22nd ITC Specialist Seminar on Energy Efficient and Green Networking (SSEEGN 2013)
20-22 November 2013, Christchurch, New Zealand

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Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Smart Grids and the Future Electrical Network:

Towards a Smarter, More Reliable and Resilient Power System

Prof. Neville Watson
21 Nov. 2013

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European Smart Grids Initiative

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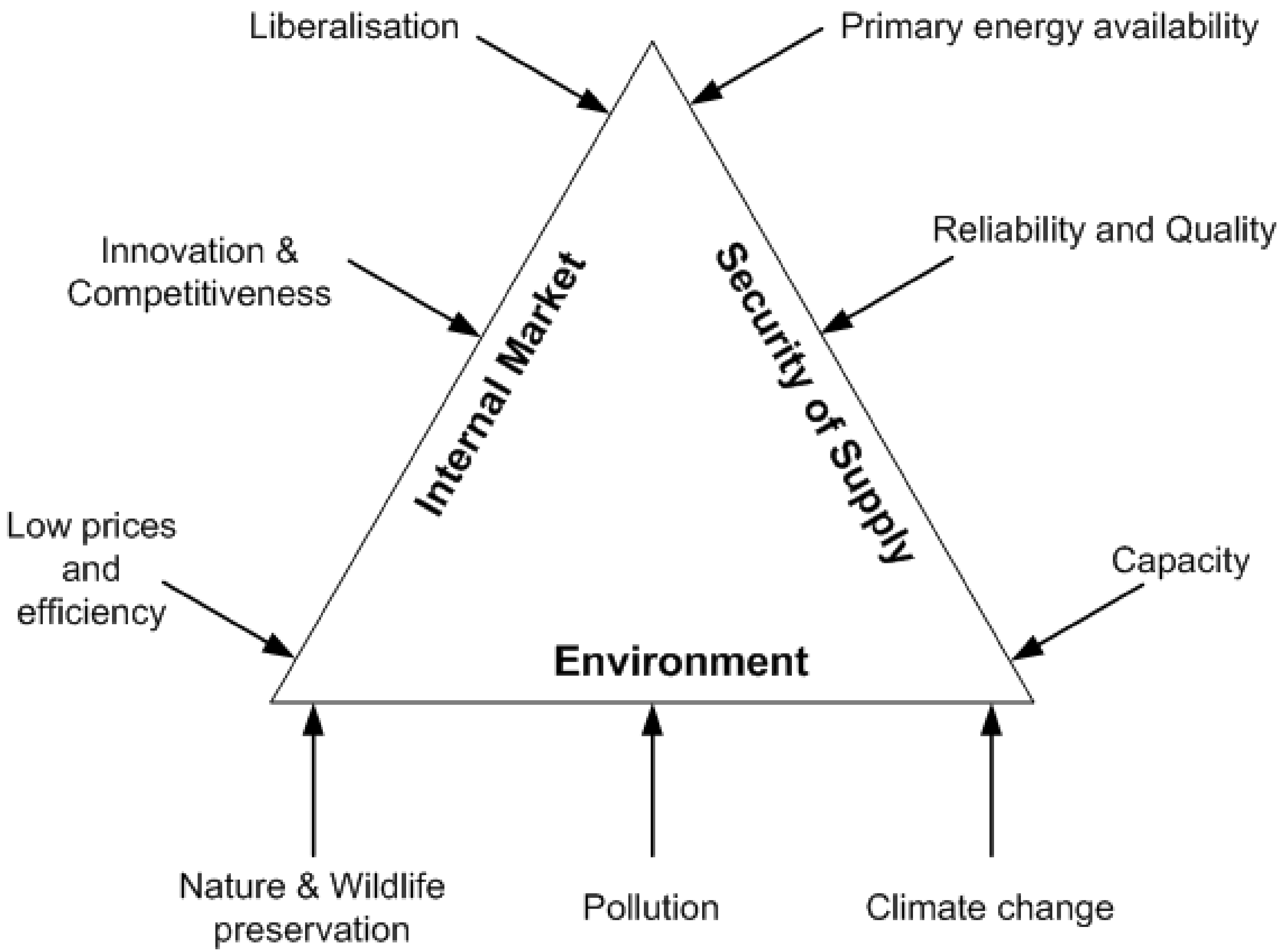

Objectives (USA)

The principal goals of the Smart Grids:

1. Enables active consumer participation
2. Accommodates all generation and storage options
3. Enables new products, services, and markets
4. Provides power quality for the digital economy
5. Optimizes asset utilization and operates efficiently
6. Anticipates and responds to system disturbances
7. Operates resiliently against attack and natural disaster

Smart Grid Overview

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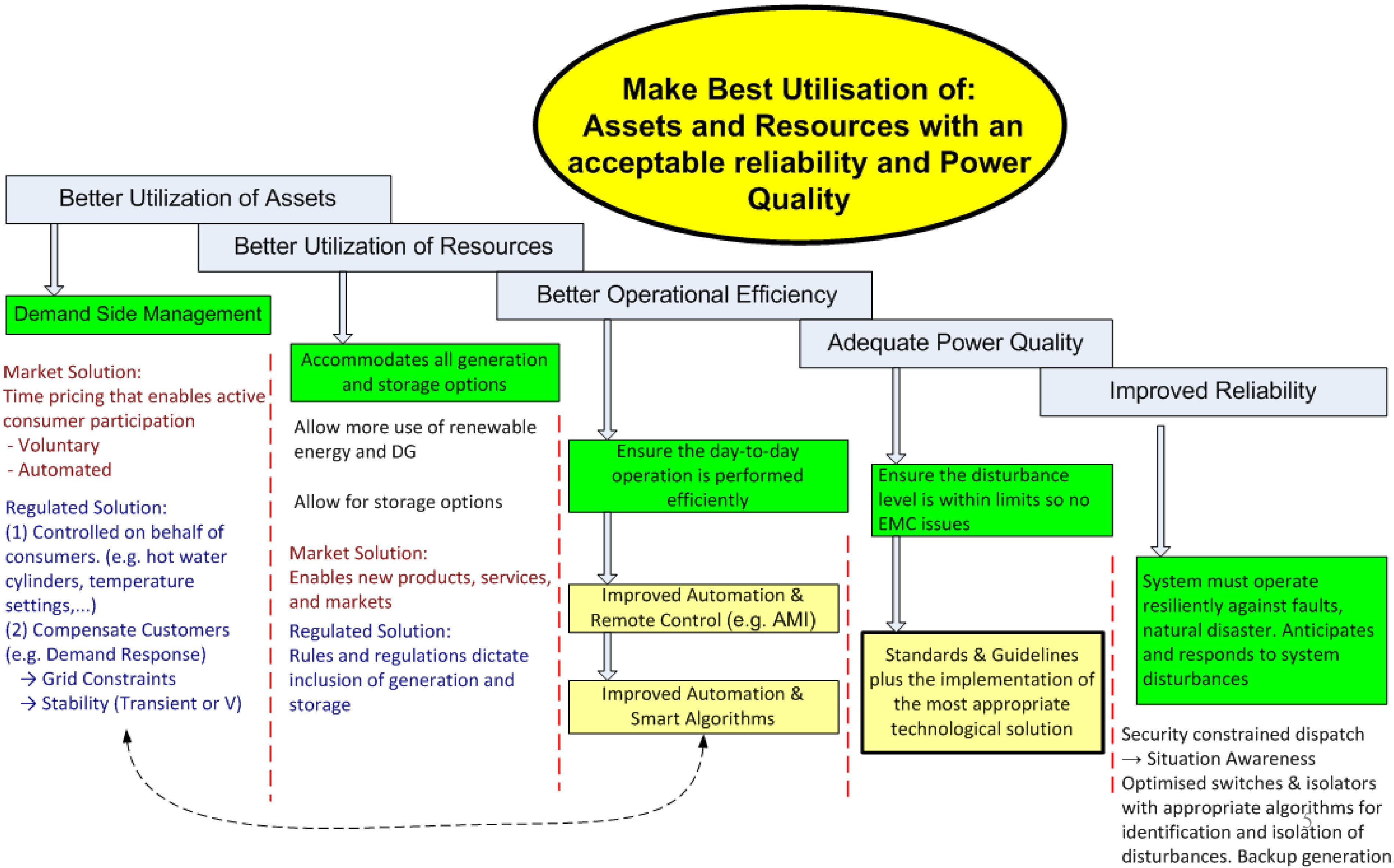

