9TH ANNUAL PITT ELECTRIC POWER INDUSTRY CONFERENCE

Presented by the Swanson School of Engineering & the Center for Energy

Smart Grid Vision for Computing

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Contents

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Smart Grid Vision Project (SGVP)

- **Objective -** Develop a “Smart Grid Vision” Report (May 2013)
    - Role of Computing, 2030 and beyond
    - Incorporate futuristic concepts
- **Purpose -** Stimulate research and development, education, standards
- **Project Groundrules and Assumptions**
    – There are no wrong visions for the future
    – Not bounded by current understanding of technology
    – Not constrained by today’s policies and practices
    – Not driving toward a common end vision – not an engineering exercise
    – Visions may be complimentary or co
- **Project Team Leadership**
    – Dr. William Sanders (UI-UC)
    – Dr. Andreas Tolk (ODU)
    – Dr. Dave Cartes (FSU)
    - Dr. Joe Chow (RPI)
    - Dan McCaugherty (Athena)
    - Steve Widergren (DOE PNNL)

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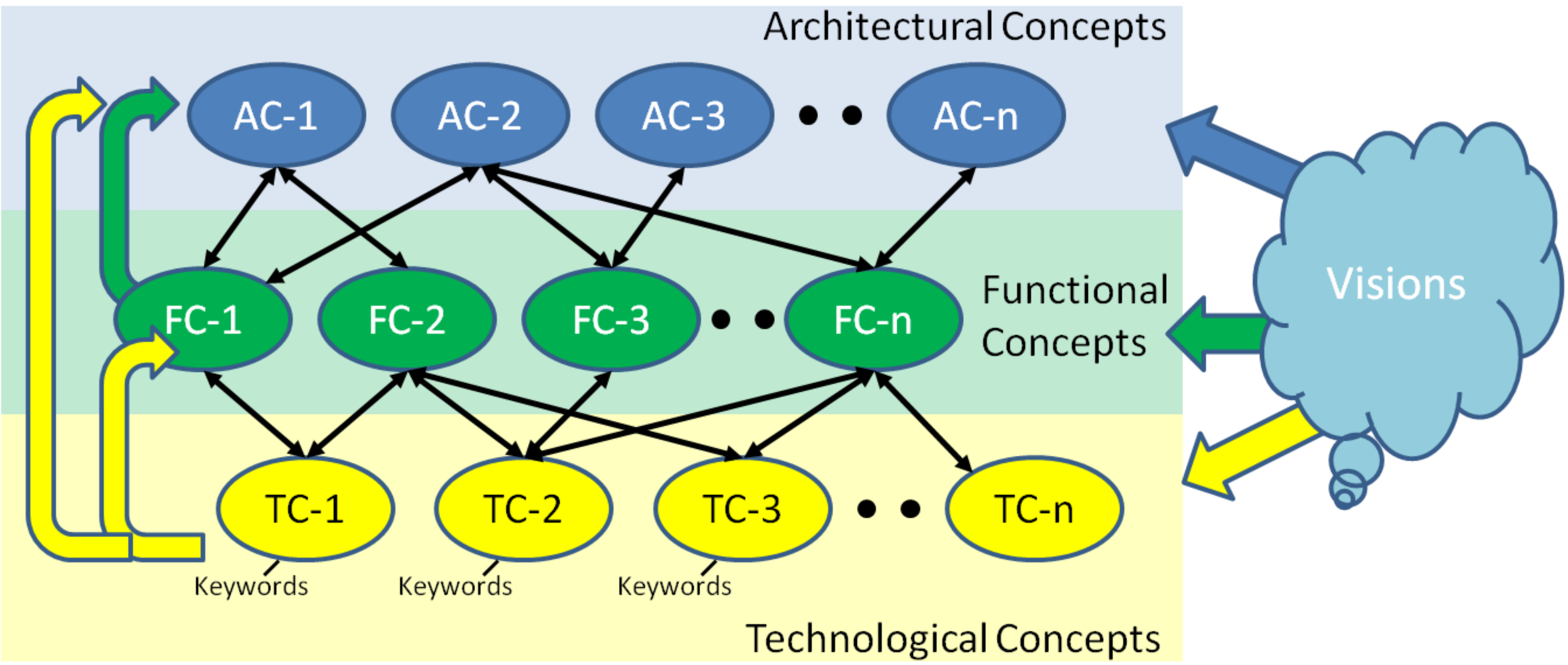
Project Approach

