USING MBSE TO EVALUATE AND PROTECT THE ELECTRICAL GRID AS A SYSTEM OF SYSTEMS

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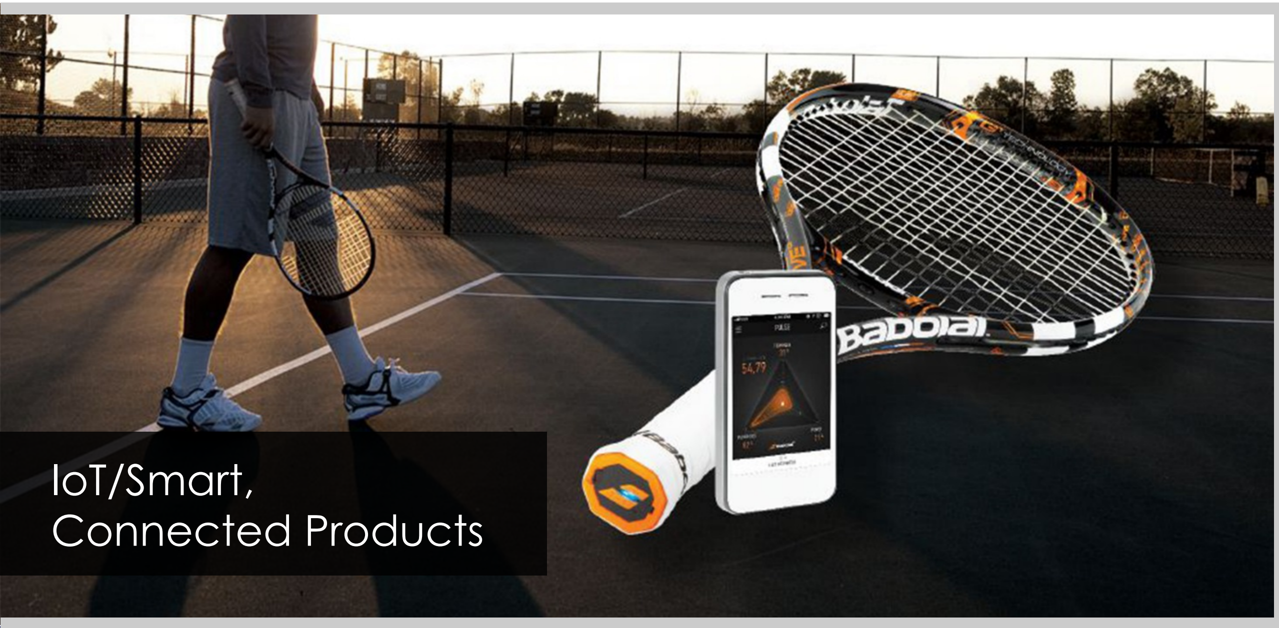
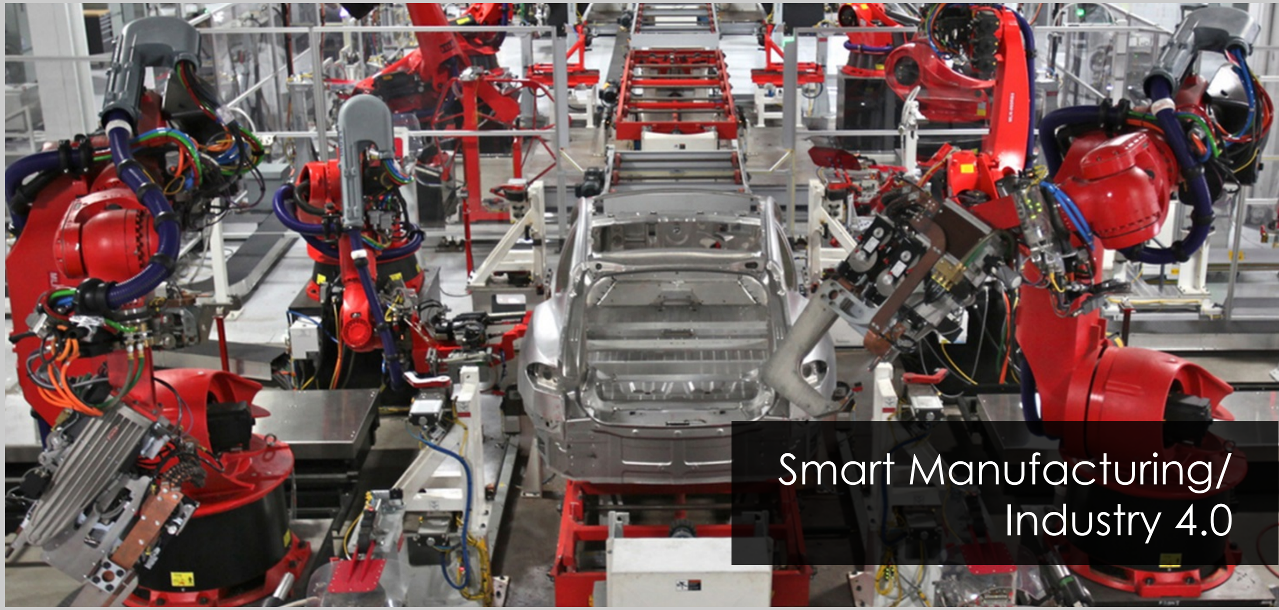
February 24th, 2017

BROAD IMPACT OF PHYSICAL & DIGITAL CONVERGENCE

ptc

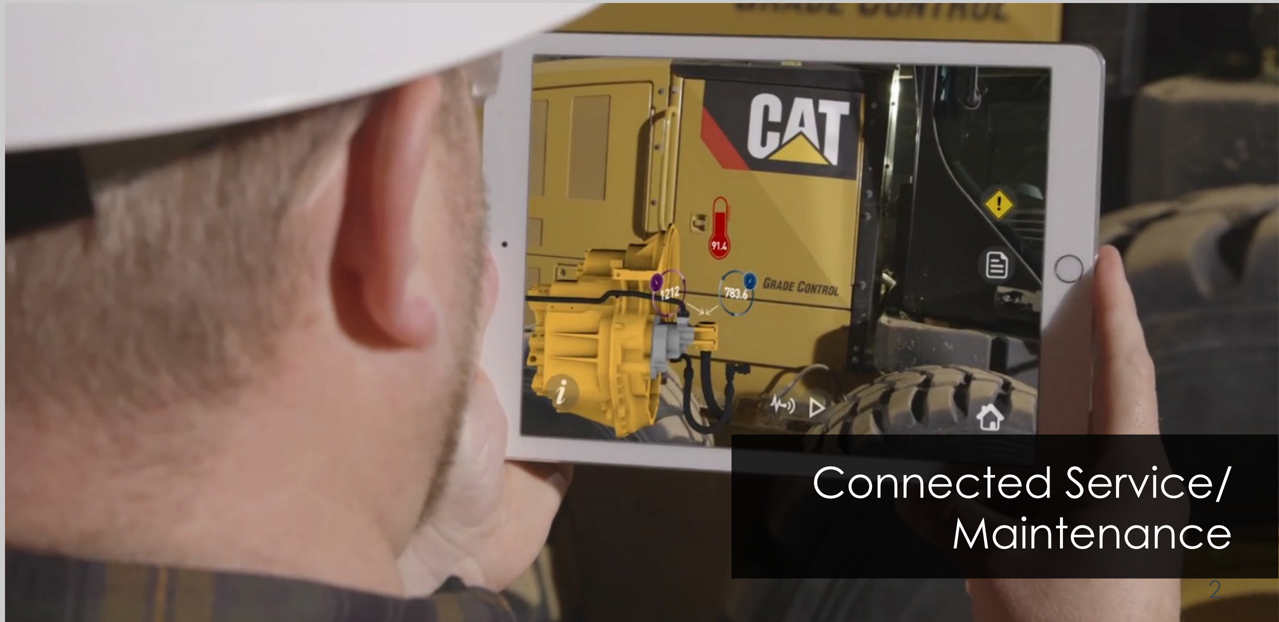


IoT/Smart,
Connected Products

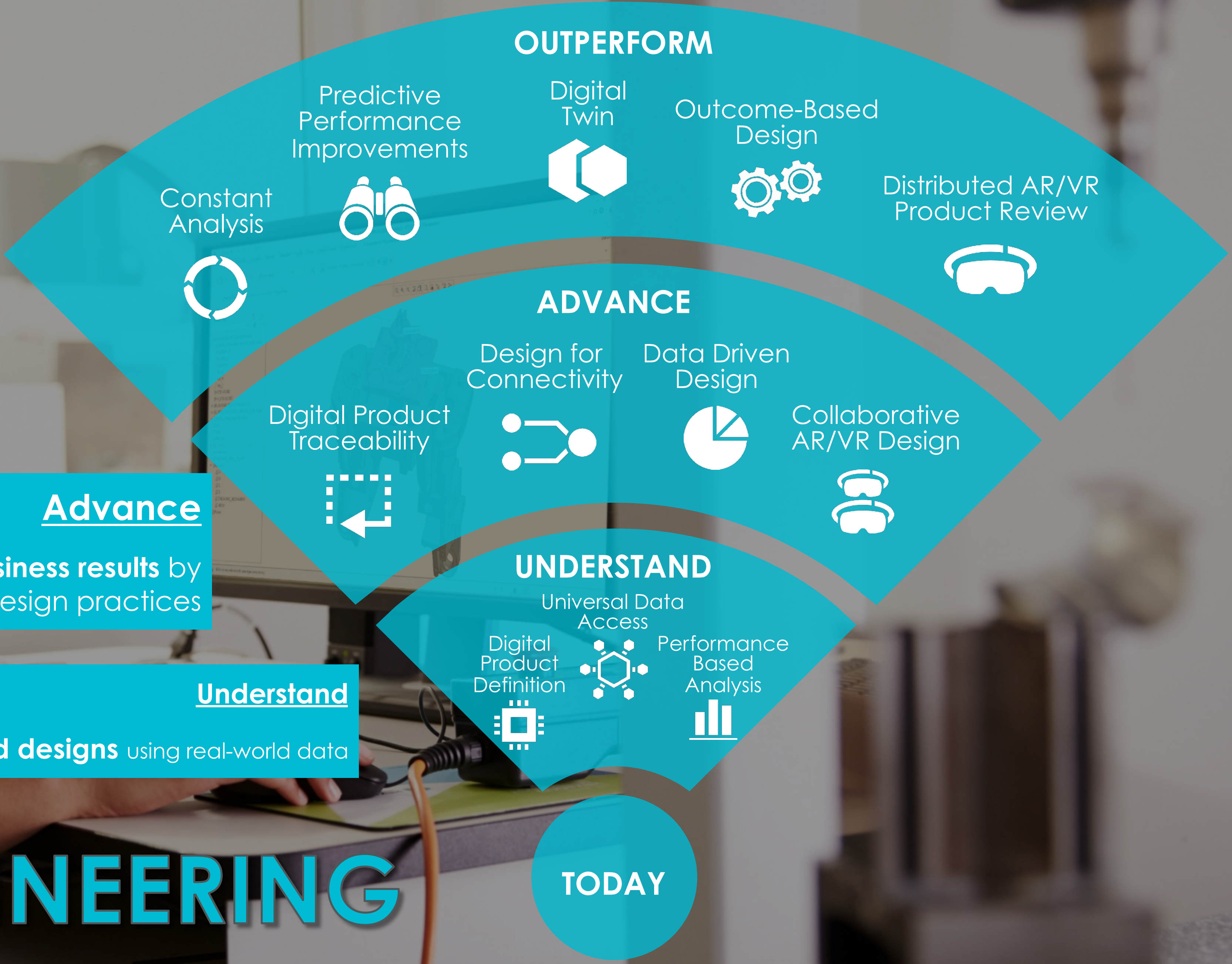


Smart Manufacturing/
Industry 4.0

Smart Cities, Fields, &
Worksites



Connected Service/
Maintenance



Outperform

Grow your market share and profitability though continuous innovation on evergreen products

Advance

Achieve **new levels of innovation and business results** by incorporating IoT technologies into your design practices

Understand

Make **better engineering decisions and designs** using real-world data

DIGITAL ENGINEERING

AGENDA

- Systems of Systems (SoS)
- The Unified Architecture Framework (UAF)
- The Electric Grid Model
- Linking SoS to systems
- Analysis modeling techniques
- Questions?

MODEL COMPONENTS

- The transmission network
  - The high voltage network comprising generating plants, substations, transmission lines, circuit breakers, high voltage transformers, etc.
  - Often at multiple voltage levels such as 69kv, 138kv, and 345kv.
  - Large geographically dispersed systems
  - Multiple operators and regulators
    - Overlapping responsibilities and control
  - Generally very reliable, resilient, dependable and flexible
    - However, most are run for profit so resources are limited
  - Thousands of interconnections and points of failure
  - Outages can be catastrophic
    - Northeast US and Canada blackout of 2003
    - European blackout of 2006
    - South Australia Blackout of September 2016

THE ELECTRIC GRID AS AN SOS

- **Operational independence**
  - The US national grid is operated by approximately 500 companies.
  - Independent operators, government institutions, municipal companies, not for profit, etc.
  - Operate independently to support their customers. Support of the overall is of secondary.
- **Managerial independence**
  - Each entity must comply with different standards, rules, laws and regulations. The North American Electric Reliability Corporation (NERC) oversees all of them.
- **Evolutionary development**
  - New systems, technologies or ConOps may be introduced by any of the companies as required to evolve and adapt to the changing environment, latest technology needs or stakeholder requirements. This will affect both the individual system as well as the SoS.
- **Geographical distribution**
  - Consists of about 300,000 km (186,411 mi) of lines and connects to Canada and Mexico.
- **Lifecycle independence**
  - Even within individual companies there will be multiple system lifecycles across asynchronous acquisition and development efforts, involving legacy systems, developmental systems, and technology insertion to meet their customer needs.

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MODELING THE ELECTRIC GRID WITH THE UAF

- The Unified Architecture Framework® (UAF®)
  - Is a generic and commercially orientated architecture framework.
  - Flexible framework that can be customized to different domains
  - Defines Enterprise Architecture (Systems of Systems)

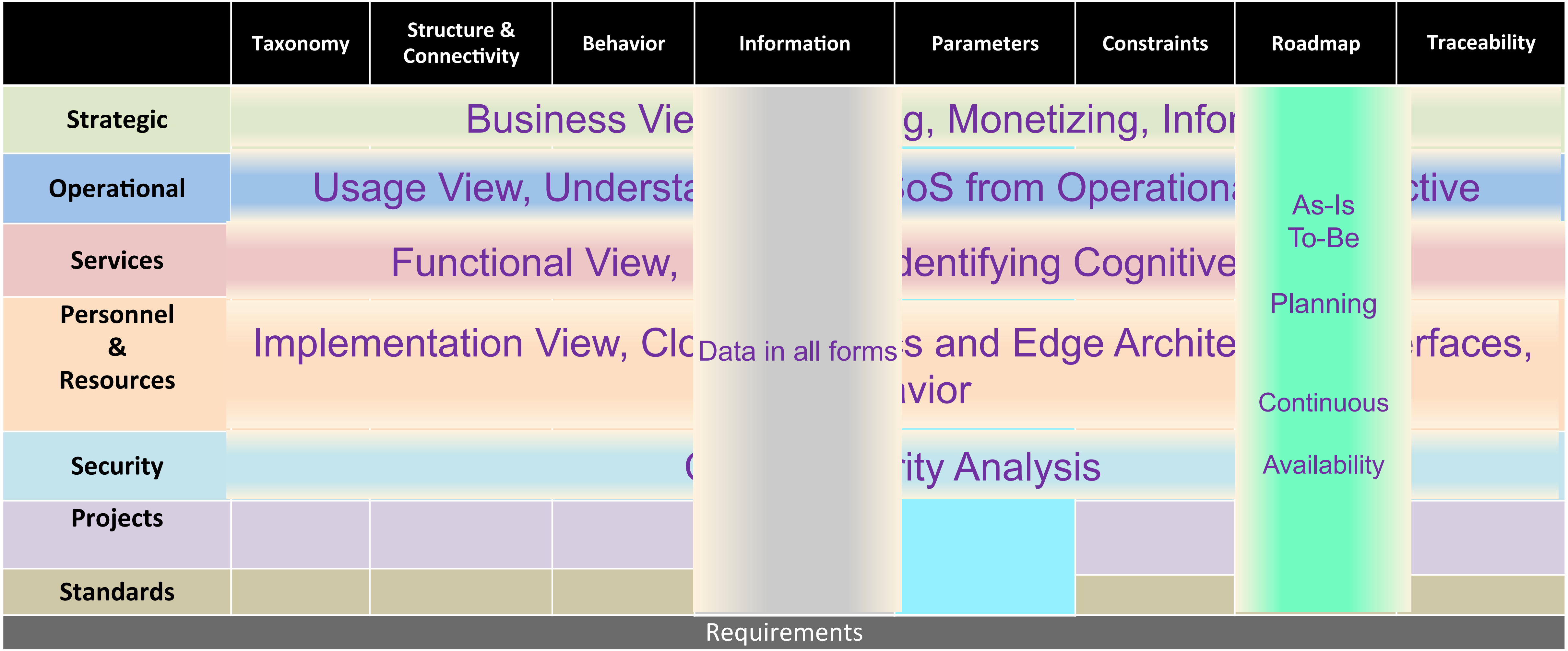
- A standard framework for defining many different aspects of complex architectures

- Supports an MBSE approach based on SysML

- Same pattern applied across different stakeholder domains

THE UNIFIED ARCHITECTURE FRAMEWORK GRID

- Rows map to different levels of focus
- Columns relate to standard means of expression
- IIC RA and some sub views can be mapped onto it



THE ELECTRIC GRID ARCHITECTURE

THE EXAMPLE MODEL – AN ELECTRICAL NETWORK

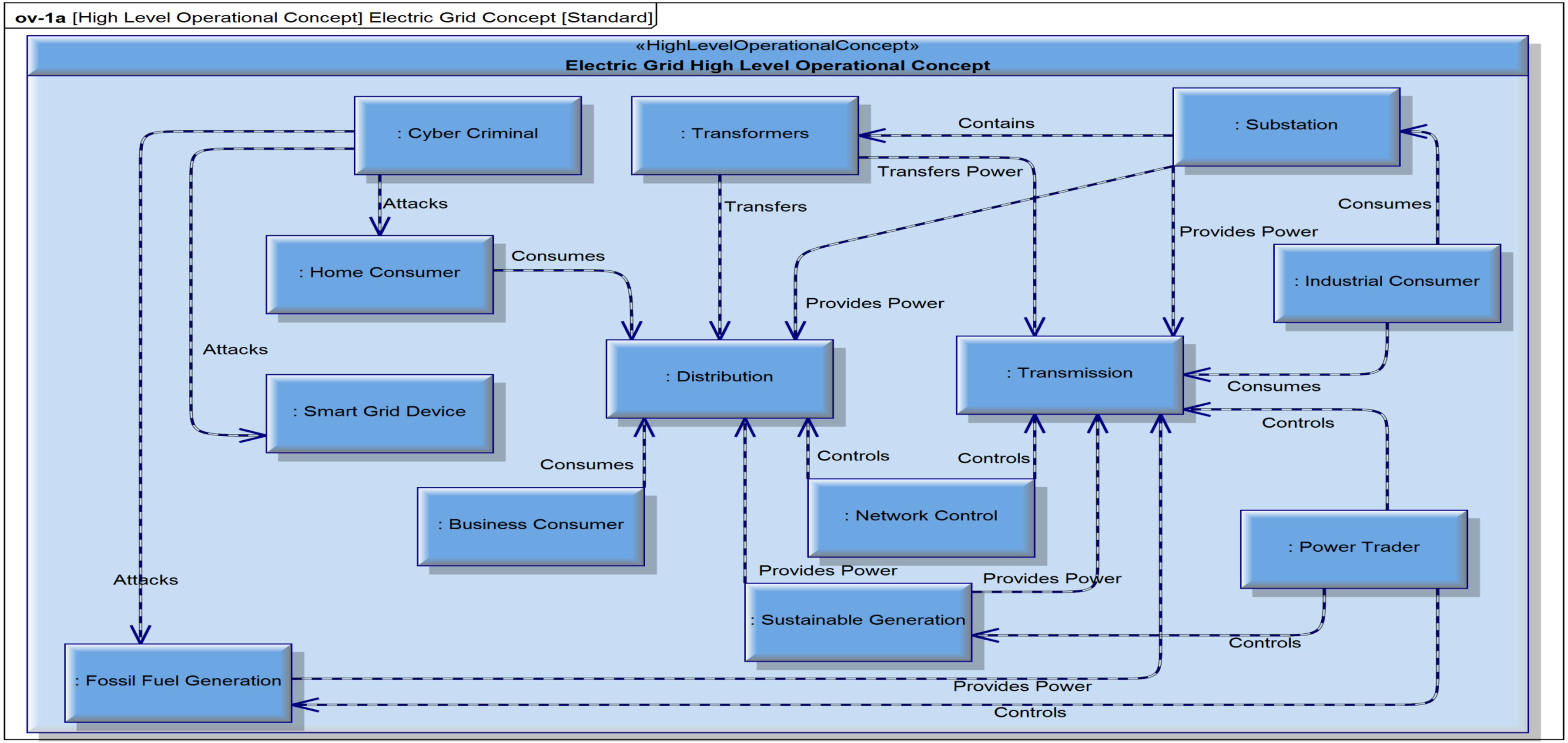
- Power systems are complex, enormous systems
- Different models are possible
  - The physical network
  - The telemetry and Supervisory Control and Data Acquisition (SCADA) system
  - The telemetered view via the SCADA system
  - The analyzed view via the load flow program
  - A simulated view for performing what-if scenarios based on current data
  - A historical view for reviewing the cause of problems and network outages
  - A model of the human operators making decisions
  - Etc.
- Consequently, a rich source for modeling