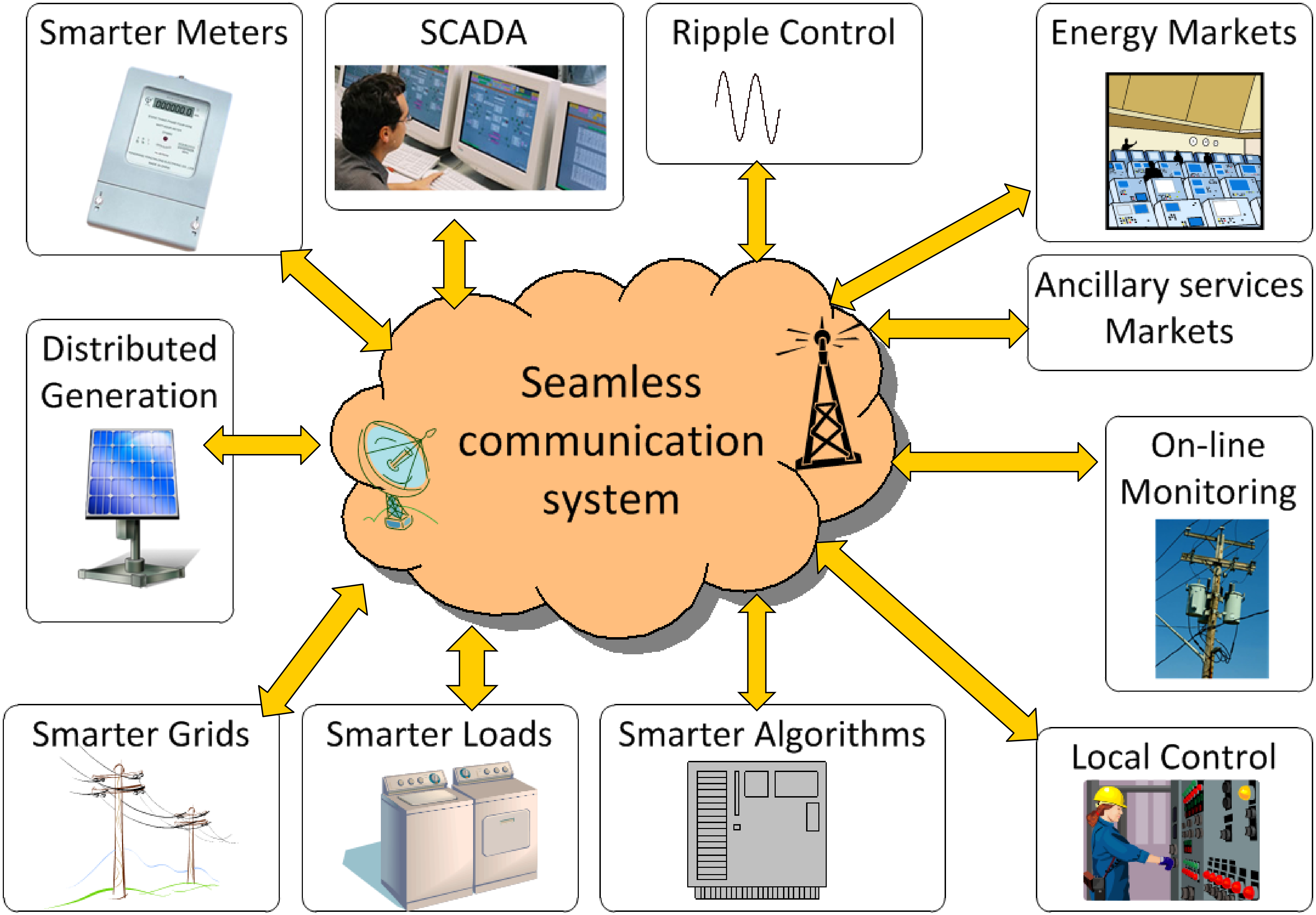
Smarter Meters
SCADA
Ripple Control
Energy Markets
Ancillary services Markets
Distributed Generation
Seamless communication system
On-line Monitoring
Smarter Grids
Smarter Loads
Smarter Algorithms
Local Control

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1. What is a "Smart Grid"?
2. How Smart is the Existing Grid?
3. The Grids of the Future.
4. Smart Grids in a New Zealand Context.

How Smart is the Existing Grid?

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Demand Side Management:

Ripple Control (e.g. Hot Water)

Demand Response – For transmission constraints

Interruptible load - For security of system

Via Pricing – Coincident peak & Capacity Charges

Special Protection Schemes

Run-back schemes – For delaying infrastructure investment

Advanced Metering Infrastructures (AMI)

There are three major elements to the system:

- A “*smart*” meter
- A communications infrastructure
- A meter data management system (MDMS)

EDMI

ELSTER

Arc-Innovations

AMI Considerations

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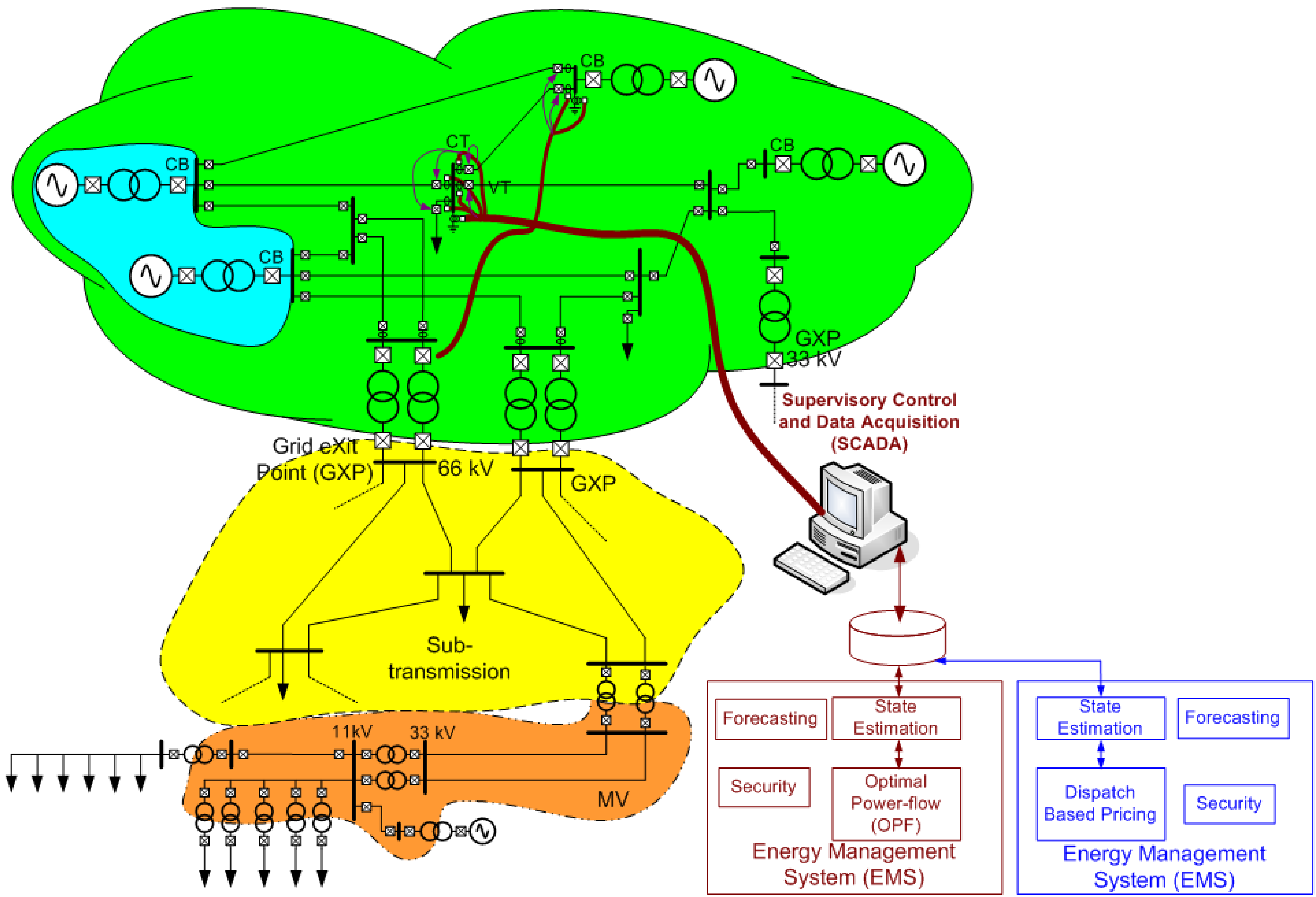
- Accuracy
- Remote readability
- Reliability & Robustness (even with equipment failure)
- Cost effectiveness
- System scalability with no bottlenecks due to number of Customers
- Integration with existing IT.
- Track record and likely longevity of the vendor
- Ability to upgrade and AMI communication infrastructure (mitigating technology obsolescence)


CB
CT
VT
CB
CB
CB
GXP
33 kV
Supervisory Control
and Data Acquisition
(SCADA)
Grid eXit
Point (GXP)
66 kV
GXP
Sub-
transmission
11kV
33 kV
MV
Forecasting
State
Estimation
Security
Optimal
Power-flow
(OPF)
Energy Management
System (EMS)
State
Estimation
Forecasting
Dispatch
Based Pricing
Security
Energy Management
System (EMS)