- Elaborate Visions in three Concept Tiers – Architectural (AC), Functional (FC), and Technological (TC)
- Visions along lower Tiers often stimulated higher Tiers



Architectural Concepts (11 Total)

- **Supply Side (4)**
  - Renewable resources
  - Energy storage & balancing
  - Integrated islands
  - Isolated islands
- **Demand Side (4)**
  - Utility demand response
  - Aggregated local energy
  - Self-owned base energy
  - Electric transportation
- **System Concepts (3)**
  - Coherent system operations
  - Complex autonomous adaptive systems
  - System and cyber security

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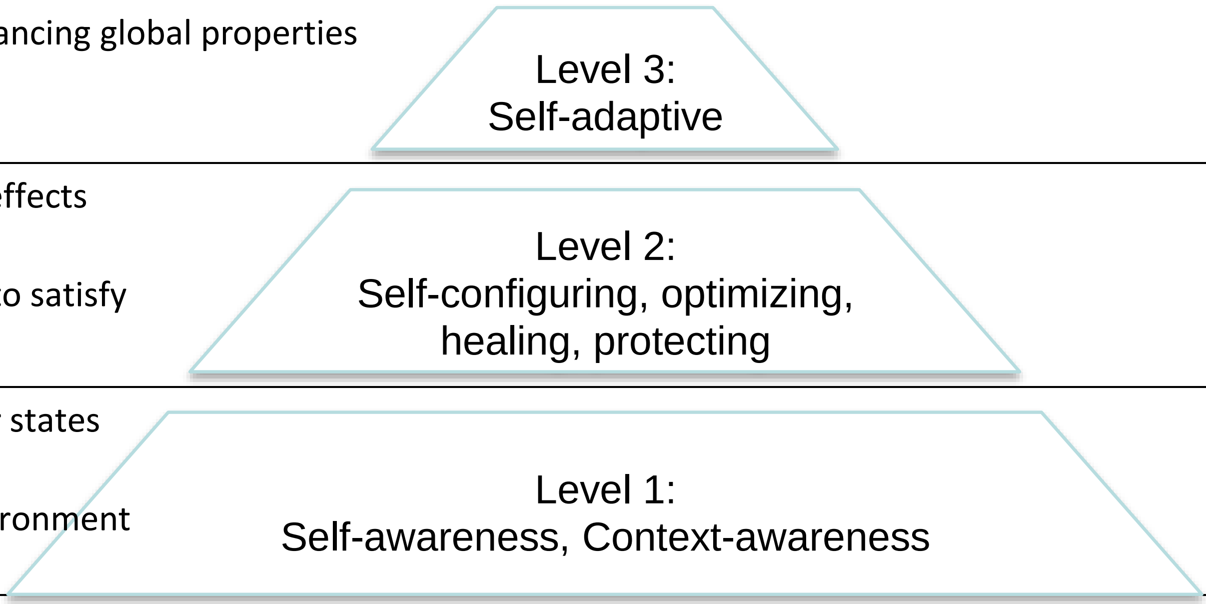
Complex Autonomous Adaptive Systems

- Intelligent self-adaptation services & information flow to other distributed grid services - balancing global properties and grid health management
- Emergent behaviors enabled

- Defend against attacks & mitigate effects
- Respond to changes
- Manage performance & resources to satisfy different users

- Sensors and intelligence to monitor states and behavior
- Awareness of location and ops environment



Hierarchical aspects of autonomy [1]

[1] Salehie, M., Tahvildari, L. 2009. "Self-adaptive software: Landscape and research challenges." *ACM Transactions on Autonomous and Adaptive Systems (TAAS)* 4, no. 2.