THE ELECTRIC GRID ARCHITECTURE

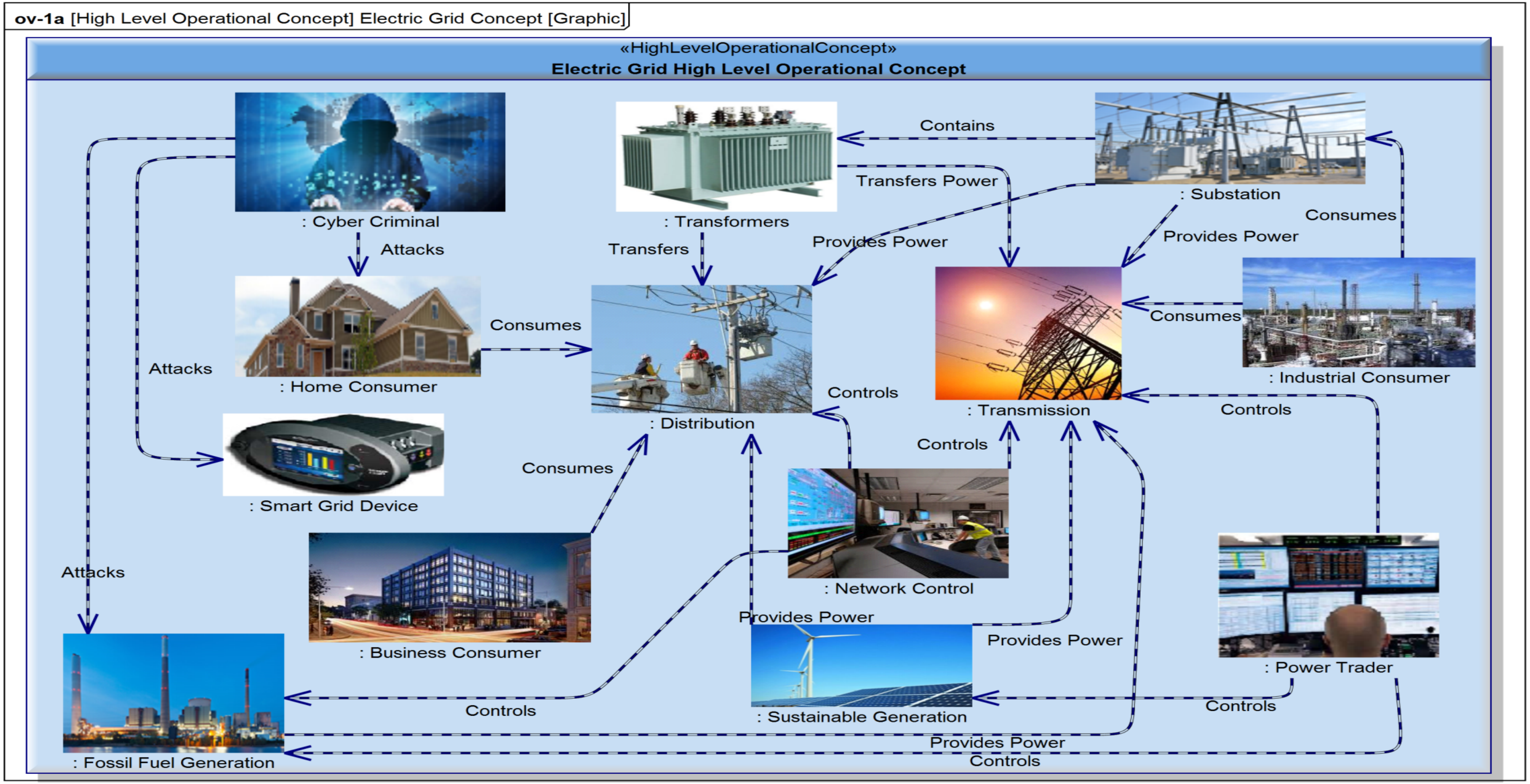
- Multi-Level Model
- Capability Based
- Defines logical and then Physical Architecture
- Supports all SysML Capabilities

ELECTRIC GRID CONCEPT DIAGRAM

- Defines system entities and their relationships

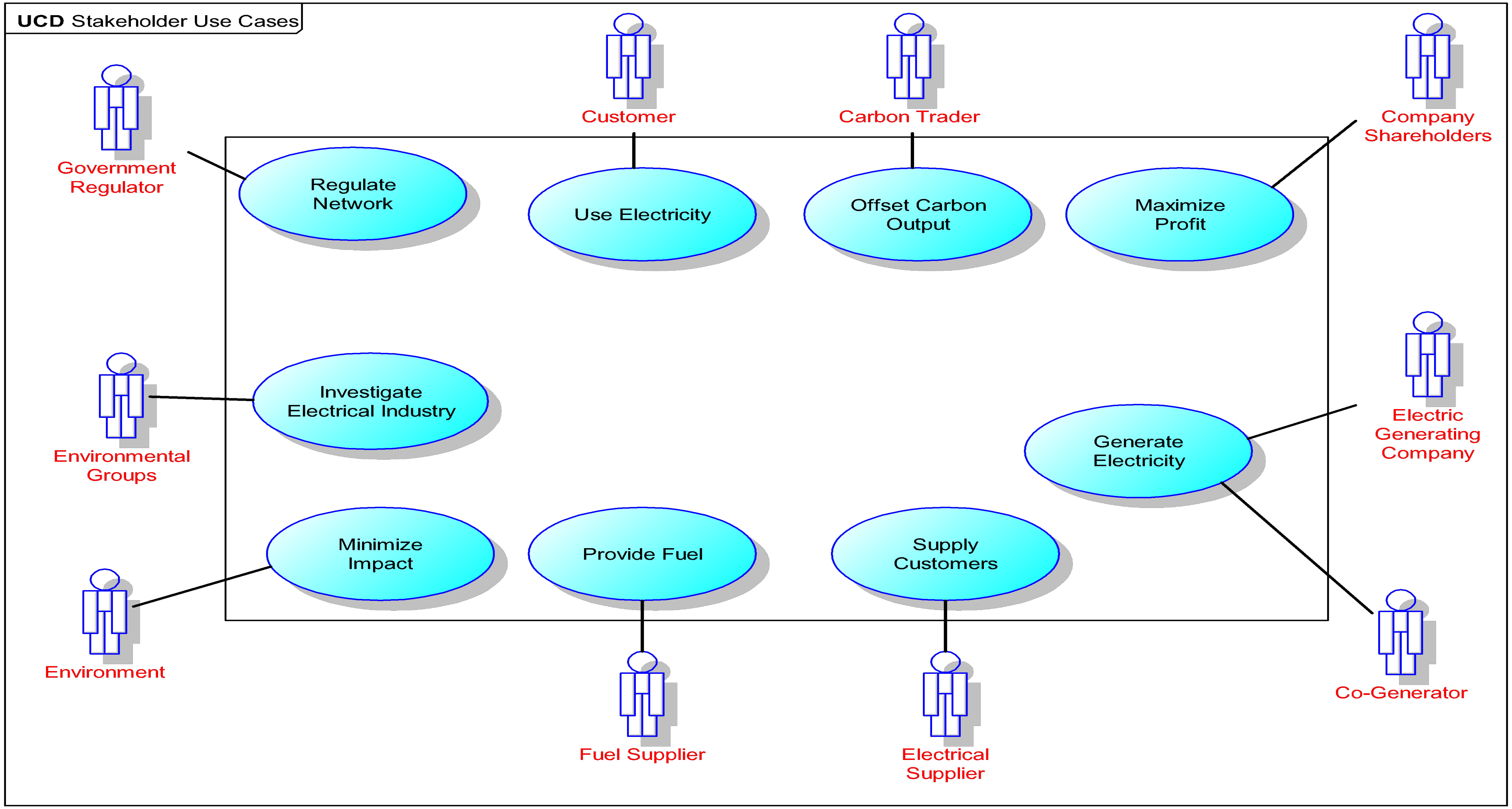


ELECTRIC GRID CONCEPT DIAGRAM - GRAPHICS



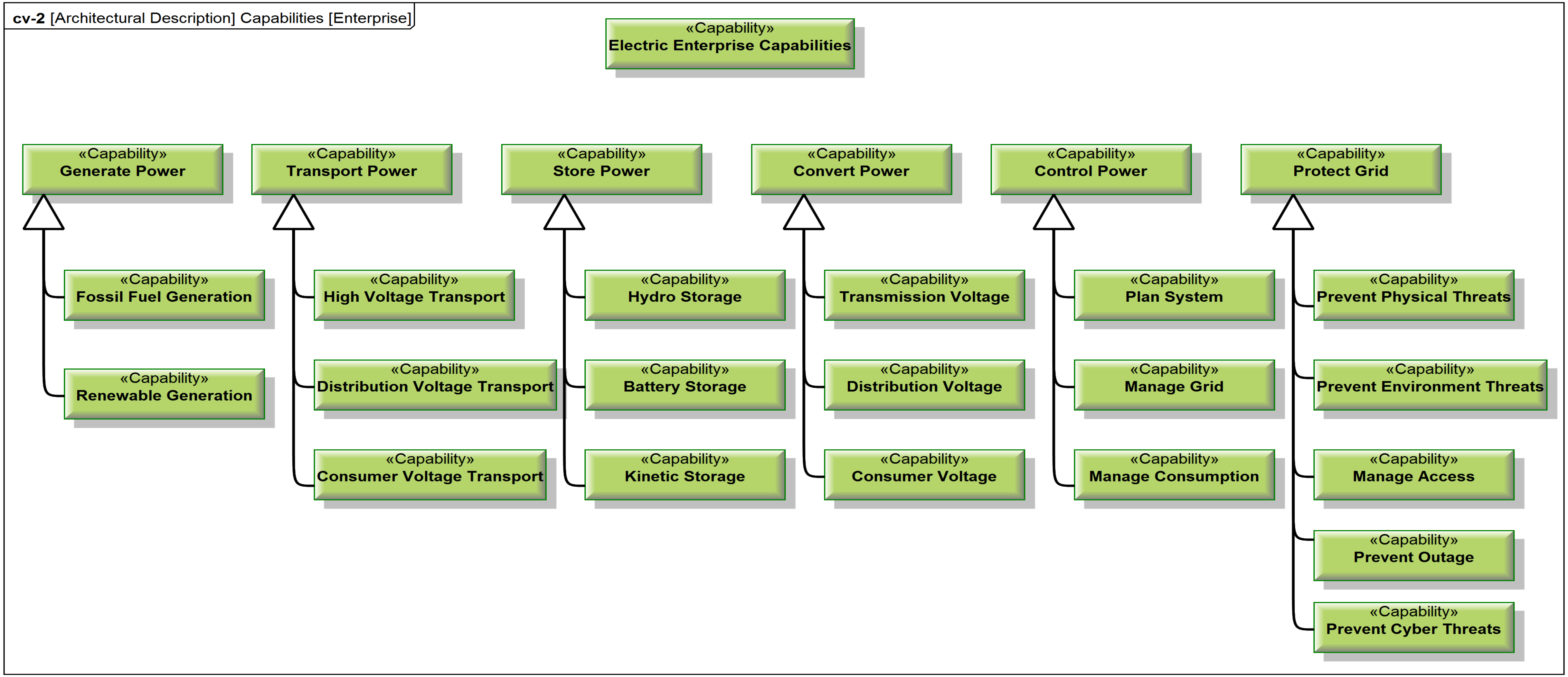
ELECTRICAL NETWORK – STAKEHOLDER VIEW

- Use cases represent goals, actors are stakeholders



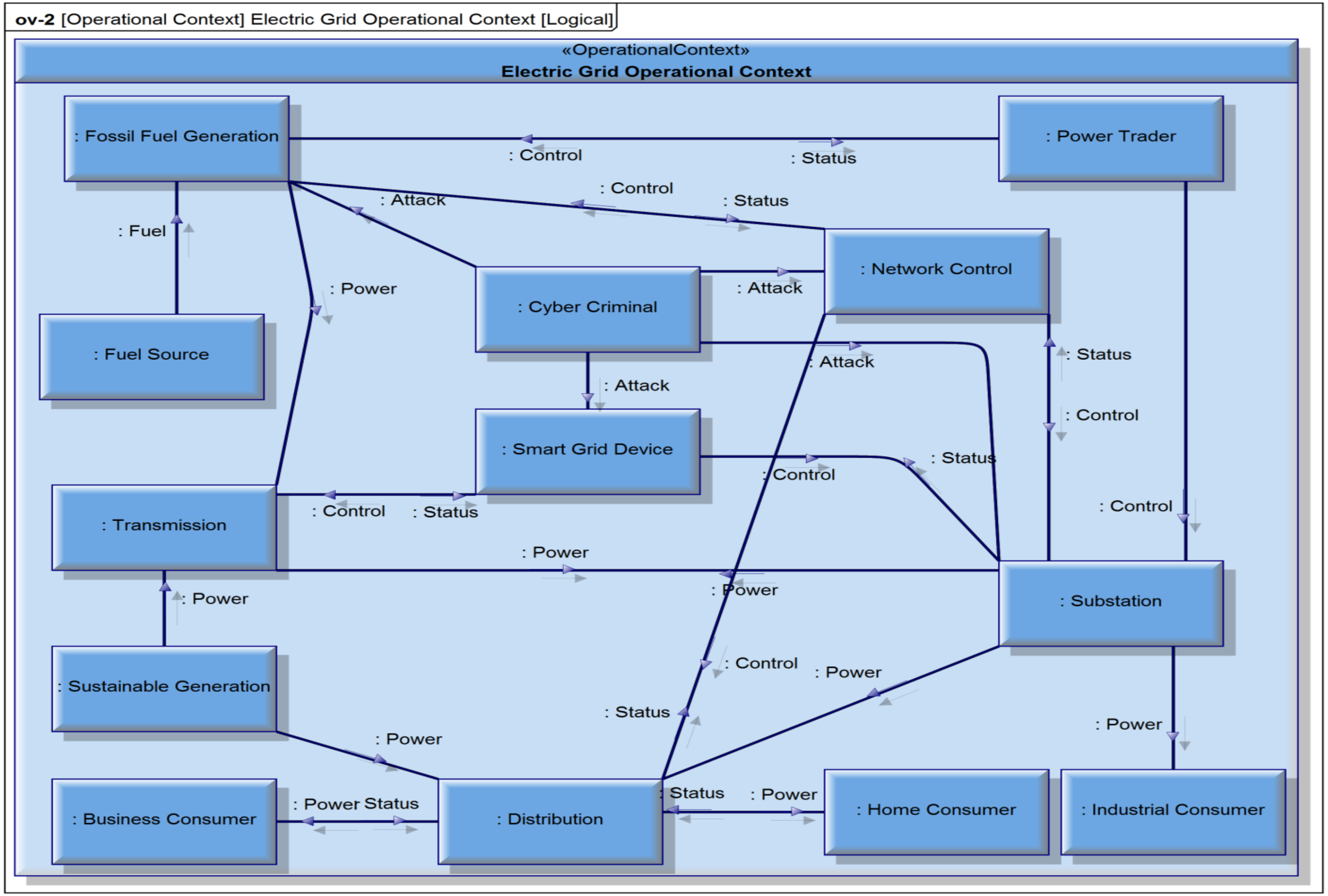
ELECTRIC GRID CAPABILITY TAXONOMY

- Defines the enterprise level capabilities.



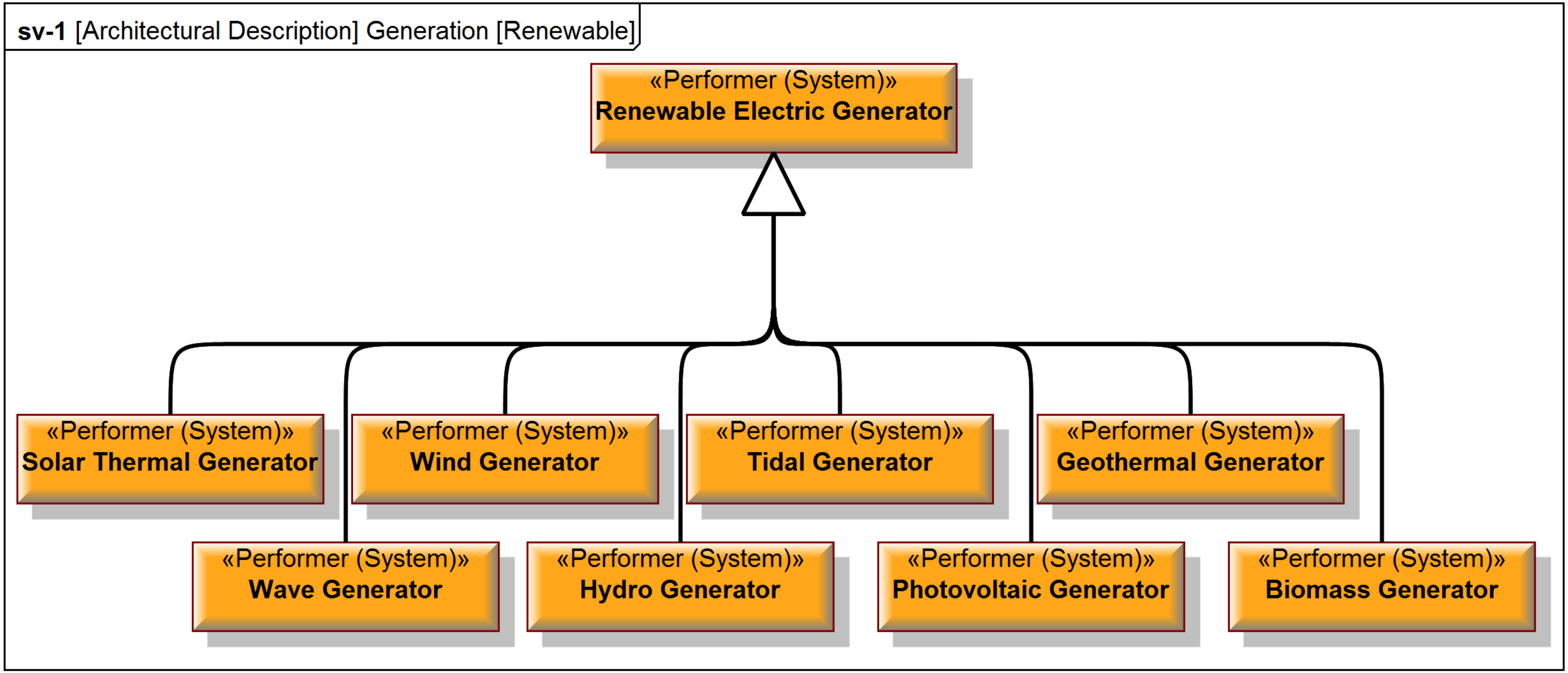
ELECTRIC GRID LOGICAL ARCHITECTURE

- Defines logical entities (Performers)
- Performer interfaces and interactions
- Shows the high-level abstract view