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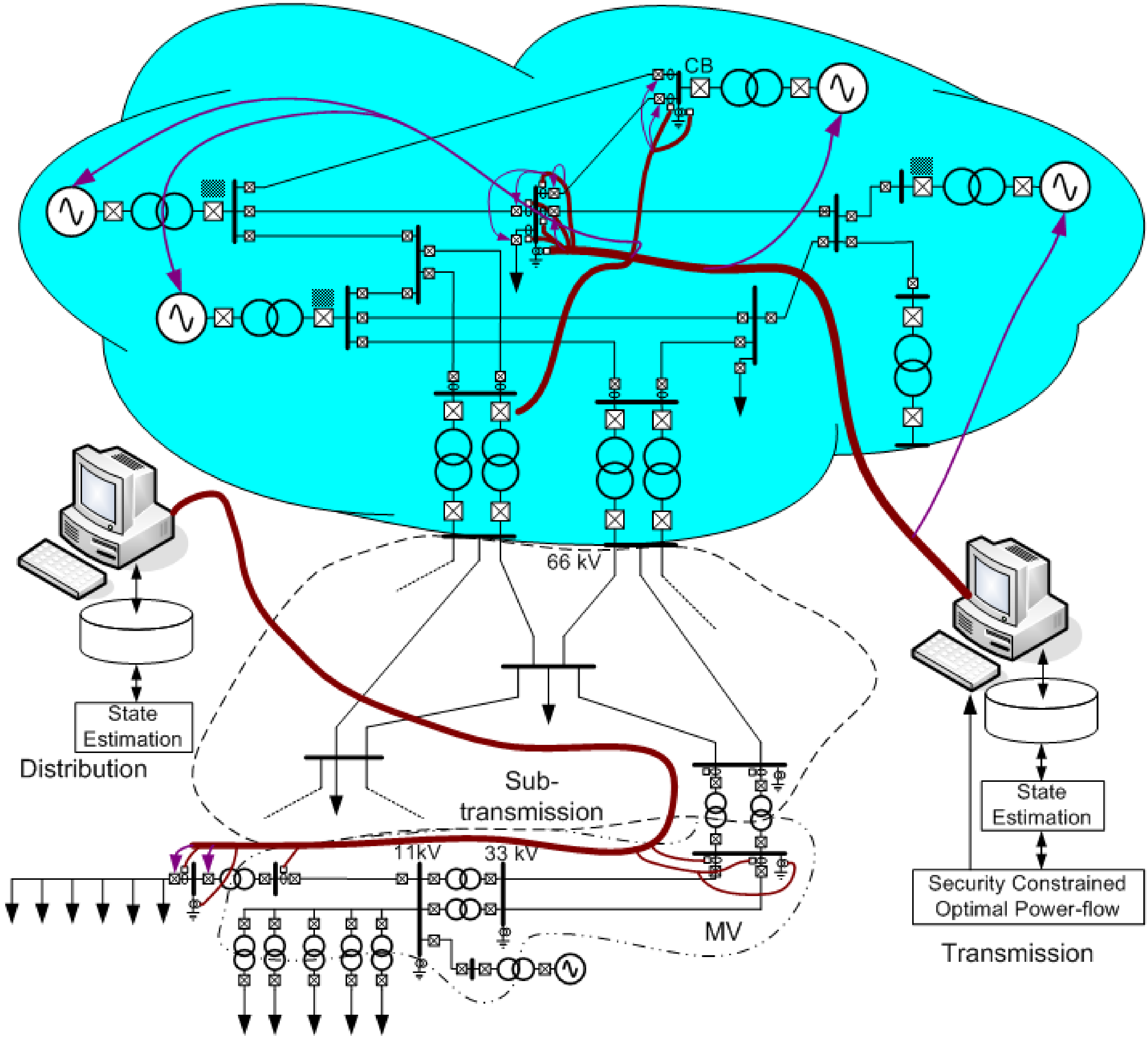
Snow Storm
6 June 2012


CB
66 kV
State
Estimation
Distribution
Sub-
transmission
11kV
33 kV
MV
State
Estimation
Security Constrained
Optimal Power-flow
Transmission


Orion
Orion

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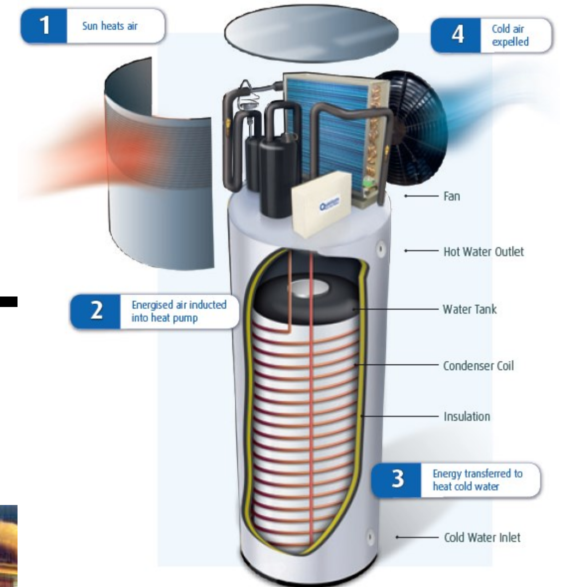
PV USA

Altamont Pass (CA)

Courtesy: Powerhouse W

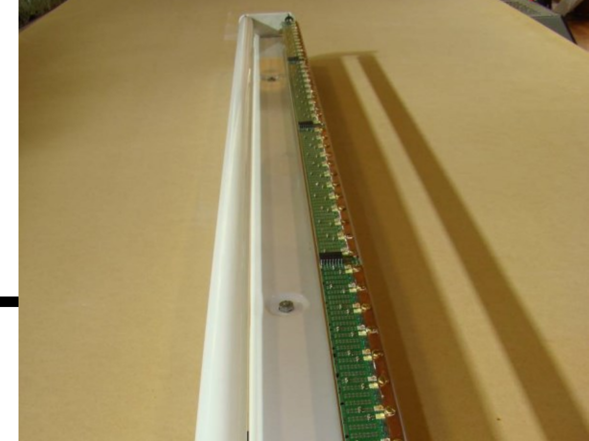

1 Sun heats air
4 Cold air expelled
Fan
Hot Water Outlet
2 Energised air inducted into heat pump
Water Tank
Condenser Coil
Insulation
3 Energy transferred to heat cold water
Cold Water Inlet

