Interoperability Requirements as an Enabler of Smart Grid Integrative Research

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Background

- Two PSERC projects on the issue of Interoperability have been completed recently:
  - *"Verifying Interoperability and Application Performance of PMUs and PMU-Enabled IEDs at the Device and System Level"*
  - *"The Smart Grid Needs - Model and Data Interoperability, and Unified Generalized State Estimator"*
- Major organization for Interoperability coordination (SGIP) is going through transition and expanding membership
- PSERC may play a major role in advancing understanding of the issue of interoperability and its impact on research

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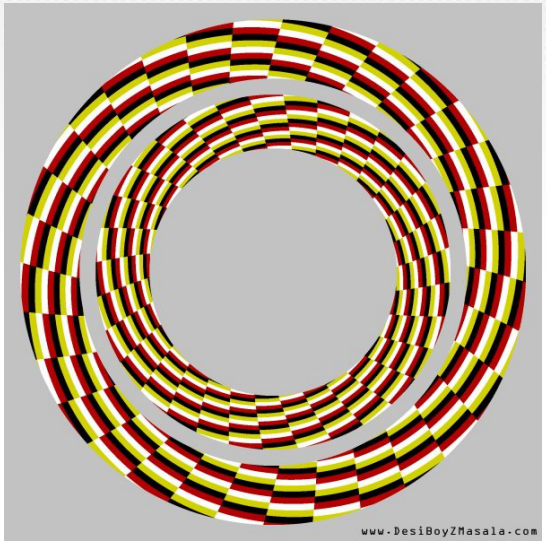


- Who brought it up
- What it entails
- When it matters
- Where it makes difference
- Why to be concerned
- How it impacts research

Who brought it up?

- Energy Independence and Security Act- EISA 2007
- Grid Wise Architecture Council-GWAC Stack
- Smart Grid Interoperability Panel- NIST Coordinated Organization

EISA Focus

- TITLE I—ENERGY SECURITY THROUGH IMPROVED VEHICLE FUEL ECONOMY
- TITLE II—ENERGY SECURITY THROUGH INCREASED PRODUCTION OF BIOFUELS
- TITLE III—ENERGY SAVINGS THROUGH IMPROVED STANDARDS
- TITLE IV—ENERGY SAVINGS IN BUILDINGS AND INDUSTRY
- TITLE V—ENERGY SAVINGS IN GOVERNMENT AND PUBLIC INSTITUTIONS
- TITLE VI—ACCELERATED RESEARCH AND DEVELOPMENT
- TITLE VII—CARBON CAPTURE AND SEQUESTRATION
- TITLE VIII—IMPROVED MANAGEMENT OF ENERGY POLICY
- TITLEIX—INTERNATIONAL ENERGY PROGRAMS
- TITLEX—GREEN JOBS
- TITLEXI—ENERGY TRANSPORTATION AND INFRASTRUCTURE
- TITLEXII—SMALL BUSINESS ENERGY PROGRAMS
- TITLE XIII—SMART GRID
- TITLEXIV—POOL AND SPA SAFETY
- TITLEXV—REVENUE PROVISIONS
- TITLE XVI—EFFECTIVE DATE

EISA Smart Grid Focus

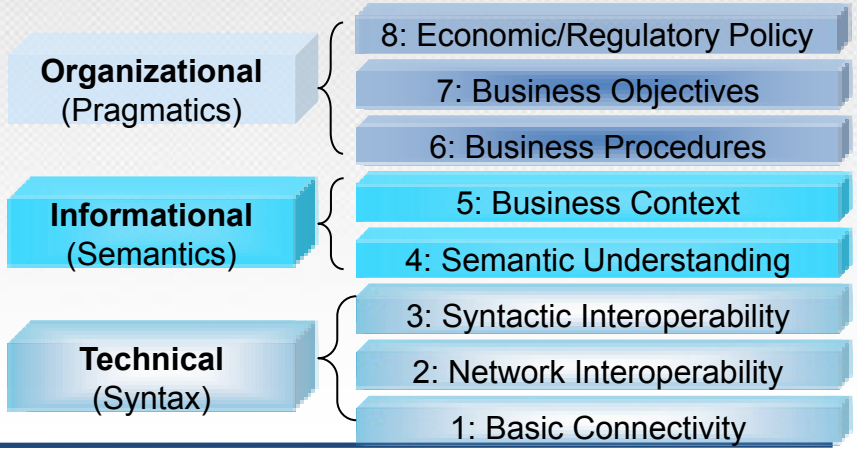
- TITLE XIII—SMART GRID
- Sec. 1301. Statement of policy on modernization of electricity grid.
- Sec. 1302. Smart grid system report.
- Sec. 1303. Smart grid advisory committee and smart grid task force.
- Sec. 1304. Smart grid technology research, development, and demonstration.
- Sec. 1305. Smart grid interoperability framework.
- Sec. 1306. Federal matching fund for smart grid investment costs.
- Sec. 1307. State consideration of smart grid.
- Sec. 1308. Study of the effect of private wire laws on the development of combined heat and power facilities.
- Sec. 1309. DOE study of security attributes of smart grid systems.

GWAC Overview

Objective

Advance interoperability to enable full-scale smart grid deployments by engaging stakeholders in defining interoperability principles, methods, and tools. Provide DOE related point of coordination for NIST in response to EISA 2007 legislation.

GWAC Stack



Life-cycle Funding Summary ($K)

Prior to FY 12	FY12, authorized	FY13, requested	Out-year(s)
$5,400K	$560K	$200K	$500K/yr

Technical Scope

- GridWise® Architecture Council (GWAC) administration
- GWAC membership – 13 independent, nationally recognized, experts across multiple domains
- Development and dissemination of smart grid interoperability related methods, tools and education
- Leadership and participation in national smart grid interoperability standards activities such as the NIST Smart Grid Interoperability Panel

Accomplishments

2006 – Interoperability Constitution

2007 – Interoperability Decision Maker's Checklist

2008 – Interoperability Context Setting Framework

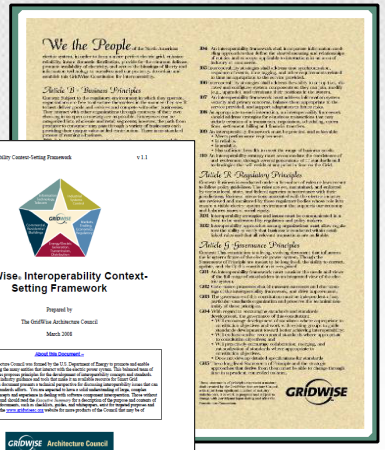
2009 – Interoperability Benefits Papers
- *Environmental Benefits*
- *Financial Benefits*
- *Reliability Benefits*

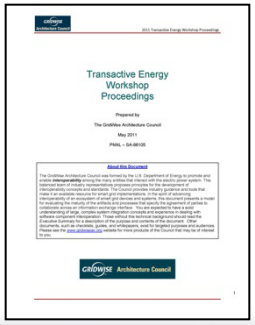
2010 - Interoperability Decision Maker's Checklist update

2011 – Smart Grid Interoperability Maturity Model Beta Version
Electrical Power Engineering Academic Landscape

2007-2012 – Grid-Interop Forum

2011-2012 – Transactive Energy Workshop

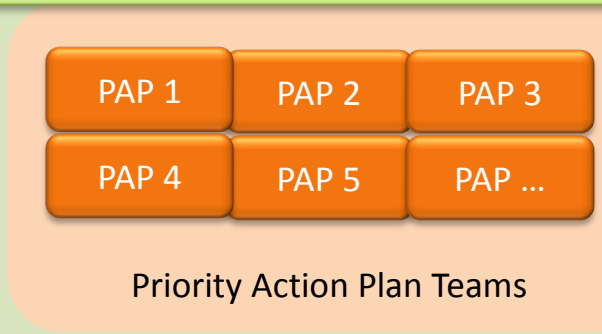




Smart Grid Interoperability Panel

- Public-private partnership created in Nov 2009
  - 786 member organizations (~100 international organizations, ~30 Canadian)
  - Over 1900 participants from 22 stakeholder categories
- SGIP supports NIST in coordinating, accelerating, & harmonizing the development of standards
  - Prioritizes standards development programs
  - Identifies requirements
  - Works with over 20 Standards Development Organizations
- SGIP Twiki: http://collaborate.nist.gov/twiki-sggrid/bin/view/SmartGrid

SGIP Organization



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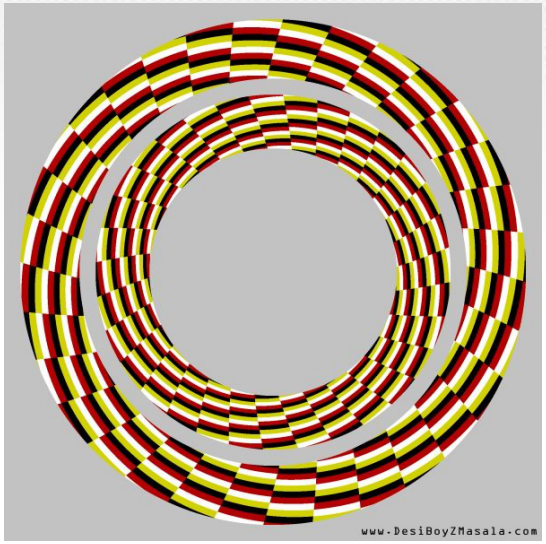


Who brought it up

What it entails

When it matters

Where it makes difference

Why to be concerned

How it impacts research

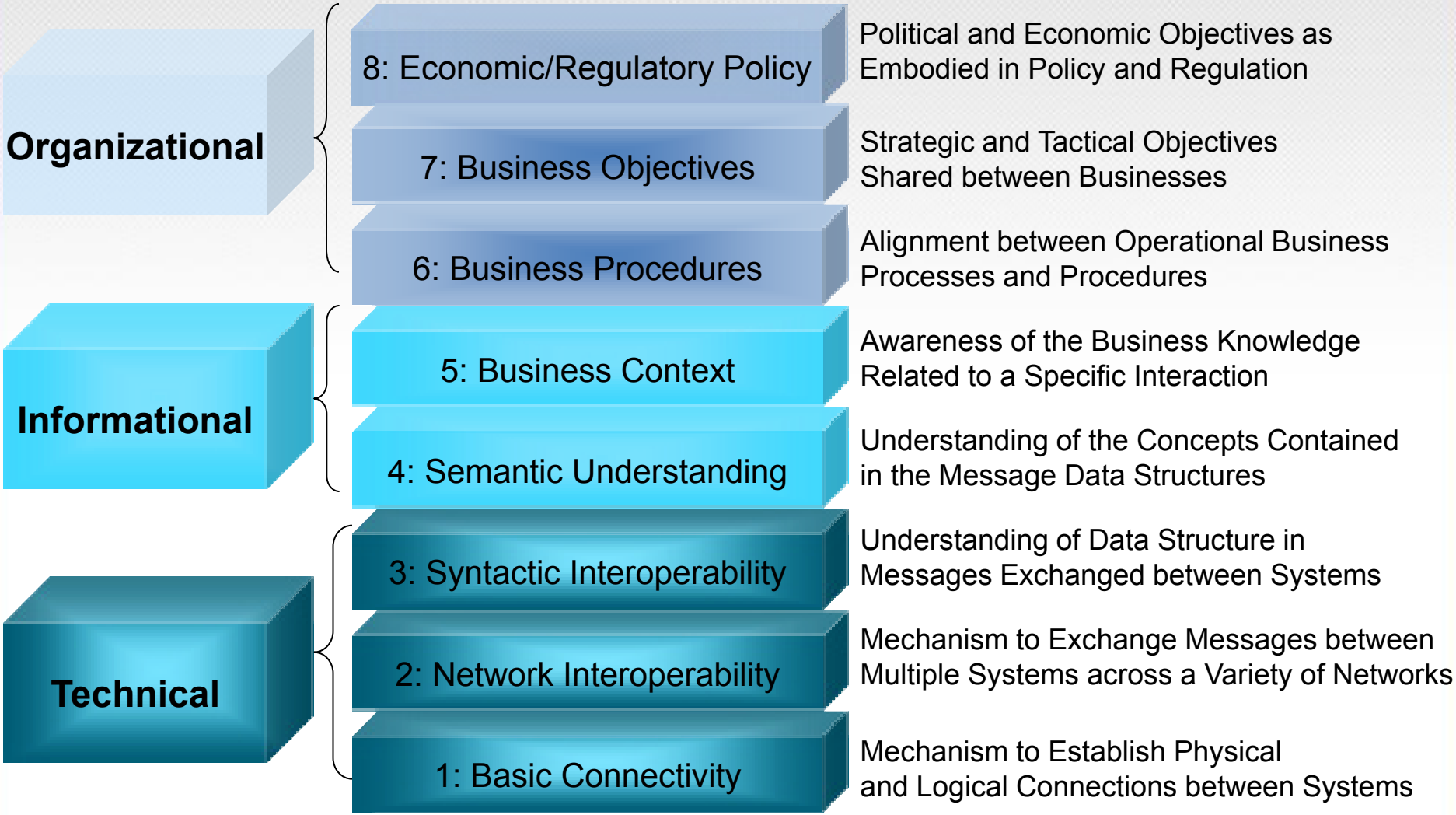
What it entails?