Functional Concepts – 27 Total

Performance (12)

- **Operations, monitoring, and control subtopic (8)**
  - Bulk system transmission dynamic operations
  - Operations congestion detection
  - Power flow forecasting in distribution networks
  - Direct load control events
  - Island-to-island stable power flow control
  - Automated grid load flow coordination
  - Process coordination of industrial manufacturing
  - Commercial and industrial building coordination
- **Planning, analysis and simulation subtopic (4)**
  - Bulk system transmission planning
  - Asset management and maintenance
  - Resilient systems
  - Command, control, and automated functions

Functional Concepts – 27 Total

Systemic (8)

- Cyber Security Subtopic (5)
  - Information security
  - Control security
  - Privacy
  - Supply chain resilience
  - Intrusion tolerance
- Software/Systems Engineering Subtopic (3)
  - Unsupervised autonomy
  - Social nodes
  - Autonomous validation

Enabling (7)

- Comm. & Networks Subtopic (3)
  - Intelligent devices/nodes
  - Converged communications
  - Hardware/Software refresh
- Visualization and Data Mgt Subtopic (2)
  - State awareness
  - Failure awareness, restoration
- Markets and Economics Subtopic (2)
  - Wholesale power market
  - Dynamic demand side markets

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Unsupervised Autonomy

- Self- optimization: Context awareness to make prioritized-based optimization decisions in seconds or minutes, without human interaction.
- Self-protect: Provide resiliency against malicious attacks by virtue of better physical and IT security protocols.
- Self-configure: Balance distribution of renewable resources and energy storage.
- Self-optimization and reconfiguration: Energy users can actively participate and tailor their energy consumption based on individual preferences (price, environmental concerns, etc.).
- Self- adaptation: Improve market efficiency by making product types (energy, ancillary services, risks, etc.) available to market participants of all types and sizes.

Technological Concepts / Functional Concepts	1: Self-integrating systems and standards	2: Distributed multi-agent architecture	3: Virtual computing architecture	4: Messaging-oriented middleware	5: Market-Inspired (transactive) control	6: Monitoring and control/modeling and simulation tools	7: Information processing for control, protection and performance qualification/performance monitoring	8:State estimation analysis algorithms	9: Contingency, preventive and corrective control analysis	10: Stochastic analysis for system operations, planning, forecasting	11: Prognostics and asset management	12: Visualization	13: Artificial Intelligence, data analytics, fast mathematics and high-performance computing	14: Internet and real-time systems	15: Software verification and validation	16: Trusted component validation	17: Portable identity – bidirectional authentication support	18: Hierarchical sense making	19: Massive parallel pattern detection	20: Patterns for implementing agile self-organizing security	21: Information security technology
1: Information security	x															x	x	x	x	x	x
2: Control security																x	x	x	x	x	x
3: Privacy	x															x	x				
4: Supply chain cyber resilience in software and hardware			x	x										x	x	x	x	x	x	x	x
5: Automated intrusion tolerance															x		x	x	x	x	x
6: More dependence on unsupervised autonomy	x	x			x		x								x	x	x		x	x	
7: Social nodes	x	x	x	x	x									x		x	x		x	x	
8: Smart Grid autonomous validation	x	x													x	x	x		x	x	
9: Proliferation of intelligent devices and nodes	x	x	x	x	x	x	x				x			x	x	x	x		x	x	
10: Secure converged communications				x										x	x	x	x	x		x	x
11: Smart Grid hardware and software refresh														x						x	
12: State awareness						x	x	x	x	x		x	x		x			x	x	x	
13: System failure awareness, emergency response and system restoration		x	x	x	x	x	x	x	x	x		x			x			x	x	x	
14: Wholesale electric power market policy, operation and design					x					x				x	x						
15: Emergent dynamic demand side markets		x			x					x				x	x						
16: Bulk system transmission dynamic operations		x	x	x	x	x		x				x	x		x						
17: Operations congestion detection		x	x	x			x	x		x			x		x						
18: Power flow forecasting in distribution networks						x	x	x		x			x								
19: Direct load control events			x	x									x	x	x						
20: Island-to-island stable power flow control			x	x	x	x	x	x				x			x						
21: Automated grid load flow coordination		x	x	x	x	x	x					x			x						
22: Advanced process coordination of industrial manufacturing		x	x	x	x	x	x					x		x	x						
23: Commercial and industrial building coordination		x	x	x	x	x	x					x		x	x						
24: Bulk system transmission planning						x				x			x								
25: Asset management and maintenance		x		x						x	x		x		x						
26: Resilient systems		x	x	x	x	x	x		x		x		x	x	x					x	
27: Advanced command, control, and automated functions		x			x	x	x	x				x	x	x	x						