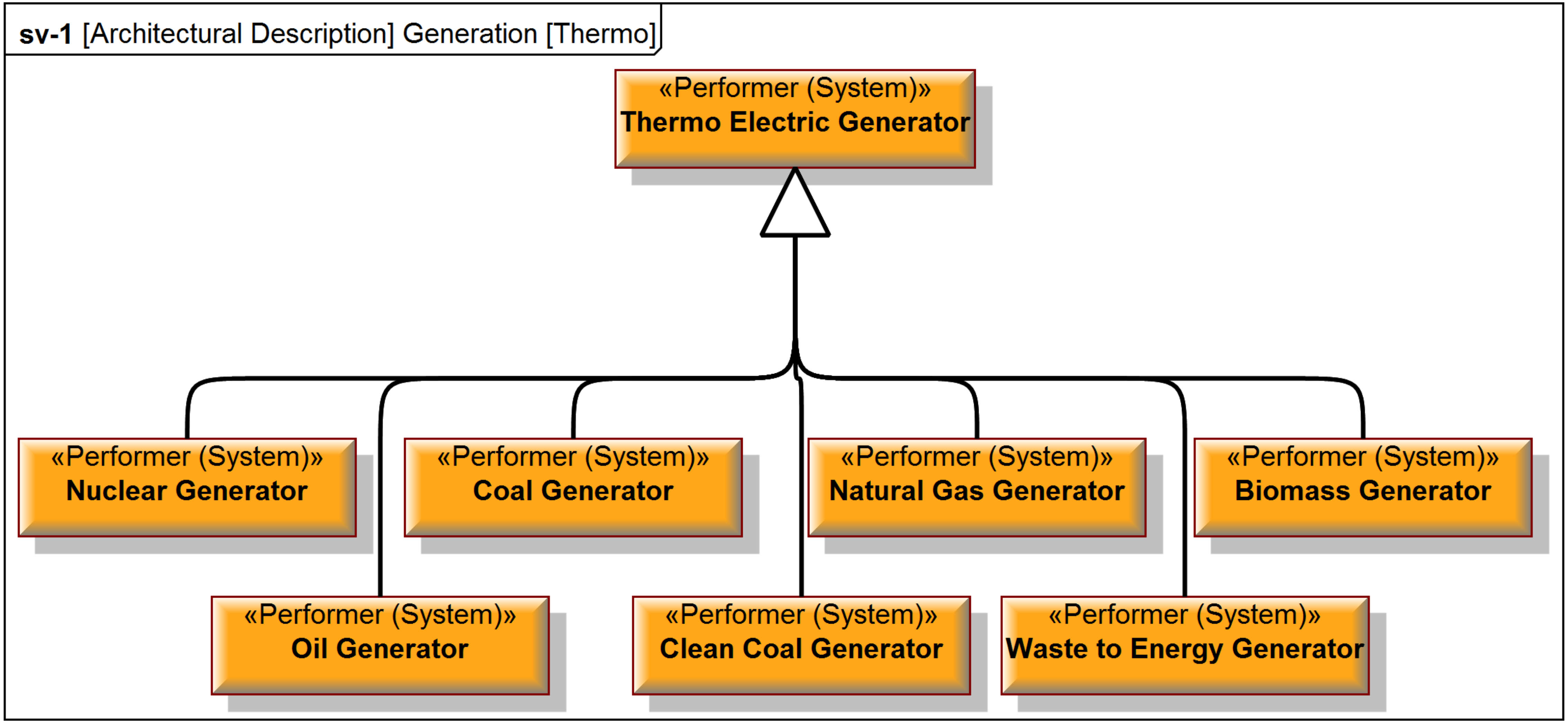
RENEWABLE ENERGY GENERATION SYSTEMS

- Taxonomy of implementing systems



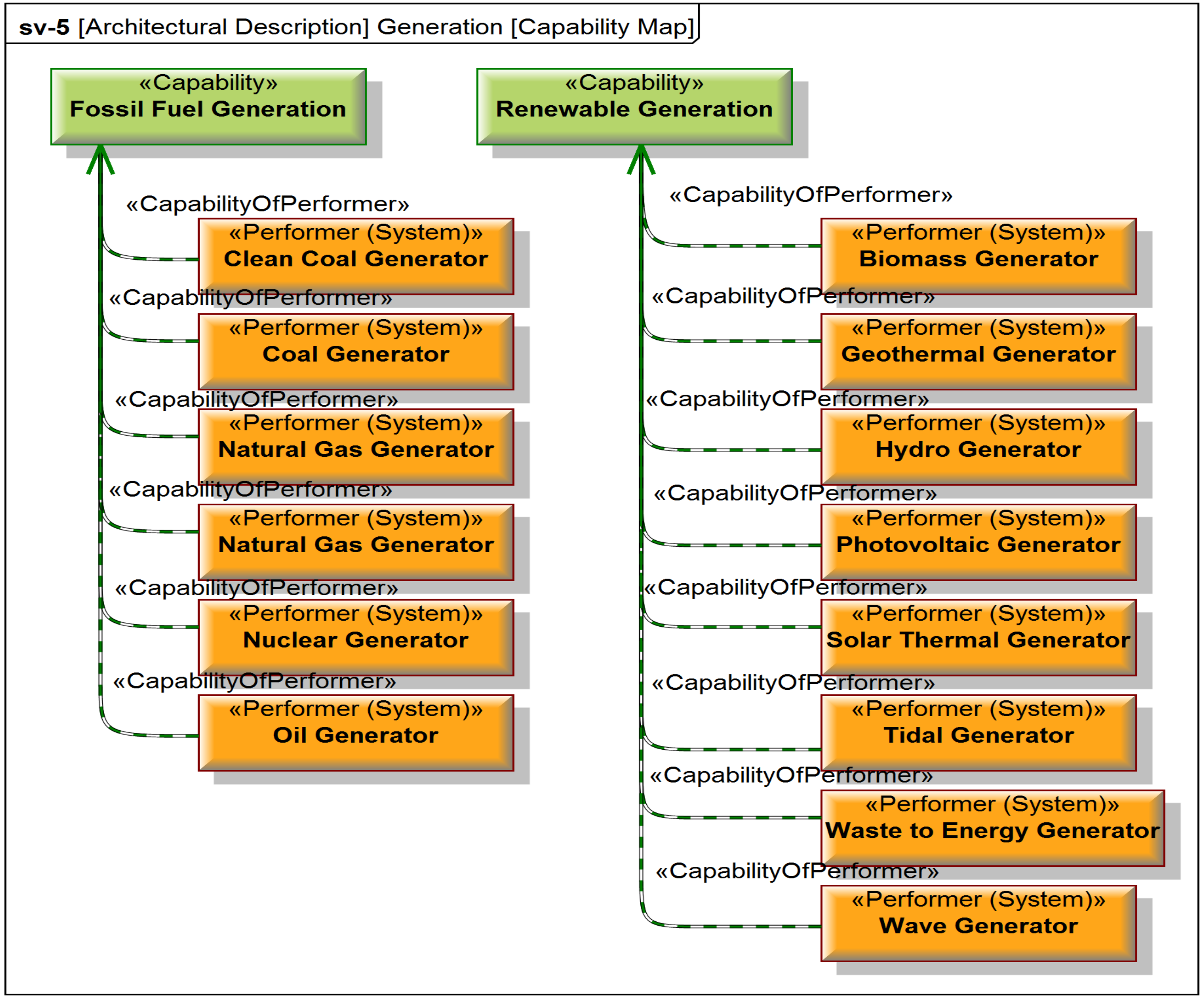
THERMO-ELECTRIC GENERATION SYSTEMS

- Taxonomy of implementing systems



CAPABILITIES MAPPING DIAGRAM

- Mapping of capabilities to implementing systems



SYSTEM TO CAPABILITY MAPPING

- Matrix summarizing the capability – system mapping

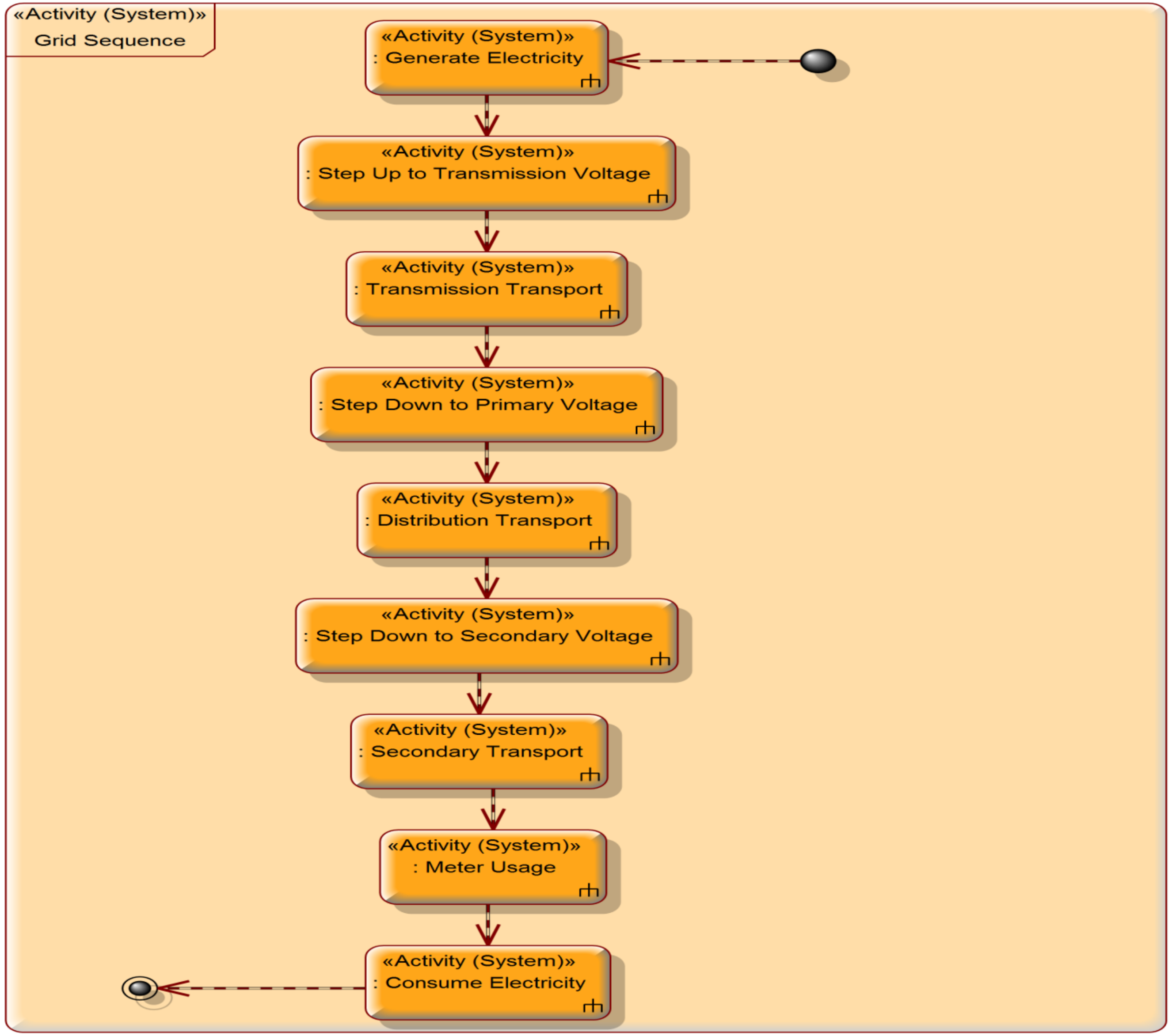
[Architectural Description] Capabilities [System]

Exhibiting Element

Exhibited Capability	«Performer (System)» Clean Coal Generator	«Performer (System)» Coal Generator	«Performer (System)» Natural Gas Generator	«Performer (System)» Nuclear Generator	«Performer (System)» Oil Generator	«Performer (System)» Demand Response	«Performer (System)» Home EMS	«Performer (System)» Load Shed Access Device	«Performer (System)» Load Shed System	«Performer (System)» Smart Appliance	«Performer (System)» Smart HVAC	«Performer (System)» Smart Lighting	«Performer (System)» Smart Meter	«Performer (System)» Smart Thermostat	«Performer (System)» Dynamic Line Rating	«Performer (System)» Substation Automation	«Performer (System)» Digital Protective Relay	«Performer (System)» Phasor Measurement Unit	«Performer (System)» Power Flow Control Device	«Performer (System)» Biomass Generator	«Performer (System)» Geothermal Generator	«Performer (System)» Hydro Generator	«Performer (System)» Photovoltaic Generator	«Performer (System)» Solar Thermal Generator	«Performer (System)» Tidal Generator	«Performer (System)» Waste to Energy Generator	«Performer (System)» Wave Generator
«Capability» Fossil Fuel Generation	X	X	X	X	X																						
«Capability» Manage Consumption						X	X	X	X	X	X	X	X	X													
«Capability» Manage Grid															X	X											
«Capability» Prevent Outage									X								X	X	X								
«Capability» Renewable Generation																				X	X	X	X	X	X	X	X

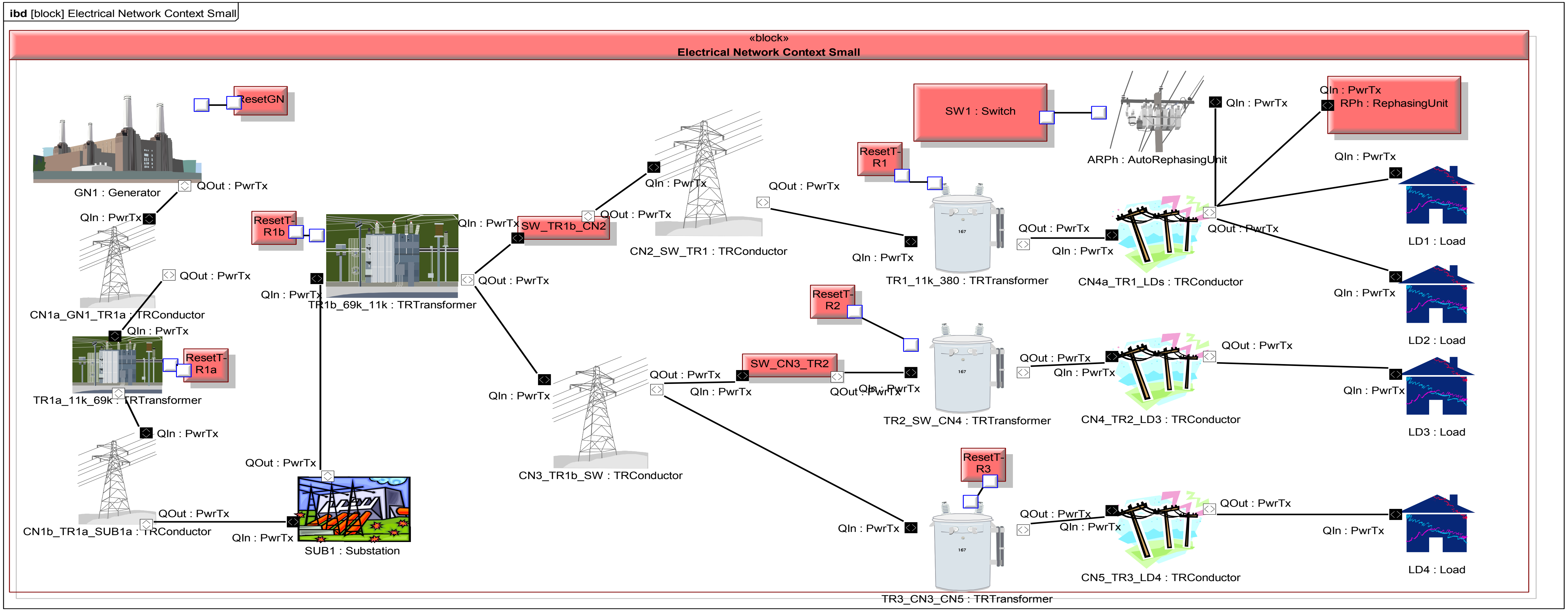
GRID ACTIVITY SEQUENCE

- Functional View
  - Defines the sequence of activities, inputs, outputs, logic, etc.



