Evolving Toward a High Assurance Smart Grid

Through a Distributed Control Architecture

Smart Grid Cyber Security
is more than just applying IT security
to grid control links

It is a total System Design approach

Tom Overman
thomas.overman@boeing.com

Brad Cohen
brad.s.cohen@boeing.com

Agenda

- High Assurance
  - A broad term encompassing dimensions of high security, high availability, high reliability
- Review of threat examples, with Lessons Learned
- Grid integration
- Threat Response:
  - An Architectural Approach to achieve a High Assurance Smart Grid

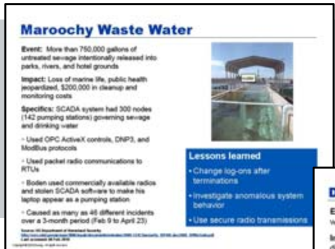
A definition

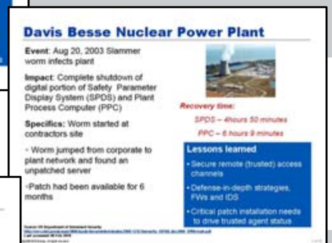
- High Assurance Smart Grid (HASG)
≠ Evaluation Assurance Level (EAL) for Smart Grid

- High Assurance Smart Grid (HASG)
≈ "integrated approaches for assuring reliability, availability, integrity, privacy, confidentiality, safety, and real-time performance of complex systems…"

See High Assurance Systems Engineering (HASE) 2010 conference web site at:
http://web.mst.edu/~hase/hase2010/

The Threat





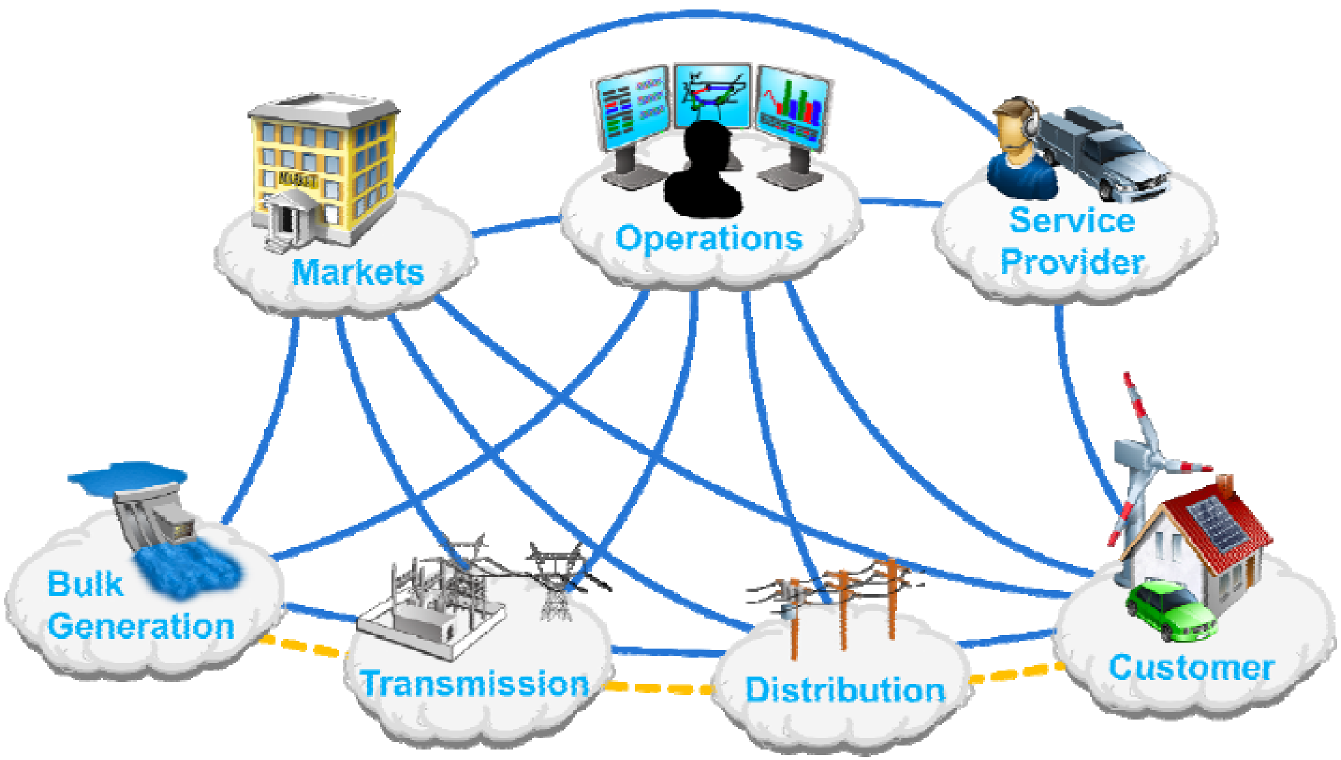
Lessons Learned (IT Solutions Approach)

- Apply appropriate security to remote access
- Critical patch installation needs to drive trusted agent status
- Data/command integrity
- Defense-in-depth strategies, Firewalls & IDS
- Delete user accounts after terminations
- Don’t perform database updates on live systems
- Don’t use administrative controls to solve system anomalies
- Identify controls to critical assets
- Integrated physical security
- Investigate anomalous system behavior
- Role based access
- Secure remote (trusted) access channels
- Trusted agents
- Use secure radio transmissions

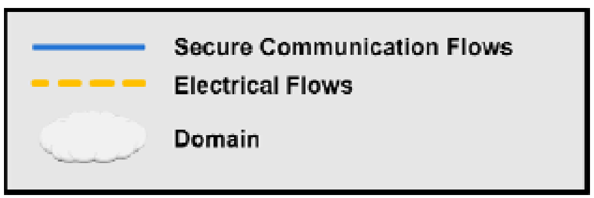
All necessary, but not sufficient

these do not address grid control *architecture*

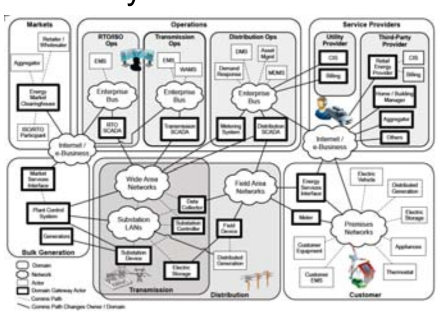
NIST Smart Grid Conceptual Reference Diagram