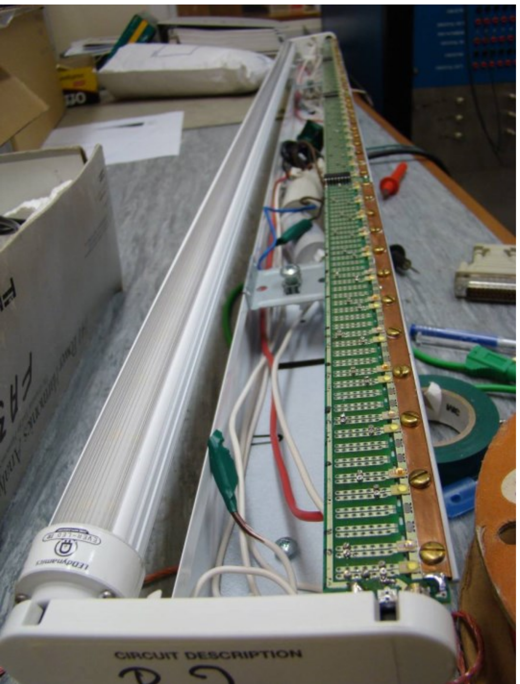

The Press


MiEV
meridian

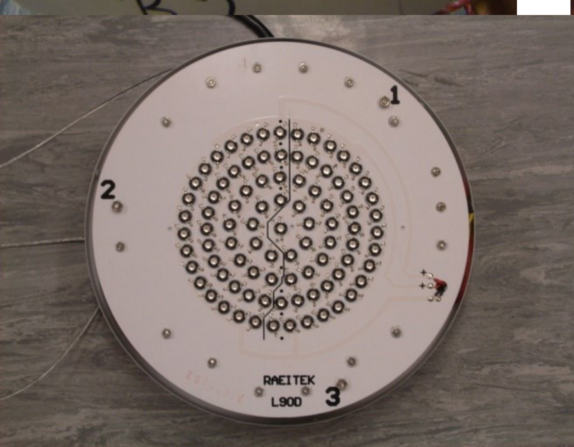

meridian
MiEV
1 MIEV

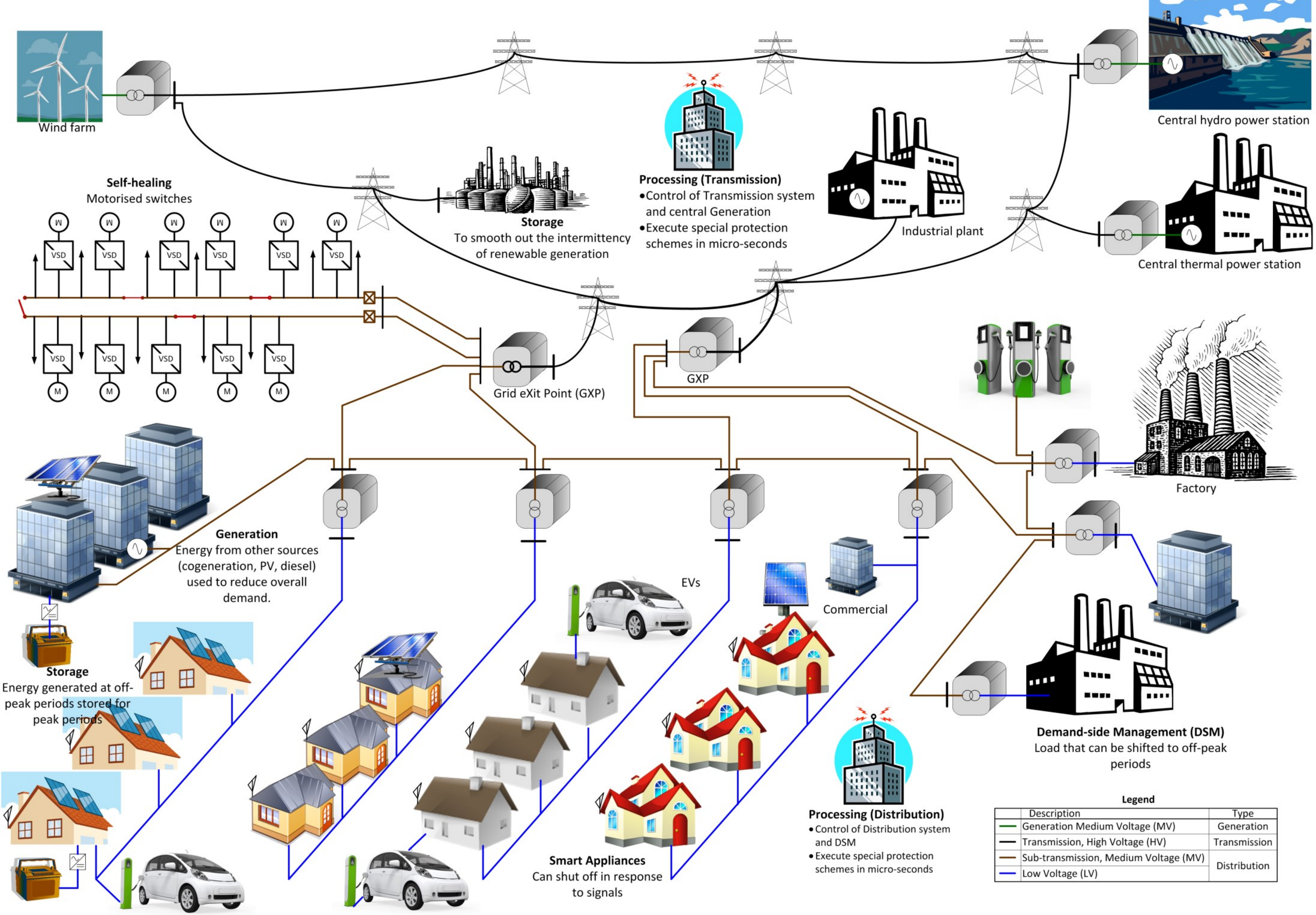

LEDdynamics

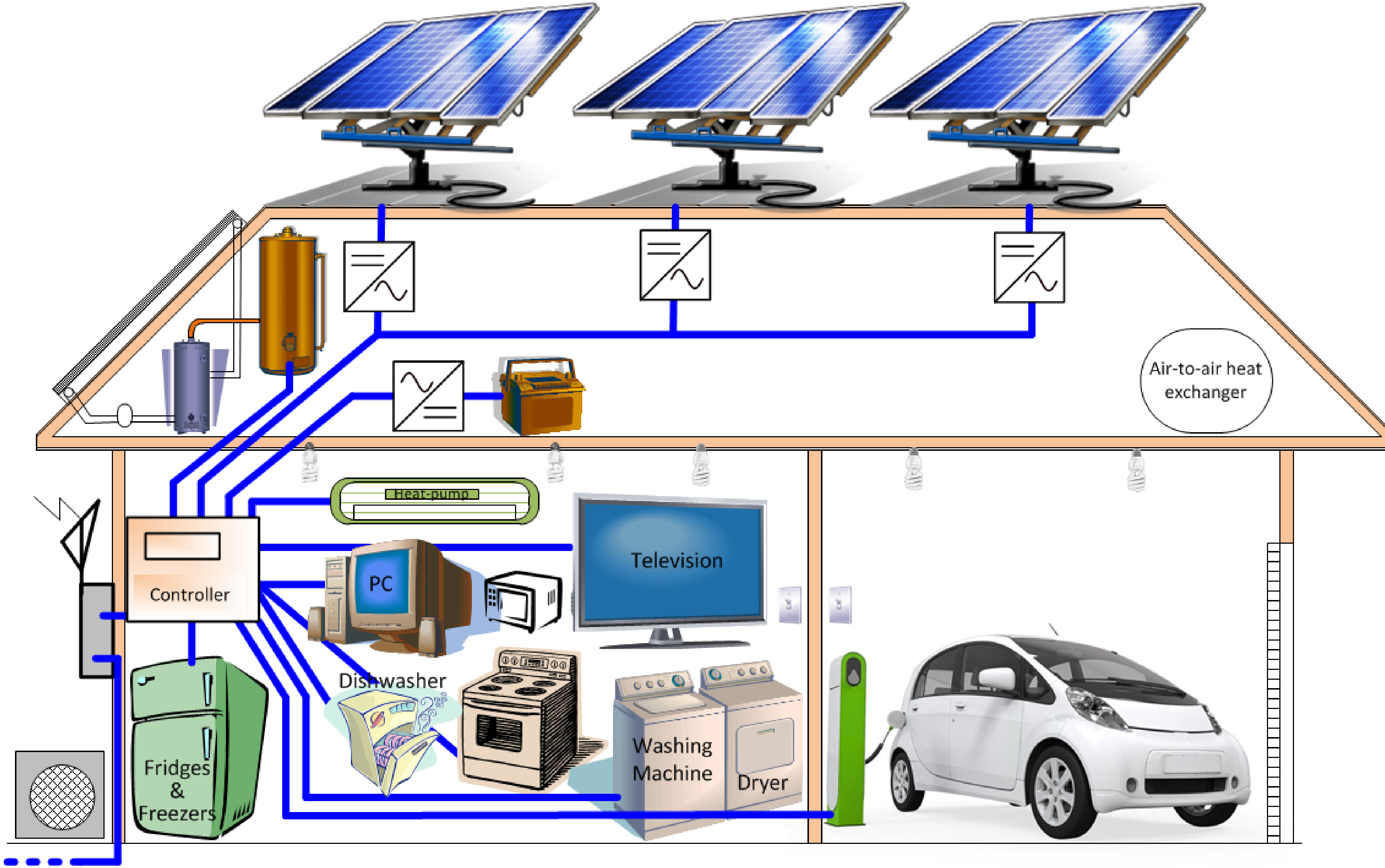


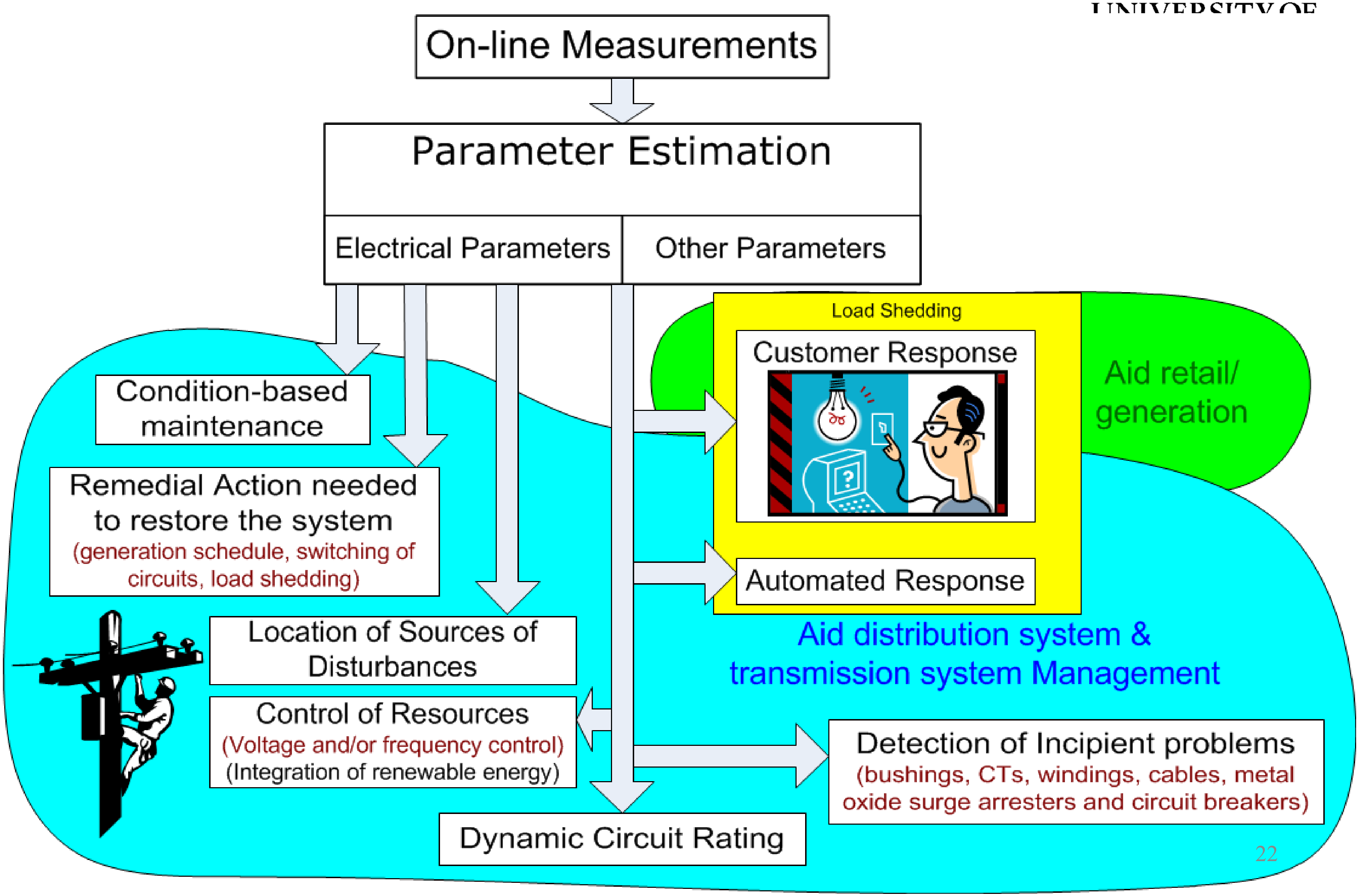

LEDdynamics
CIRCUIT DESCRIPTION


EMERGENCY TRIP
10
11


1
2
3
RAEITEK
L900


Wind farm
Central hydro power station
Processing (Transmission)
•Control of Transmission system and central Generation
•Execute special protection schemes in micro-seconds
Industrial plant
Central thermal power station
Self-healing
Motorised switches
M
VSD
Storage
To smooth out the intermittency of renewable generation
Grid eXit Point (GXP)
GXP
Factory
Generation
Energy from other sources (cogeneration, PV, diesel) used to reduce overall demand.
EVs
Commercial
Storage
Energy generated at off-peak periods stored for peak periods
Smart Appliances
Can shut off in response to signals
Processing (Distribution)
•Control of Distribution system and DSM
•Execute special protection schemes in micro-seconds
Demand-side Management (DSM)
Load that can be shifted to off-peak periods
Legend
Description
Type
Generation Medium Voltage (MV)
Generation
Transmission, High Voltage (HV)
Transmission
Sub-transmission, Medium Voltage (MV)
Low Voltage (LV)
Distribution


Air-to-air heat exchanger
Heat-pump
Controller
PC
Television
Dishwasher
Washing Machine
Dryer
Fridges & Freezers


On-line Measurements
Parameter Estimation
Electrical Parameters
Other Parameters
Condition-based maintenance
Remedial Action needed to restore the system
(generation schedule, switching of circuits, load shedding)
Location of Sources of Disturbances
Control of Resources
(Voltage and/or frequency control)
(Integration of renewable energy)
Dynamic Circuit Rating
Load Shedding
Customer Response
Automated Response
Aid retail/ generation
Aid distribution system & transmission system Management
Detection of Incipient problems
(bushings, CTs, windings, cables, metal oxide surge arresters and circuit breakers)

Grid Management

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1. Centralized dispatch of generation