SIMPLE NETWORK TOPOLOGY

- Simple network showing generation, transmission, and distribution systems

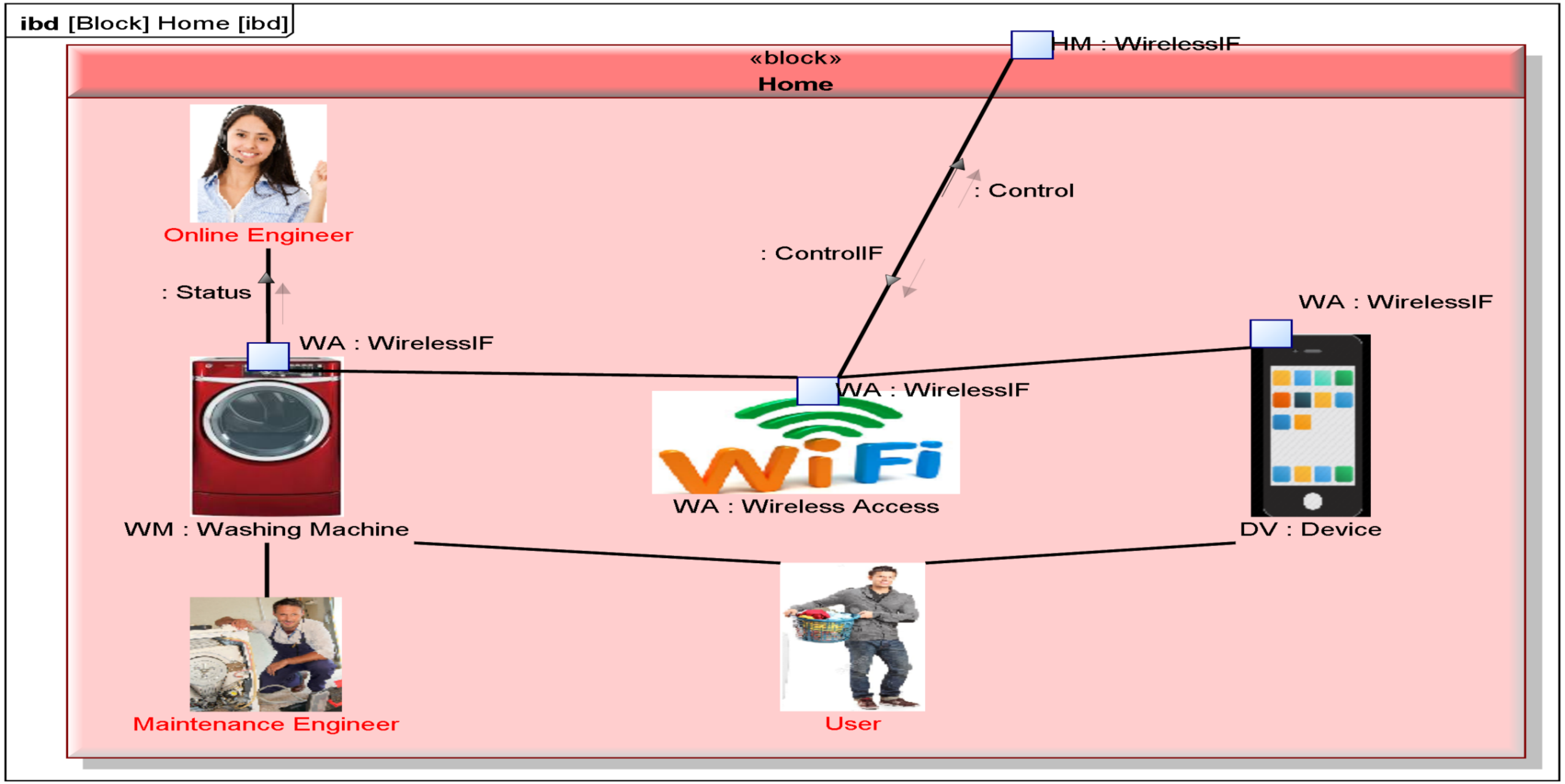


SOS TO SYSTEMS MODELING

TASK: MODIFY THE WASHING MACHINE TO TAKE ADVANTAGE OF OFF-PEAK POWER TARIFFS

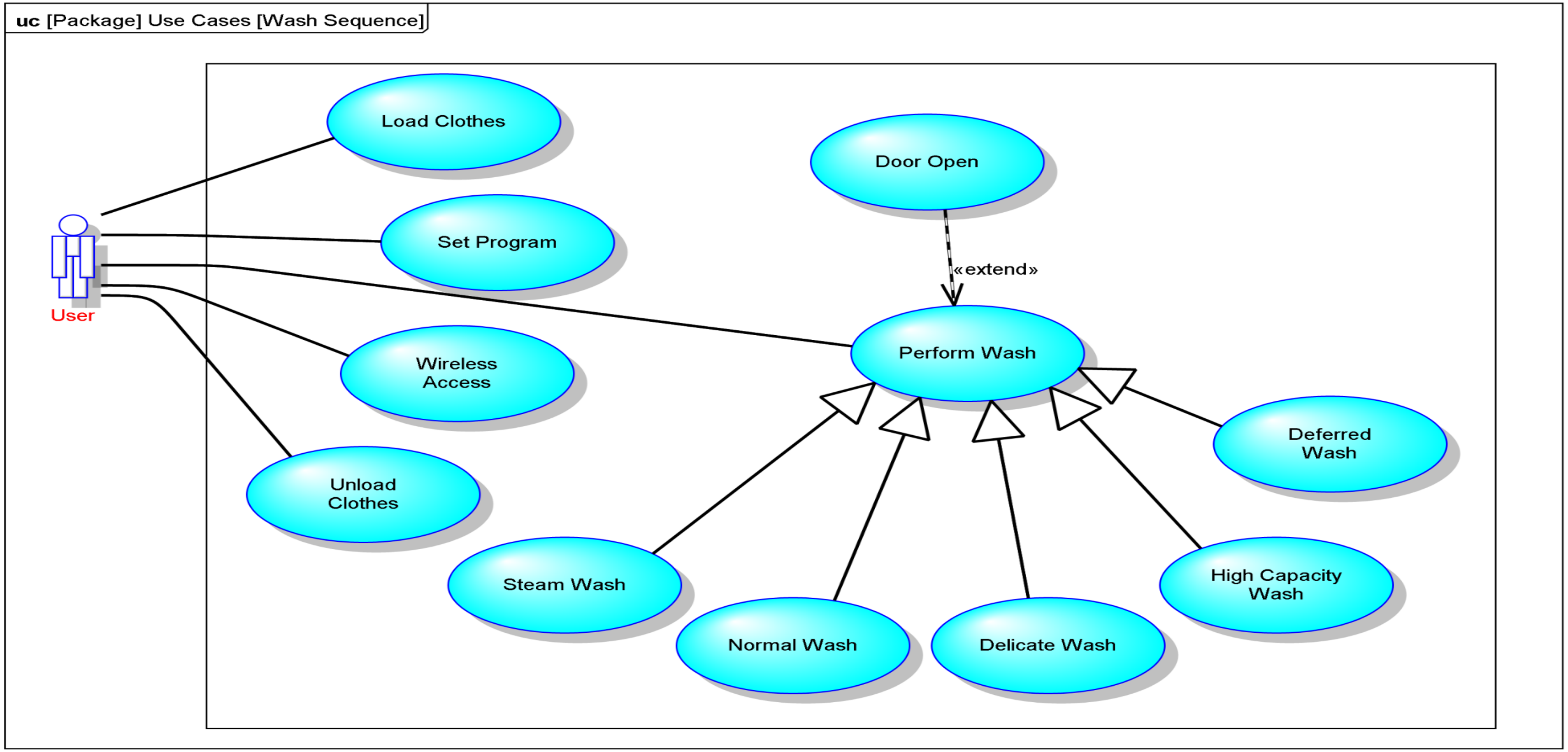
SMART, CONNECTED WASHING MACHINE

- Implementation View
  - People, systems, interactions, interfaces and connections



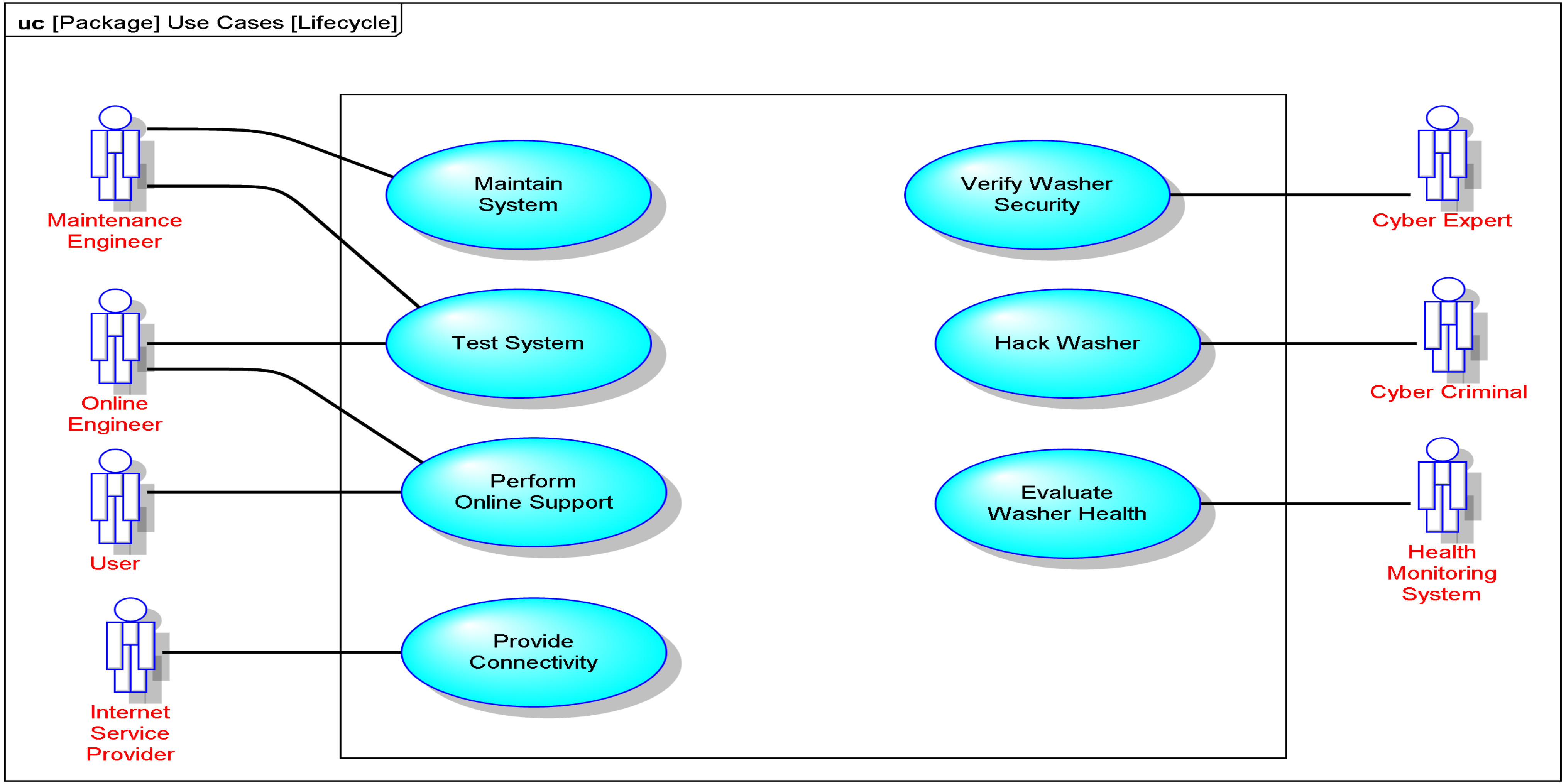
WASHER USE CASES

- Usage View
  - Standard washer use cases, plus online access, health monitoring and deferred washing



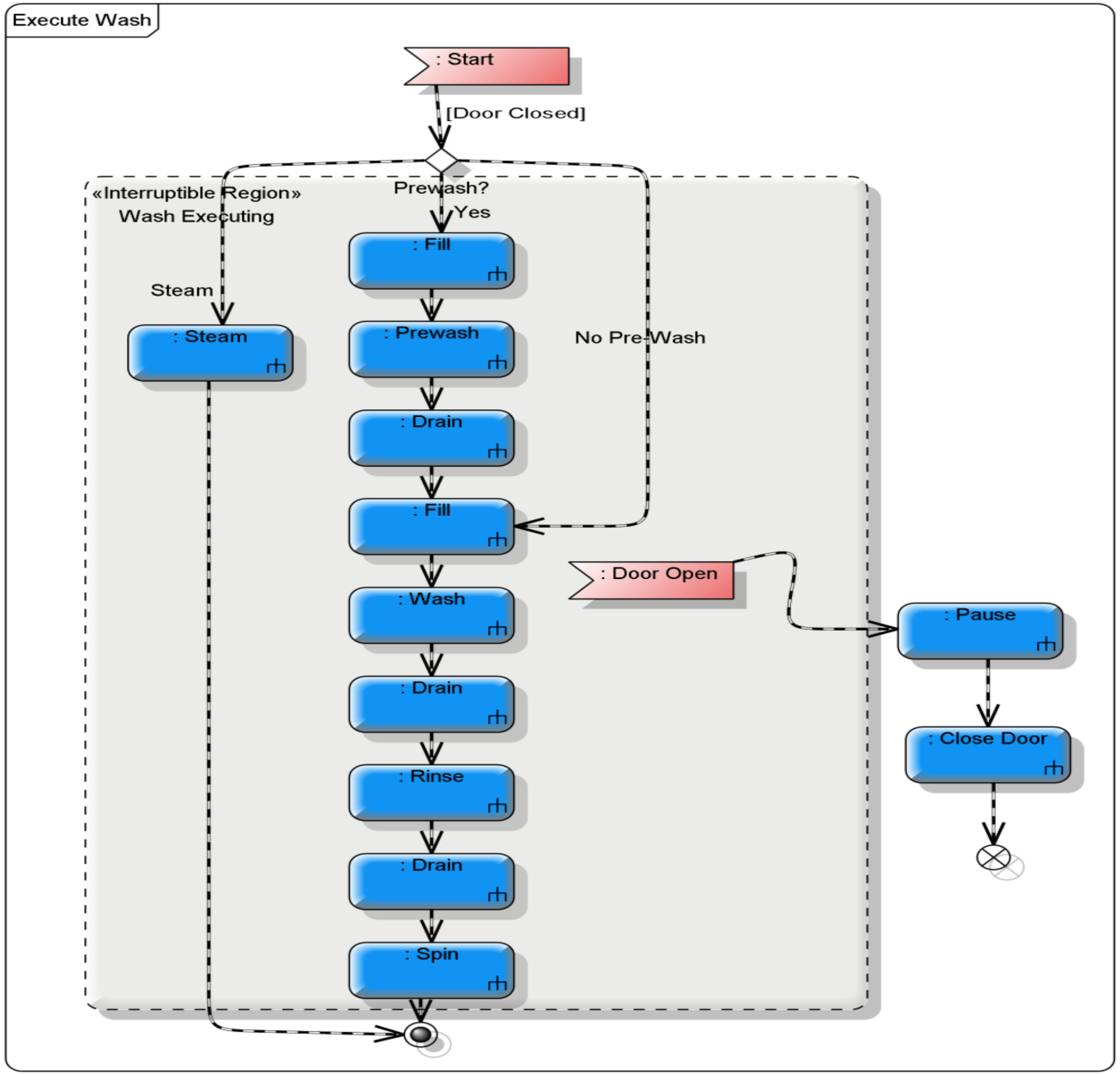
LIFECYCLE USE CASES

- Usage View includes use cases and misuse cases, actors and bad actors



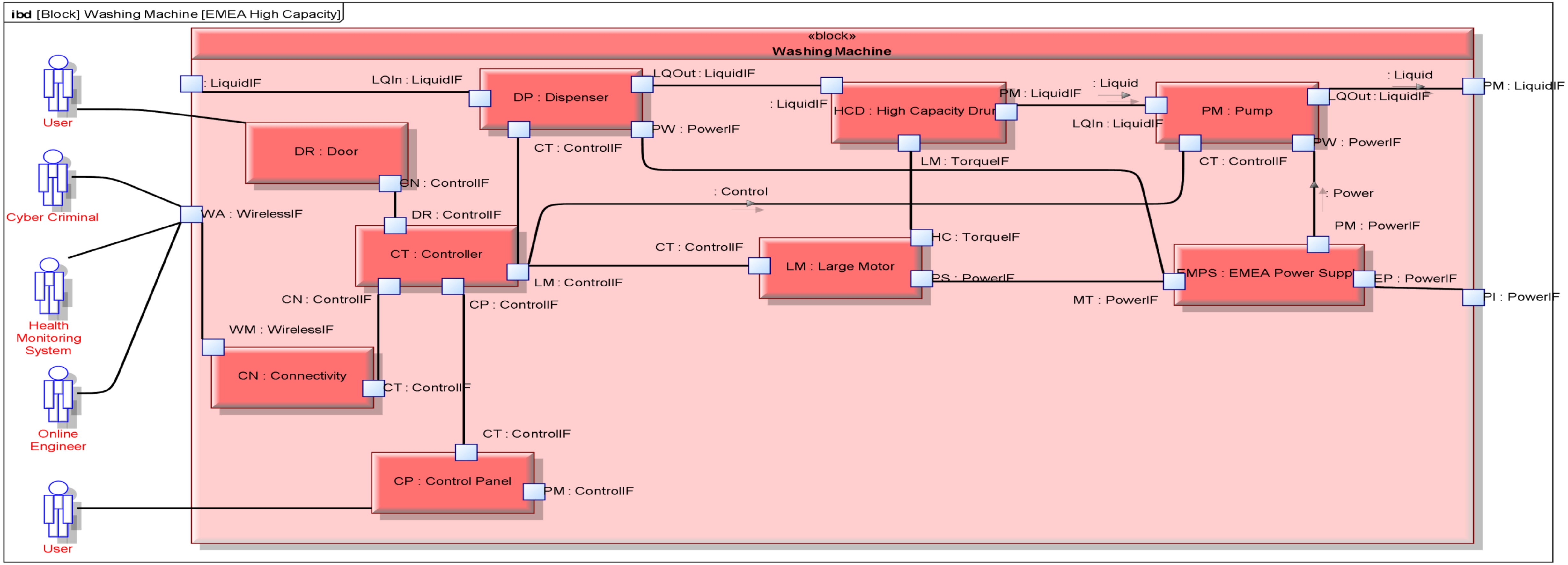
WASHER ACTIVITY SEQUENCE

- Functional View
  - System Activities for the wash sequence
  - Includes door open during wash sequence



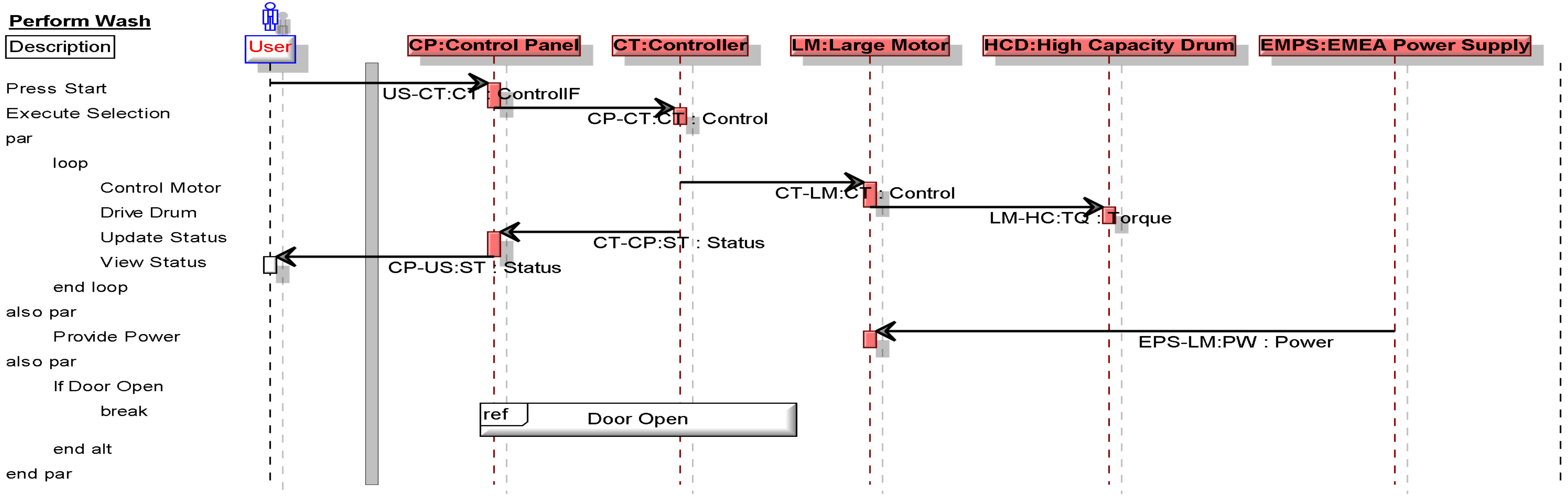
WASHER COMPONENTS IMPLEMENTATION

- Implementation View
  - Shows “Good” and “Bad” actors and their interactions with the system
  - Also shows internal connectivity



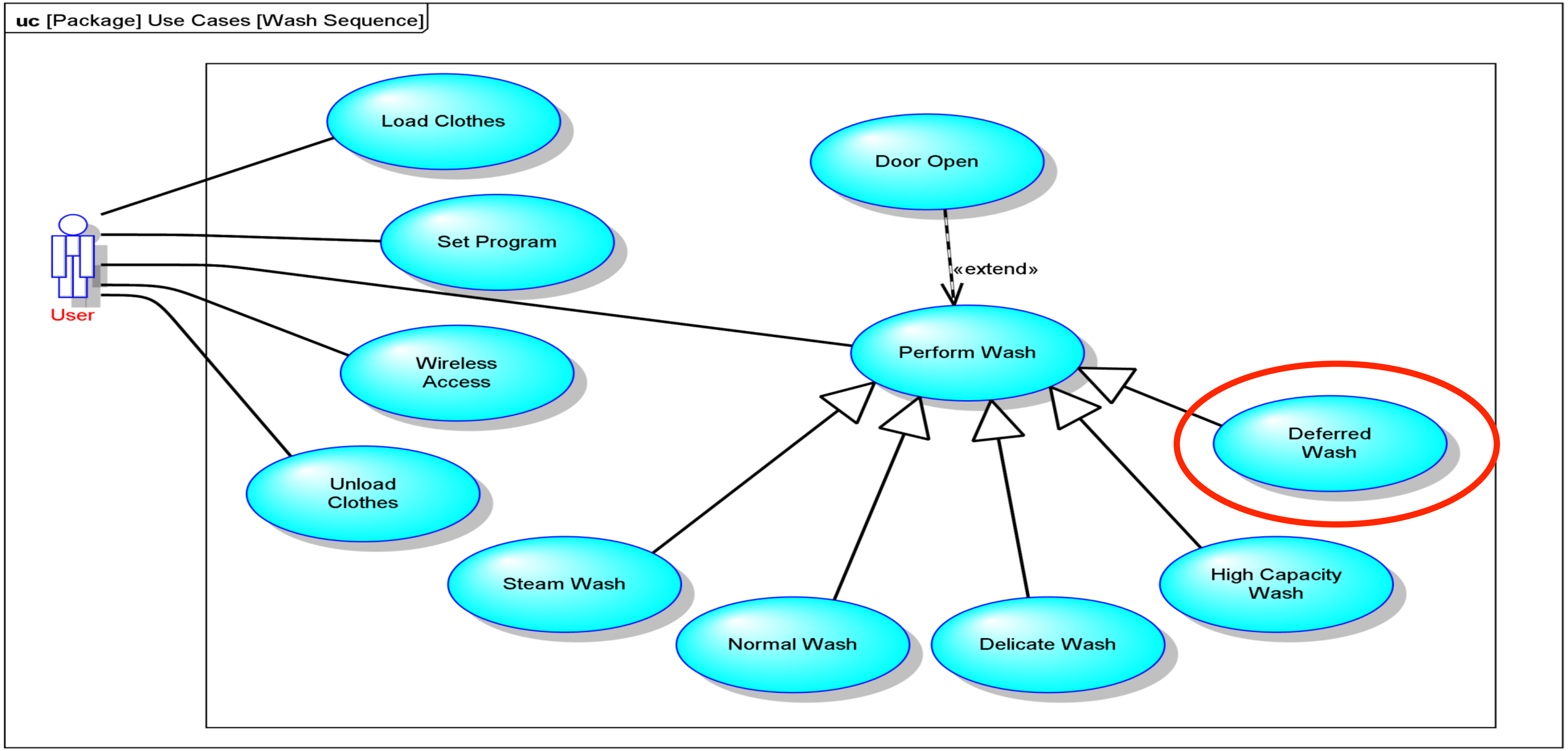
WASH SEQUENCE

- Shows the sequence of interactions between the actor and the internal washing machine systems