- Developing Framework to enforce it
- Coordinating standards to make it happen
- Performing research to bridge the gaps

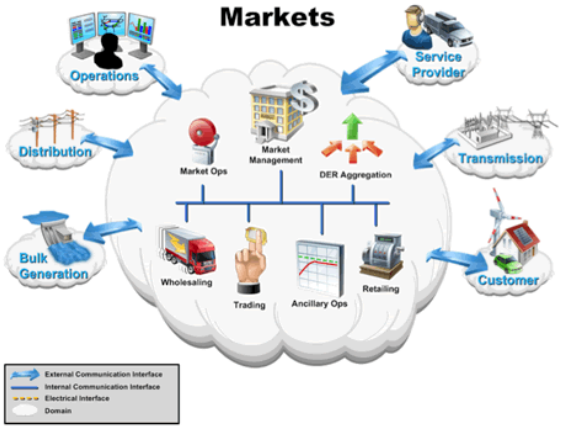
System Integration Philosophy

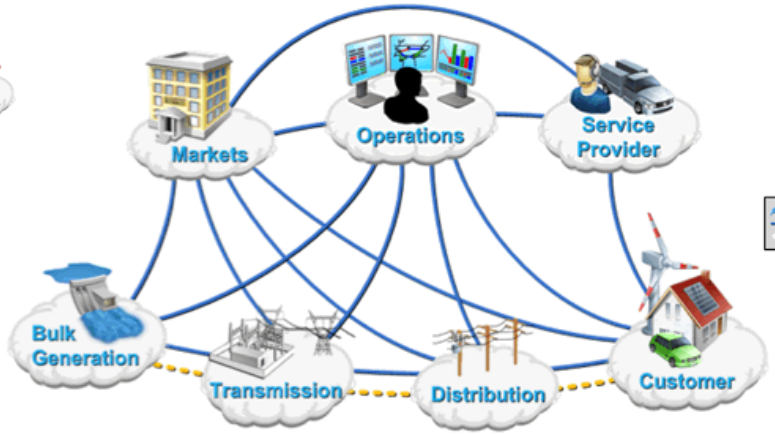
- Agreement at the interface
  - Create an interaction contract
  - Terms and conditions, consequences for failure to perform…
- Boundary of authority
  - Respect privacy of internal aspects on either side of the interface (technology choice and processes)
- Decision making in very large networks
  - Decentralized/autonomous decision-making
  - Multi-agent v. hierarchical approach
  - Addresses scalability, evolutionary change, eases integration
- Role of standards in the framework
  - Encourages standards for improving interoperation
  - Agnostic to specific standards and technologies

