
- Power system architecture
- Power system design requirements
- Power system modeling

- Collaborative Discussions!
Vehicle Platform Trends

- More electrical demands on engines and auxiliary loads
  - Fly-by-wire – robust control and protection
  - Advanced capabilities and communication

- Applications need power generation, distribution, protection, conversion and energy storage

- High reliability, availability, transportability

- Advanced survivability and safety

- Voltage characteristics are NOT converging

- Precision controls for performance and efficiency
## Power System Components

<table>
<thead>
<tr>
<th>Function</th>
<th>Purpose (Components)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
<td>Creates/provides usable energy (battery, engine, external power)</td>
</tr>
<tr>
<td>Distribution Path</td>
<td>Provides energy transfer (wiring harnesses, distribution channels)</td>
</tr>
<tr>
<td>Control</td>
<td>Manage energy flow (converters, protection circuits, dashboard controls)</td>
</tr>
<tr>
<td>Load</td>
<td>Energy-using devices (motors, lights, communication equipment)</td>
</tr>
<tr>
<td>Indication</td>
<td>Measure power parameters (meters, sensors, diagnostics, feedback)</td>
</tr>
</tbody>
</table>
Power System Architecture

Data Storage

To Application Databus

Alarms and Indicators

PUSHM
(Power system management and control)

Battery Charging/Discharging System

Energy Storage

Propulsion Load

Propulsion Load System

Vehicle Load

Vehicle Load

Vehicle Load

Vehicle Load

External DC Loads

Mission Load

Mission Load

Mission Load

Mission Load

Mission Load

External AC Loads

AC Load

AC Load

AC Load

High-power Load

High-power Load

Data and Control

Power

AC Bus

Low Voltage DC Bus

DC/AC Inverter

Mission Load Power Converter Unit

External Source Power Filter/Converter (Shore, Generator)

Bi-directional Power Converter

Low Voltage DC Bus

Vehicle Load

AC Load

AC Load

High Voltage DC Bus

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Power Components - Sources

- Internal – Engine, alternator, on-board vehicle power
- External AC – AC generators, “shore power”
- External DC – DC generators, auxiliary source, solar
- Energy storage – Vehicle battery, UPS, battery packs, capacitor banks, flywheels
- Trade-off of performance characteristics
- Parallel, switchover and shared power
- Grounding, filtering, conditioning
Power Components - Path

- Power distribution, busses, wiring
- Partitioning and conversion architectures
- Custom to application, but can be modular
- Keys: Efficiency, performance, partitioning
- Protect mission-critical components
- Derating and growth
- Isolation and separation
Power Components - Control

- **Converters**: diverse characteristics, passive/active, efficiency, pf correction, isolation, regulation, cost
- **Conditioning**: voltage/current limiting, rectification, pf correction, harmonic control, TEMPEST
- **Protection**: System safety, G/B/S, lightning, surge, E-stop
- **Power management**: System monitoring/control, BIT, fault detection/isolation, interlock and distribution control
- **Load shedding**: Disable by functional group to mitigate faults and extend power operation
- Requirements customized to application
- Complexity decreases reliability
Power Components - Loads

- Vehicle loads – propulsion, air conditioner, lights, etc.
- Mission loads – communications, radar, refrigeration, etc.
- Survivability/safety – GPS, collision avoidance, etc.
- Entertainment – radio, game systems, cell phones, etc.
- Trends: Growing number of loads and power demands
- Partitioning: support shedding, interlock, flow management
- Bi-directional sources: Power source or sink
- External loads: limit and protect
- Analysis must consider static, transient and peak loads
Power Components - Indication

- Monitors: voltage, current, phase, BIT, feedback controls
- Improve fault tolerance
- Health monitoring, management
  - Source integrity
  - Protection devices
  - Converter monitoring
  - Propulsion system
  - Energy management
  - Fault reporting
- Hardware & software indicators

### Storage Devices

<table>
<thead>
<tr>
<th>Storage Devices</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit Voltage</td>
<td>21.6 V</td>
</tr>
<tr>
<td>Unit Capacity</td>
<td>39 Ah</td>
</tr>
<tr>
<td>Unit Weight (w/pack)</td>
<td>22 lb</td>
</tr>
<tr>
<td># Storage Units</td>
<td>11</td>
</tr>
<tr>
<td>Total Capacity</td>
<td>429 Ah</td>
</tr>
<tr>
<td>Total Energy Cap</td>
<td>9266.4 Wh</td>
</tr>
<tr>
<td>Total Weight</td>
<td>242 lbs</td>
</tr>
</tbody>
</table>