OPERATIONAL USE CASES

- Usage View
  - Let's revisit the deferred wash use case



LOAD LIMITING PATTERNS

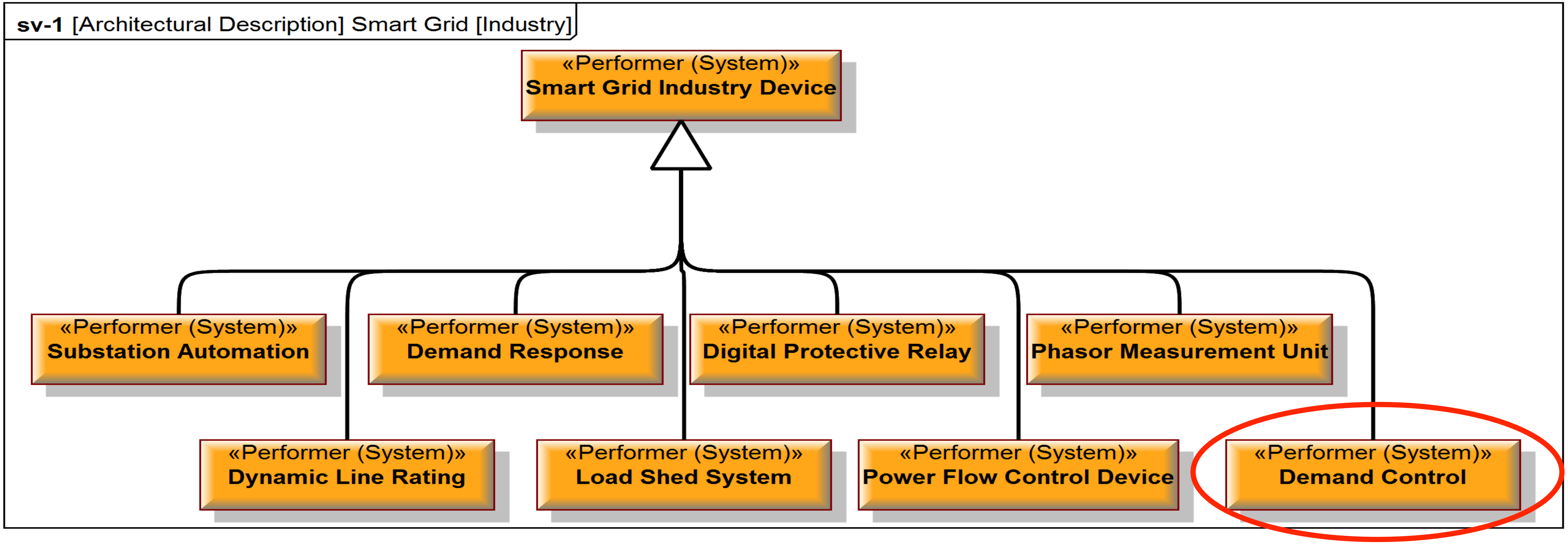
- Load Shedding Pattern
  - Reduces electric demand through voluntary curtailment of electric loads.
  - Normally during peak load times from 10am to 2pm.
  - Credits are awarded to participating customers for the amount of load reduction they provide.
  - Typically done manually, but can involve remote access by company to turn off water heaters, turn off/down A/C
  - Also available for commercial customers such as factories

- Demand Control Pattern
  - A different pattern for Deferred Wash
  - Customer will request wash at off-peak time
  - To avoid 2 million washers turning on at once, customer requests permission to wash.
  - Demand Control App interacts with Provider and SCADA system
  - Grants permission if load OK
  - Otherwise, washer waits a set period and requests again.

- Both patterns require cyber security evaluation

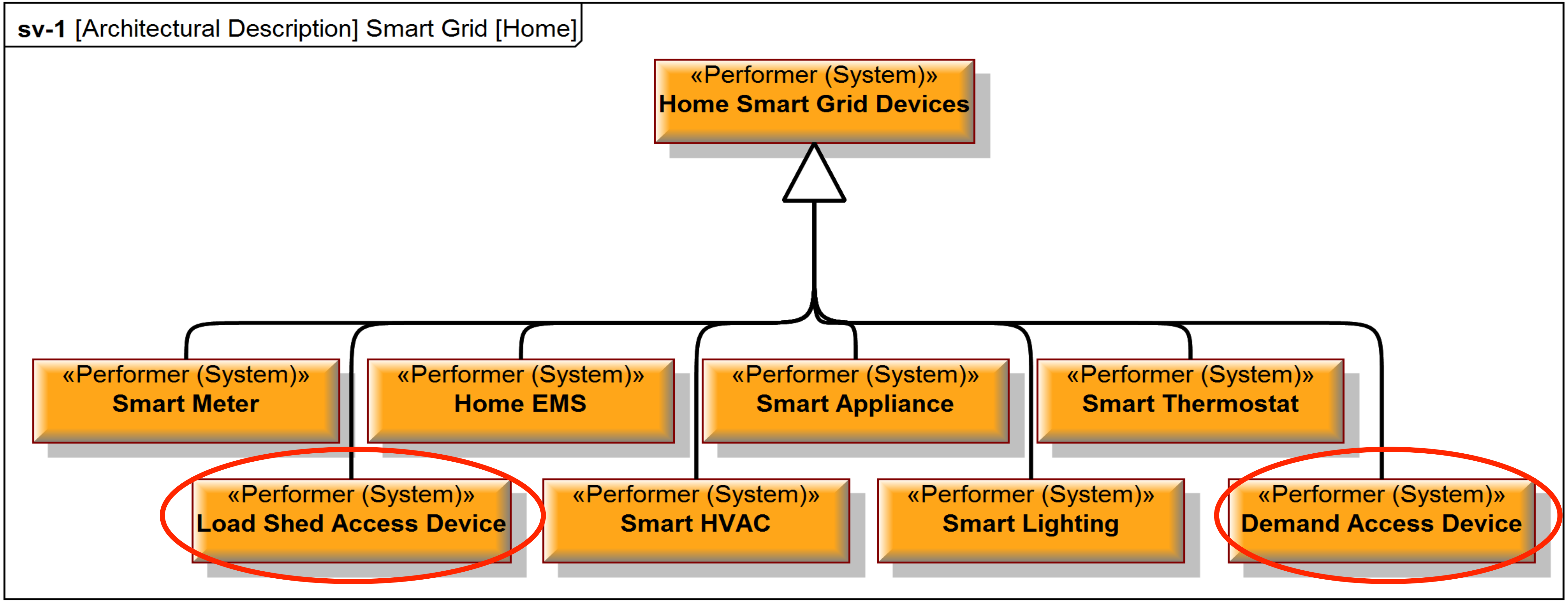
SMART GRID INDUSTRY DEVICES

- Taxonomy of smart grid industry devices (supply side)



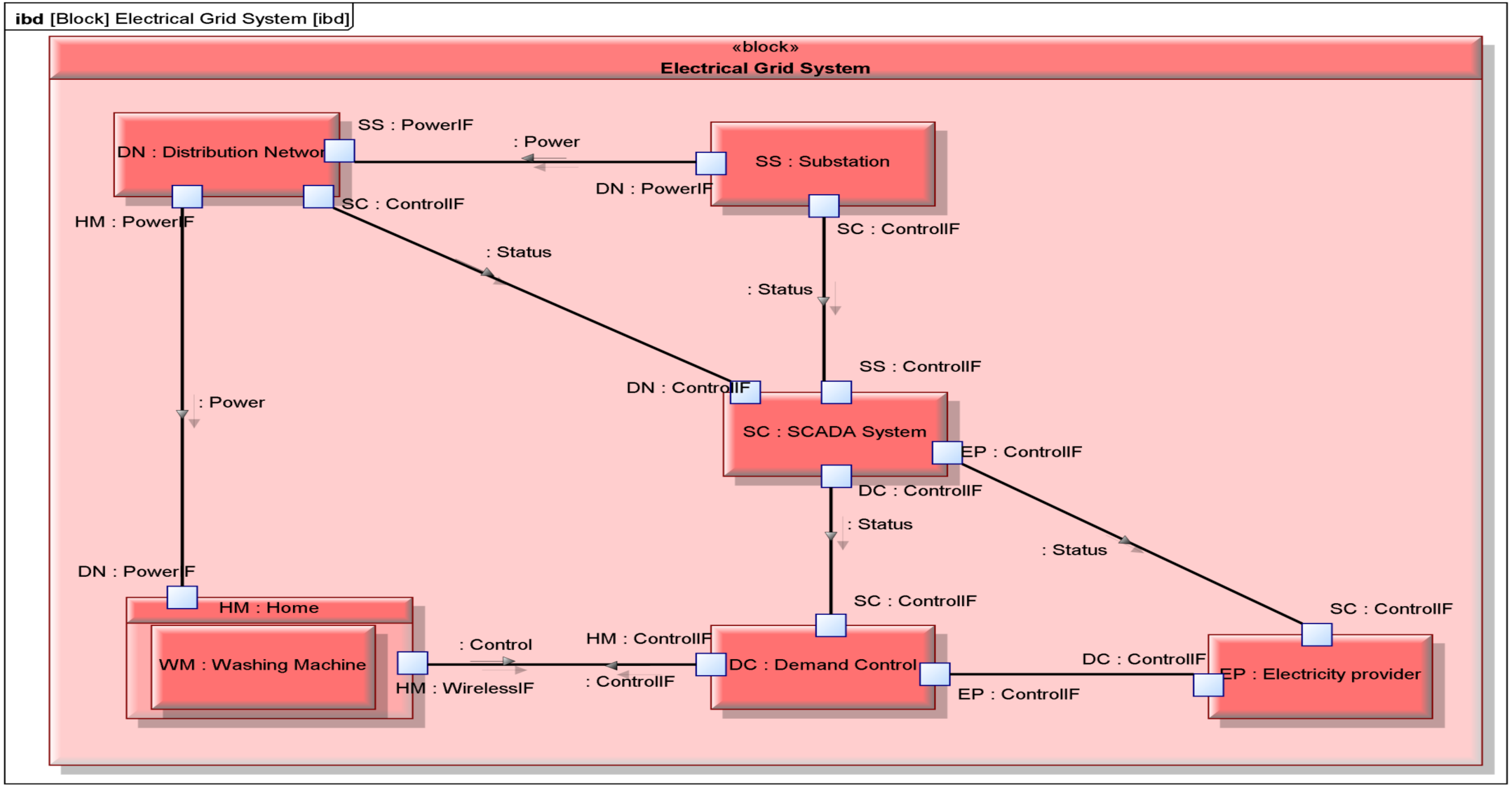
HOME SMART GRID DEVICES

- Taxonomy of smart grid industry devices (consumer side)



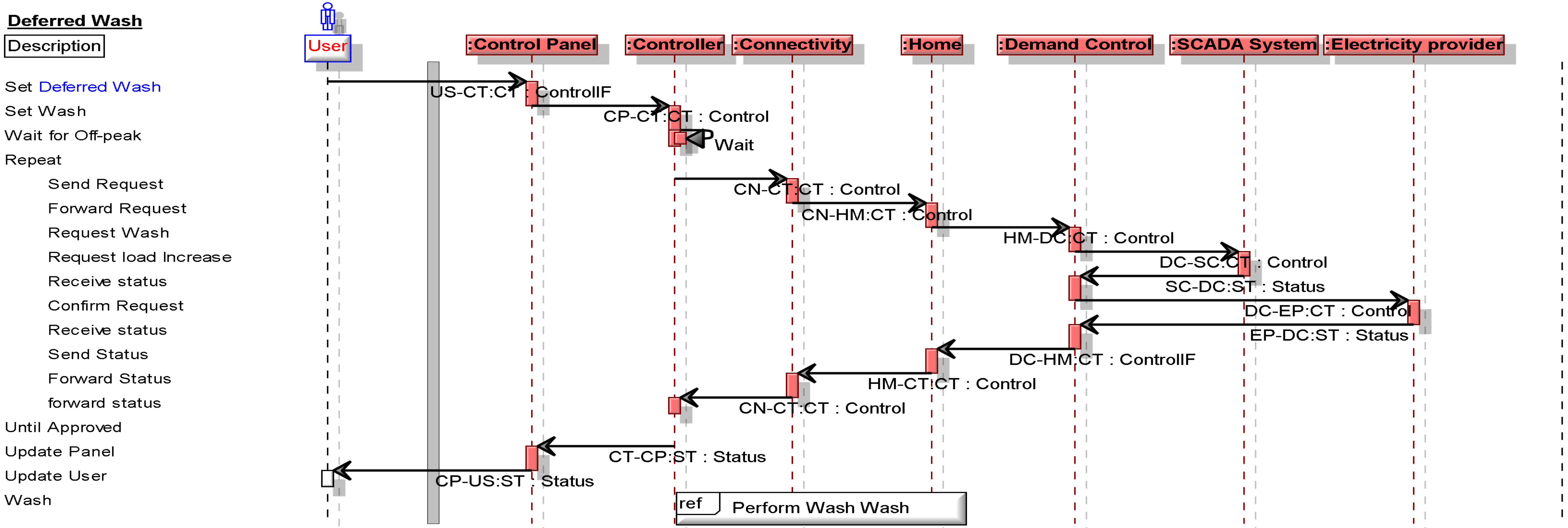
WASHER DEMAND CONTROL

- Washing machine connected to the smart grid systems



DEFERRED WASH SEQUENCE

- Implementation View
  - Customer programs deferred wash.
  - At off-peak time, washer will request permission to wash.
  - Demand control system will either approve or reject.
  - System will poll until approved or canceled.



ANALYSIS OF SYSTEMS OF SYSTEMS

1. UAF Security Views
2. KDM Analytics – Risk Analysis
3. The Industrial Internet Consortium (IIC) Smart Grid Test Bed
4. Schneider – Augmented Reality
5. Bill Schindel - Pattern-Based Systems Engineering (PBSE)
6. Casey Shull – Common Recovery Model
7. Prime Solutions Group – Big Data Analytics
8. LMCO Cyber Systems Attack Simulation
9. PTC Thingworx Smart Data Analytics
10. Agent Based Systems

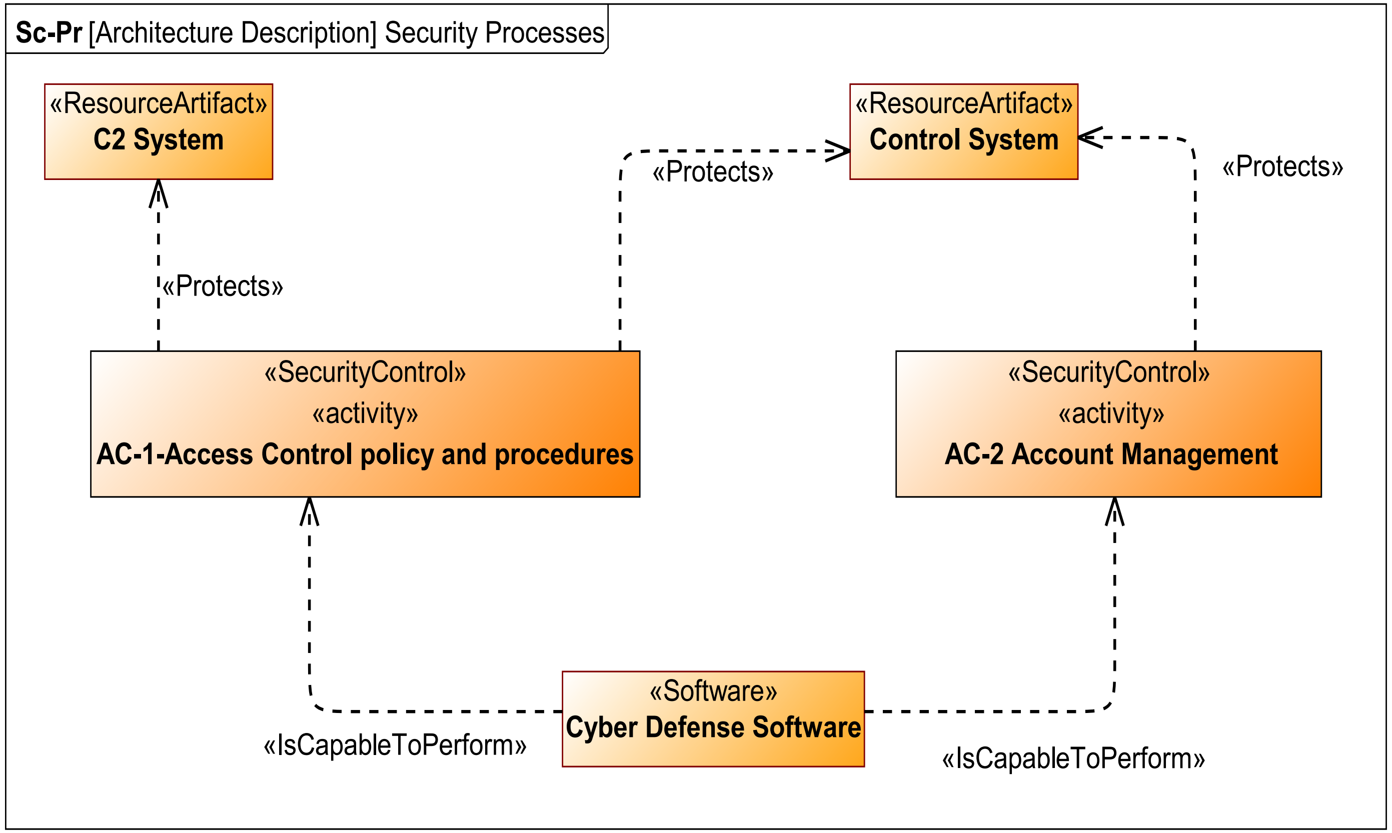
UAF SECURITY VIEWS

- The security domain (Sc) describes security assets and security enclaves. Sc views define the hierarchy of security assets and asset owners, security constraints (policy, laws, and guidance) and detail where they are located (security enclaves).
- **Stakeholders:** Security Architects, Security Engineers. Systems Engineers, Operational Architects.
- **Concerns:** addresses the security constraints and information assurance attributes that exist on exchanges between resources and OperationalPerformers
- **Definition:** illustrates the security assets, security constraints, security controls, families, and measures required to address specific security concerns.