NIST Smart Grid Framework 1.0 Sept 2009

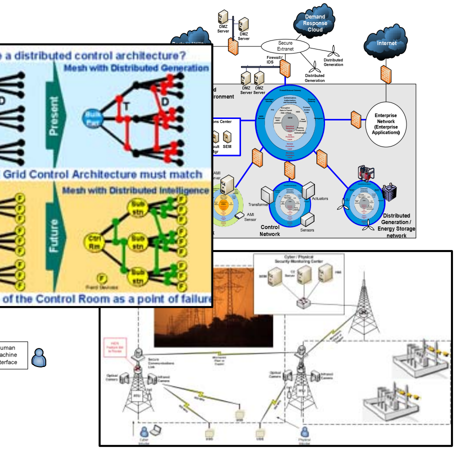


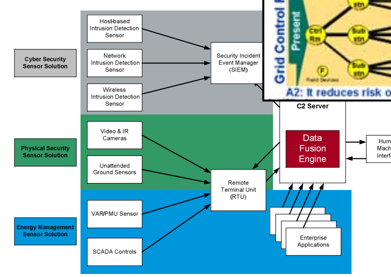
System Details

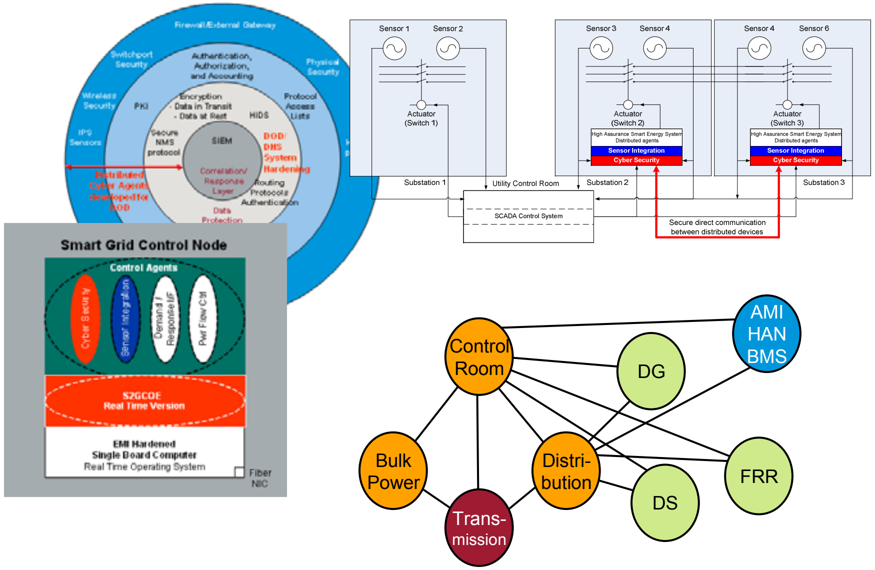


High Assurance Smart Grid Attributes

- Integrated Energy Management, Cyber Security and Physical Security with Defense in Depth
  - Including strong Role Based Access Control (RBAC) ***for people and devices***
- Secure distributed architecture enables autonomy and eliminates single point of failure
- Assume compromise in the system (through accident, malice or system failure) ***and engineer energy control systems accordingly***
- **Auto-Responsive (AR) Loads**
  - if you can't remotely control it,
    the remote control can't be compromised







Creating a High Assurance Smart Grid
requires utilizing the best attributes from multiple disciplines

Defense in Depth Model

See NERC Smart Grid Task Force Report ***Reliability Considerations from the Integration of Smart Grid***

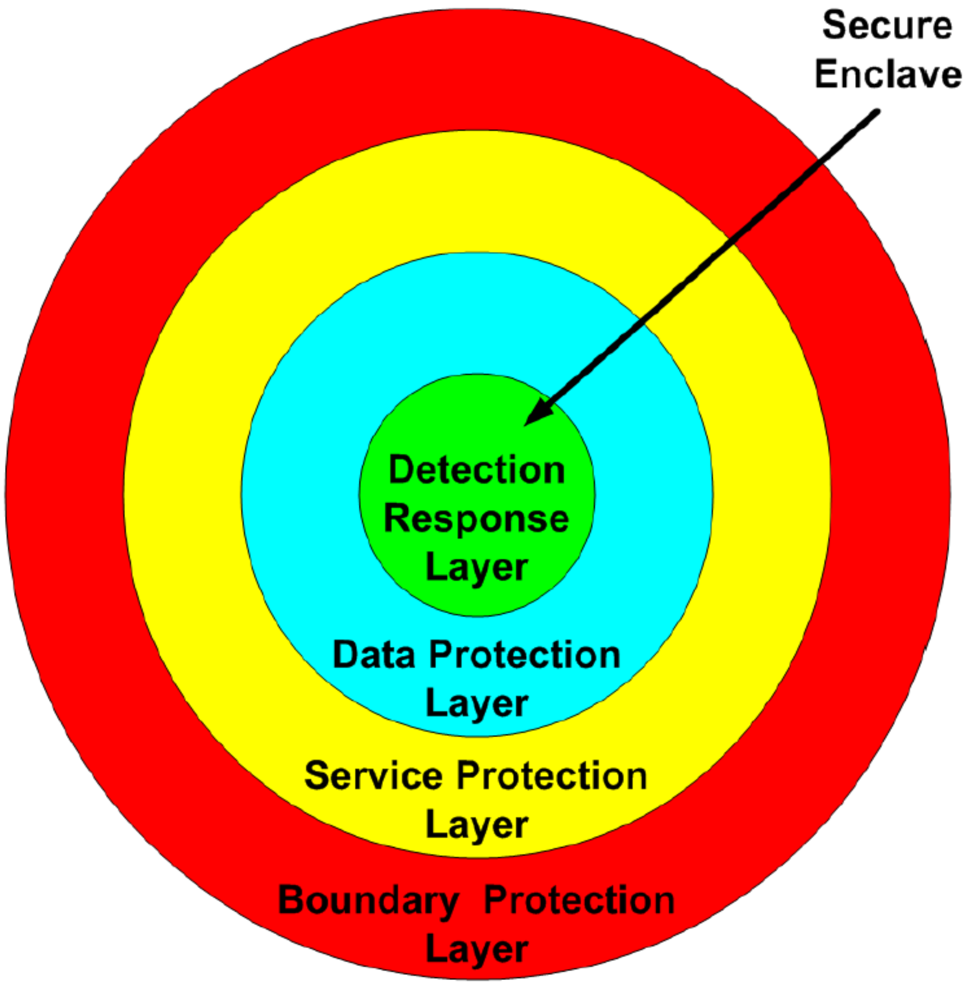
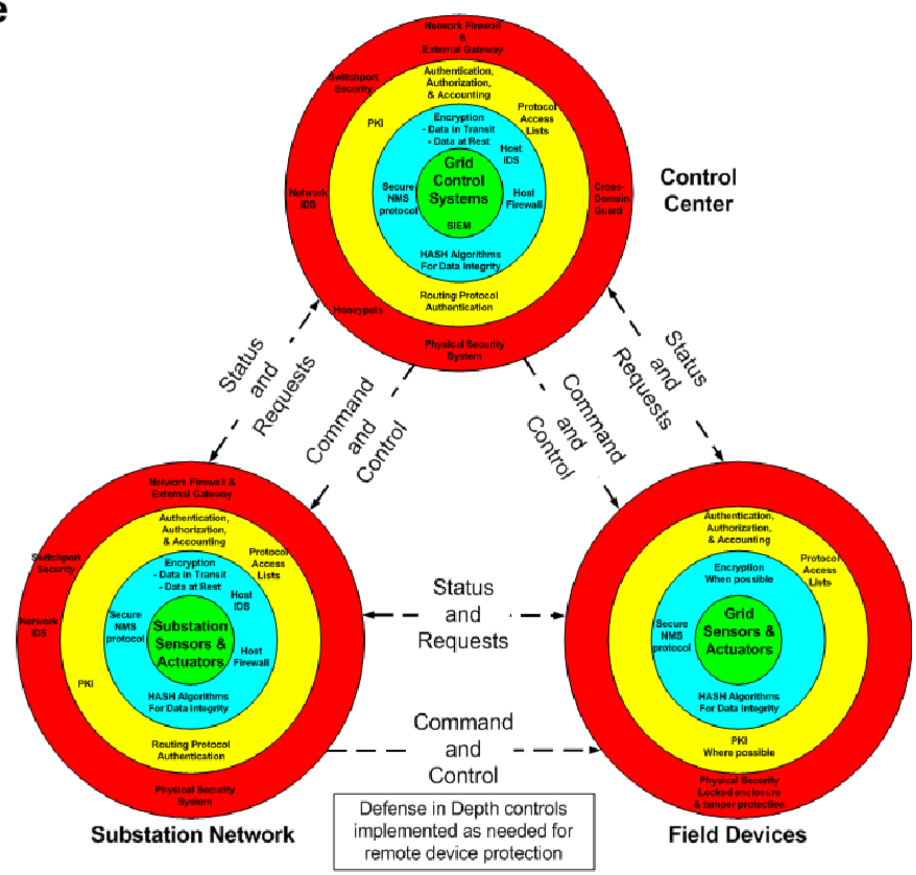