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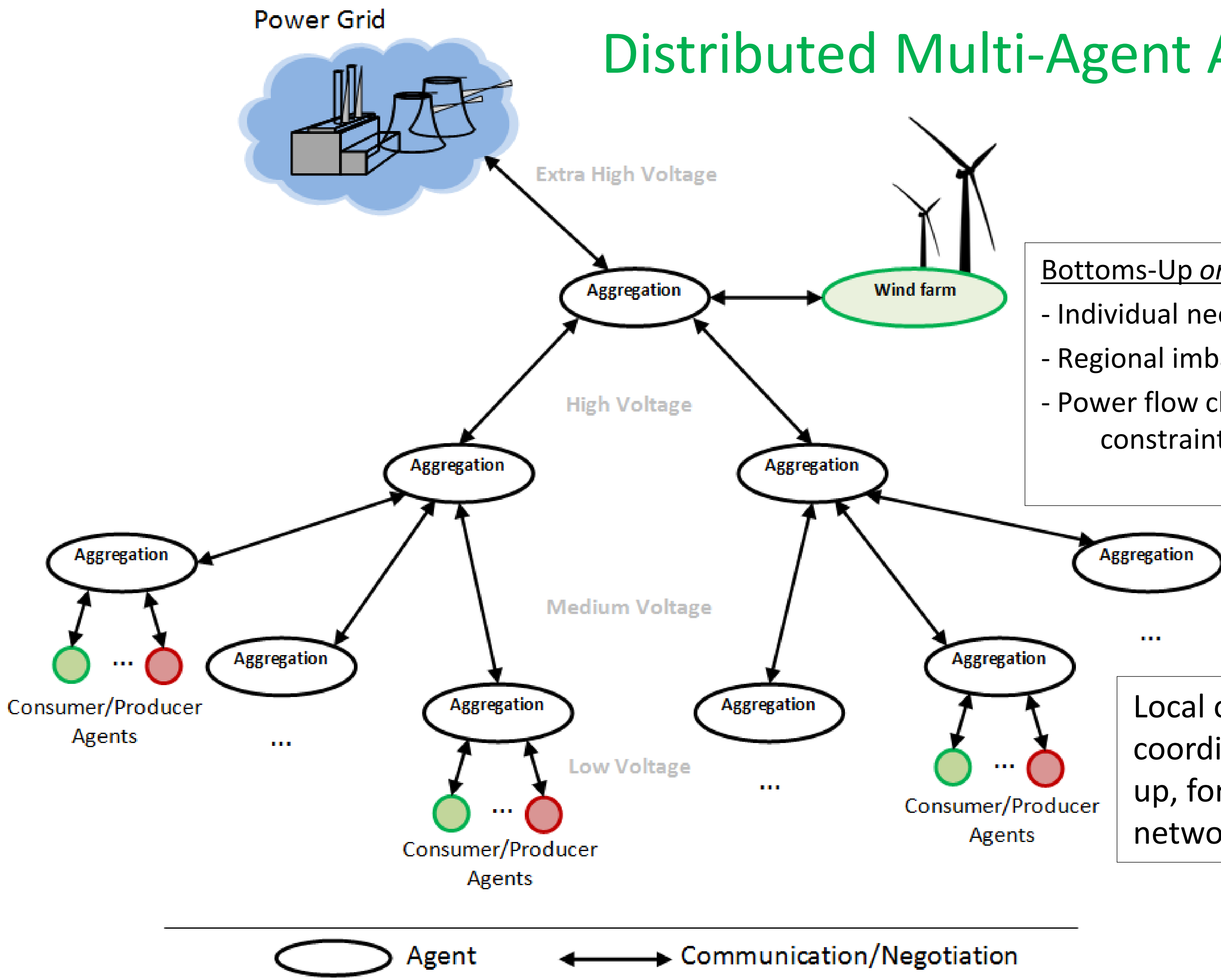
Technological Concepts (21 Total)

- **Distributed System Architecture (4)**
  - Self-integrating systems and standards
  - Distributed multi-agent architecture
  - Virtual computing architecture
  - Messaging-oriented middleware
- **Computer Applications (7)**
  - Market-Inspired (transactive) control
  - Monitoring and control/modeling and simulation tools
  - Signal processing for control, protection and performance qualification/performance monitoring
  - State estimation analysis algorithms
  - Contingency, preventive and corrective control analysis
  - Stochastic analysis for system operations, planning, forecasting
  - Prognostics and asset management