2. SCADA
3. Ripple Control
4. Distributed Controllers using local information only

- On-Line Monitoring
- Smarter Metering
- Smarter Grids
- Ubiquitous Communication system

Demand Side Management

1) Customer participation (give the customers the information and let them respond). e.g. Time of use metering. → Needs to be automated

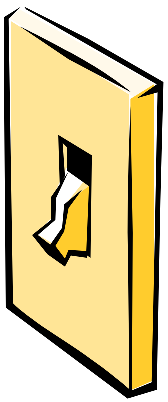
2) Smart algorithms for control in the home/business. Smart algorithm in:

a) the meter (which communicates with the smart appliances).

b) the appliances themselves.

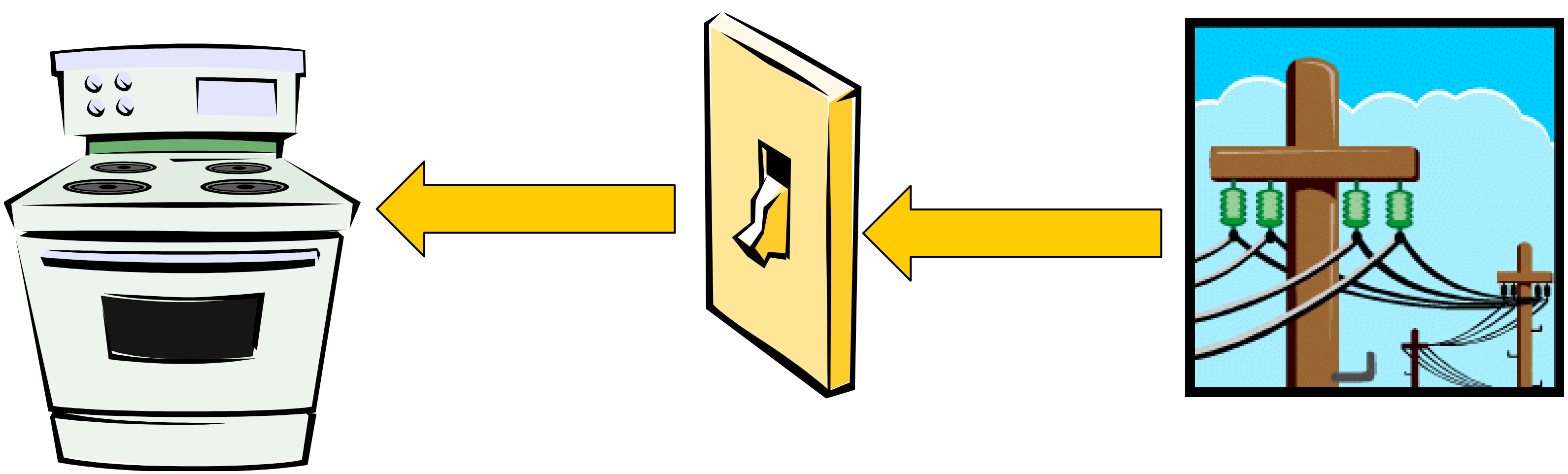
c) home management system.

3) Centrally controlled



Present System

- Presently, any appliance is free to demand power.
- The network has no practical option but to supply, even if it causes an overload of voltage violation.
- Only certain loads can be interrupted to manage demand without customer inconvenience.



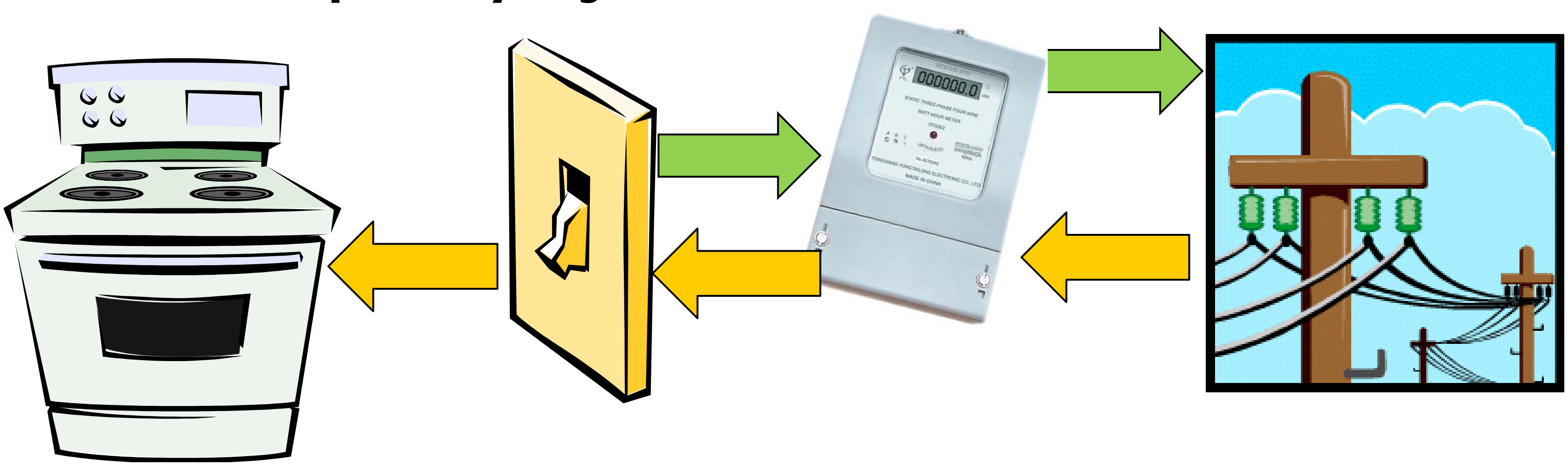
Let’s Assume …

1. Each area continues to evolve logically.
2. General convergence occurs.
3. Platforms emerge *(software, hardware & communications).*
4. These platforms interconnect smoothly.
5. Protocols are not a barrier (*either via suitable Standards or "Protocol Conversion Service Providers"*).

The focus then becomes "Applications"

Agent Based Approach (or Contract Manager)

- Suppose appliances had to **request** power instead.
- The network could respond with its ***terms*** to supply.
- These "*terms*" could vary with time and location, subject to the network's ability to supply.
- Meter becomes a **Contract Manager** ensuring both customer and utility respect the **Contract Terms**.
- Manages requests to the network to exceed supply limits **without penalty** if grid conditions allow.



Same thing next layer up. The local substation also has a "*Contract Manager*" function, to manage its own contract with its neighbours in the grid.

This manages transformer loading and has **its** contract with the *zone* substation supplying it.

And so on, up the line, until the "request to connect" can be either ***satisfied*** or ***denied without penalty***.