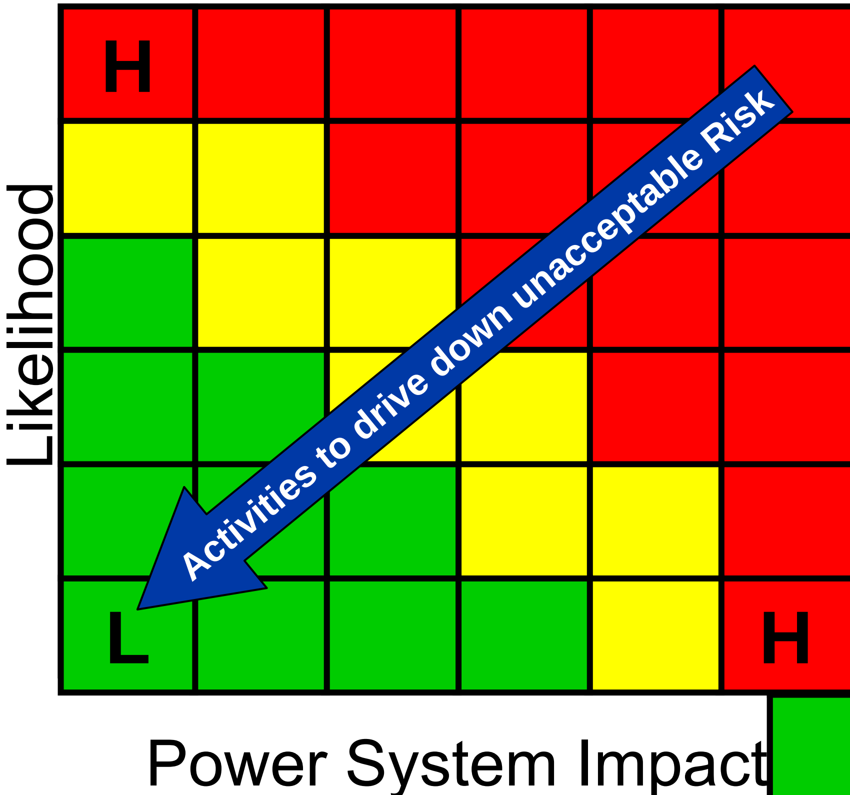
Figure 6: Cyber security defense-in-depth model

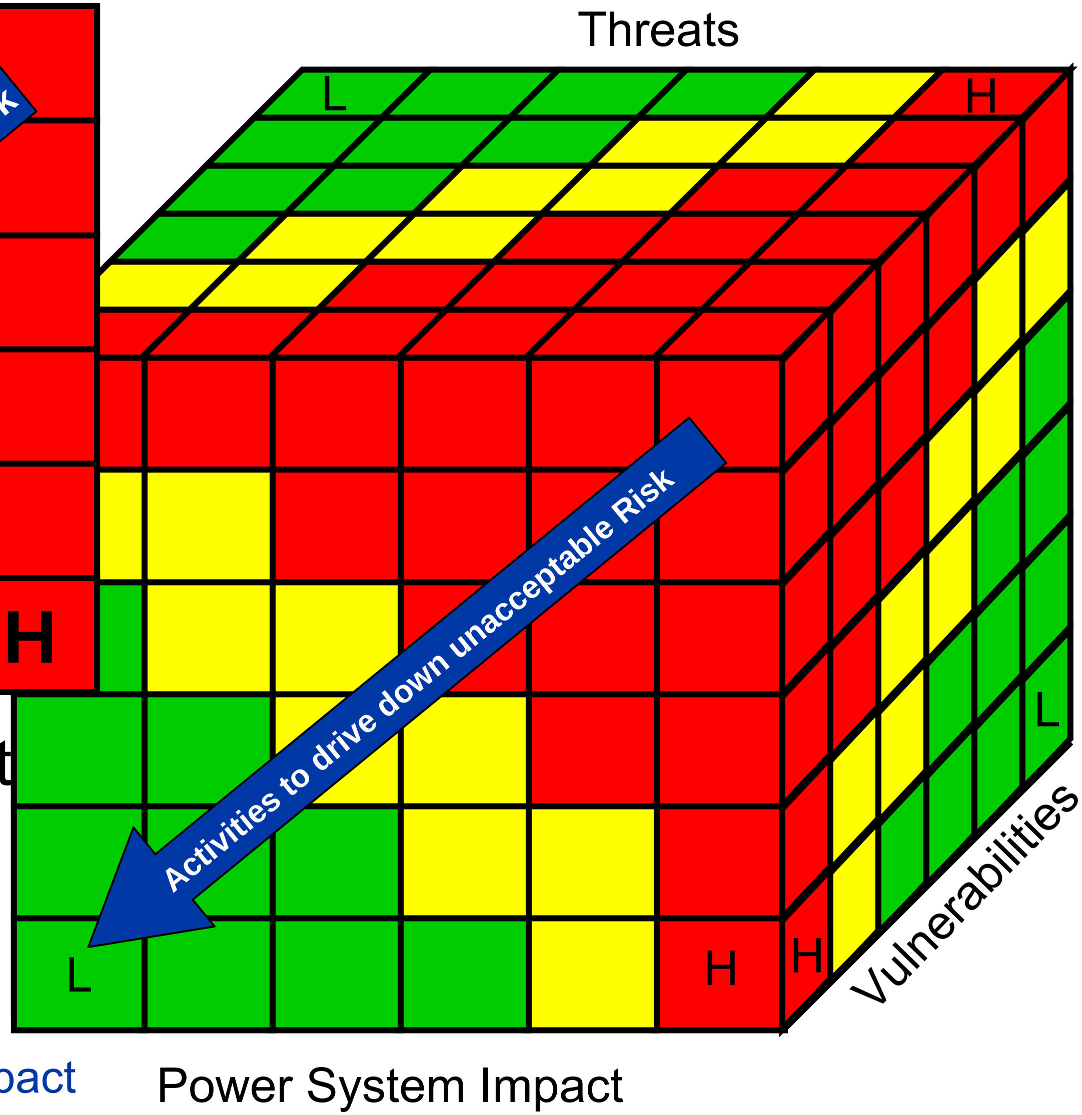
Figure 7: Cyber security defense-in-depth example