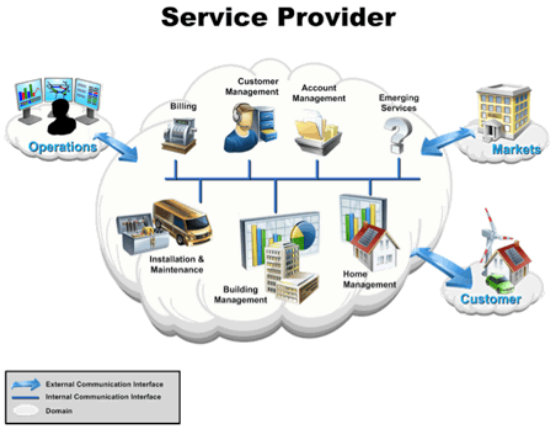
Interoperability Framework

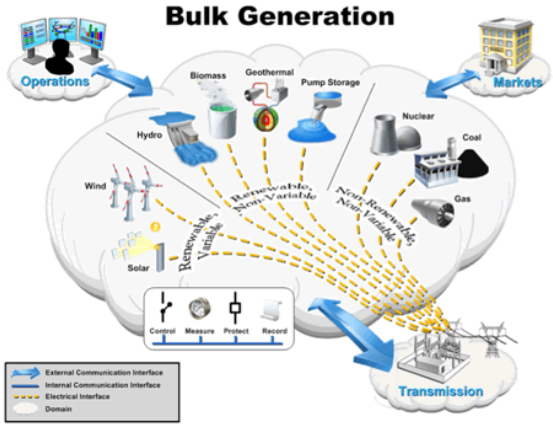


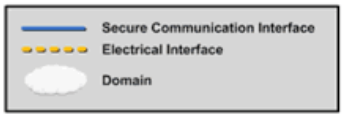
Electricity Grid Domains



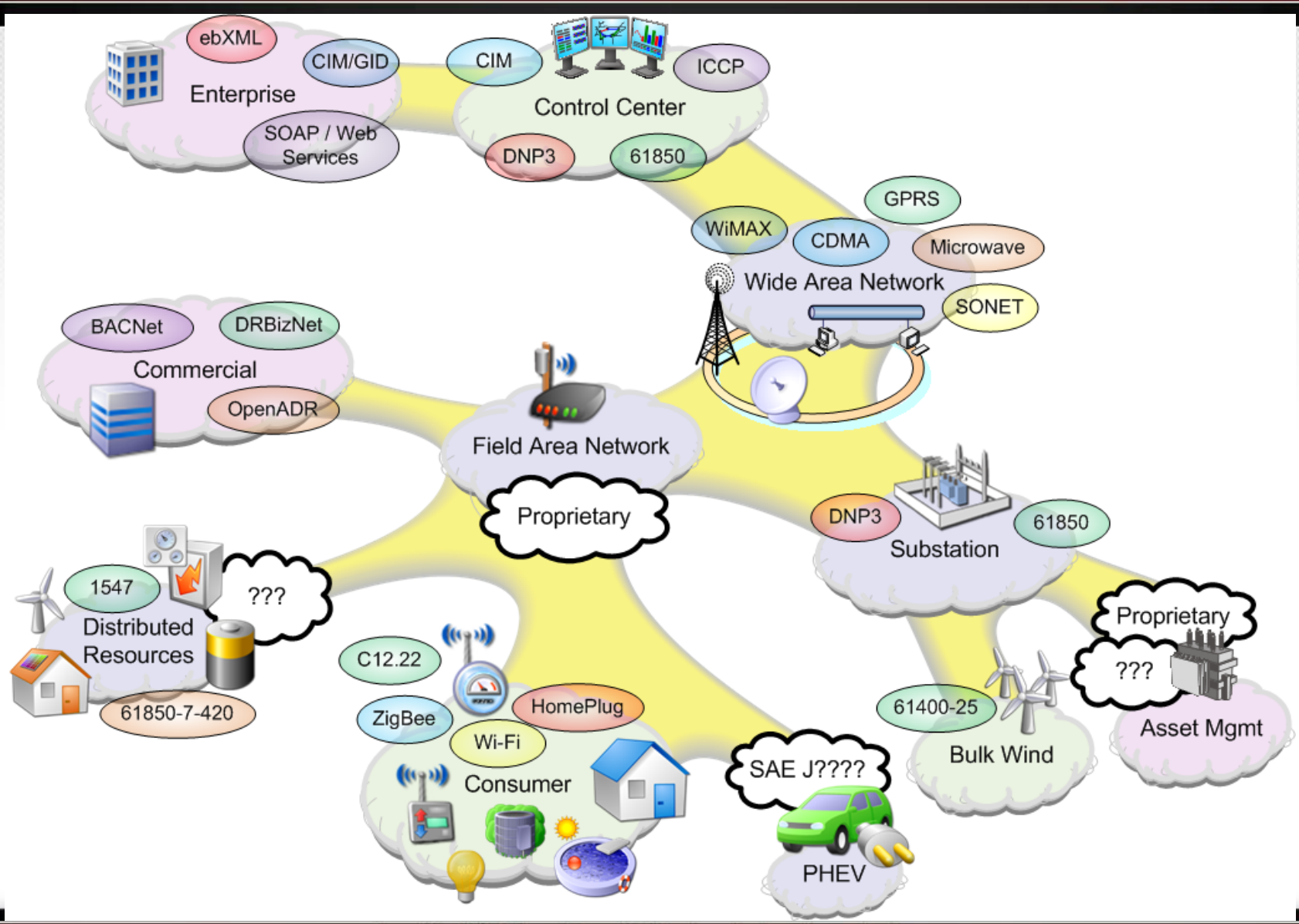




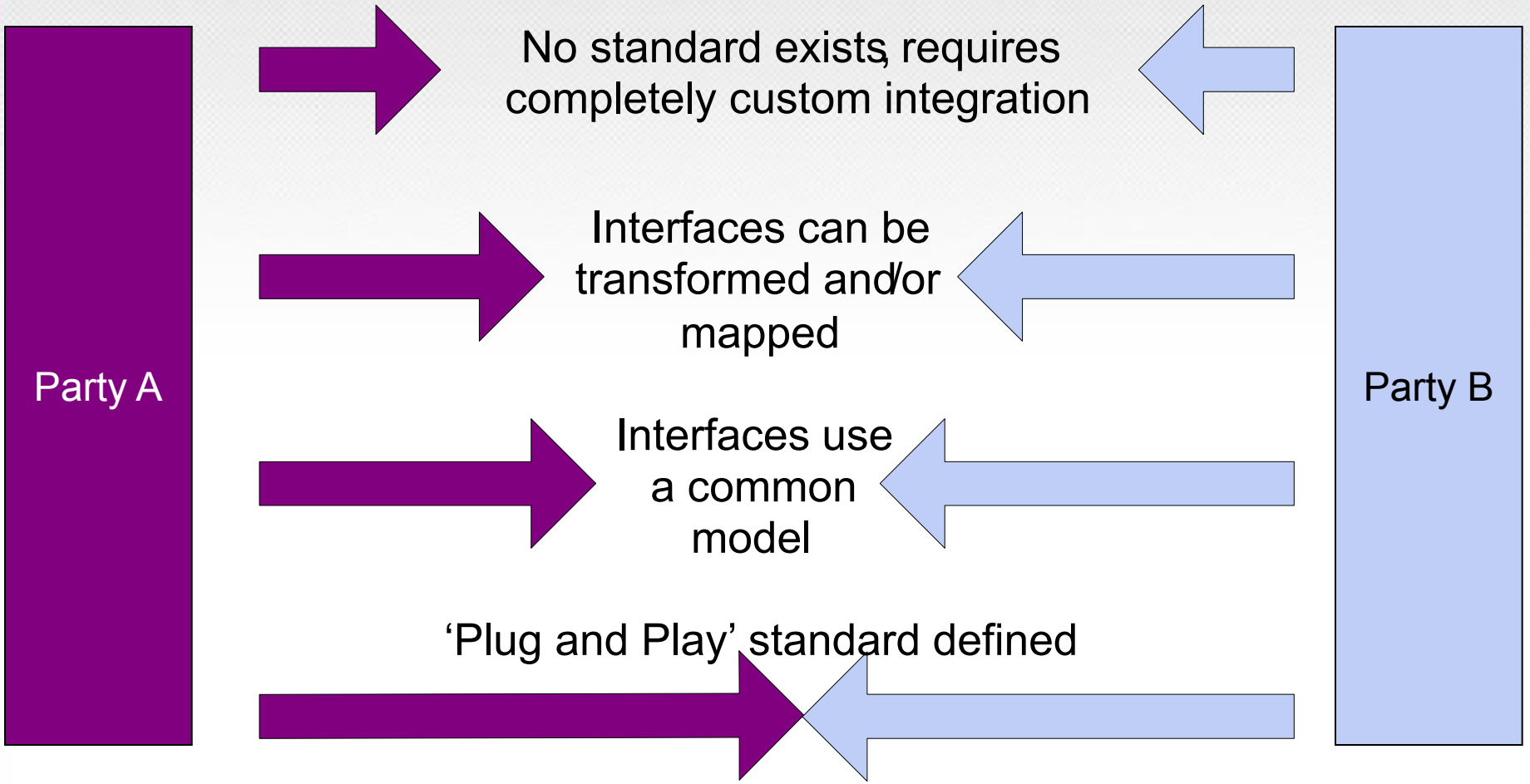




Focus: Standards

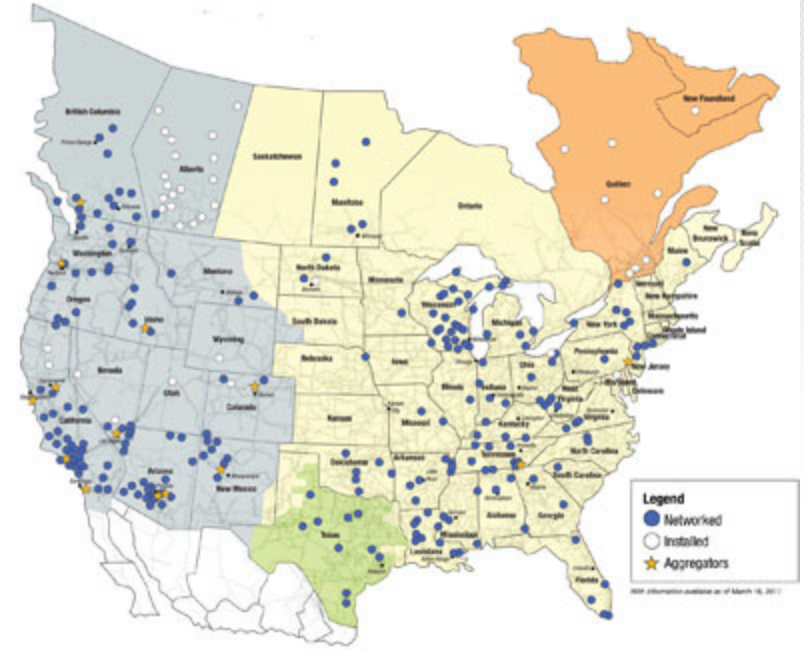


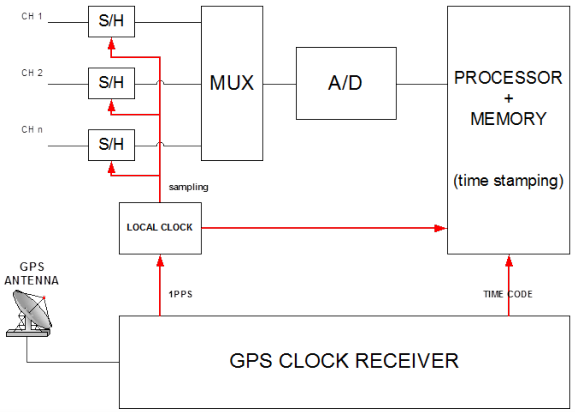
Distance to Integrate

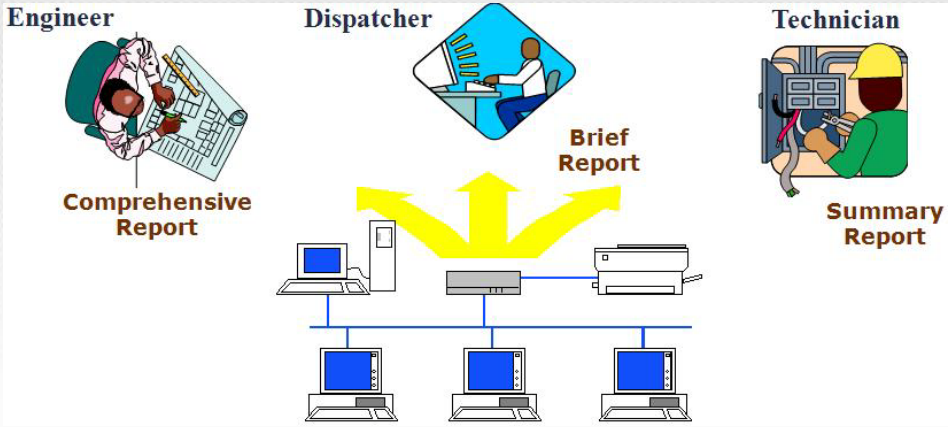


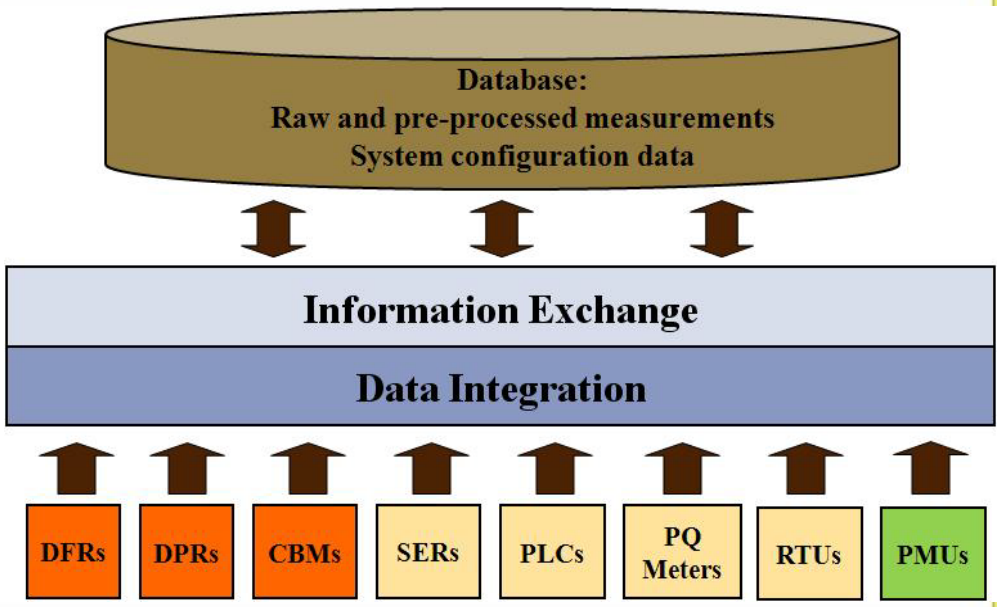
Credit: Scott Neumann, UISol position paper

Research Examples









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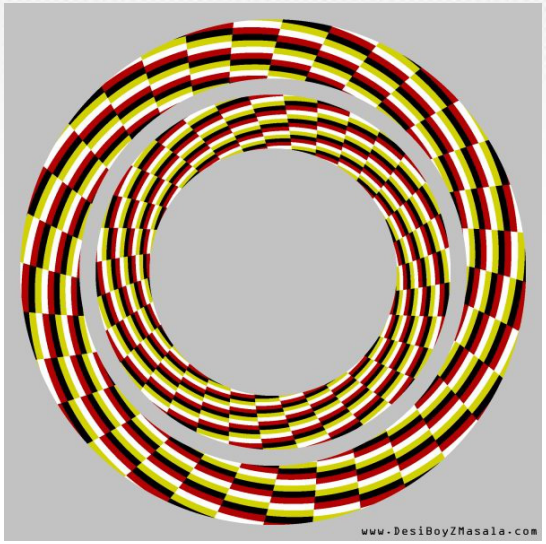


Who brought it up

What it entails

When it matters

Where it makes difference

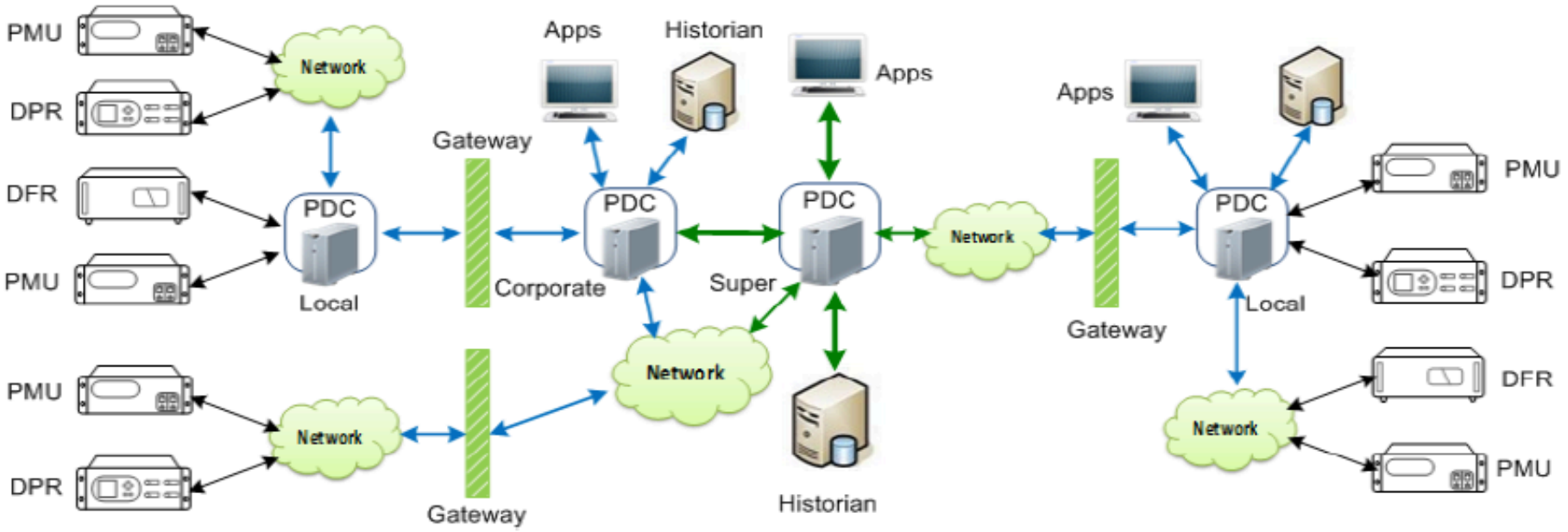
Why to be concerned

How it impacts research

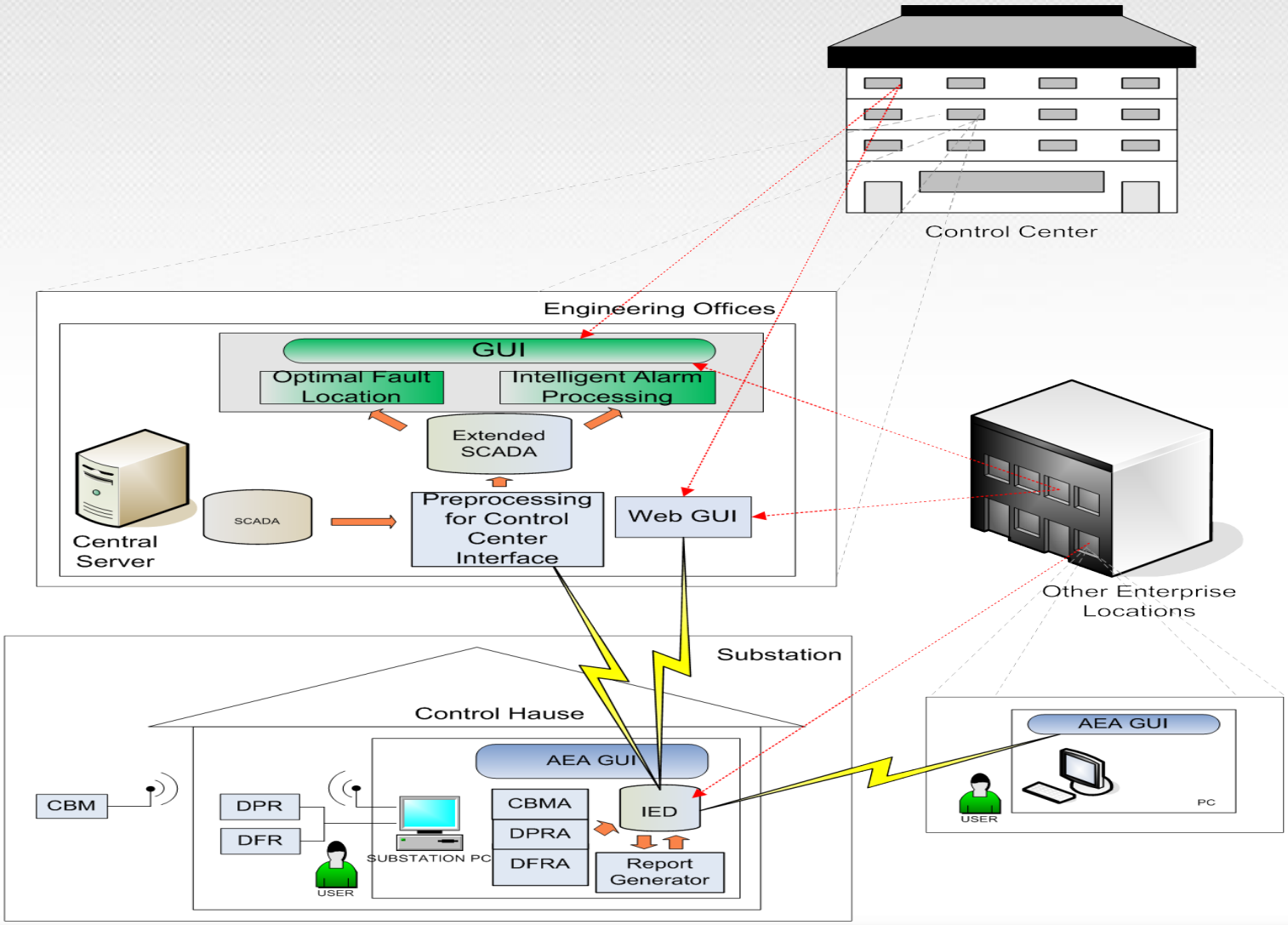
When it matters?