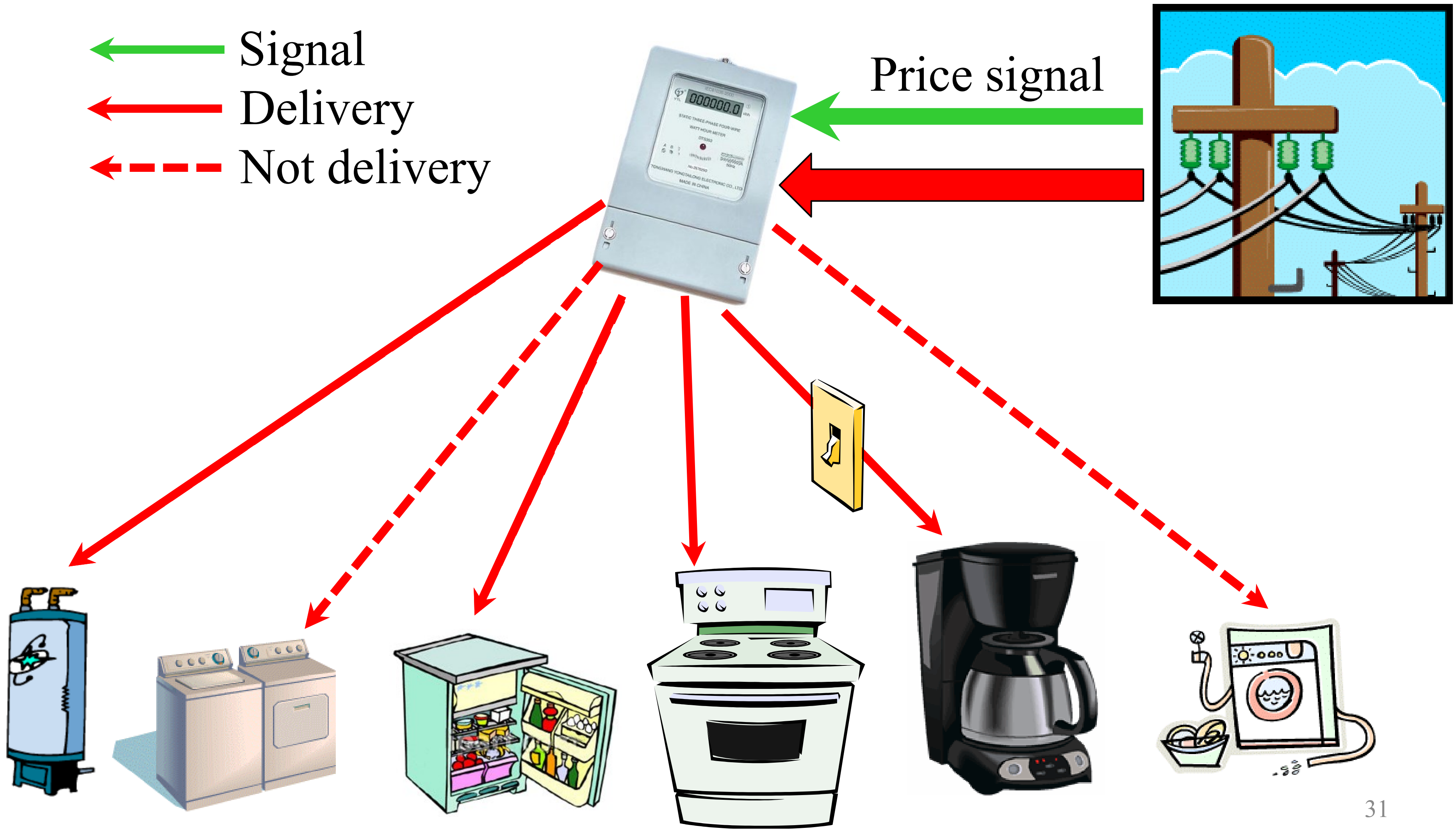
Grid loads manage themselves using customer defined appliance priority to allocate available supply through a "*request to connect*" mechanism.

Self-Managing Grid

- Loads and Generators manage themselves
- Information requested & supplied as needed
- “Central dispatch” function is not required
- Dispatch now becomes highly distributed
- Networks become two-way trading grounds
- Well-defined rules of conduct to participate
- The system manages itself via contracts
- No one is “in charge” (*just like the Internet*)

Smart Meter central

"Smart" algorithm in Meter



“Smart” algorithm in Appliances

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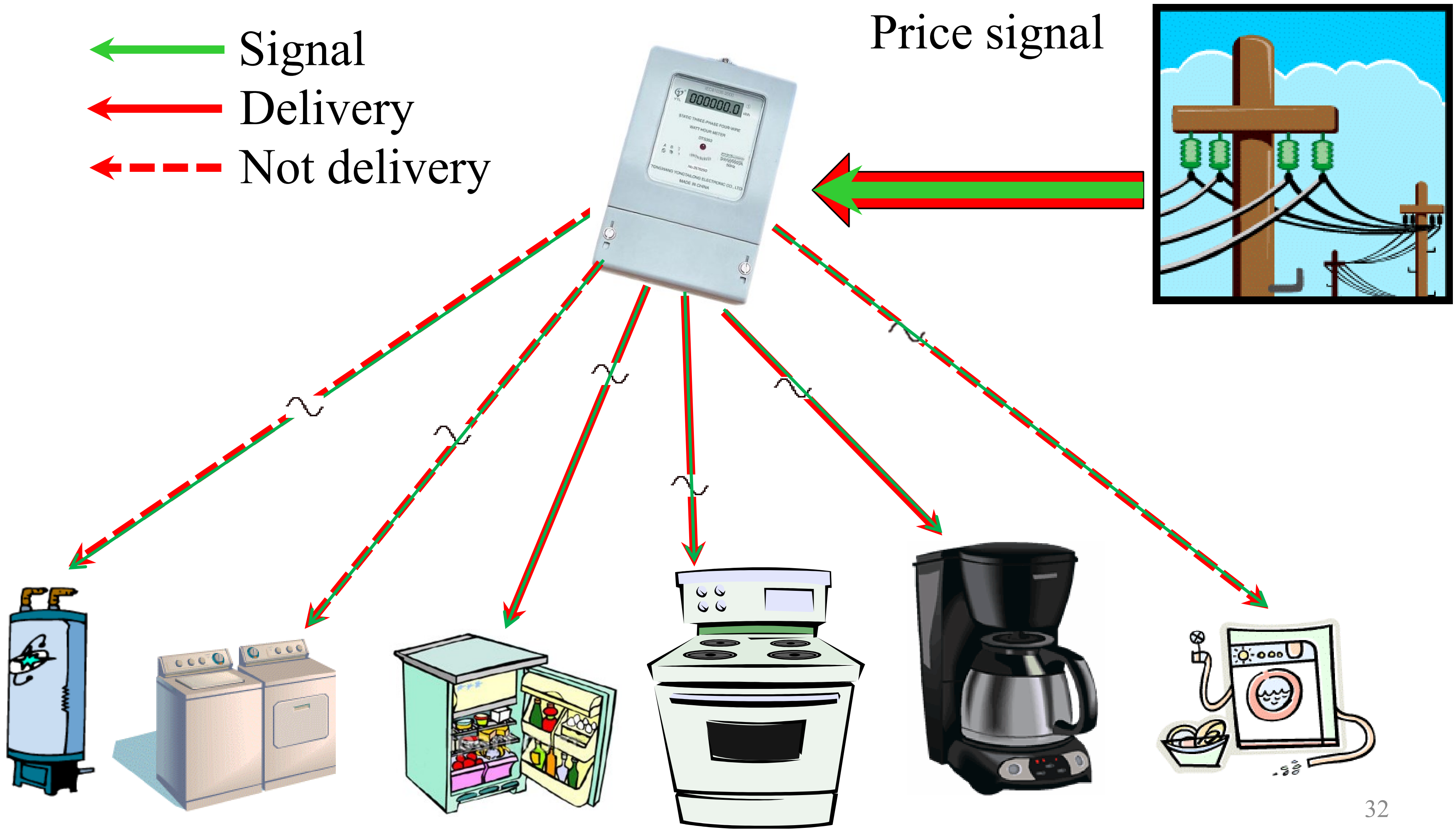