http://www.nerc.com/files/SGTF_Report_Final_posted.pdf

Risk Management Approach to Selecting Security Controls

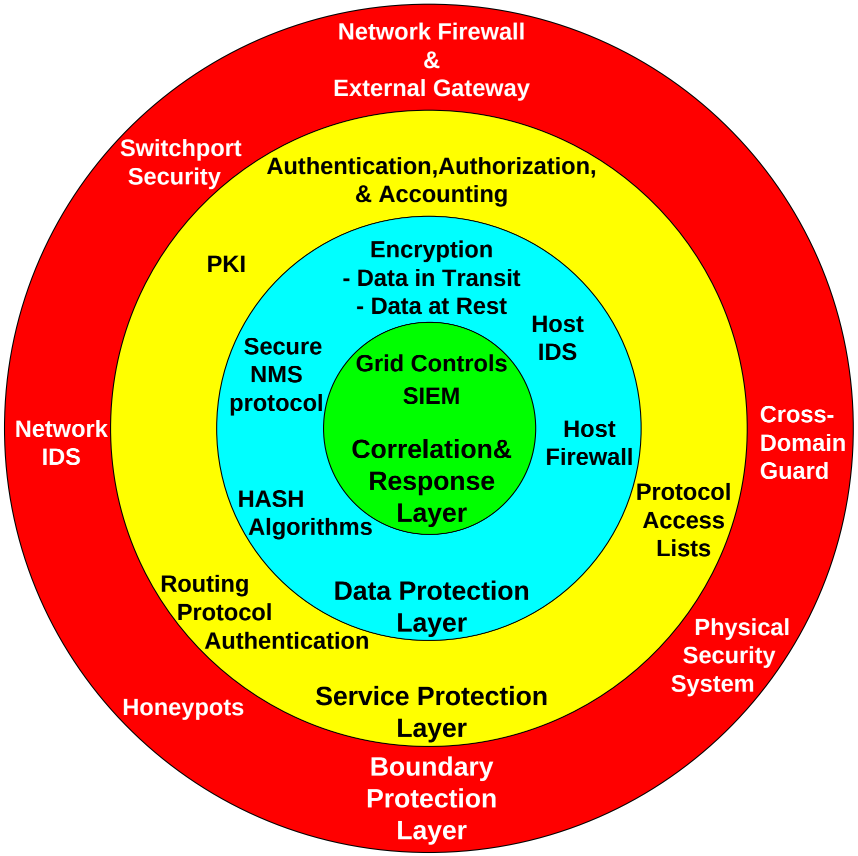


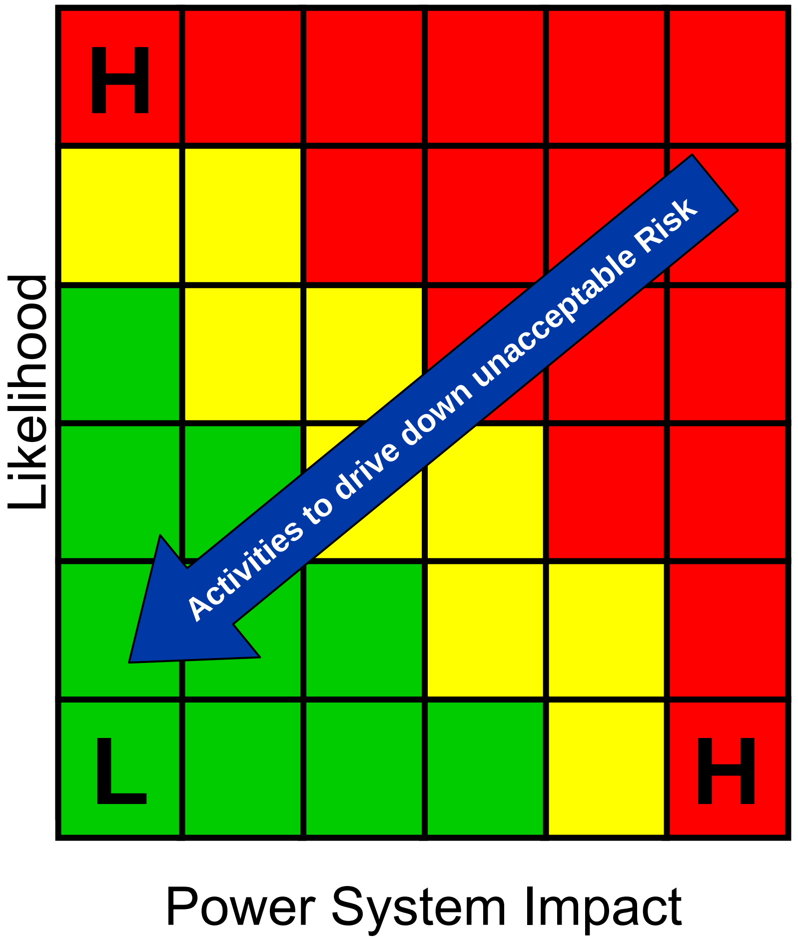


Risk = Likelihood x Impact

Risk = Threat x Vulnerability x Impact

Cyber Security Defense in Depth & Risk Management

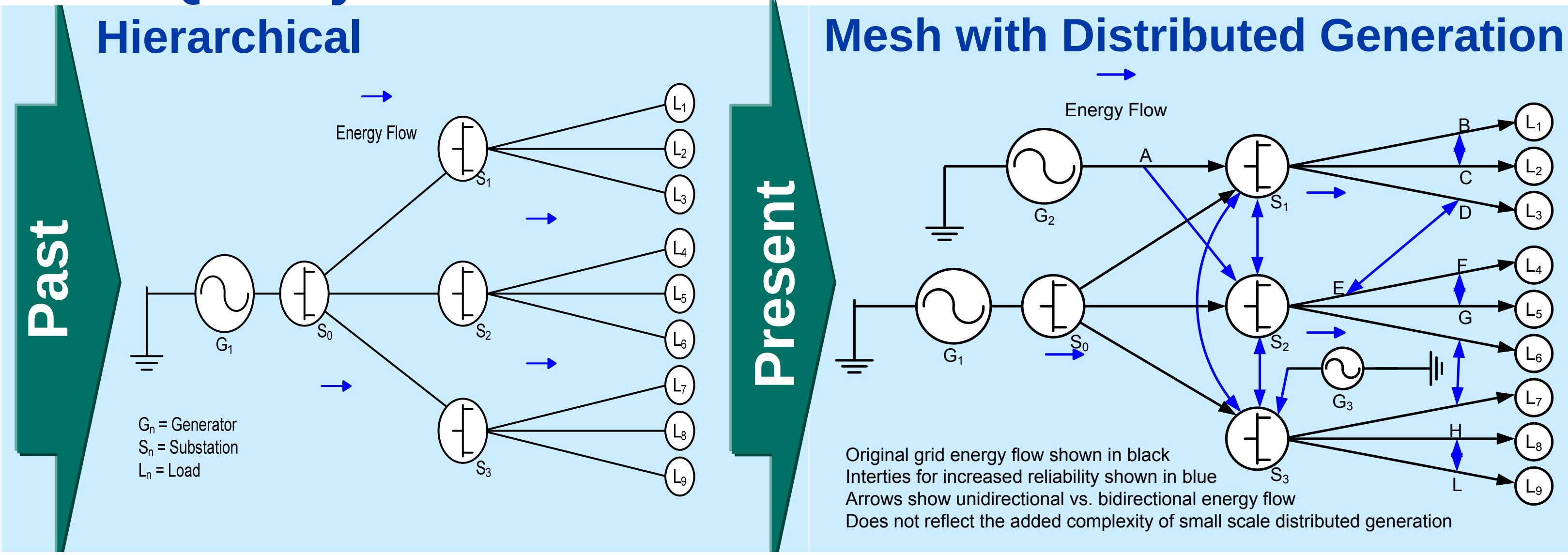




Defense in Depth & Risk Management Assessment determine which controls are needed at each node or type of node

Q: Why have a distributed control architecture?