- Dealing with integration
- Utilizing Existing Standards
- Identifying gaps and coordination issues

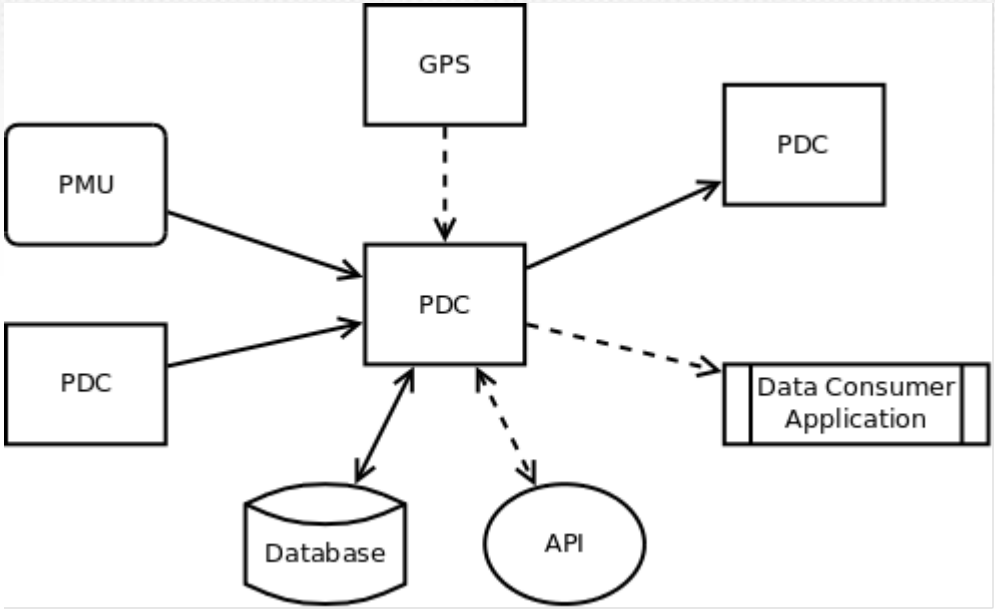
Synchrophasor End-to-end solution



Automated Data Analytics End-to-end solution

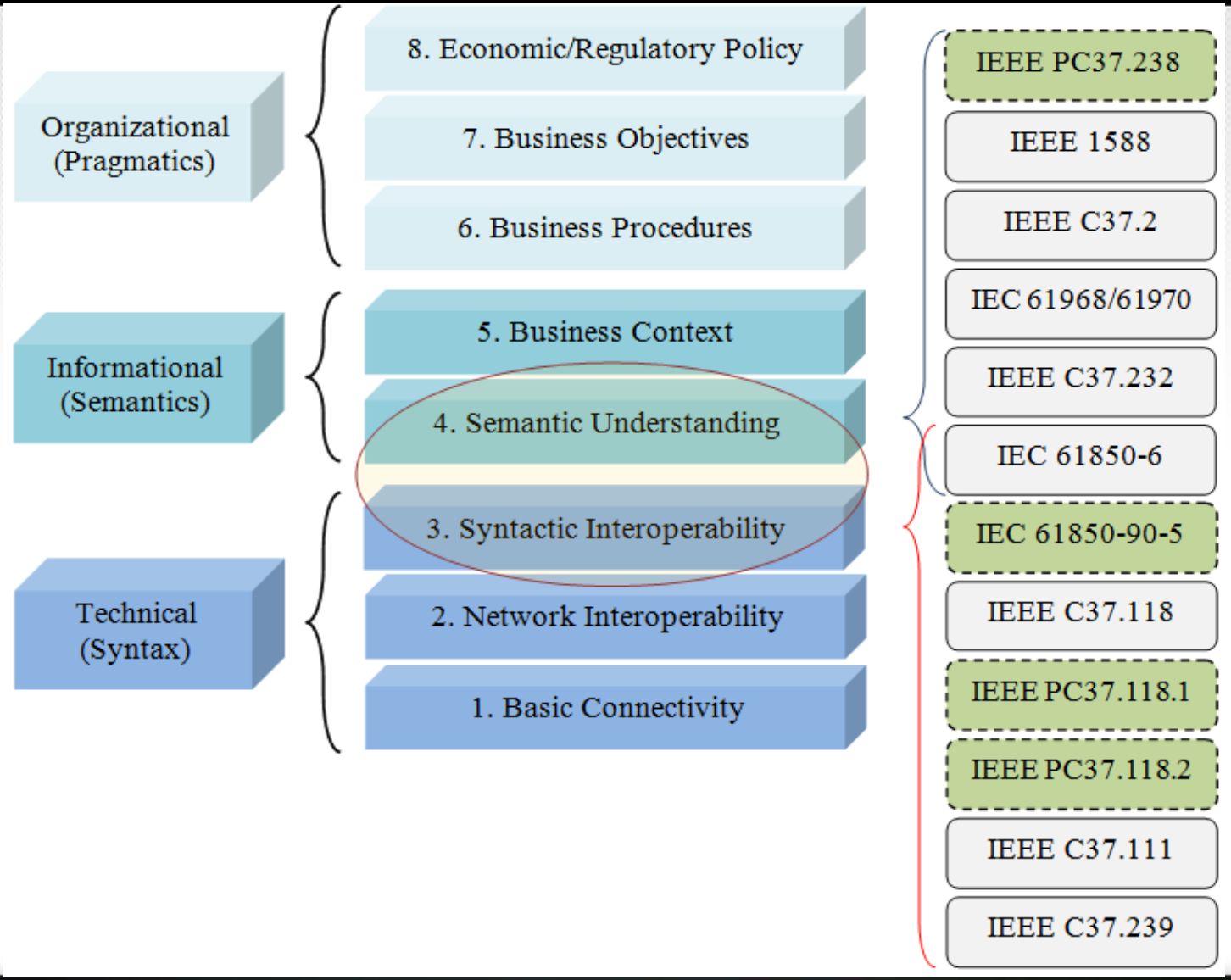


Synchrophasor standards plurality

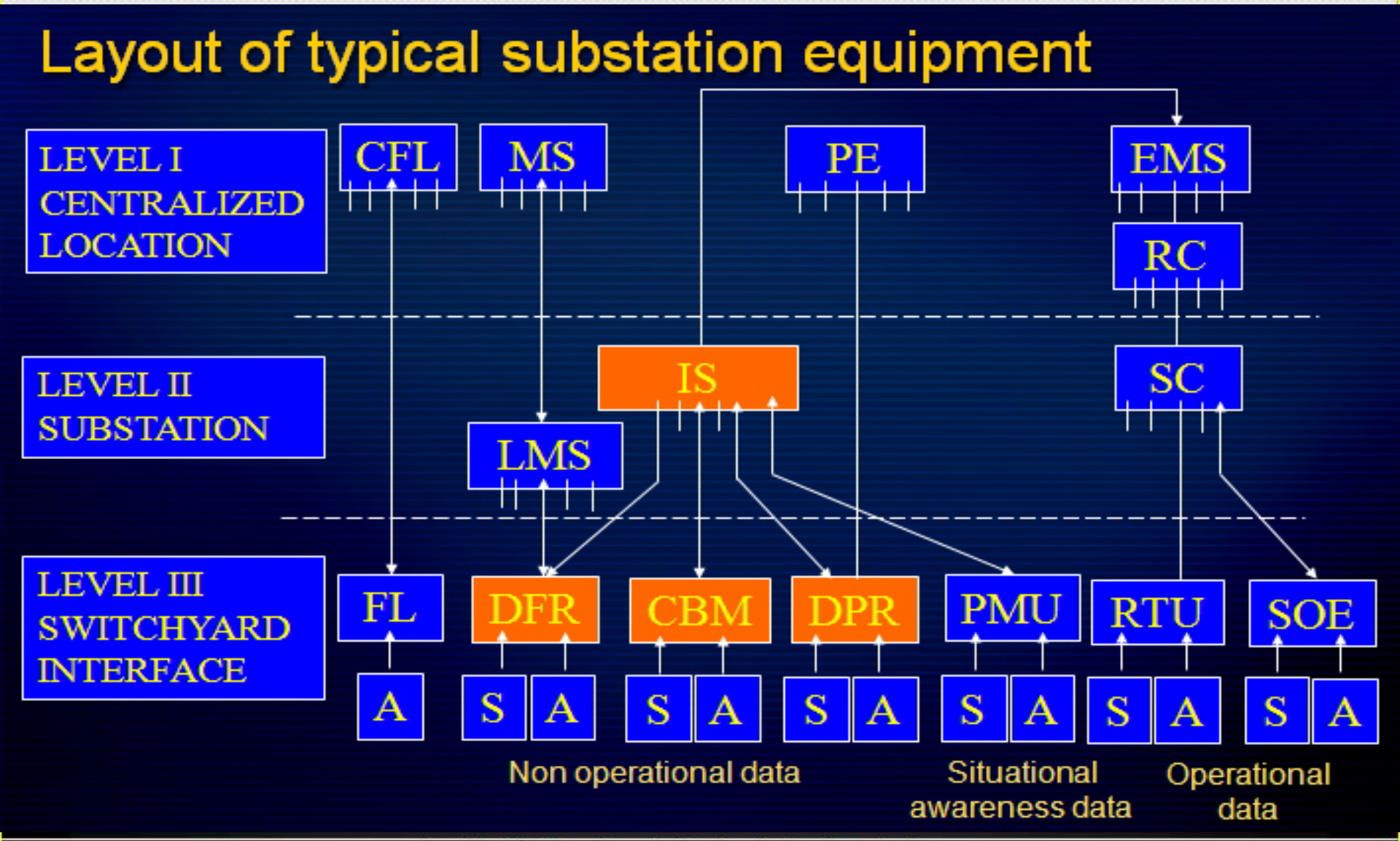


- IEC 61850 (90-5)
- IEC 61970/61968
- IEEE 37.118-2005
- IEEE 37.111-1999
- IEEE 37.232-2007
- IEEE 37. 239-2010
- IEEE 37.238-2011
- IEEE 37.118.1-2012
- IEEE 37.118.2-2012
- IEEE 37. 242-2012
- IEEE 37.244-2012
- NERC CIP 2-7