Control of Appliances

Domains

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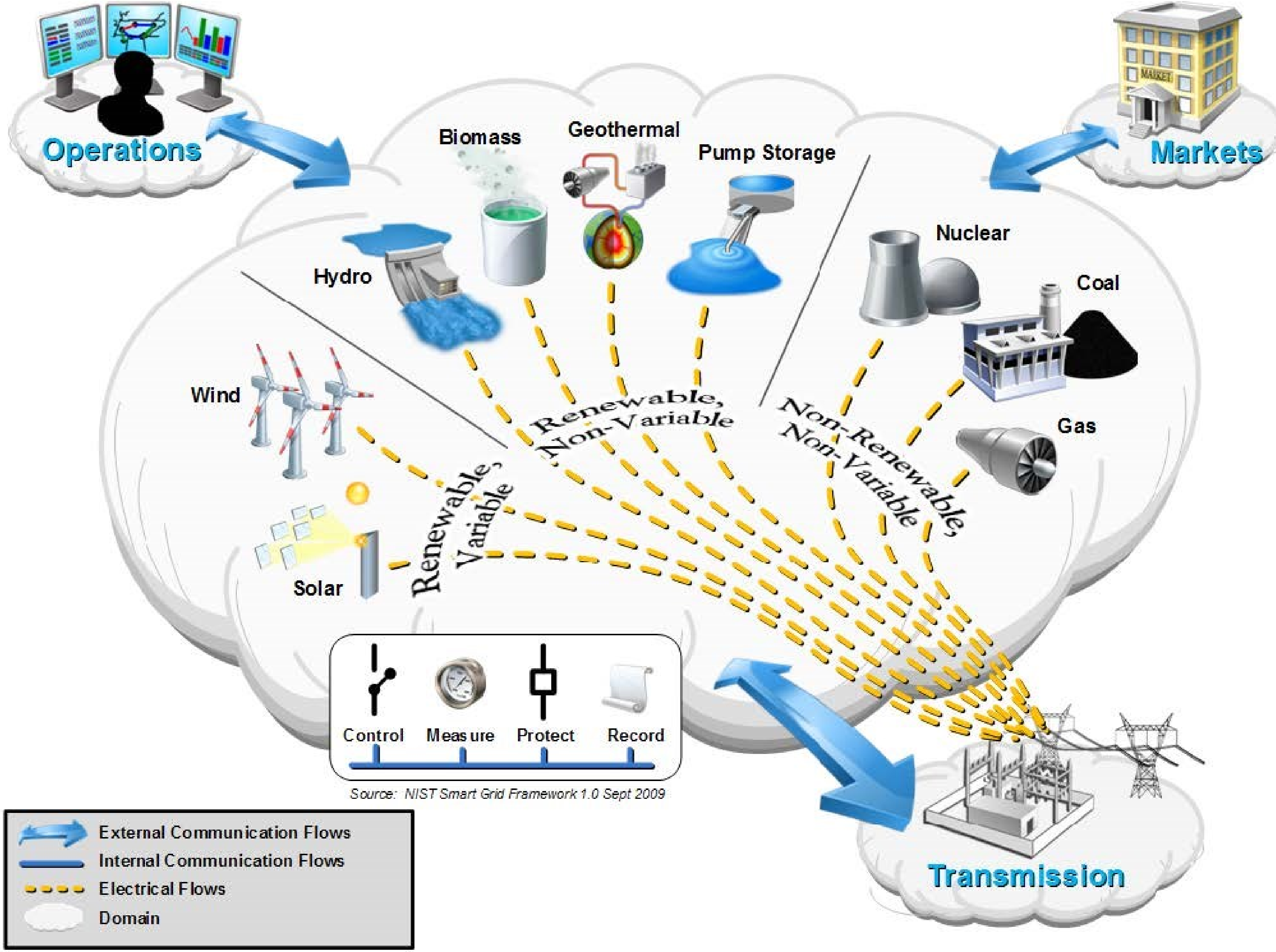
Domain	Description
Bulk Generation	The generators of electricity in bulk quantities
Transmission	The carriers of bulk electricity over long distances
Distribution	The distributors of electricity to and from customers
Customer	The End user of electricity
Operations	The Managers of the movement of electricity
Service Provider	The organizations providing services to the electricity industry
Markets	The Operators and participants in the electricity market

Domains contain many “applications” and “actors”

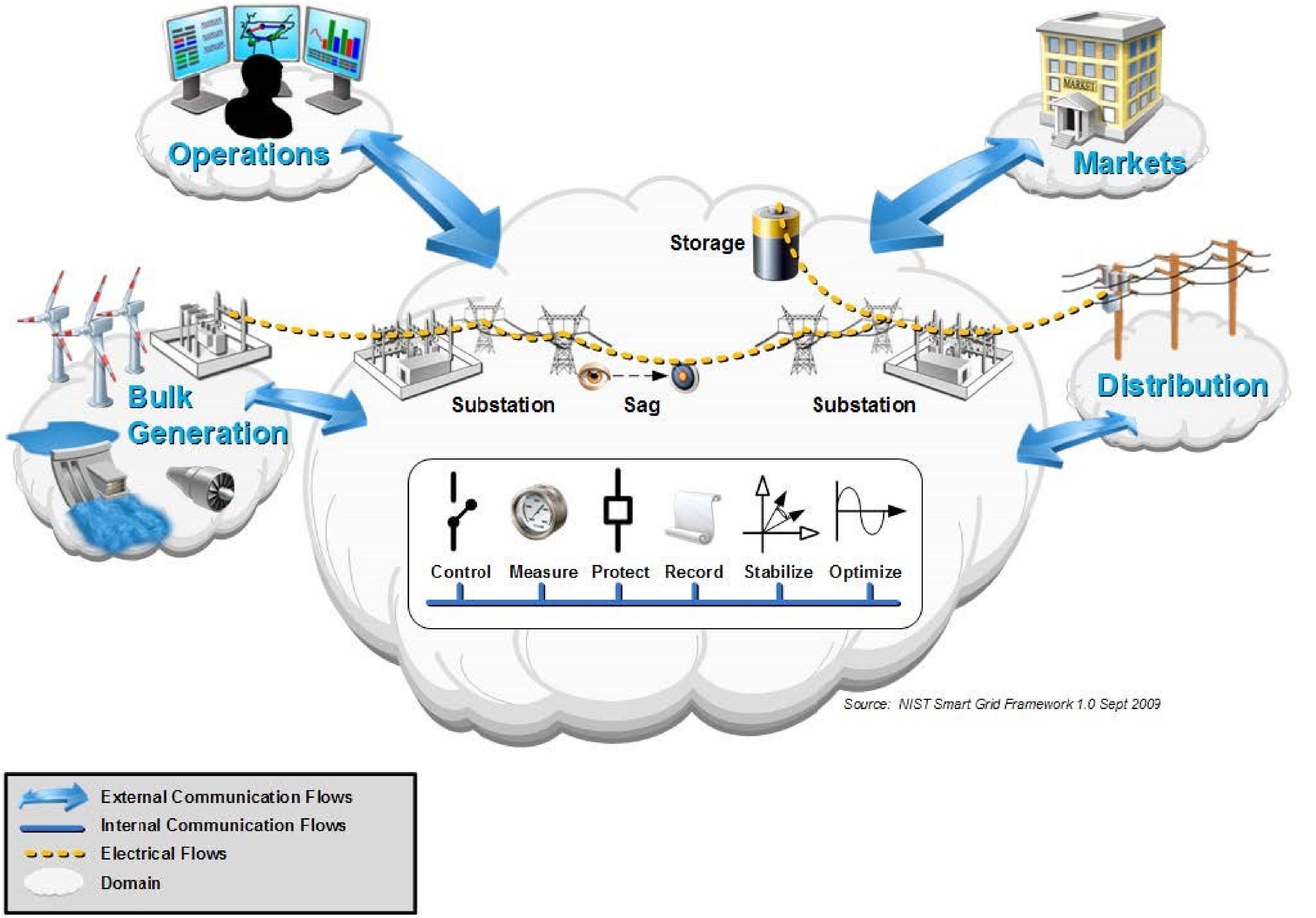
- **Actors** may be devices, computer systems, or software programs and/or organizations that own them. Actors have the capability to make decisions and exchange information with other actors through interfaces.
- **Applications** are the tasks performed by the actors within the domains

