Intelligent Power Systems for Human Deep Space Exploration
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Agenda

• Mission Needs
• What is Intelligent Power?
• Intelligent Power Architectures
• Development Approach
• Wrap-up
Incremental steps to steadily build, test, refine, and qualify capabilities that lead to affordable flight elements and a deep space capability.
What is the problem?

- Communication and recovery times are longer than any previous experience

<table>
<thead>
<tr>
<th>Mission</th>
<th>Duration of Mission After Incident</th>
<th>Communication Latency Time</th>
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<tbody>
<tr>
<td>Deep Space Habitat</td>
<td>9 months to 1 year</td>
<td>15 to 45 mins.</td>
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<tr>
<td>Apollo/Orion</td>
<td>3 – 5 days</td>
<td>1 to 2 sec.</td>
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<tr>
<td>Mount Everest</td>
<td>1 – 2 days</td>
<td>Real time</td>
</tr>
<tr>
<td>Deep Sea Submersible</td>
<td>8 hours</td>
<td>Real time</td>
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<tr>
<td>Shuttle</td>
<td>2 – 5 hours</td>
<td>Real time</td>
</tr>
<tr>
<td>Submarine</td>
<td>1 – 2 hours</td>
<td>Real time</td>
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- Power Is Most Critical System On Board Vehicle
  - System will need a high level of availability
  - System will need to operate autonomously for long periods of time
Potential Deep Space Vehicle Power System Characteristics

- Power 10 kW average
- Two independent power channels with multi-level cross-strapping
- Solar array power
  - 24+ kW Multi-junction arrays
- Lithium Ion battery storage
  - 200+ amp*hrs
  - Sized for deep space or low lunar orbit operation
- Distribution
  - 120 V secondary (SAE AS 5698)
  - 2 kW power transfer between vehicles

Deep space vehicle concept
Notional Deep Space Vehicle Power Architecture

BCDU: Battery Charge / Discharge Unit
MBSU: Main Bus Switching Unit
PDU: Power Distribution Unit
RPCM: Remote Power Controller Module
SARU: Solar Array Regulator Unit
So What is Intelligent Power?
In the 1960’s, the operational vision for a spacecraft was routine and mundane for the astronauts – autonomous operation of core systems.
What is Intelligent Power?

Intelligent Power uses advanced hardware and control technology to autonomously manage and control distributed power generation and storage assets, power distribution networks, and loads for both near earth and space exploration systems.
Intelligent Power System Requirements

- **Master Requirements**
  - Power system shall provide up to two years of autonomous operations between habitations
  - Power system shall permit humans to consent to any operations / actions above the direct control layer (reactive) during habitation

- **Derived requirements**
  - The Intelligent control shall safely manage the energy generation and storage systems
  - The Intelligent control shall safely manage the power distribution system
  - The Intelligent control shall advise and consent on loads management
  - The Intelligent control shall operate the power system in one of three states – Preventative, Restorative and Emergency.
  - The Intelligent control shall manage the health of the power system
  - During human habitation the Intelligent control shall perform contingency analysis and recommend correction action in response to an anomalous event
  - During uninhabited operation the Intelligent control shall perform contingency analysis and take corrective action in response to an anomalous event.
Intelligent Power Architecture
Present power systems rely on continuous real-time support of mission control
Present Power Management and Control

Mission Control

Long Term Mission Oversight

Coordination / Contingency Management

Energy Management

Power Network Security

Loads Management

Direct Control Layer

Generation Control
- Array Regulation
- Array Pointing

Energy Storage Control
- Battery Regulation
- SOC Monitoring

Distribution Control
- Fault Protection
- Switch Configuration

Power System

Loads
- Load Activation
- Load Monitoring
Future space needs to have less dependence on the ground and more on internal intelligence.
Potential Control Architectures

Centralized Coordination

- Distributed Control with Centralized Coordination
- Traditional Hierarchical Multilayer Control

DC = Direct Control Layer
IA = Intelligent Agent
Multi-layer Hierarchical Power System Control

Long Term Mission Oversight

Coordination/Contingency Mgmt

Energy Management

Power Network Security

Generation Control

Energy Storage Control

Distribution Control

Loads Management

Mission Control

Intelligent Power Control

Direct Control Layer

Load Activation

Load Monitoring

Power System

- Array Regulation
- Array Pointing
- Battery Regulation
- SOC Monitoring
- Fault Protection
- Switch Configuration
- Load Activation
- Load Monitoring
Agent Based Power System Control

- Long Term Mission Oversight
- Energy Management
  - Array Regulation
  - Array Pointing
- Power Network Security
  - Battery Regulation
  - SOC Monitoring
- Distribution Control
  - Fault Protection
  - Switch Configuration
- Generation Control
- Energy Storage Control
- Loads Management
  - Load Activation
  - Load Monitoring

Power System

Mission Control

Intelligent Power Control

Direct Control Layer
State machine model of power system condition

- Preventative state -- Normal operation, continue indefinitely without interruption
- Emergency State -- Fault occurs – relieve system stress and prevent further deterioration
- Restorative State -- System is degraded but safe – restore power flow to all loads in a safe manner in minimum time

The overall objective of the power control is to service as much demand as possible without exceeding constraints.
Intelligent Power Development Approach
Intelligent Control Development Strategy

Power Sources

Energy Storage

Controller Hardware

Data to anchor simulation

Intelligent Control Test Bed

R/T Simulator

Hardware in the loop interface

Control Algorithms

Power Distribution Hardware

Hardware in the loop interface
Distributed Heterogeneous Simulation

- 6 High speed multi-core PC’s with 8 processors each
- Total of 48 processors
- PC’s interconnected through high speed Ethernet
- Middleware provides synchronized interconnection of any number of dynamical subsystem simulation processors
- Multi-use model library of spacecraft power system components
- DHS-enabled to support time synchronization and real-time execution
- Support transition from modeling/design environment to hardware/HIL implementation
Power System Control

- Objective is develop distributed controls with
  - Centralized coordination
  - Agent based coordination
- Direct layer of reactive control is implemented using the Programmable Logic Controller (PLC)
- Controllers communicate using Common Industrial Protocol over Ethernet, Devicenet or Controlnet
- Discrete / analog outputs permit interfacing with “real power hardware”
- Central coordination or Agent based control is implemented using additional processors
  - Communication is achieved using a “blackboard technique”
Implementation of control strategies to develop and demonstrate multiple phases of Intelligent Control.
Intelligent Power Development Status

- Completed set-up of the Intelligent Power Control Lab
- DHS simulation computers and distributed computing middleware has been installed
- Initial power system simulation is up and running
- Installed Satellite Tool Kit (STK) for orbit navigation and state information
- Distributed controller hardware has been installed
- Initial set of controller requirements have been defined
- On track for an initial controller demonstration at the end of CY 2013
Wrap-up

- We need Intelligent Power Systems for long term operation far from earth

- Several types of control approaches and architectures are possible of achieve the implementation

- Utilization of real-time simulations, hardware in the loop and power system test beds can achieve the goal
References

• 2001: A Space Odyssey Internet Resource Archive