Synchrophasor Standards gaps



Automated data analytics Standards plurality



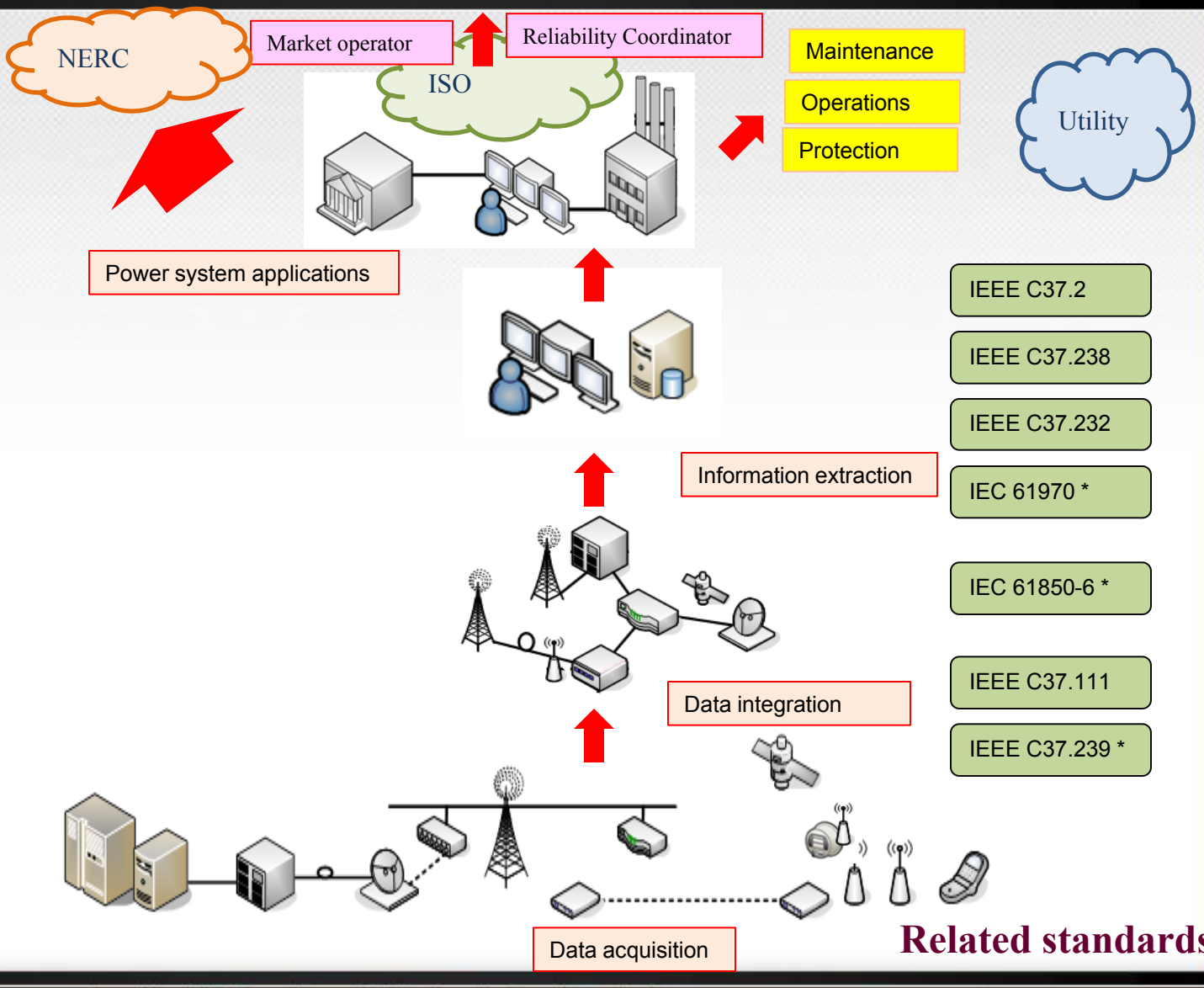
Automated data analytics Standards gaps

Smart Grid Center

TEXAS A&M ENGINEERING TEES

8. Economic/Regulatory Policy
7. Business Objectives
6. Business Procedures
5. Business Context
4. Semantic Understanding
3. Syntactic Interoperability
2. Network Interoperability
1. Basic Connectivity

GWAC Stack



Related standards

- IEEE C37.2
- IEEE C37.238
- IEEE C37.232
- IEC 61970 *
- IEC 61850-6 *
- IEEE C37.111
- IEEE C37.239 *

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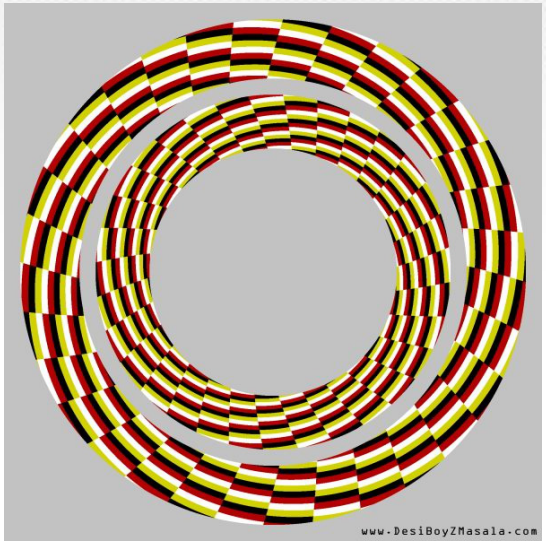

Who brought it up

What it entails

When it matters

→ Where it makes difference

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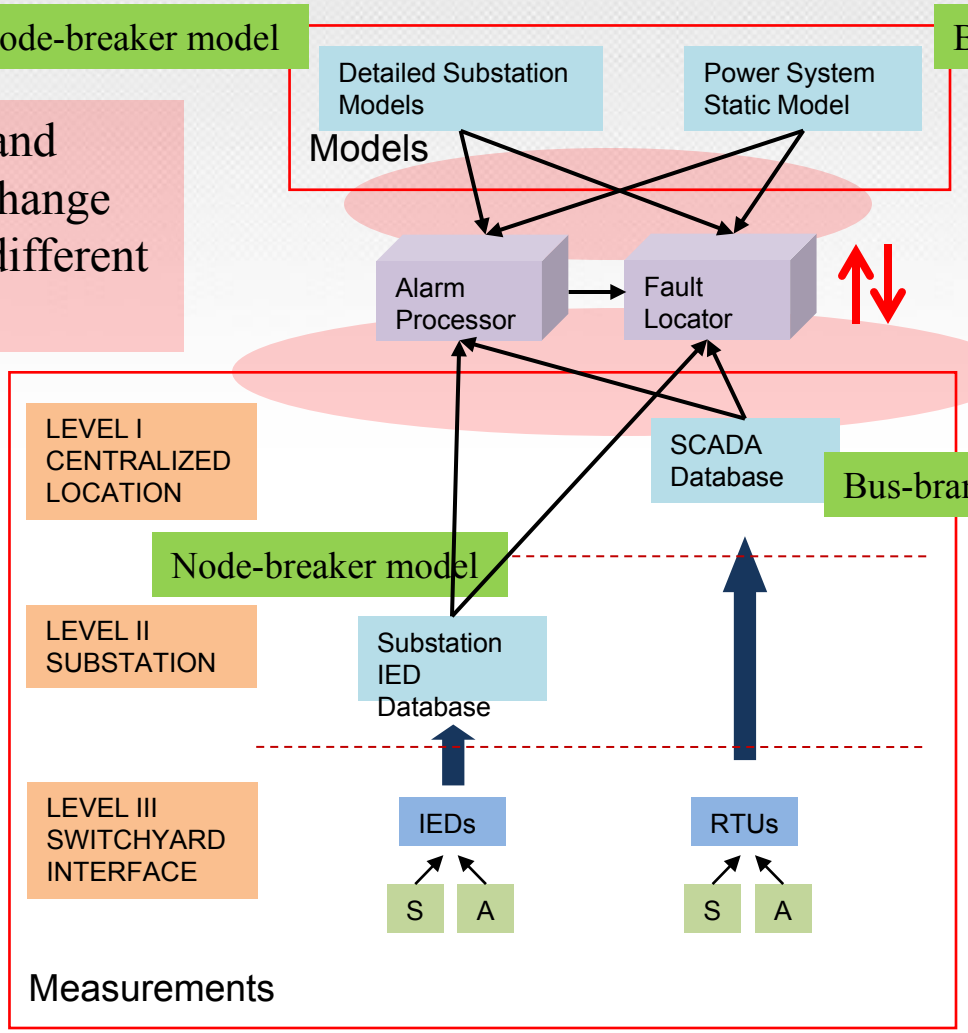
How it impacts research

Where it makes difference?

- Automated Data Analytics Example:
  - Envisioning new applications
  - Implementing new solutions
  - Achieving cost-benefit goals
  - Allowing future developments

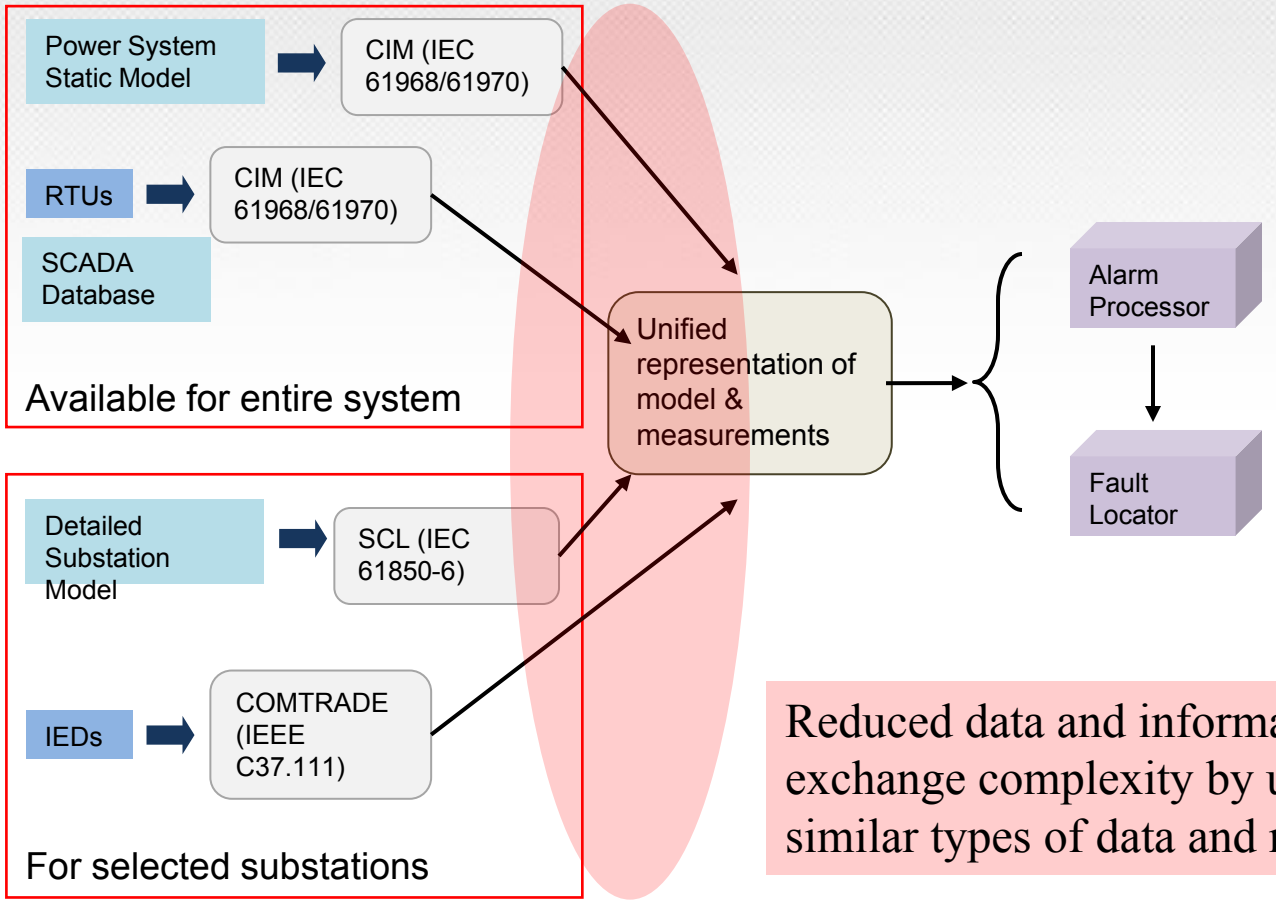
Alarm Processing & Fault Location

Too many data and information exchange needs between different types of models



Correlation required between nomenclature of different formats

Proposed Solution

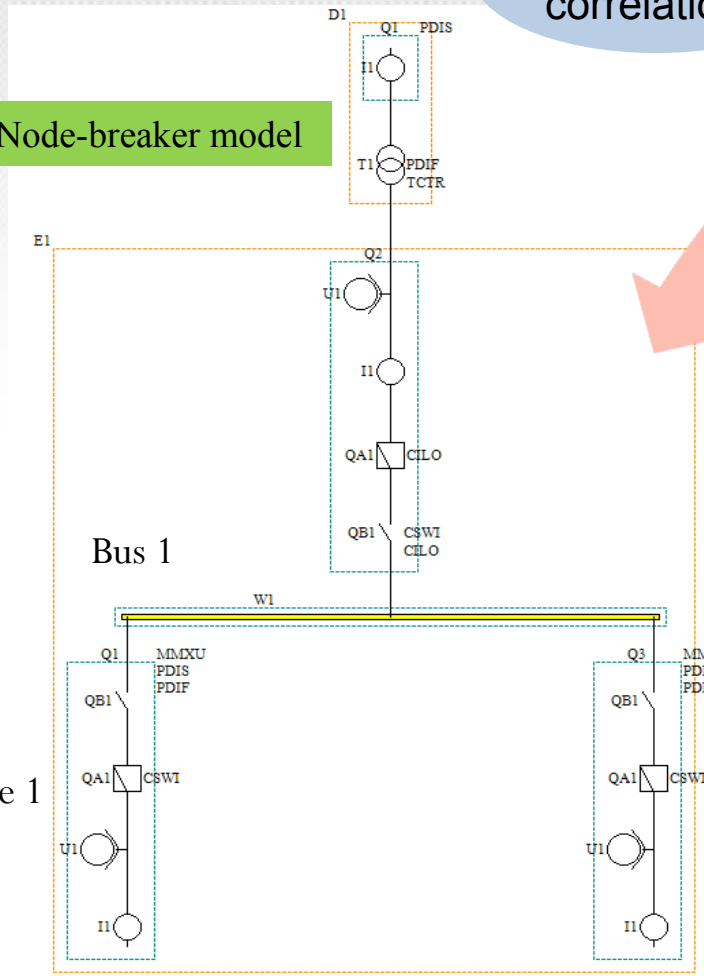


Reduced data and information exchange complexity by using similar types of data and model