SYSTEM CYBER CONTROLS

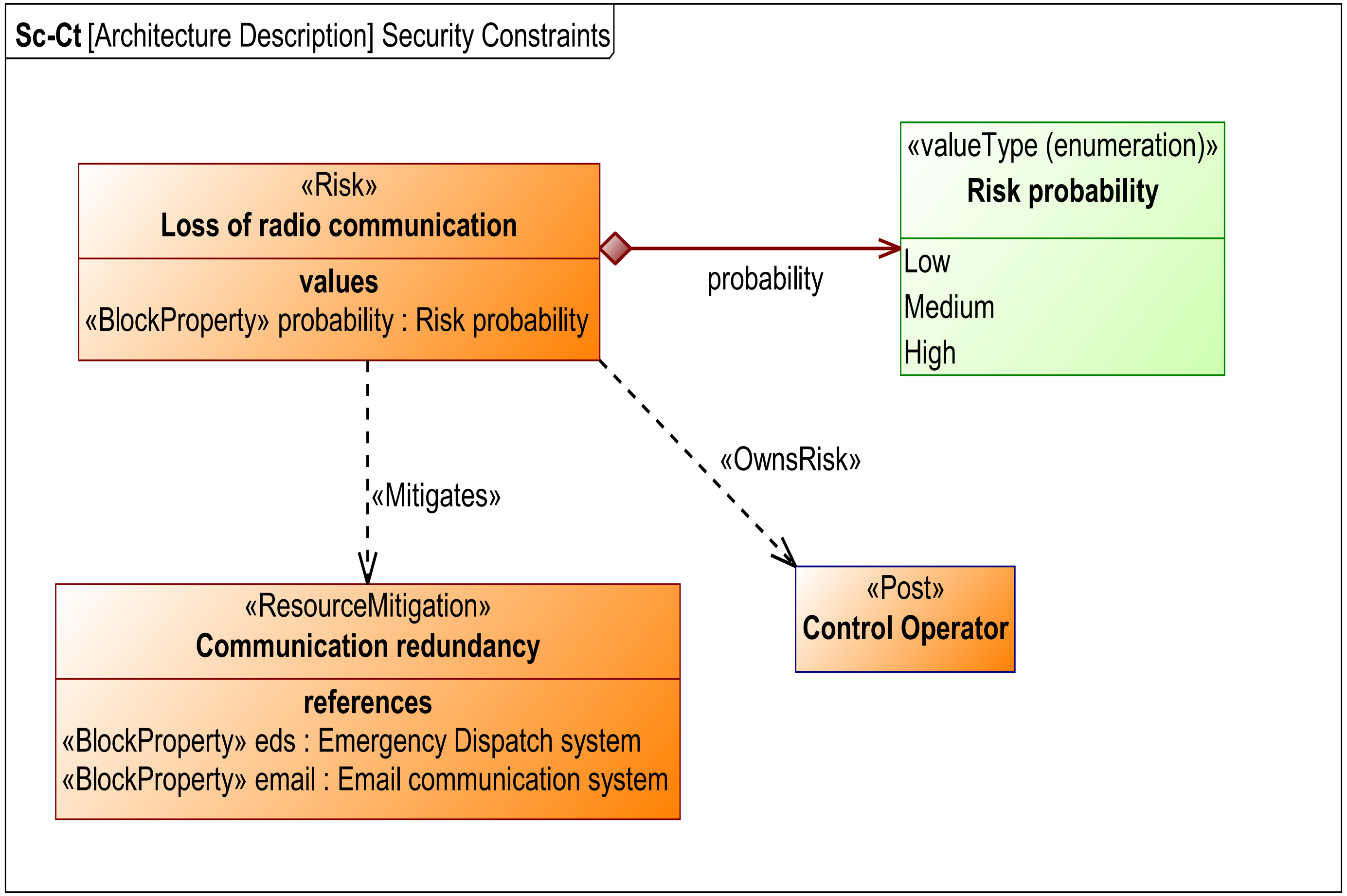
- Describes processes that apply or implement security controls/enhancements to assets located in enclaves and across enclaves.

- The cyber defense software provides access control policy and procedures and account management for the C2 system and the control system.



SECURITY CONSTRAINTS FOR COMMUNICATIONS SYSTEM

- Shows how risk and risk mitigation may be associated with systems and information/data.
- Describes the security constraints for the emergency dispatch system. It defines the risk probabilities, who owns the risk and the mitigating elements.



KDM Analytics

Working Together to Build Confidence

Risks Analysis

Djenana Campara

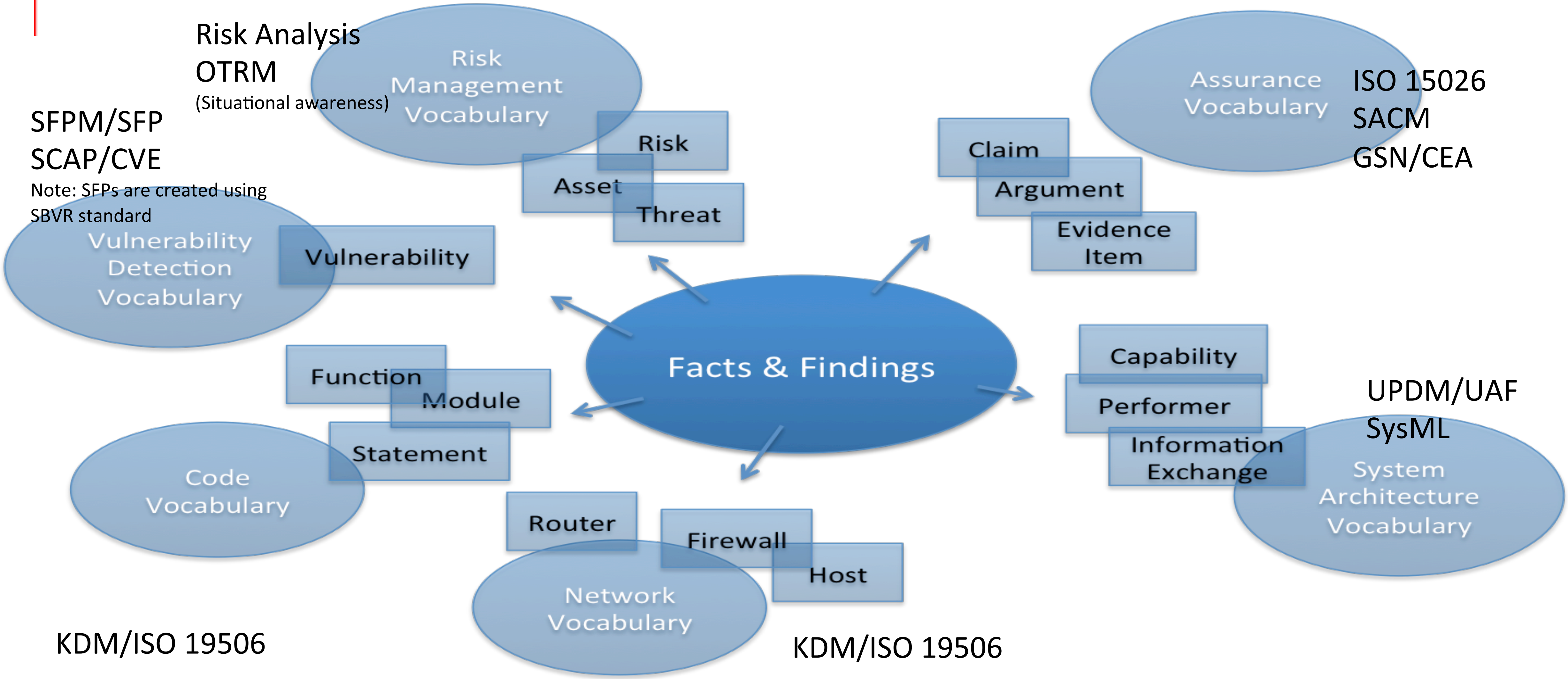
Chief Executive Officer

Member, Object Management Group Board of Directors

Chair, System Assurance Task Force

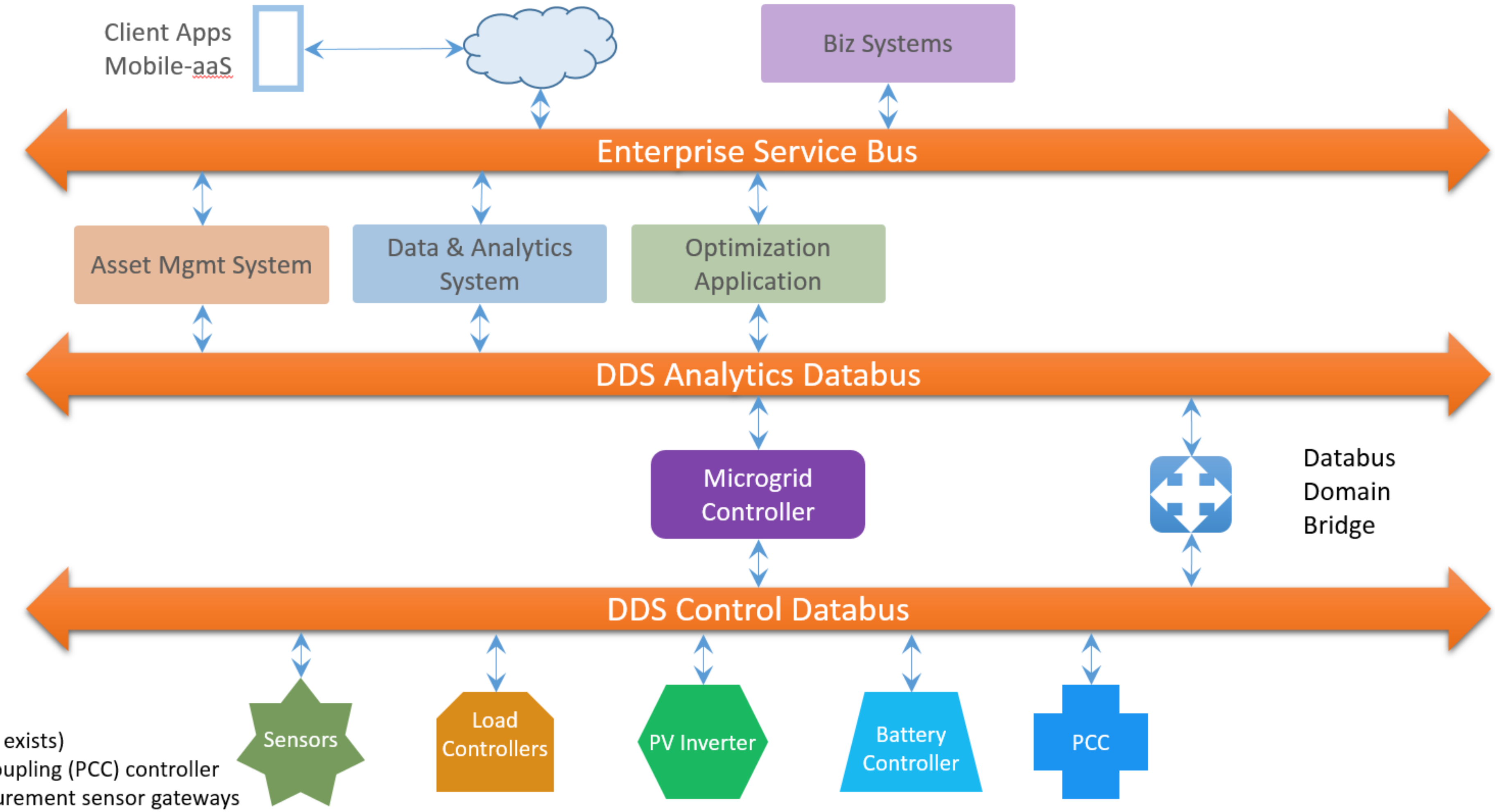
Ecosystem Foundation: Common Fact Model

Data Fusion & Semantic Integration



Tools integration possible only through standards

THE INDUSTRIAL INTERNET CONSORTIUM SMART GRID TEST BED



- Battery controller
- Solar array inverters
- Wind controller (if it exists)
- Point-of-common-coupling (PCC) controller
- Power quality measurement sensor gateways
- Various load equipment