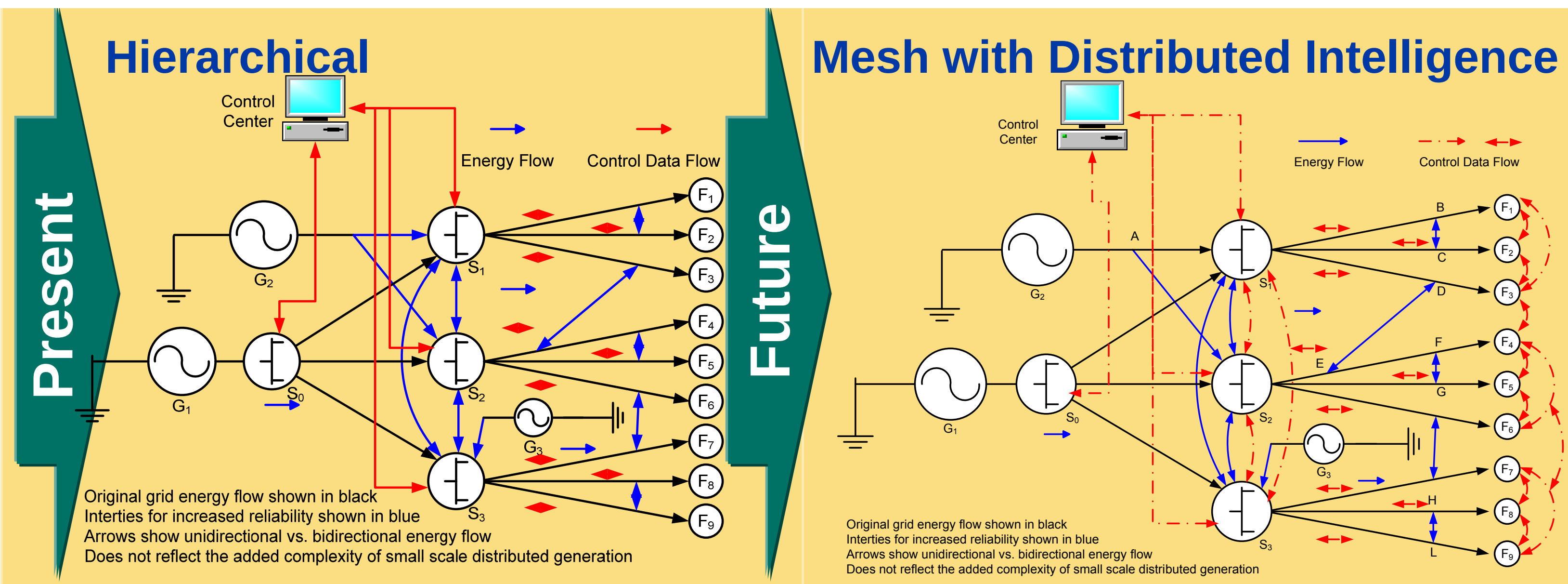
Energy Flow



Energy **Distributed Network**

A1: The Grid and Grid Control Architecture must match

Grid Control Flow



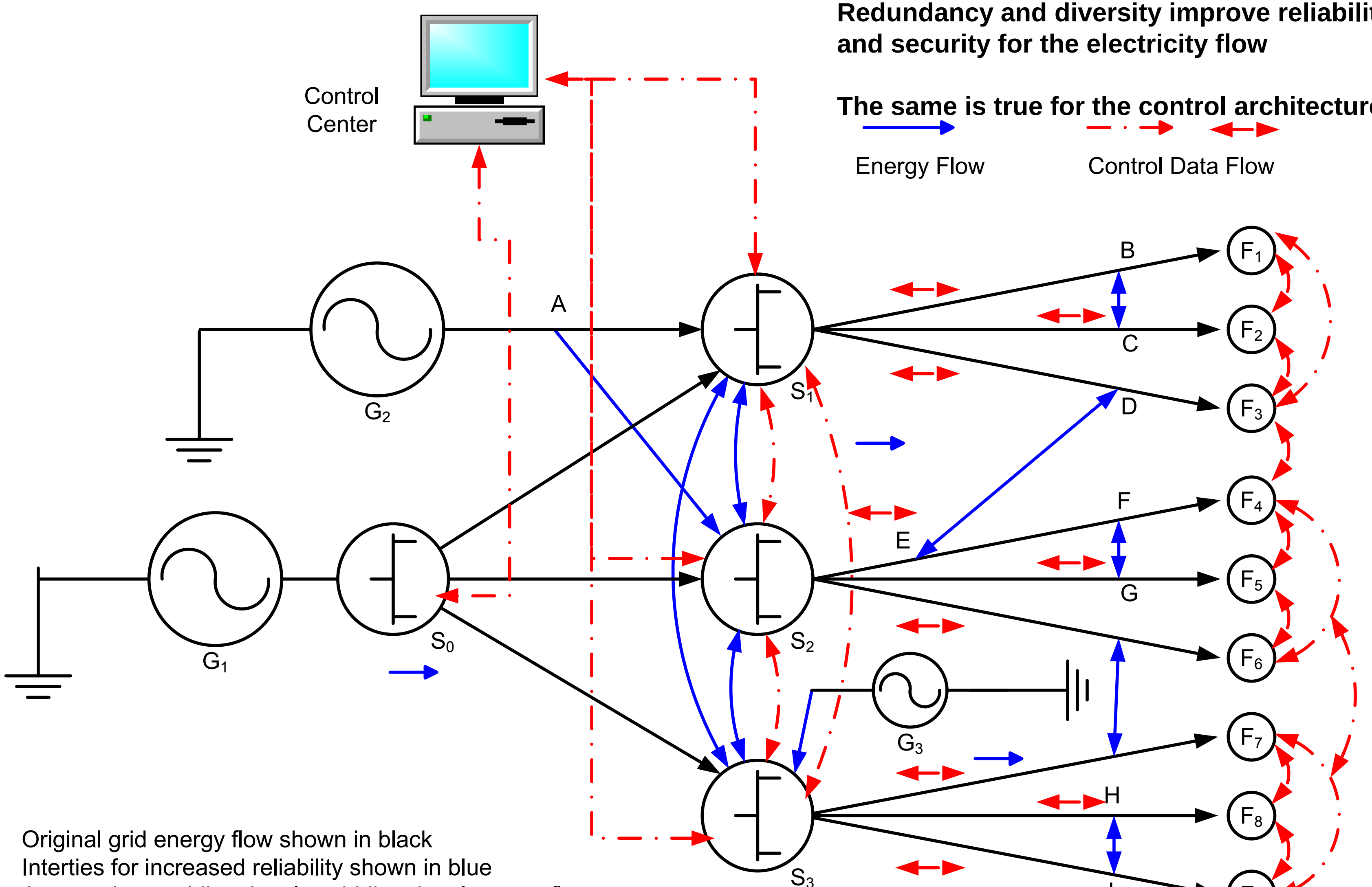
Control **Distributed Network**

A2: It reduces risk of the Control Room as a point of failure

Distributed Energy → Distributed Control

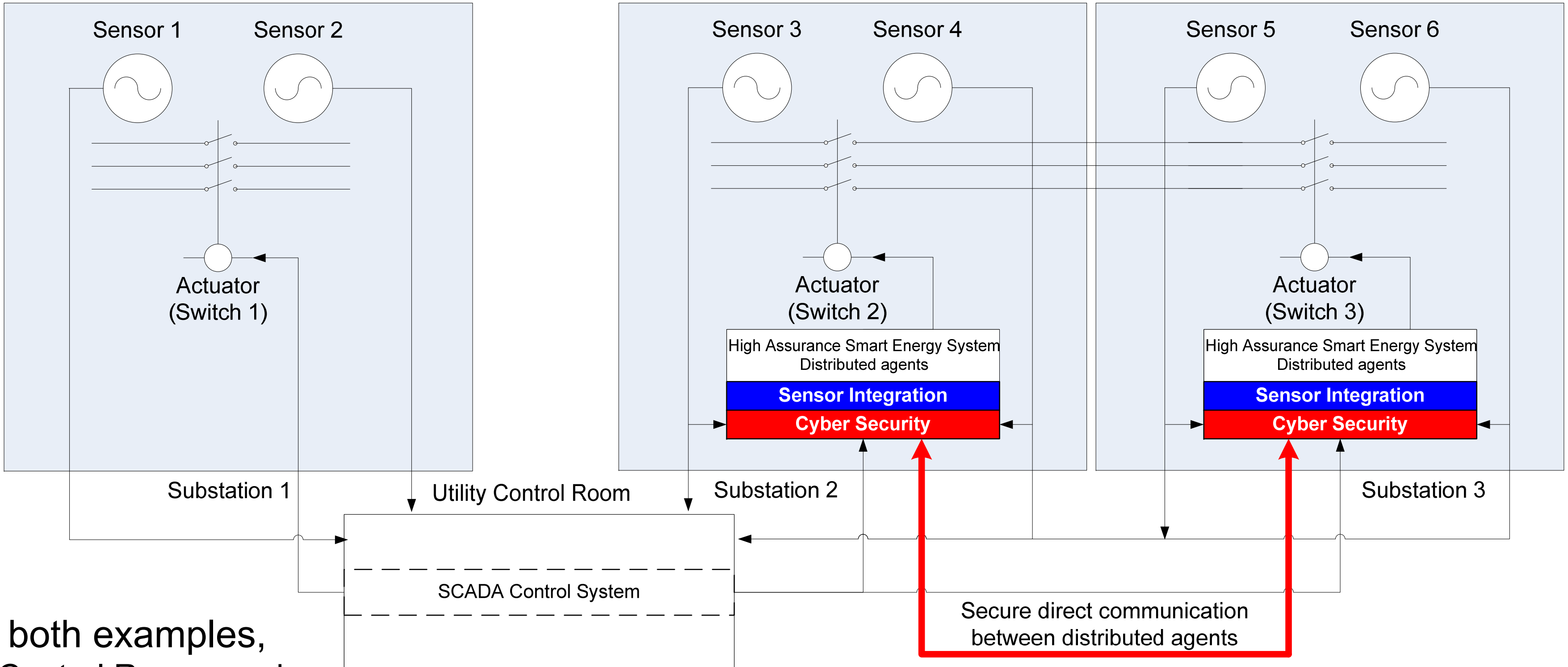
Redundancy and diversity improve reliability and security for the electricity flow

The same is true for the control architecture



Original grid energy flow shown in black
Interties for increased reliability shown in blue
Arrows show unidirectional vs. bidirectional energy flow
Does not reflect the added complexity of small scale distributed generation