Cost-effective solution

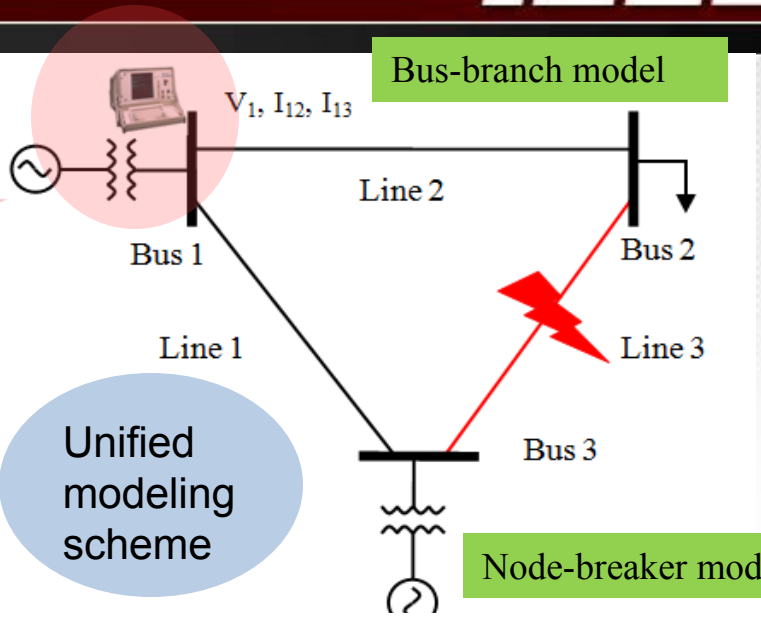
CIM-SCL correlation

Node-breaker model



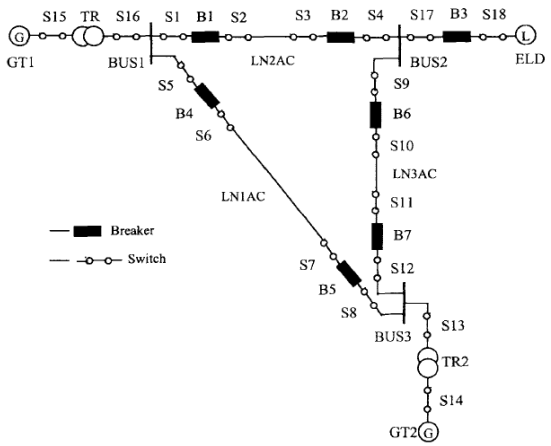
Substation Diagram from SCL

Bus-branch model



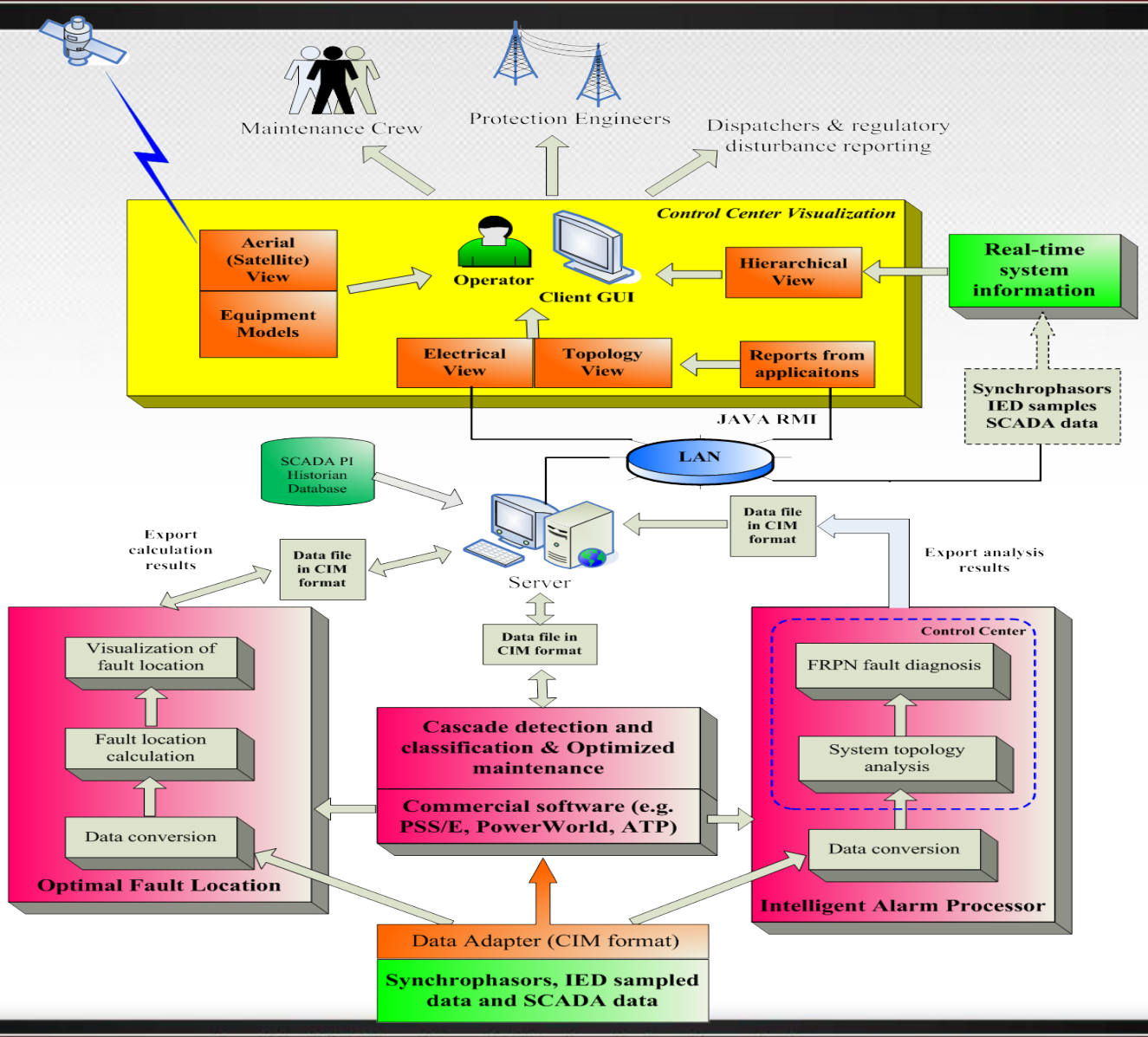
Unified modeling scheme

Node-breaker model

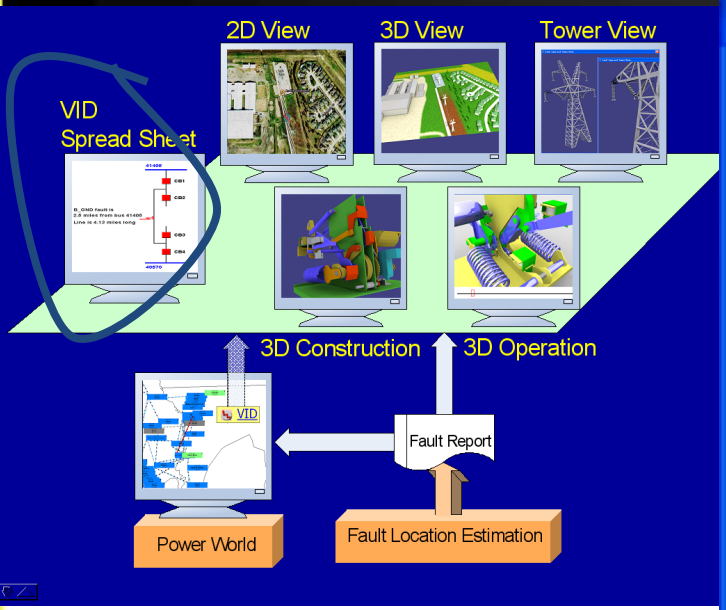


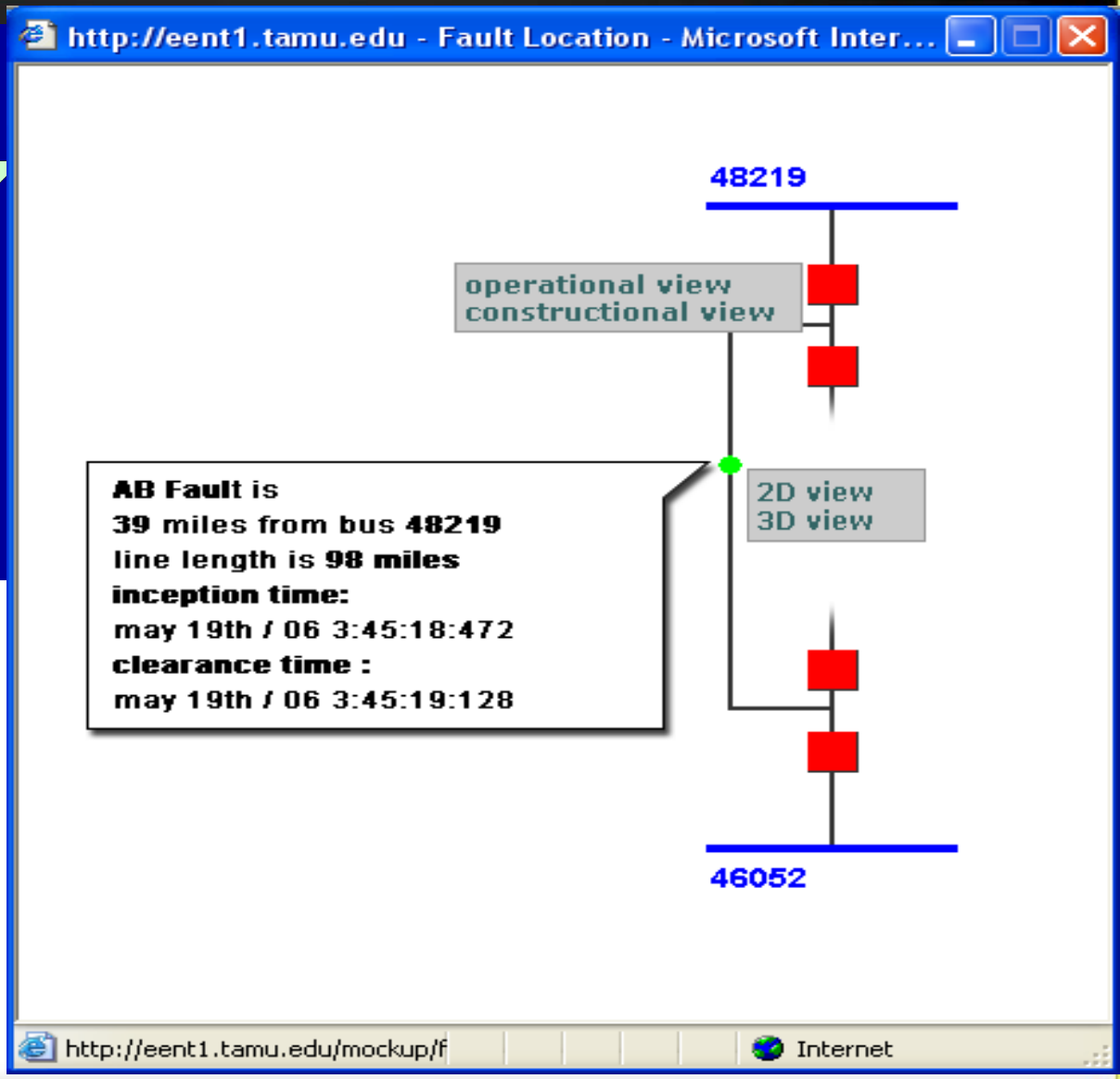
3 bus power system network

System Architecture