Augmented Reality in Power Systems

Path to Cyber Physical Systems

Shawn Hanegan
Systems Engineering Domain Leader
Schneider Electric

Columbiad Augmented Reality

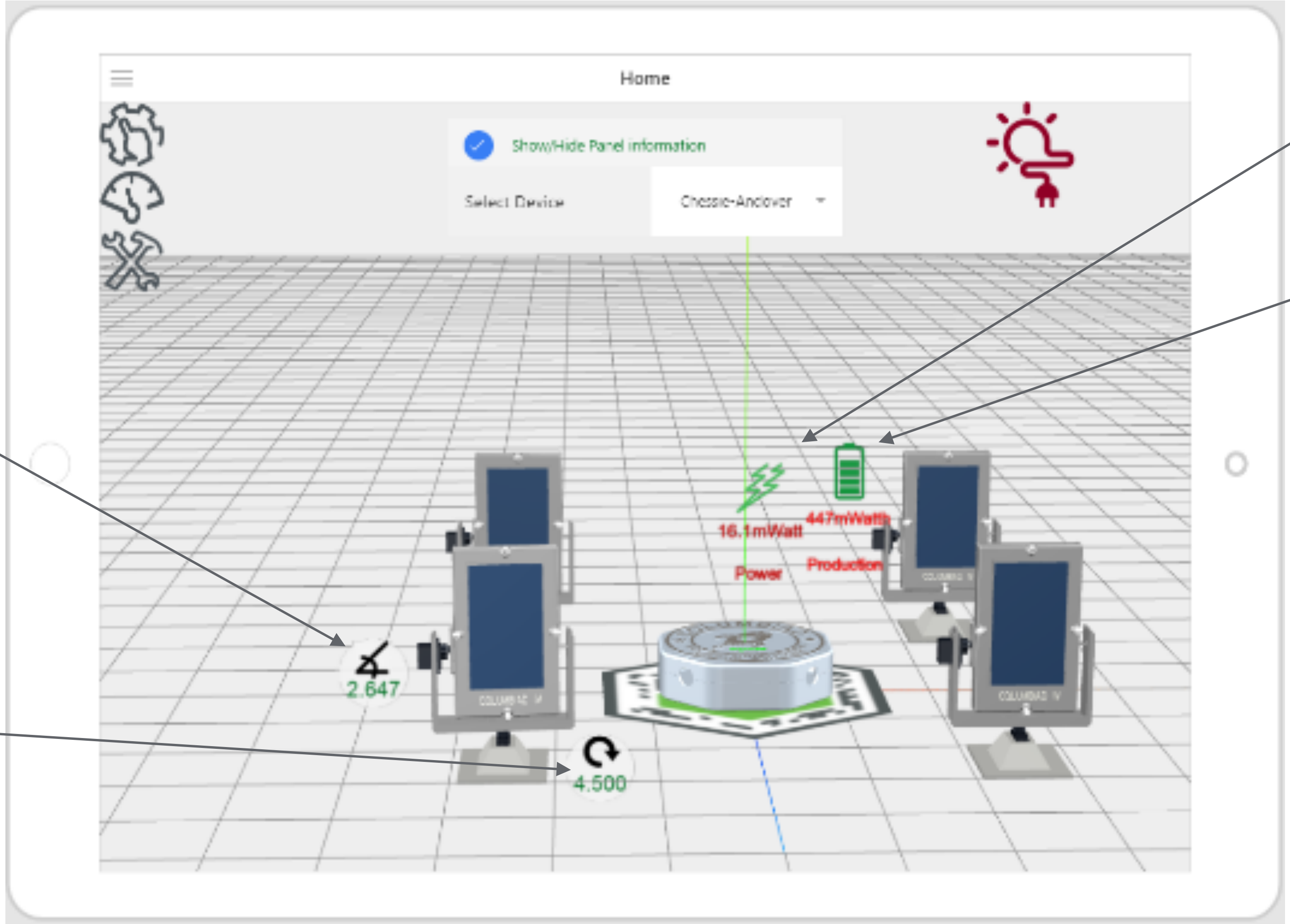
Each Solar Panel Module is IOT-enabled

Instantaneous Power Sensor Data

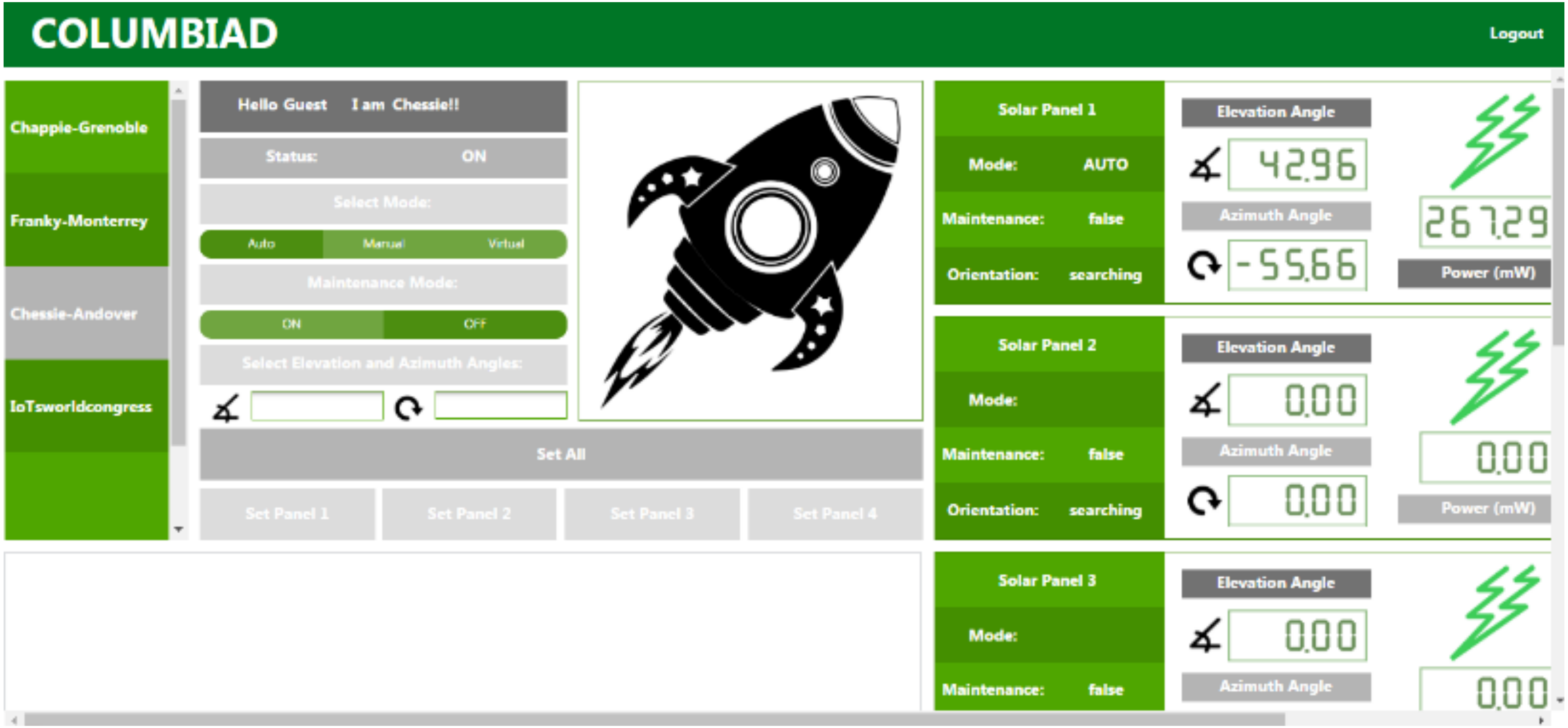
Cumulative Power Data

Elevation Sensor Data

Azimuth Sensor Data

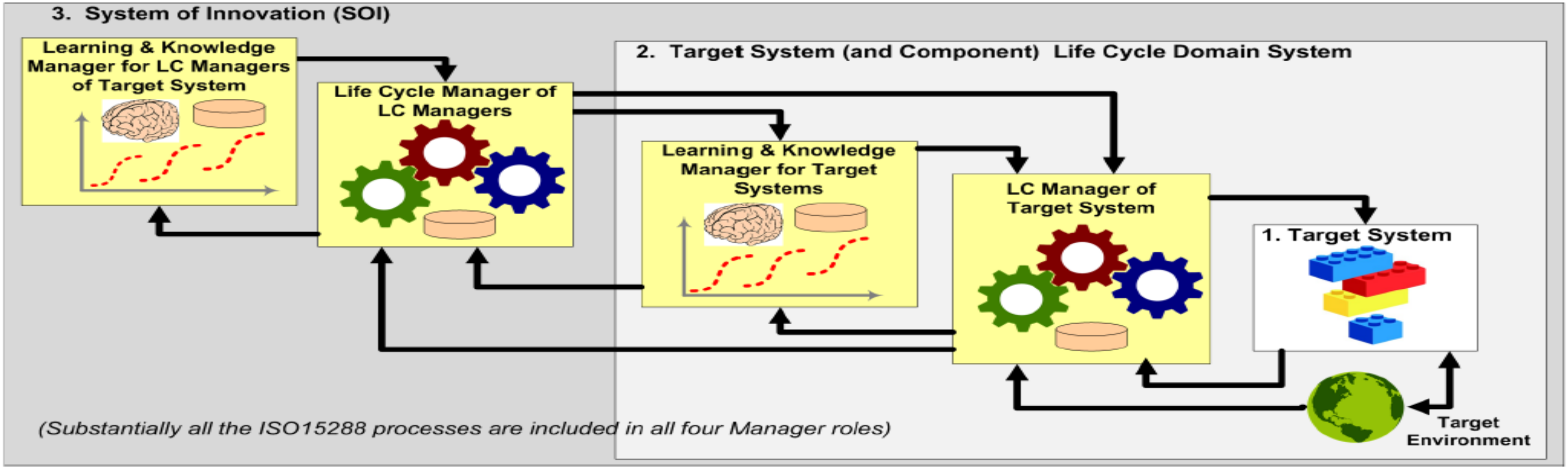


Columbiad IV Web View



ENERGYTECH16

Track 1 (MBSE) Data Collection—Using Model-Based Facilitation



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schindel@ictt.com

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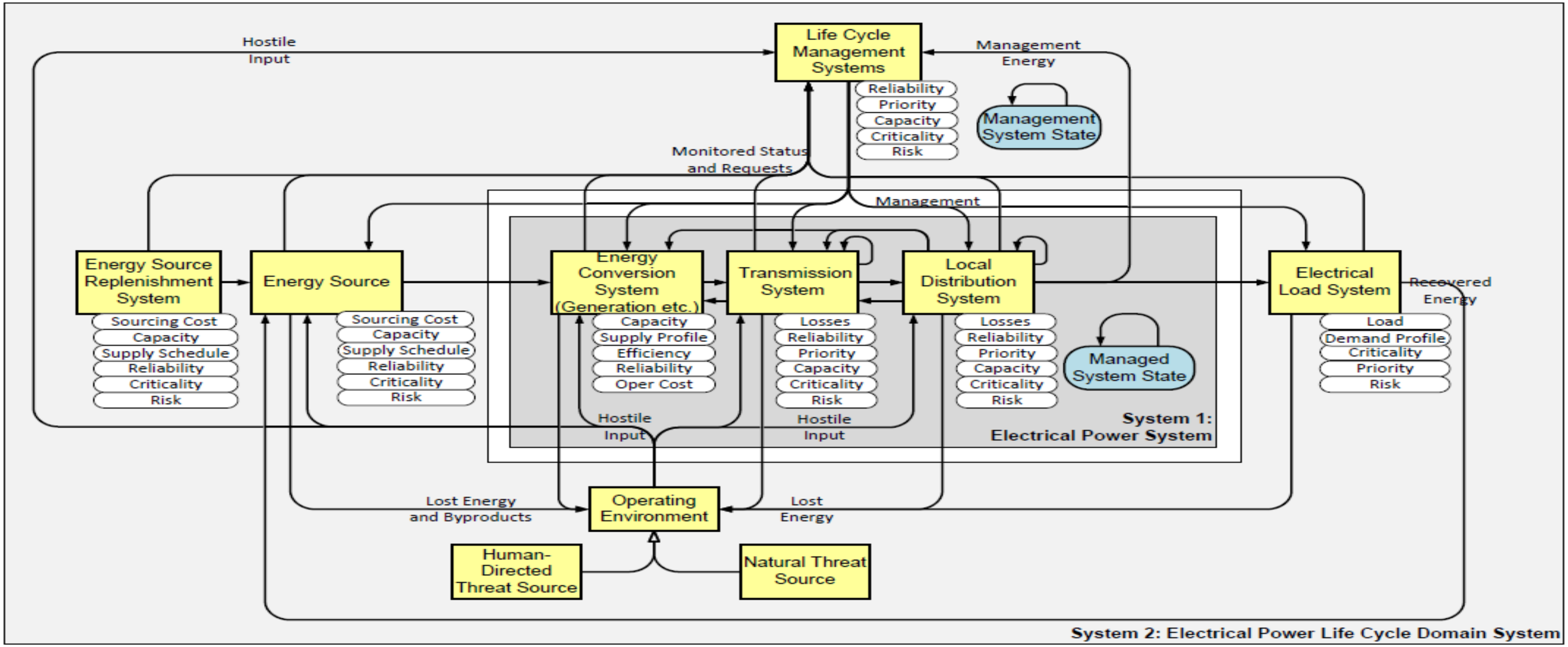
Understand your systems.

V1.6.1

Electrical Power Domain : System 1, System 2

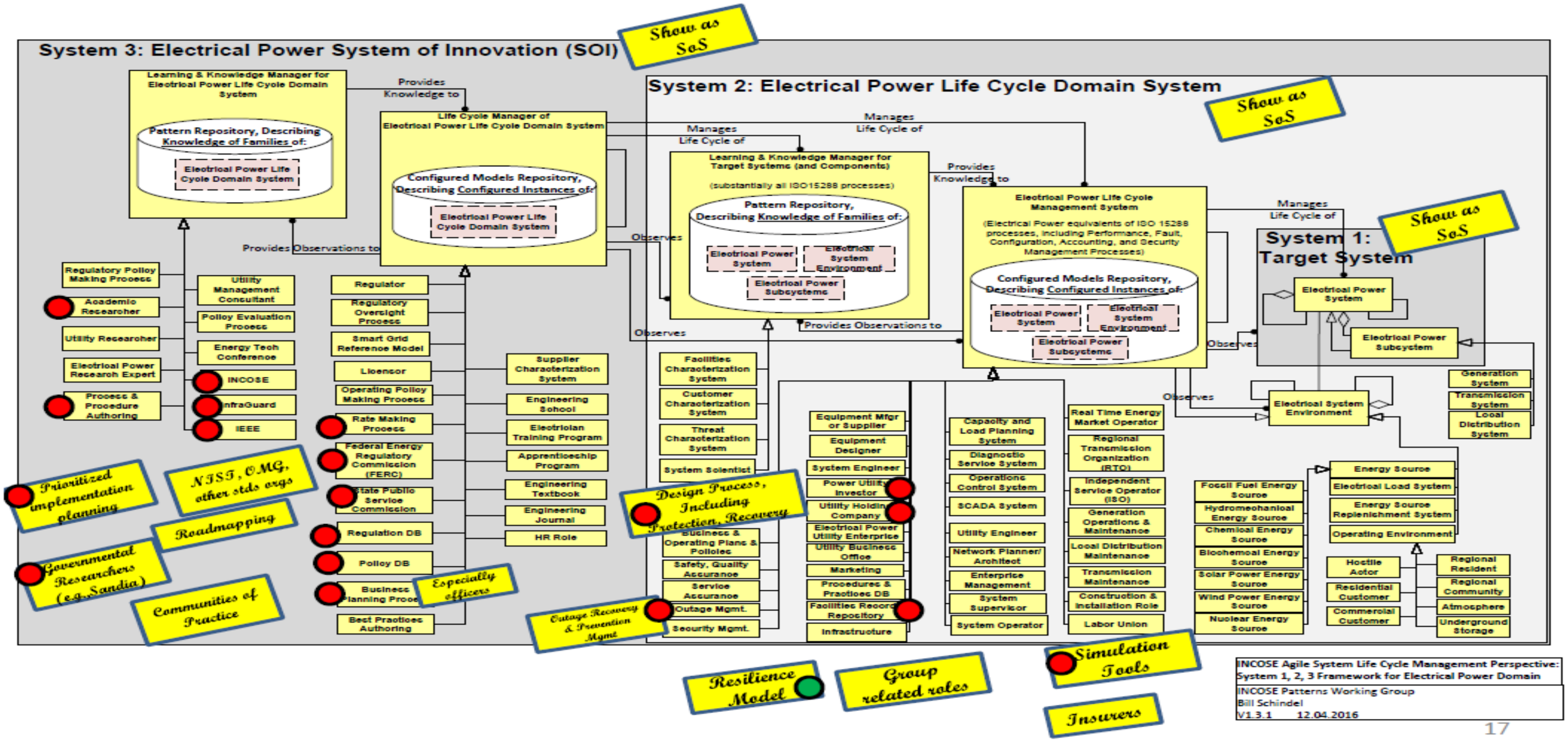


INCOSE Agile System Life Cycle Management Perspective: System 1 & 2 Summary, for Electrical Power Domain

INCOSE Patterns Working Group
Bill Schindel schindel@ictt.com

V1.3.2 12.04.2016

Electrical Power Domain : System 2, System 3



INCOSE Agile System Life Cycle Management Perspective: System 1, 2, 3 Framework for Electrical Power Domain

INCOSE Patterns Working Group
Bill Schindel
V1.3.1 12.04.2016

Common Recovery Model (CRM) for Electric Utility System Outage Recovery

Presented by: Casey Shull November 29th, 2016

Team Leader / Operations Manager Crisis and Outage Recovery Major OH Engineering

Indianapolis Power & Light Co.

Purdue University Doctoral Student

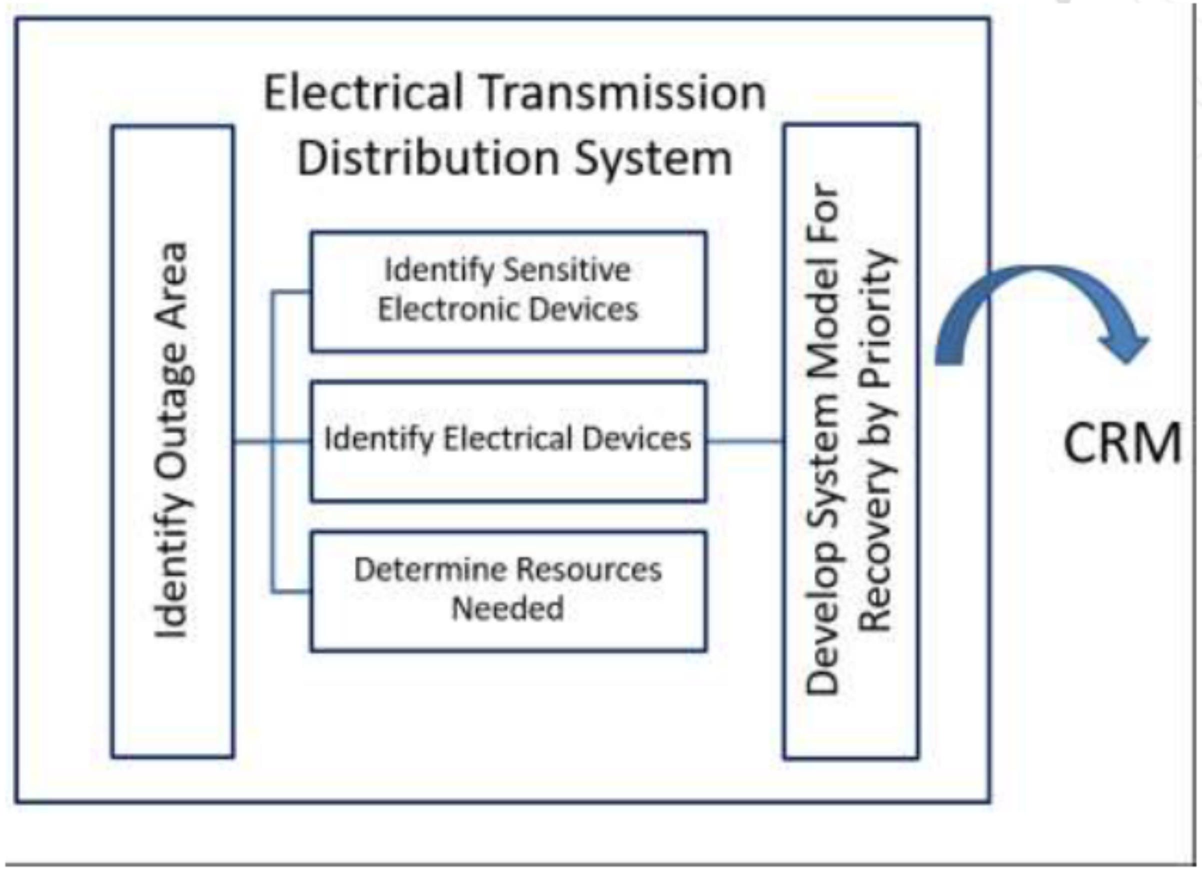
PURDUE
POLYTECHNIC

ENERGYTECH16

November 28-30 at Wolstein Center
Cleveland, Ohio
www.energytech2016.com

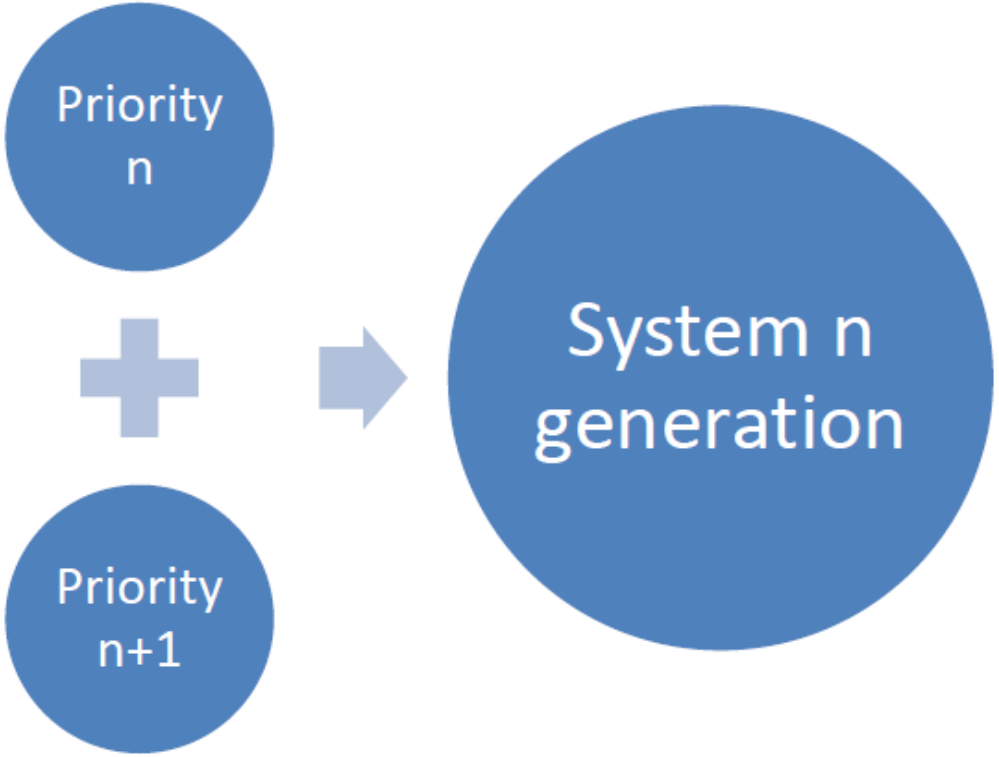
CRM Basic Model

All electric utilities have plans and methodologies in place to restore electricity due to small events, generally weather related, causing outage. Collection of existing plans and data can help to develop CRM.



CRM iterative process

Restore power to priorities identified by MBSE model. Aggregate priorities (total power) to provide "black start" power to generation.



PURDUE POLYTECHNIC

21st Century Grid Management – Big Data Analytics

Joseph Marvin

Prime Solutions Group, Incorporated

November 29, 2016

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Cleveland, Ohio
www.energytech2016.com

What Problems Are We Addressing

- "Advanced technologies to **plan, manage, monitor, and control** electricity delivery are needed to enable safe and reliable two-way flow of electricity and information, support growing numbers of distributed energy resources, and support customers participating in electricity markets as both power suppliers and demand managers."
- RD&D opportunities exist… "Develop high-fidelity **planning models, tools, and simulators and a common framework for modeling, including databases**."

PSG
PRIME SOLUTIONS GROUP, INC.

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November 28-30 at Wolstein Center
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What's new in our work?

- Enterprise approach looking down upon the ***'network of networks'*** associated with generation, transmission, distribution, and consumption.
- Embraces and exploits **uncertainty** quantification to define our knowledge bounds enabling confidence in trust and risk adjusted decision making.
- Builds upon advanced tools and capabilities around graph-based models, simulation and **optimization**… This technique uses them differently.
- Our approach exploits modern computer science:
  - **Big Data Analytics** (parametric and graph-based) including access to legacy data store and streaming data.
  - A **hybrid IT infrastructure** of both storage (structured and unstructured) and software.

Uncertainty Quantification

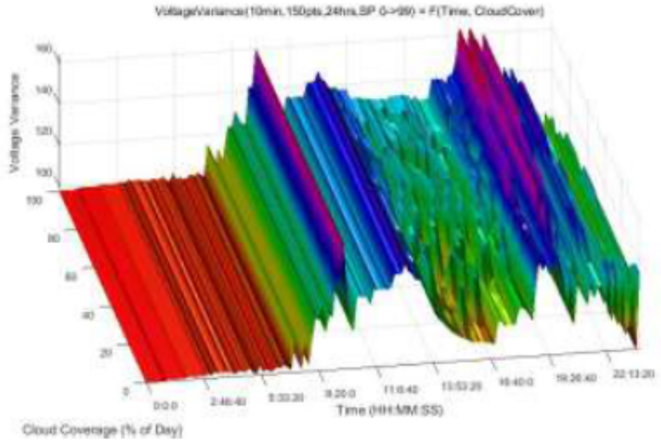
Forward Propagation of Mixed Uncertainty

PRIME SOLUTIONS GROUP, INC.

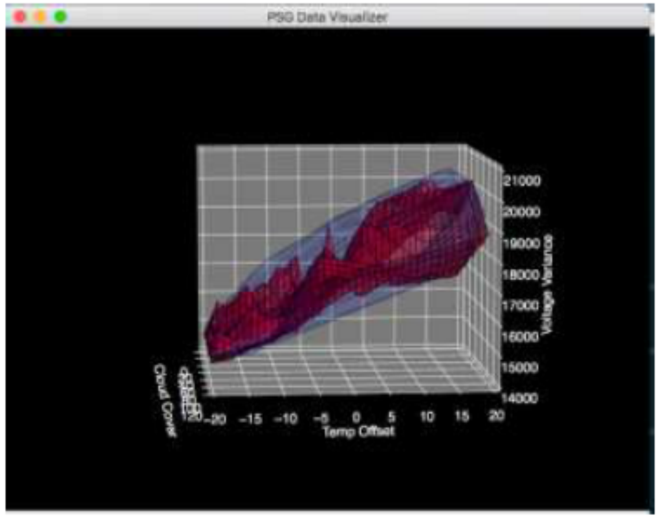
Voltage Variance (Y1) and Feeder Looses (Y2) as a function:

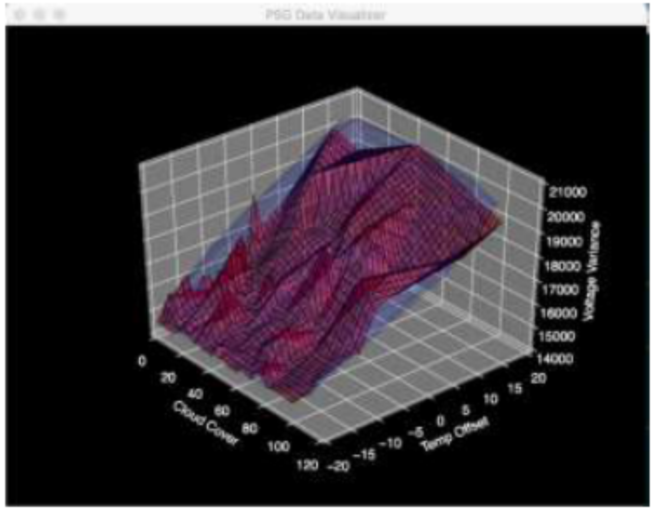
- CloudCover (Percentage of 24 hr period in which clouds were present, evenly distributed over 24 hr period)
- SolarAreaFactor (0-30) -> SolarArea(SqFt) = SAFactor/0.0114
- SolarPenetration (0-100%)
- Temp Offset (TMY_Temp-20 to TMY_Temp+20)
- Cooling setpoint (69-79)