High Assurance Smart Grid Substation Example



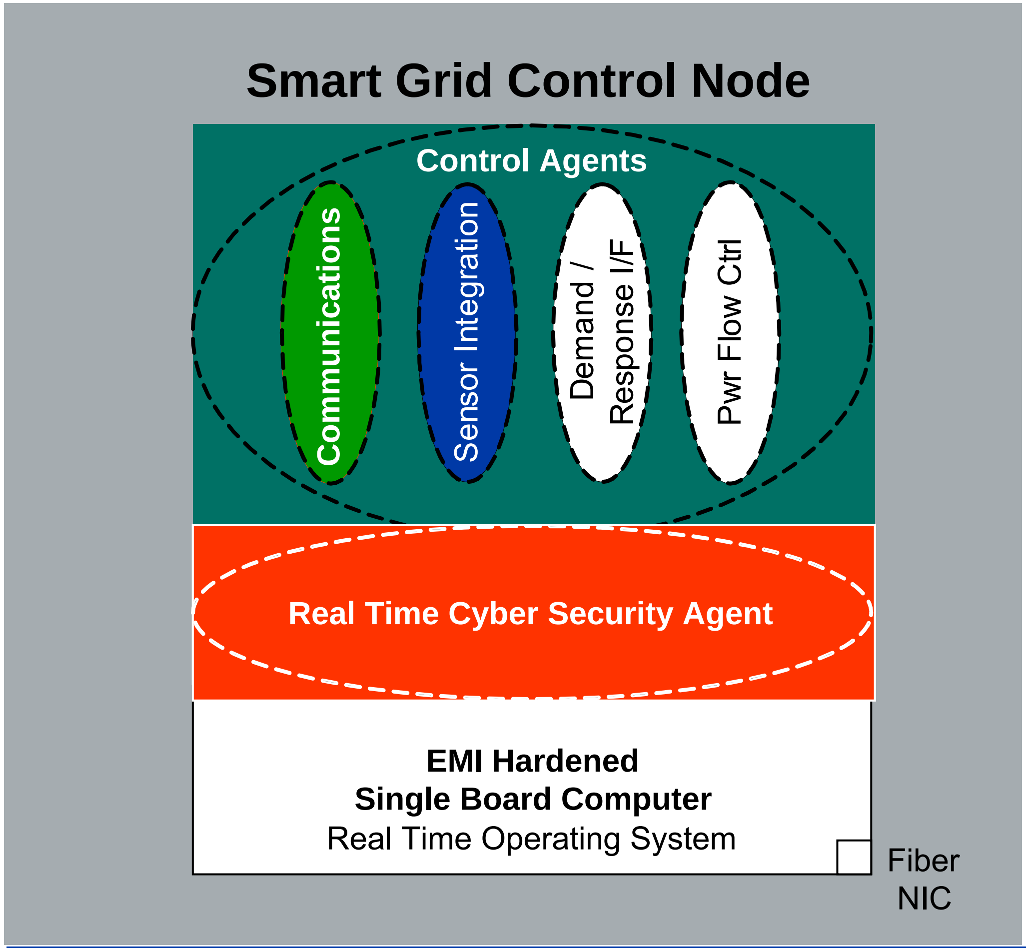
In both examples,
- Control Room sends command to close
- Grid segments are out of phase, which will cause damage if actuator closes

In Substation 1, Actuator 1 trusts the command, activates, resulting in damage

In Substation 2, Actuator 2 receives a command to close, ***directly validates of local sensor status and Substation 3 status***, and refuses the command

High Assurance Smart Grid comes only from <u>integrating</u> Cyber Security, Physical Security, and Distributed Energy Management

Strong Distributed Cyber Security Enables Trusted Distributed Intelligence for Energy Control



- Not just “Distributed Agents” but Distributed Intelligence
  - Many Agents are just “Rules-Based”
  - Autonomy requires Distributed Intelligence
- Software Control Agents for:
  - Grid Management
  - Cyber Security
  - Physical Security

Distributed Control Agents assure no action is taken based on a single input HASG leverages distributed cyber agents developed for DOD

Why have Load Control?

- Because Loads are not smart enough to manage themselves

Potential Solutions

- Increase automation and security to achieve load device control over individual devices or groups of devices
- Increase the ability of loads to manage themselves in response to grid conditions

An Ethernet Comparison to the Electricity Network

Shared Attributes

- Shared media: many nodes, one set of ‘network’ wires per ‘subnet’
- Congestion: overloading impacts quality of service
- Non-Deterministic: highly reliable when “over-engineered”, but no guarantee of service
- Peak loads: impacted by predictable but random patterns (predictable random distributions)

Non-shared Attribute

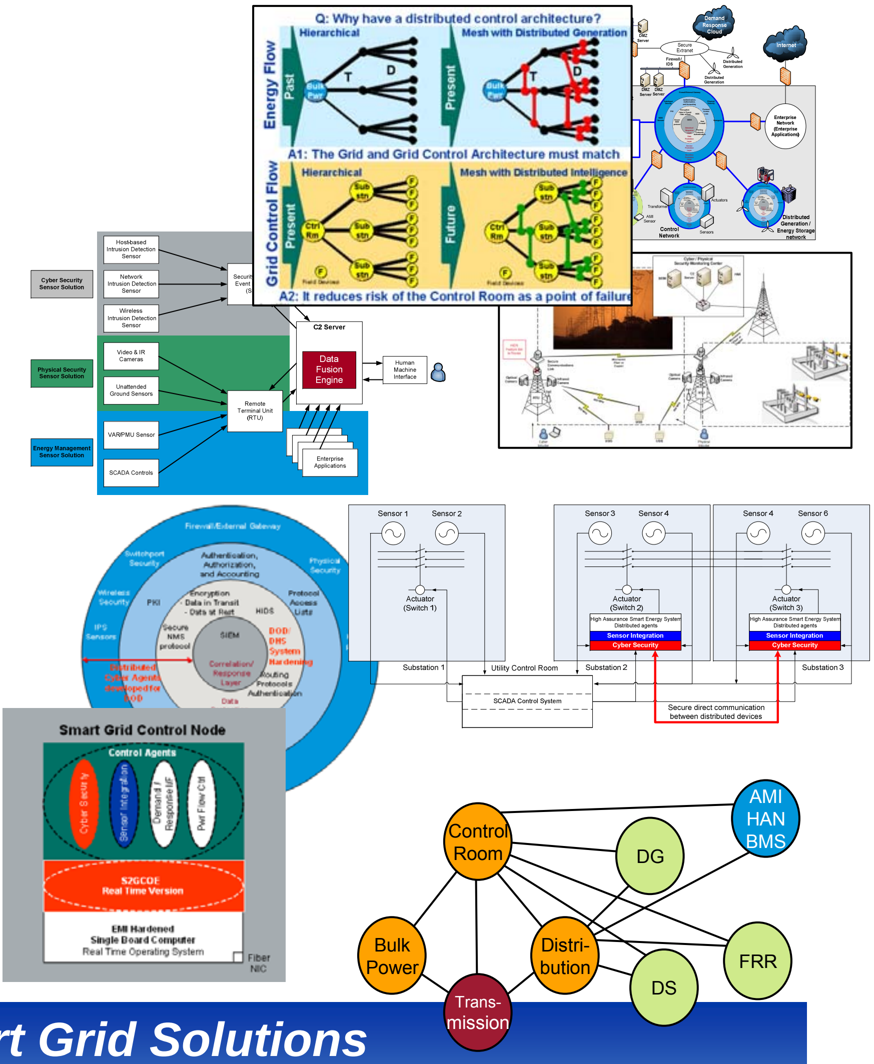
- Ethernet has ***randomness*** built into controls to increase reliability of data throughput