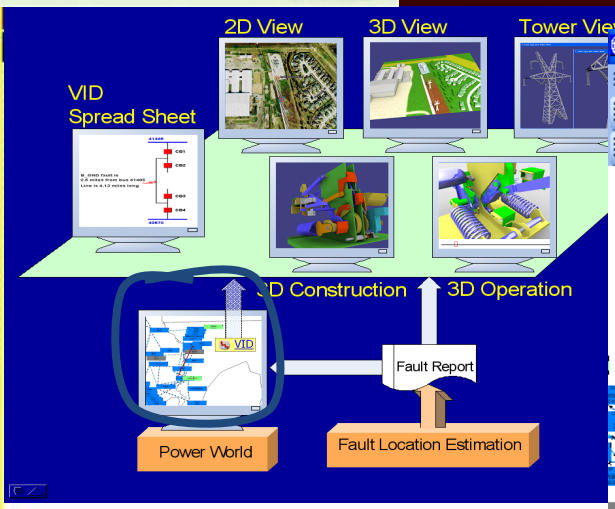


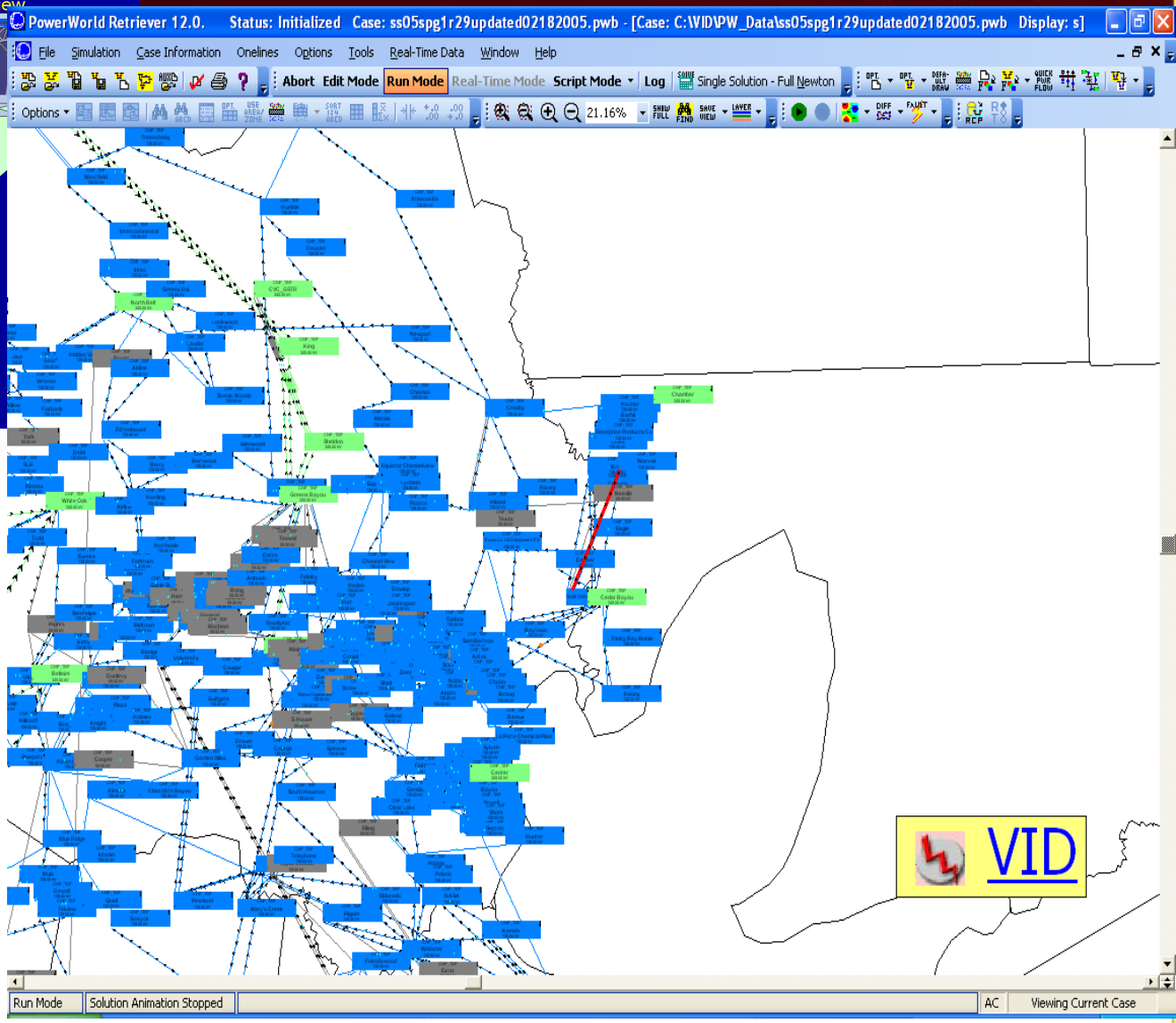
Operators



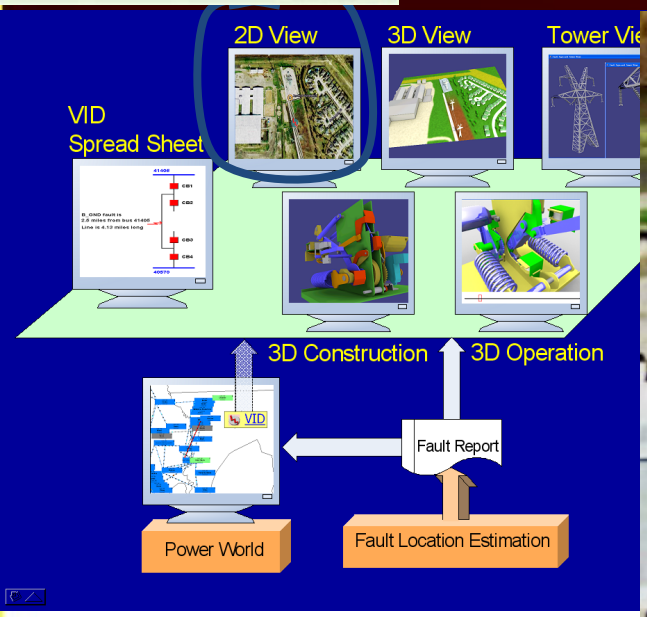


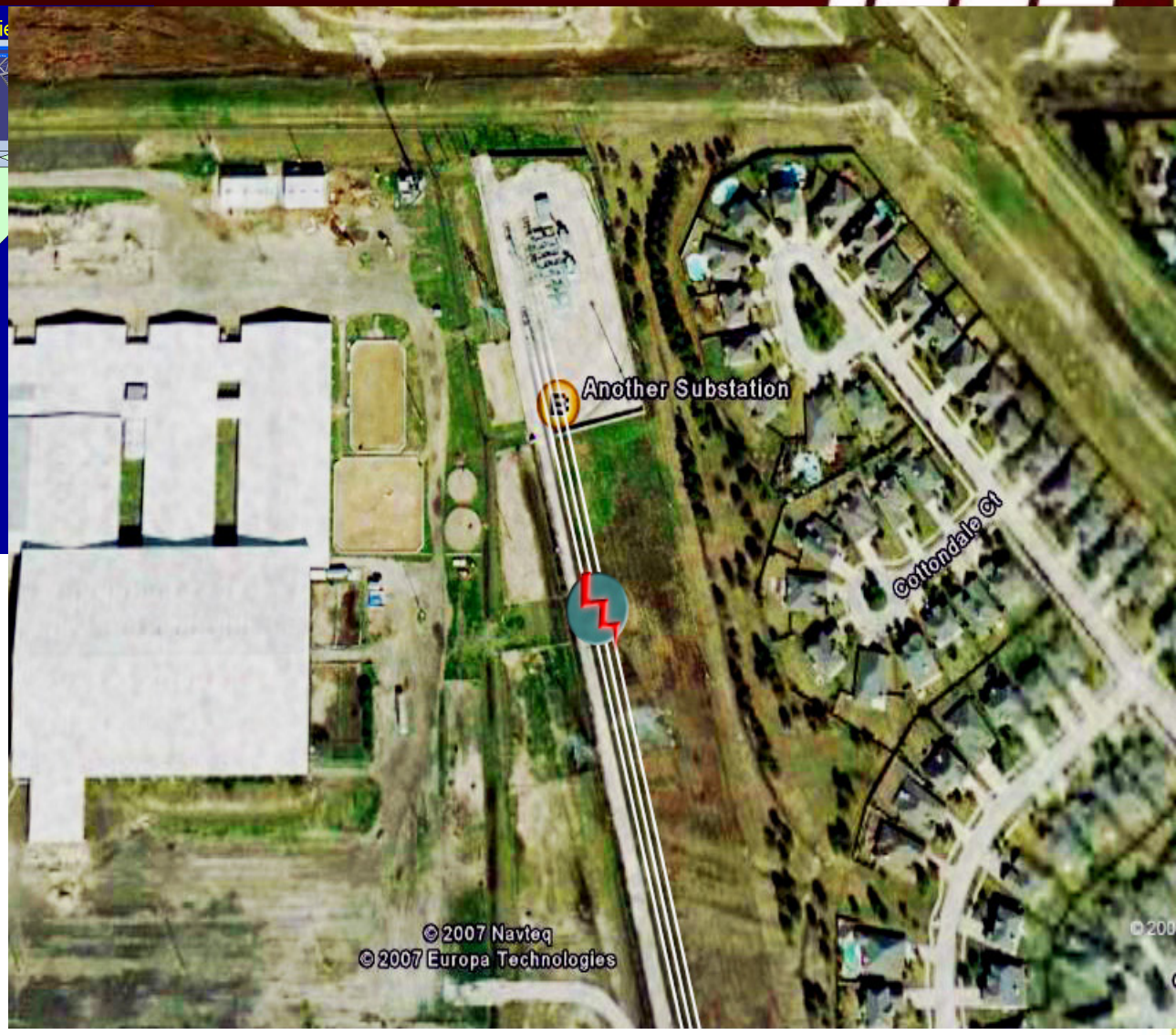
Fault Indication



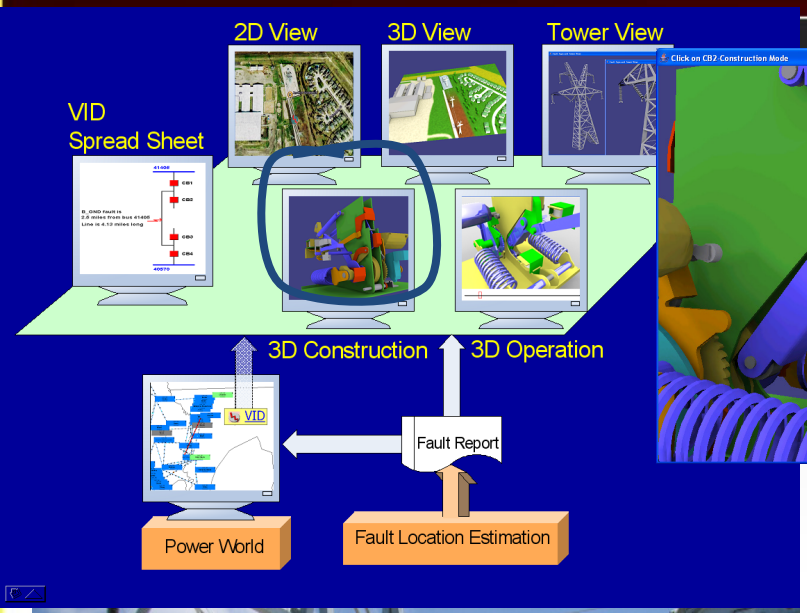


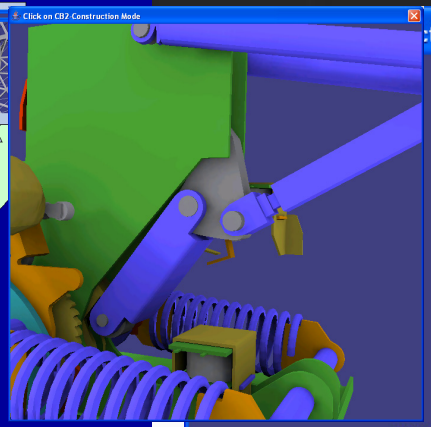
2D Satellite Image





CB Construction View





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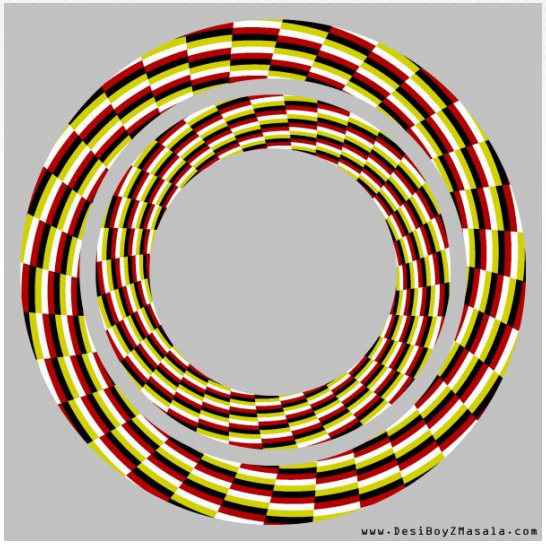