Technological Concepts

- **Information Science (4)**
  - Visualization
  - Artificial Intelligence, data analytics, fast mathematics and high-performance computing
  - Internet and real-time systems
  - Verification and validation
- **Cyber Security (6)**
  - Trusted component validation
  - Portable identity – bidirectional authentication support
  - Hierarchical sense making (HSM) and collaborative HSM agent networks
  - Massive parallel pattern detection
  - Patterns for agile self-organizing security
  - Information security technology

Distributed Multi-Agent Architecture



<u>Bottoms-Up *organic* control</u>

- Individual needs negotiated
- Regional imbalances smoothed
- Power flow checked against stability constraints

Local optimization coordinated step-wise up, forming ever-larger networks

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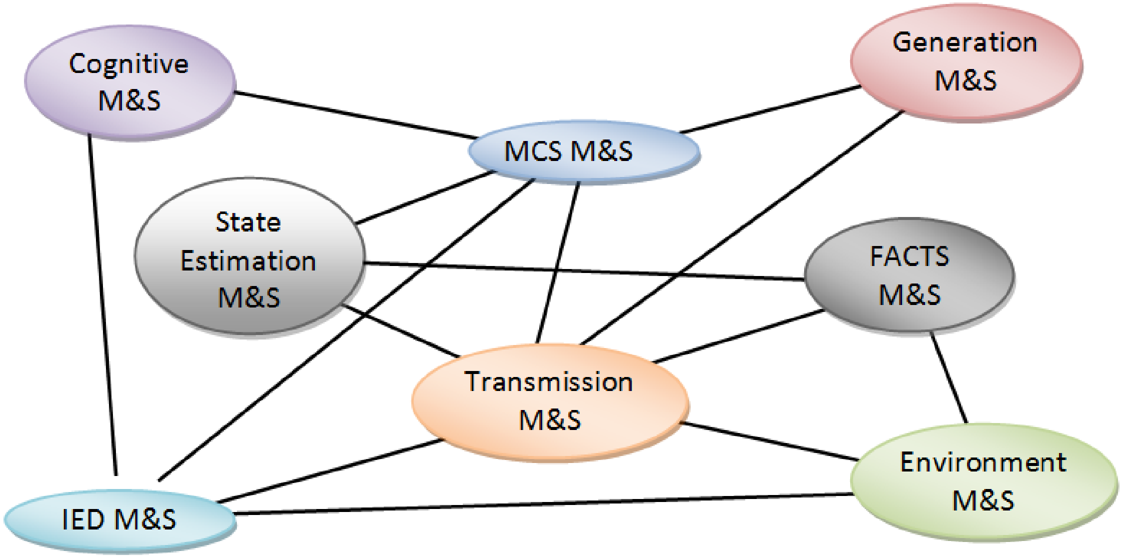
Monitoring and Control/Modeling and Simulation (M&S) tools



Problem:

- Proprietary M&S tools do not interact
- Difficult to leverage integrated M&S component capability for dynamic SCADA system simulation

Future Vision:

- Standard data exchange formats
- Scalable fidelity
- Accommodate third party M&S tools (e.g., state estimation)
- Grid device vendors supply compatible models
- Uses – grid design, planning, operations

Verification and Validation

- Future Smart Grid is beyond the scale of existing high integrity systems
- Traditional specify -> build -> test -> deploy approach not applicable
  - Systems configurations evolve in real time
  - Control is adaptive to environment and configuration
- V&V and deploy sequence:
  - New system component in passive mode and provides behavioral characteristics
  - Component behaviors evaluated. If pass - incorporated into system model
  - System behavior re-verified using updated system model
  - If system behavior passes, component becomes active participant
- Models of system element behaviors subject to formal methods
  - Use of domain specific modeling languages
  - Computational intelligence needed to guide the verification mechanism
- Continuous run-time verification needed for adaptive elements
  - High performance simulations constantly evaluating emergent behaviors

Future Work

- Smart Grid Computing Roadmap
- Re-address the visions in 2 to 5 years
  - Impact of emerging sciences
  - New smart grid concepts

Roadmap Approach

- Step 1: Establish roadmap for each of the 7 Functional Vision Subtopics
  - Identify dependencies and order of events (technologies, standards, etc.) to achieve vision states across:
    - Near: 0-5 Yrs
    - Mid: 5-10 yrs
    - Far: 10+ years
  - Filter out technologies that will emerge independent of smart grid needs
- Step 2: Identify strategic technology progression
  - Identify most impactful technologies that require smart grid driven influence
  - Establish time-phased investment priorities

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