### Energy Flow Analysis

- Loads engaged: 1
- Present Storage SOC (%): 27%
- Energy Supply Status: Surplus 2684 W
- Hours to charge to 100%: 2.3 hours
- Hours to discharge to 10%: Not discharging
- Power Draw (W): 716

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Power System Requirements

- AC Generation Systems
  - General
  - Steady State
    - Voltage
    - Voltage unbalance
    - Voltage modulation
    - Waveform characteristics
    - Frequency steady-state
    - Frequency modulation
    - Phase voltage displacement
Power System Requirements

■ AC Generation Systems
  ● Transient
    – Voltage transients
    – Voltage spikes
    – Total harmonic distortion
    – Power interruptions
    – Frequency transients
    – Frequency variations
DC Generation Systems
- Voltage
- Voltage ripple
- Voltage transients
- Voltage spikes
- Power interruptions
AC Utilization Equipment

- Compatibility with AC Generation equipment
- Power utilization
- Voltage drop
- Inrush Current
- Current distortion
- Voltage distortion
- Power Factor
- Phase balance (three-phase equipment only)
- Voltage modulation due to equipment
- Fault detection
- Transparency time
- Protection against phase reversal
DC Utilization Equipment

- Compatibility with DC Generation equipment
- Voltage drop
- Inrush Current
- Transparency time
- Protection against polarity reversal
- DC ripple voltage due to equipment
An aircraft is a compilation of equipment from many diverse vendors
- Different generation systems
- Different utilization systems

Only the integrator knows what everyone is doing

Equipment standards and requirements

How can we be assured that all the equipment will work well together?

“Trust, but verify.”

Ronald Reagan
AC Network Quality

RAT Start-up sequence

Total EHA’s power consumption

Maximum peak power
AC Network Analysis

AC Network Quality

RAT Start-up sequence

Voltage at P.O.R
(spectral analysis)

THDv at P.O.R

THD: 3.87%

Freq: 504.81
DC Network Quality & Stability

BCRU power-up (without battery)

Input voltages at equipments terminals
DC Network Analysis

DC Network Quality & Stability

BCRU power-up (without battery)

Input currents of supplied equipments

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Network configuration logics validation

Electrical configuration management

Power sources availability & contactors status

Busbars voltage

Power cut due to network reconfiguration

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Modeling and Simulation can be used for:
- Requirements analysis
- Collaboration with partners
- Interoperability test
- Support Real-time Hardware in the Loop (HIL)
- Power flow analysis
- Support of life-cycle processes
Risk Mitigation through Power Simulation

- Early feasibility evaluation and benchmarking among a wide array of powertrain technologies
- Early change/risk management
- Collaboration and communication across the integrated program team
- Simplified, modular implementation and integration
- Constant and immediate feedback
- Evolving powertrain platform to meet true application needs
- Prototype enhancement throughout project life-cycle
- Life-cycle planning and growth demonstration
- Comparison of field test data with simulated experimental data
- Adjustable demarcation between simulation and hardware-in-the-loop
Test bed for your power system development

Functional decomposition, design, component integration

Understand integration of modules
  - Multiple sources and loads
  - Converters (DC/DC, DC/AC, AC/AC, AC/DC)
  - Filter operation

Mitigation of instabilities
  - Three-phase balancing
  - Power conditioners
  - Modulation
  - Ripple and harmonics
  - Power factor correction

Opal-RT Simulation
Power System Simulation

Source ... Path ... Control ... Load ... Indication
Heirarchical Modeling
Compare control operation
Where has On Target applied these technologies?

- Power system engineering for platform integrators
  - Airbus
  - Boeing

- Utilization equipment models
  - EBHA system
  - A400M winch and crane
  - Cargo handling system
  - UAV actuator control
  - HEV propulsion system
  - Fuel control system
  - Generator controls
  - Vehicle power management system

- Our own products
  - PUSHM
  - Quad-channel actuator control system
  - Motor Control Electronics
**Scenario:**

Imagine sitting comfortably on an airplane, enjoying a new issue of your favorite magazine. All of a sudden, as you fly over the Equator, the plane does a fast 180-degree roll, and you find yourself in an inverted flight. The pilot announces over the loudspeaker “Hmmm… that doesn’t seem right. Are there any systems engineers onboard?”

The software development for the F-16 fighter plane experienced this exact failure mode during simulation flight testing. It was resolved in the fielded design.

If this failure occurred in real-life, the aircraft and pilot would be lost.
Closing Thoughts

- The need for
  - Advanced, complex systems
  - Best practices and lessons learned
  - Safety and reliability
  - Performance evaluation
  - Design validation
  - Normal range and robust operation assessment
  - Integration and verification

- The value of prototyping

- Product development is about communication
  - Among developers
  - With customers

- Credit: Many photos provided by Mr. Michael Gallagher, MARCORSYSCOM