Who brought it up

What it entails

When it matters

Where it makes difference

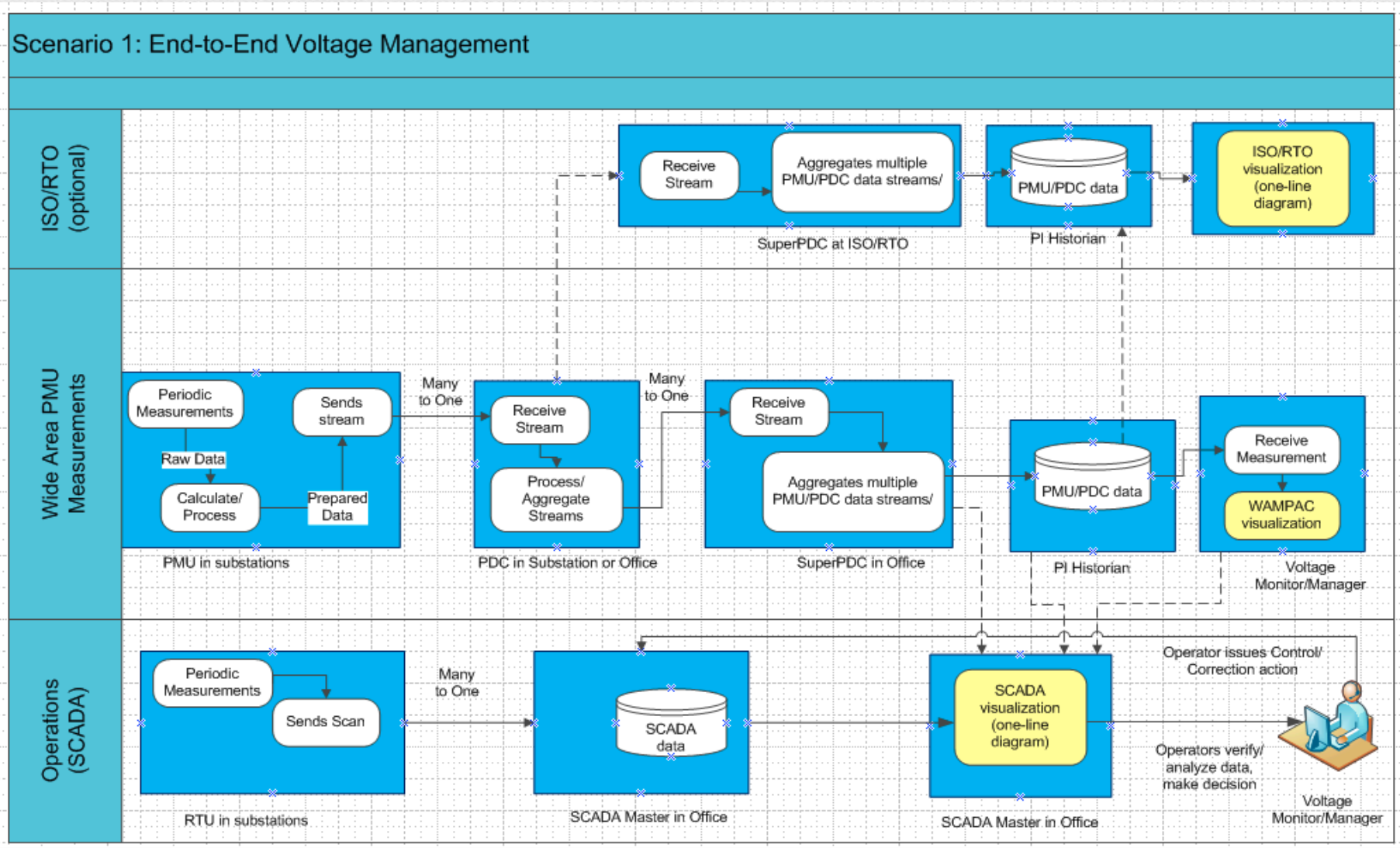
Why to be concerned

How it impacts research

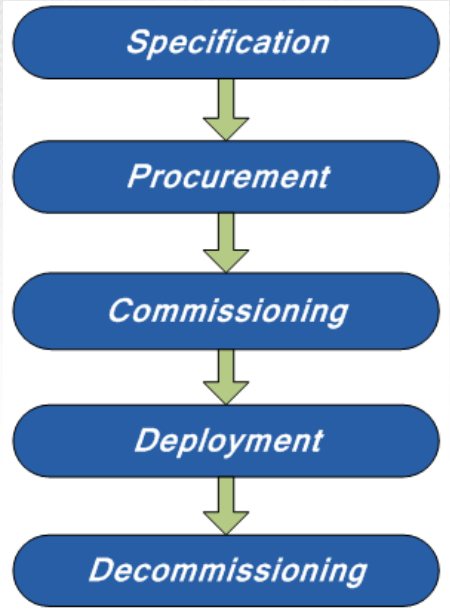
Why to be concerned?

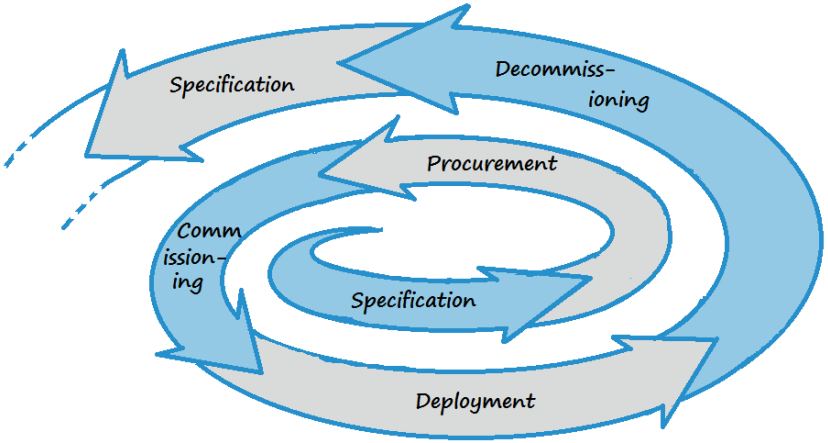
- Synchrophasor system solution example:
  - Standards non-compliance creates viability issues
  - Standards interoperability gaps inhibit effective implementation
  - Research results are not easy to validate and demonstrate

Voltage measurement



System evolution





Products tested

- PMU and PMU-enabled IED
- PDC
- Time Synchronization devices

PMU and PMU-enabled IED	SEL 421x2, SEL 351, GE N60, ABB RES 521, SIMENS R, USI 2002, AMETEK, NI PMU
PDC	GPA OpenPDC, SEL 3373, EPG ePDC
Time Synchronization	Symmetricom Xli, RuggedCom 2288 AREVA P594, Hopf 6875

Conformance Test Results

PMU	Class	Steady State Test									Dynamic State Test								
		Magnitude Variation			Phase Angle Variation			Frequency Variation			Measurement Bandwidth			Frequency Ramp			Step Change		
		TVE	FE	RFE	TVE	FE	RFE	TVE	FE	RFE	TVE	FE	RFE	TVE	FE	RFE	RT	DT	MO
A	P	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	F	F	F
	M	S	S	S	S	S	S	F	S	S	S	F	S	F	F	F	S	F	F
A-1*	P	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	F	S	F
	M	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	S	S	F
B	P	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	S	F	S
	M	S	S	S	S	S	S	S	S	S	F	F	S	F	F	F	S	F	S
C	P	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	S	S	S
	M	S	S	S	S	S	S	S	S	S	S	S	S	F	F	F	S	S	S
D	P	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	F	F	F
	M	S	S	S	S	S	S	S	S	S	F	F	S	F	F	F	S	F	F
E	P	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	F	S	F
	M	S	S	S	S	S	S	F	S	F	F	F	S	S	F	F	S	S	F
F	P	S	S	S	S	S	S	F	S	S	S	F	S	F	F	F	S	S	S
	M	S	S	S	S	S	S	F	S	S	F	F	S	F	F	F	S	S	S
G	P	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	F	S	F
	M	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	S	S	F
H	P	S	F	S	S	F	S	S	F	S	S	S	S	S	F	F	S	S	S
	M	S	F	S	S	F	S	S	F	S	S	S	S	S	F	F	S	S	S

*PMU A-1 is an upgraded firmware of PMU A. P: Class P; M: Class M.
TVE: total vector error; FE: frequency error; RFE: rate of change of frequency error;
RT: response time; DT: delay time; MO: maximum over/under shoot
S stands for “Satisfied”; F stands for “Failed”.

Interoperability Test Results

Interoperability test between PMUs and Time Synchronization Options

Device		Clock A				Clock B				Clock C				Clock D			
		C1	C2	C3	C4	C1	C2	C3	C4	C1	C2	C3	C4	C1	C2	C3	C4
PMU A-1	P	S	S	F	F	N	N	N	N	F	F	F	F	S	S	F	F
	M	S	S	F	F					F	F	F	F	S	S	F	F
PMU B	P	N	N	N	N	S	S	F	F	N	N	N	N	N	N	N	N
	M					S	S	F	F								
PMU C	P	S	S	F	F	N	N	N	N	S	S	F	F	S	S	F	F
	M	S	S	S	F					S	S	F	F	S	S	S	F
PMU F	P	S	F	F	F	N	N	N	N	S	F	F	F	S	F	F	F
	M	S	F	F	F					S	F	F	F	S	F	F	F

C1 - C4: Amplitude Variation, Frequency Variation, Modulation, Frequency Ramp.
P: class P; M: class M.
S stands for “Satisfied”; F stands for “Failed”; N stands for “Not Functional”.

Interoperability Test Results

Interoperability test between PMUs and PDCs

	PMU A	PMU A*	PMU B	PMU C	PMU D	PMU E	PMU F	PMU G	PMU H
PDC A	S	S	S	S	S	S	S	S	S
PDC B**	F	F	F	S	S	S	N	S	S
PDC C***	S	S	S	F	F	F	F	F	F

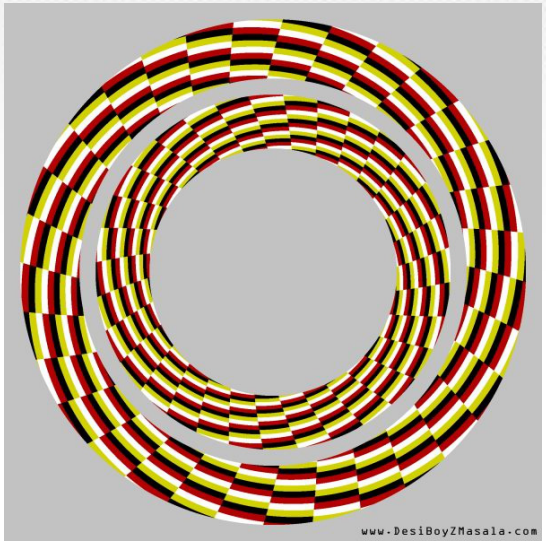
S stands for “Satisfied”; F stands for “Failed”; N stands for “Not Functional”.

* PMU A-1 is an upgraded firmware of PMU A.

** This PDC requires an additional adapter to support serial port communication.

*** This PDC only supports serial port communication, but it has two Ethernet ports available for upgrade to support Ethernet communication

OUTLINE



Who brought it up

What it entails

When it matters

Where it makes difference

Why to be concerned

How it impacts research

How it impacts research?

- The need to understand Interoperability issues creates need for further research
- Lack of Interoperability delays effective integrative research
- The interoperability requirements impact ability to demonstrate research results

Q/A

Together - building a prosperous future

where energy is
clean, abundant, reliable, safe, secure and affordable