Dakota's Latin Hypercube uncertainty quantification technique

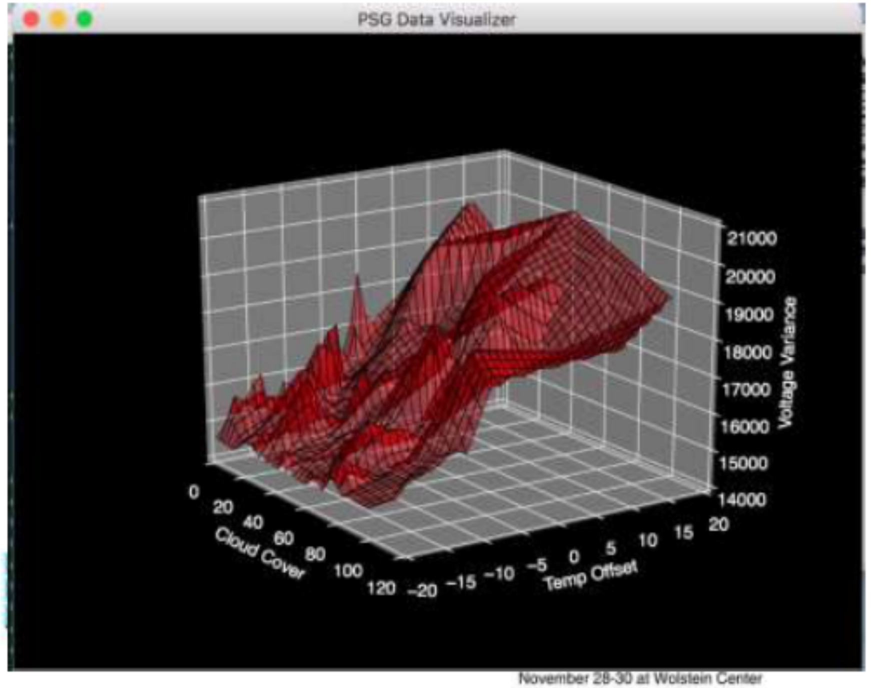


Voltage Variance – Cloud Cover - Time





Optimal and bounded performance subspaces, voltage variance



November 28-30 at Wolstein Center
Cleveland, Ohio
www.energytech2016.com

Modeling Cyber Attack Surface on the Power Grid

2016 NDIA Systems Engineering Conference

Ambrose Kam

Lockheed Martin

Oct 27 2016

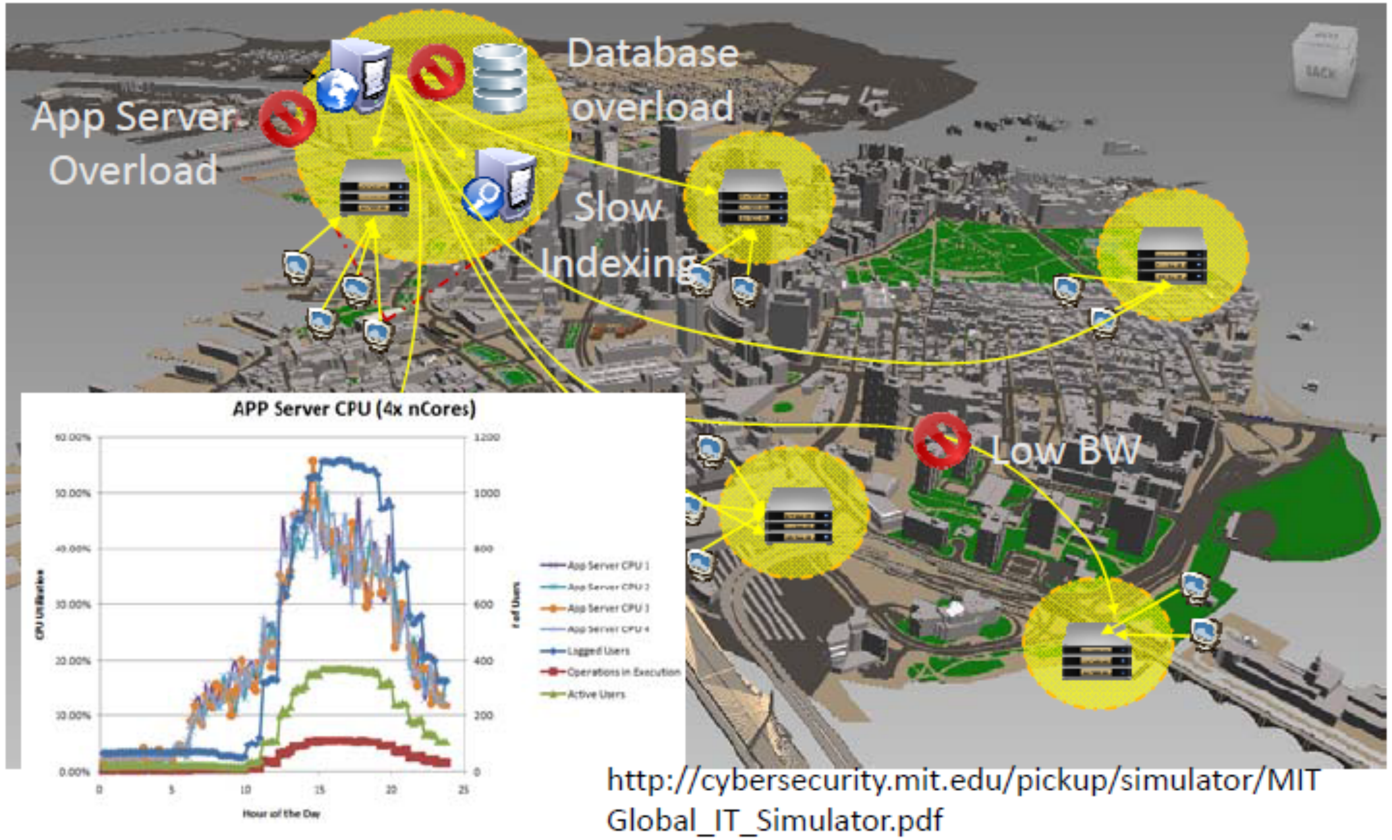
Model Integration

- LM's Cyber Attack Simulation Tool
  - Network topology
  - Model Recon phase (IP Scan, OS Probe, Phishing, etc.)
  - Model specific CVEs (Black Energy, KillDisk)
- MIT's Global IT Infrastructure
  - Network topology
  - Data Movement (VPN Access)
  - Remote Desktop
  - Control & Operate
  - Tools & Tech

NextGenLM

Adapting it to Cyber

Cyber Attack Simulation – Network Map + Application Map + Use Cases



http://cybersecurity.mit.edu/pickup/simulator/MIT Global_IT_Simulator.pdf

THINGWORX ANALYTICS END-TO-END DEEP DIVE

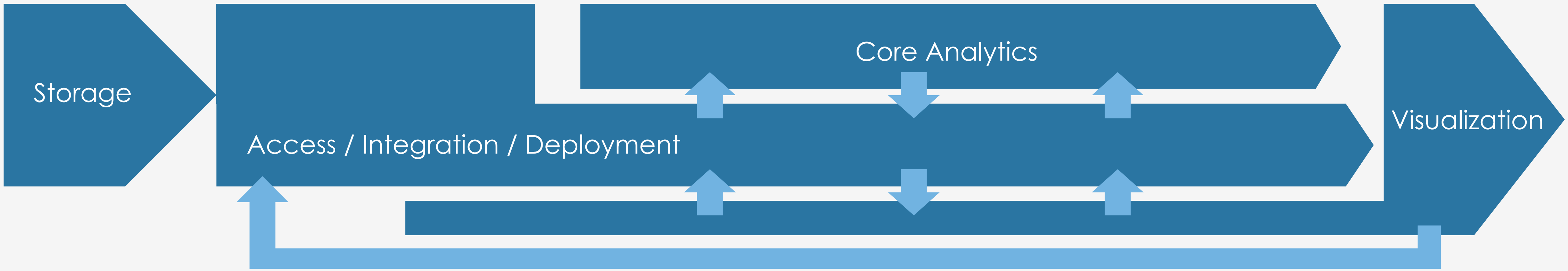
June 5, 2017

thingworx®

THE ANALYTICS VALUE CHAIN: DATA TO INSIGHTS

thingworx

Data → **Insights**



Ingestion of data sets into DB for **real-time** or long-term access.
Includes hardware infrastructure required for storage

Aggregation, transformation and integration of the collected data to prepare for modeling and processing.
Includes data management and data quality validation

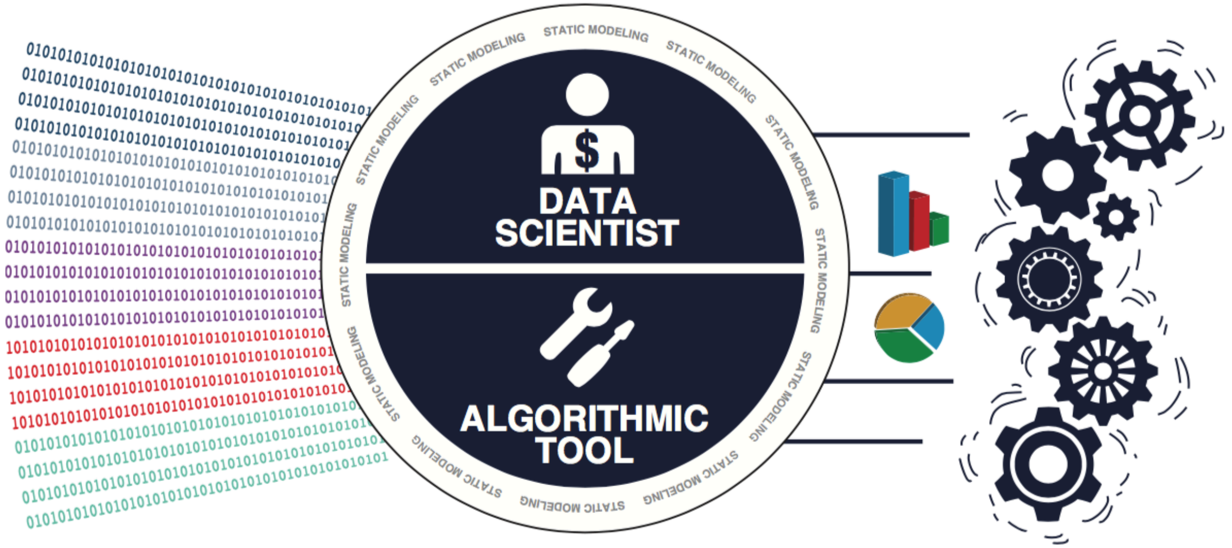
Modeling leverages different **Core Analytics** based on the use cases

Advanced Analytics

- **Descriptive / Diagnostic analytics**
- **Predictive analytics**
- **Prescriptive analytics**
- **Real-Time analytics**
- **Artificial Intelligence**
  - **ML**
  - **NLQA**
  - **…**

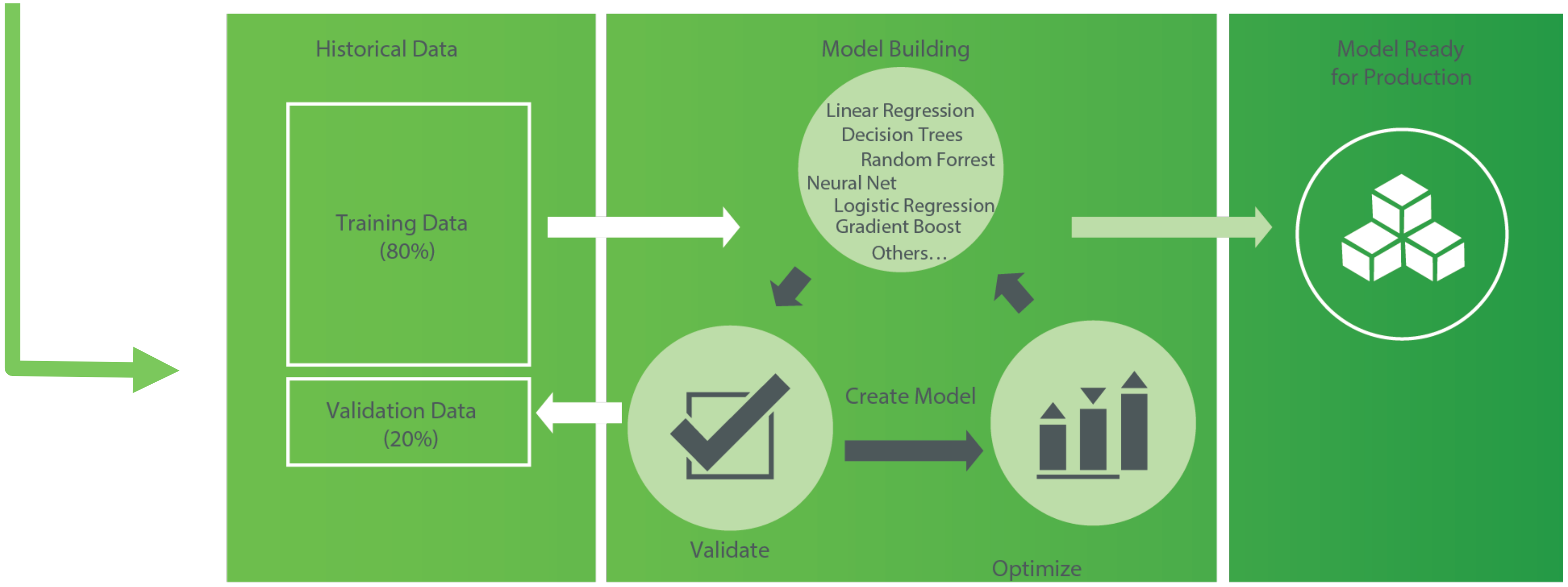
Presentation of the insights to the end user.
In the form of reports, charts, dashboards, or mashups

Source: ABI Research, Edge Analytics in IoT 1Q 2017, Gartner Analytic data science platforms



Limited by Human Performance	Fewer Insights	Less Accessibility Corporate-wide	Static Modeling Approach

AUTOMATION MAKES TRADITIONAL PROCESS LESS BURDENSOME & MORE SCALABLE

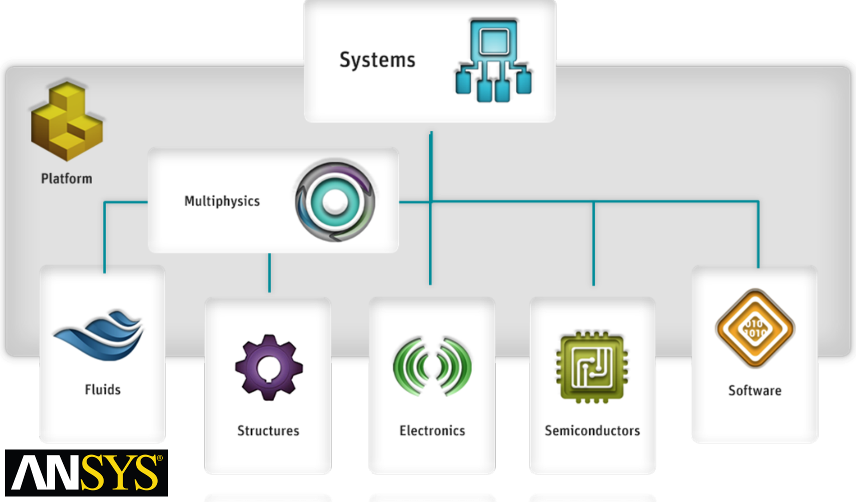


SIMULATION-BASED DIGITAL TWIN VALUE

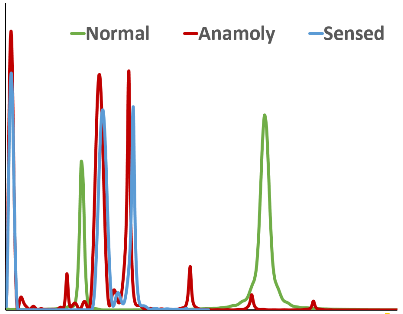
thingworx

As Designed

MULTIPHYSICS SYSTEMS SIMULATION



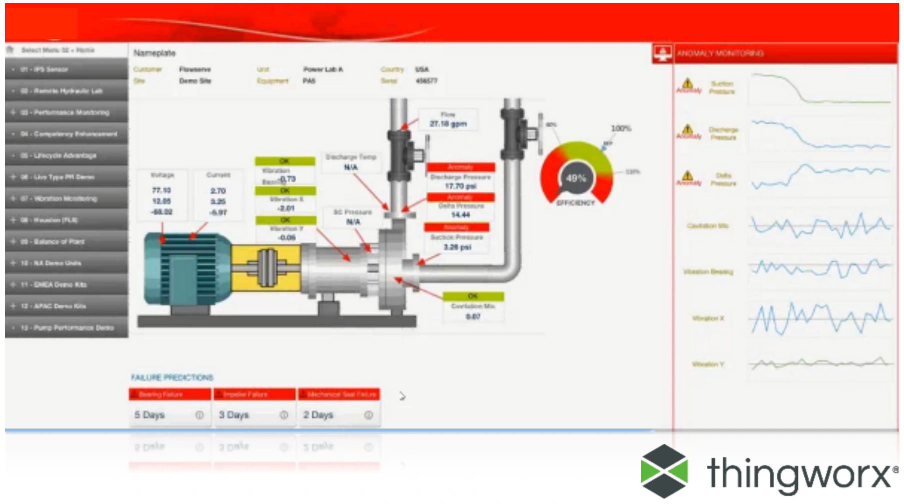
Digital Signatures



Virtual Sensors

As Operated

INTEGRATED IOT ASSETS & ECOSYSTEMS



Design Decisions

- Cost
- Weight
- Efficiency
- Robustness

Operational Decisions

- Prognostics/Life
- Performance Mgt./Opt.
- Diagnostics/FMEA/RCA
- Fleet Optimization

Agent Based Modelling Capability at University of Wollongong

Contact Professor Peter Campbell

pcampbel@uow.edu.au

0429 080 141

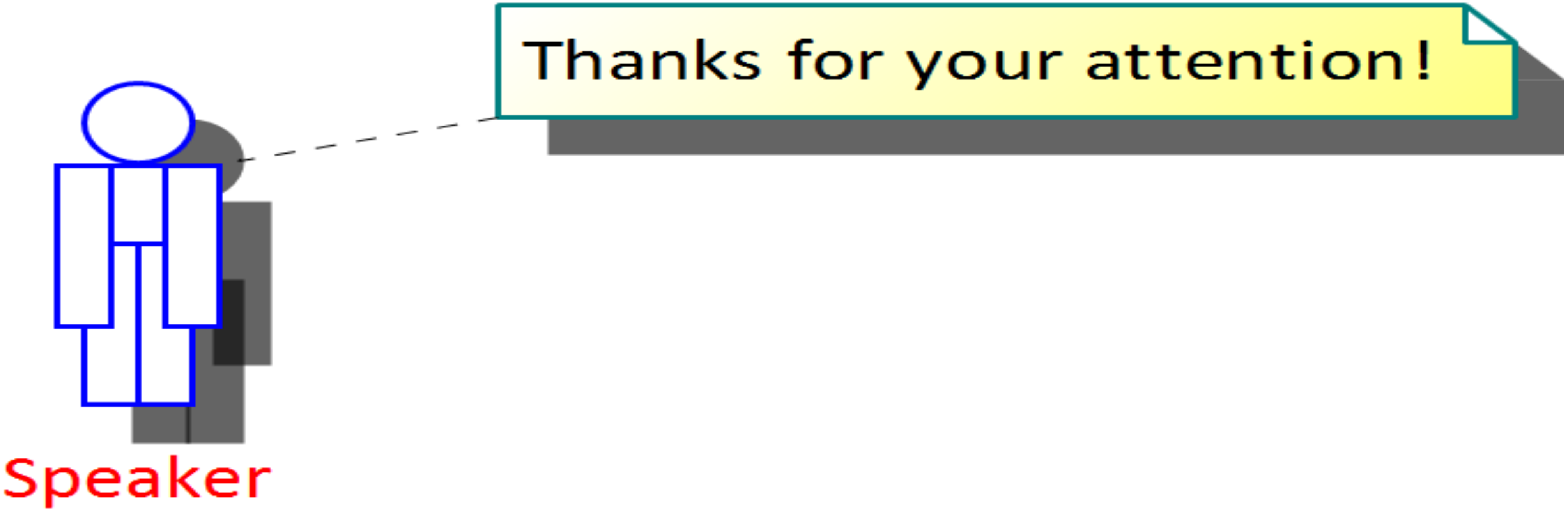
Modelling Experience

- The staff at UOW have developed ABM based applications to address a range of social, defence and infrastructure related issues including:
  - Modelling the travel and work behaviour of 113,000 residents of the Randwick and nearby suburbs of Sydney for transportation options re quality of life
  - Freight rail traffic into Port Kembla from NSW source regions
  - IED red teaming in Afghanistan
  - Passenger movement across rail platforms
  - Large scale hospital operation
  - IPB for special operations missions
  - Interdiction of drug trafficking across the Caribbean
- ABM modelling tools used include Repast Simphony, Net Logo and Any Logic

SUMMARY AND CONCLUSION

- A variety of tools are used in the electrical industry for designing, managing, controlling, running, evaluating and forecasting the electric grid and its needs.
- Specialty tools developed over a number of years that are well suited to the energy industry of the 20th century.
- The electric grid of the 21st century needs to cope with the smart grid, cyber-attacks, space weather, Electro-Magnetic Pulse (EMP) weapons, proliferation of clean energy sources, phase-out of fossil fuels, etc.
- We need to approach the problem from a systems engineering point of view
- Systems engineering will provide that new way of thinking, and MBSE for SoS with UAF and SysML integrated with specialty tools will provide the means to realize the solutions.

QUESTIONS AND ANSWERS



Thank You!

Matthew Hause
PTC

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PLATFORM
ptc
Unlock the value created by the convergence
of the physical and digital worlds
SOLUTIONS