Auto-Responsive (AR) Load Control

- PNNL Study – load senses grid frequency
  - Reduce Load when frequency is below 59.95Hz (for example)
    - ***HOWEVER, use a random function (say, 5-20 minutes) for when to resume load***
    - Avoids creating rapid grid load oscillations
    - Same concept (but different time constraints) as Ethernet Collision Detection & Retry Timing
    - Provides a gradual increase in load after underspeed
  - Increase load when frequency is above 60.05Hz (for example)
    - And drop load immediately when frequency goes back below 60.05Hz
    - Provides a clipping function for overspeed
- AMI Meter Connect/Disconnect Functions
  - Function is service connect/disconnect, not life safety of workforce
  - Use a random function (say, 5-20 minutes, rectangular distribution) for when meter responds
    - Avoids potential for rapid shocks to system if AMI control network is compromised
- Overall, avoids complexity of having to build an expanded control network with hundreds of millions of control nodes on a national basis

High Assurance Smart Grid Attributes

- Integrated Energy Management, Cyber Security and Physical Security with Defense in Depth
  - Including strong Role Based Access Control (RBAC) ***for people and devices***
- Secure distributed architecture enables autonomy and eliminates single point of failure
- Assume compromise in the system (through accident, malice or system failure) ***and engineer energy control systems accordingly***
- **Auto-Responsive (AR) Loads**
  - if you can't remotely control it, the remote control can't be compromised



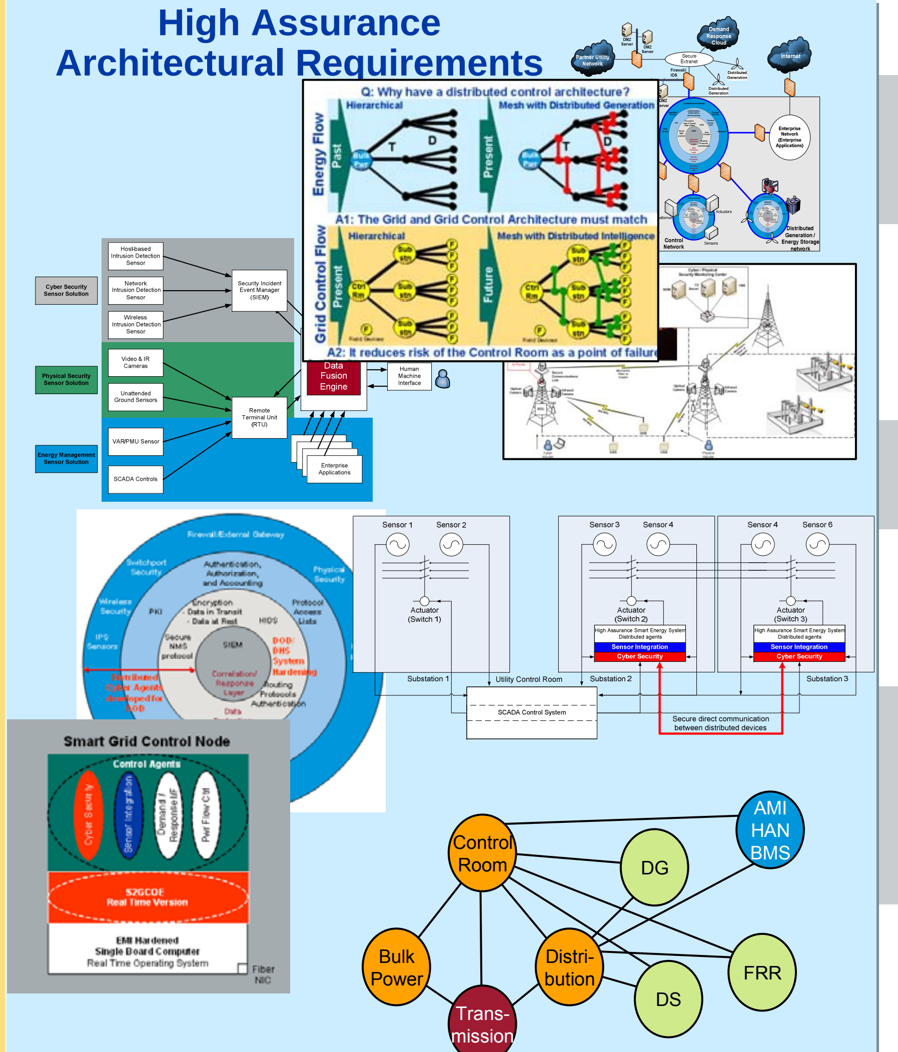
High Assurance Smart Grid Solutions utilizing the best attributes from multiple disciplines

The Solution – A System Design Approach

IT Lessons Learned

- Apply appropriate security to remote access
- Critical patch installation needs to drive trusted agent status
- Data/command integrity
- Defense-in-depth strategies, Firewalls & IDS
- Delete user accounts after terminations
- Don't perform database updates on live systems
- Don't use administrative controls to solve system anomalies
- Identify controls to critical assets
- Integrated physical security
- Investigate anomalous system behavior
- Role based access
- Secure remote (trusted) access channels
- Trusted agents
- Use secure radio transmissions

High Assurance Architectural Requirements



Smart Grid Cyber Security is more than just applying IT security to grid control links – It is a total System design approach

The Integrated Solution for a High Assurance Smart Grid: Energy Management, Cyber Security and Physical Security

1. Engineer energy control systems using High Assurance principles
   – From utility, aviation, space and government systems
2. Defense in depth
   – Best attributes of cyber security in a layered approach
3. Risk management approach to selecting cyber security controls
   – Select from Defense in Depth controls based on Risk Assessment
4. Distributed intelligence
   – For Cyber Security, Physical Security and Grid Management
5. Increase use of Auto-Responsive (AR) load management
   – Enhance grid stability without expansive Command & Control systems
   – If you can't remotely control it, the remote control can't be compromised

High Assurance Smart Grid Solutions –
An integrated approach across multiple disciplines