Bulk Generation

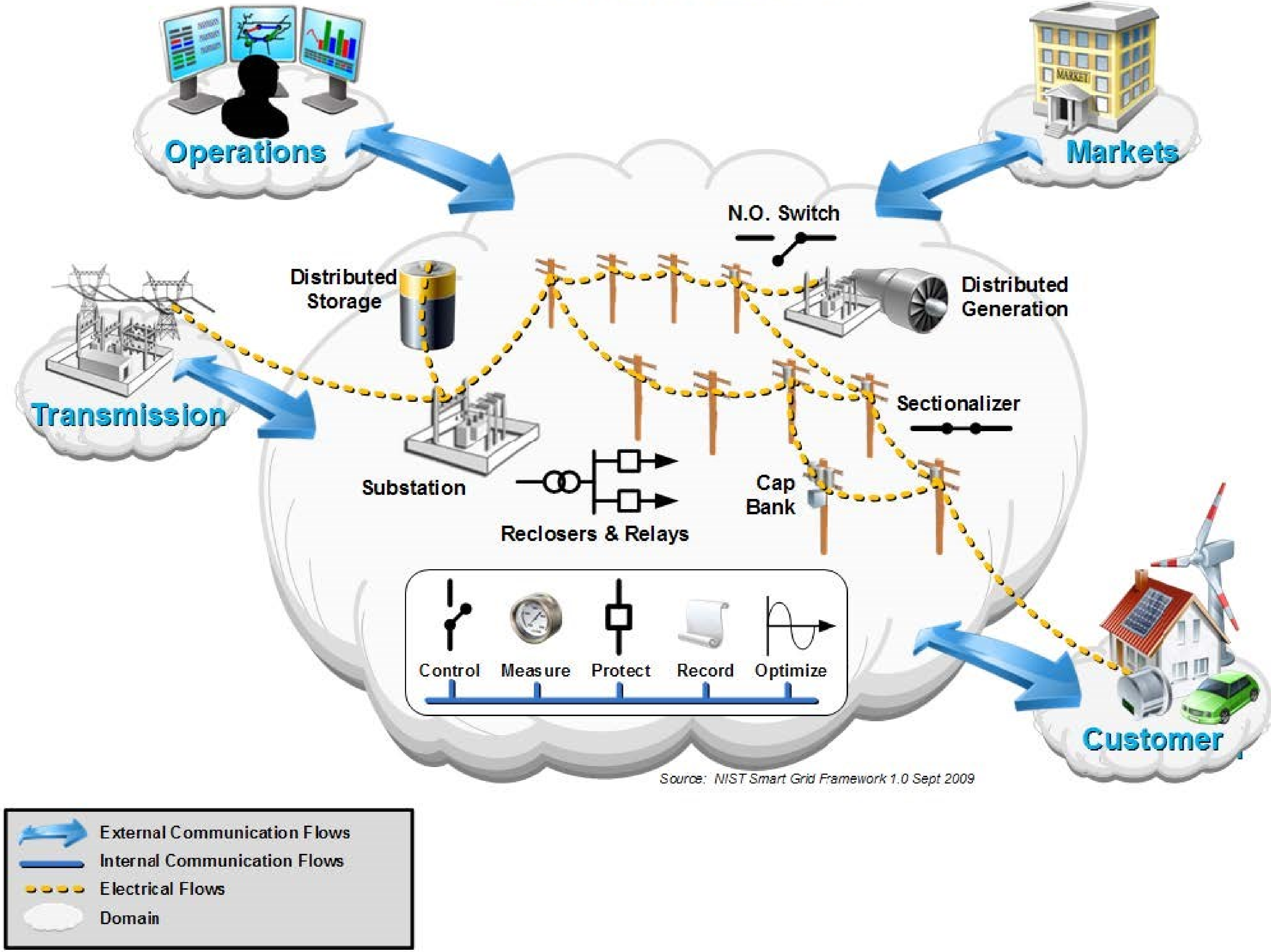


Source: NIST Smart Grid Framework 1.0 Sept 2009

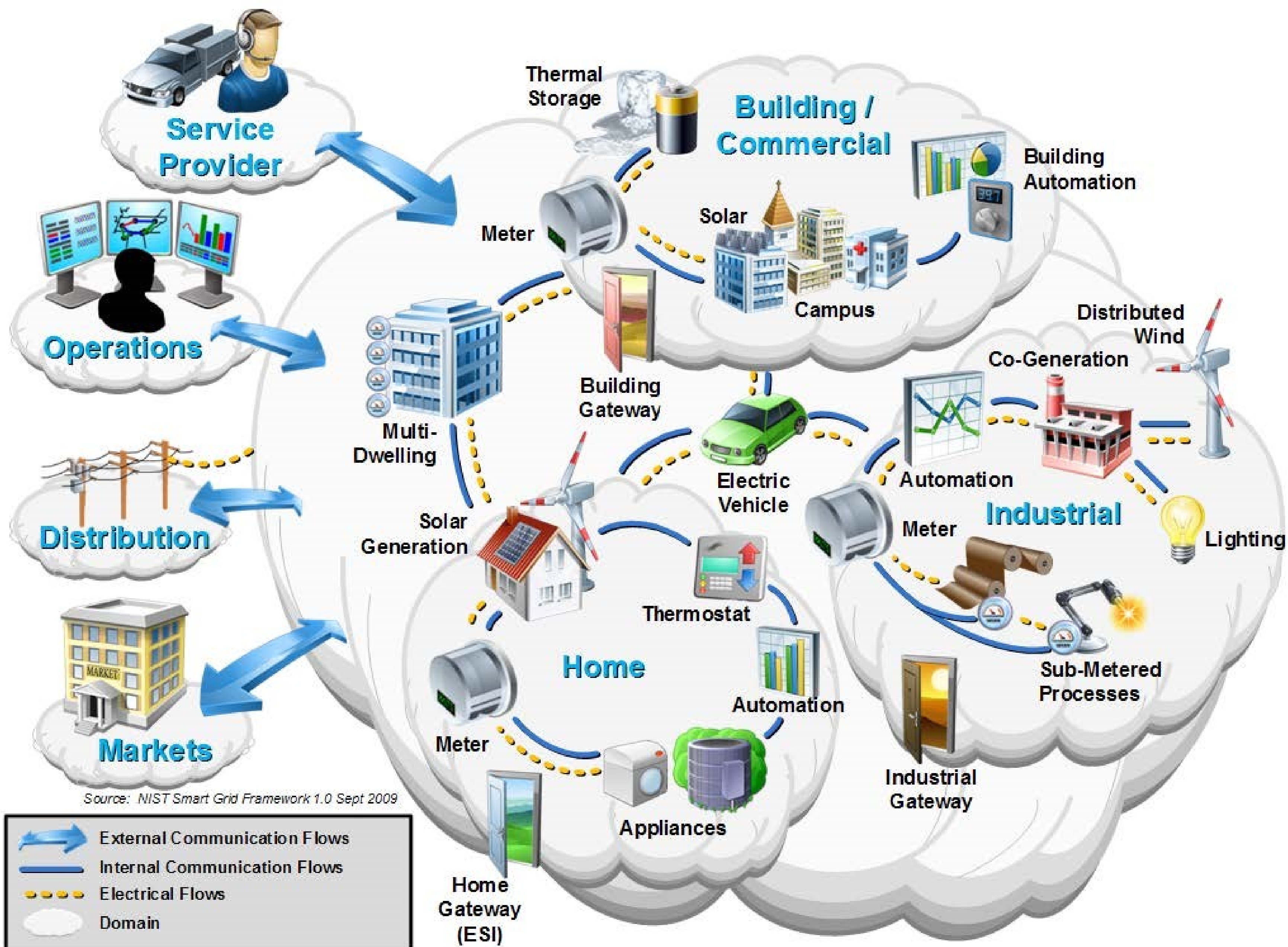
Transmission



Distribution

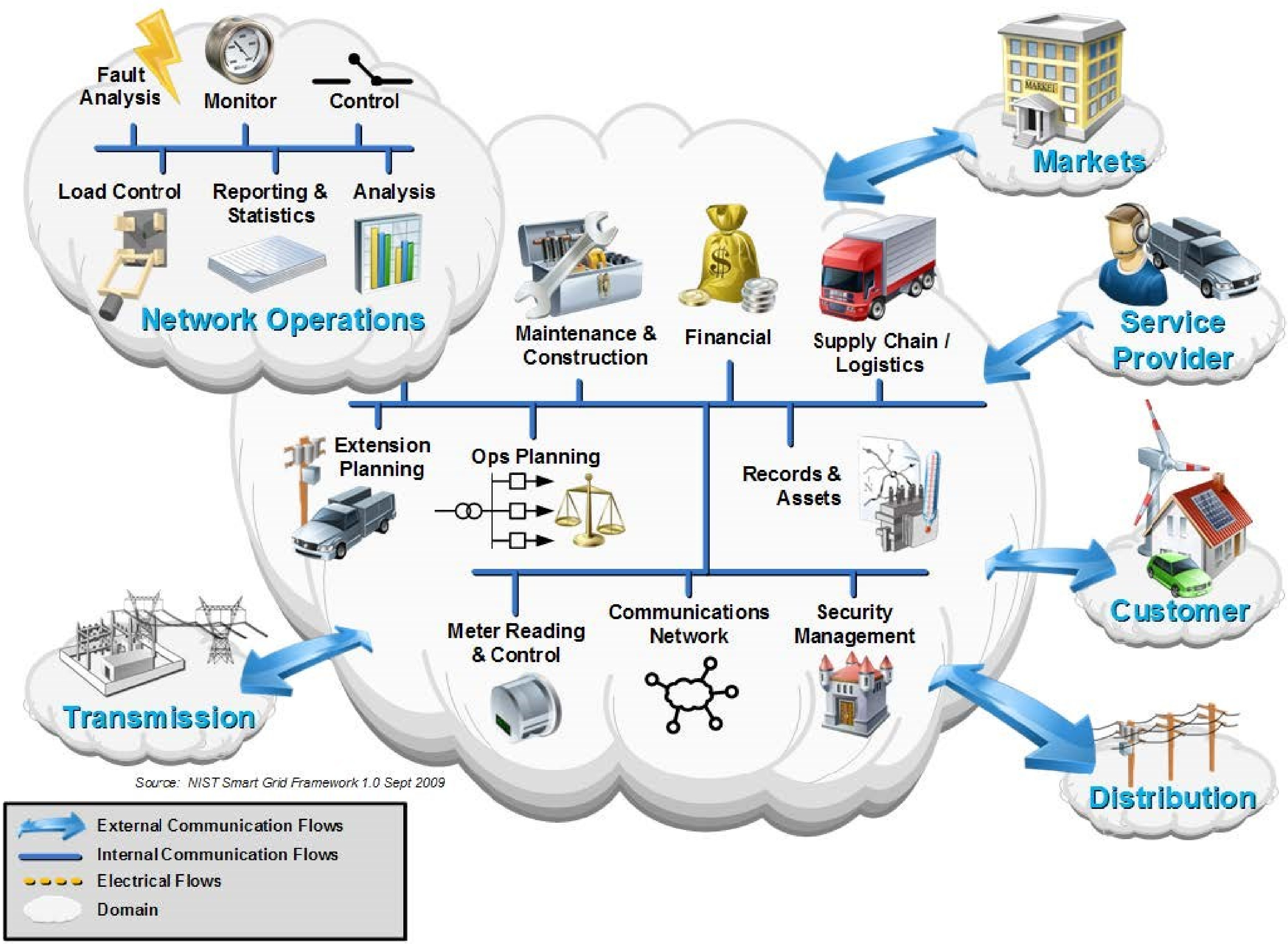


Customer



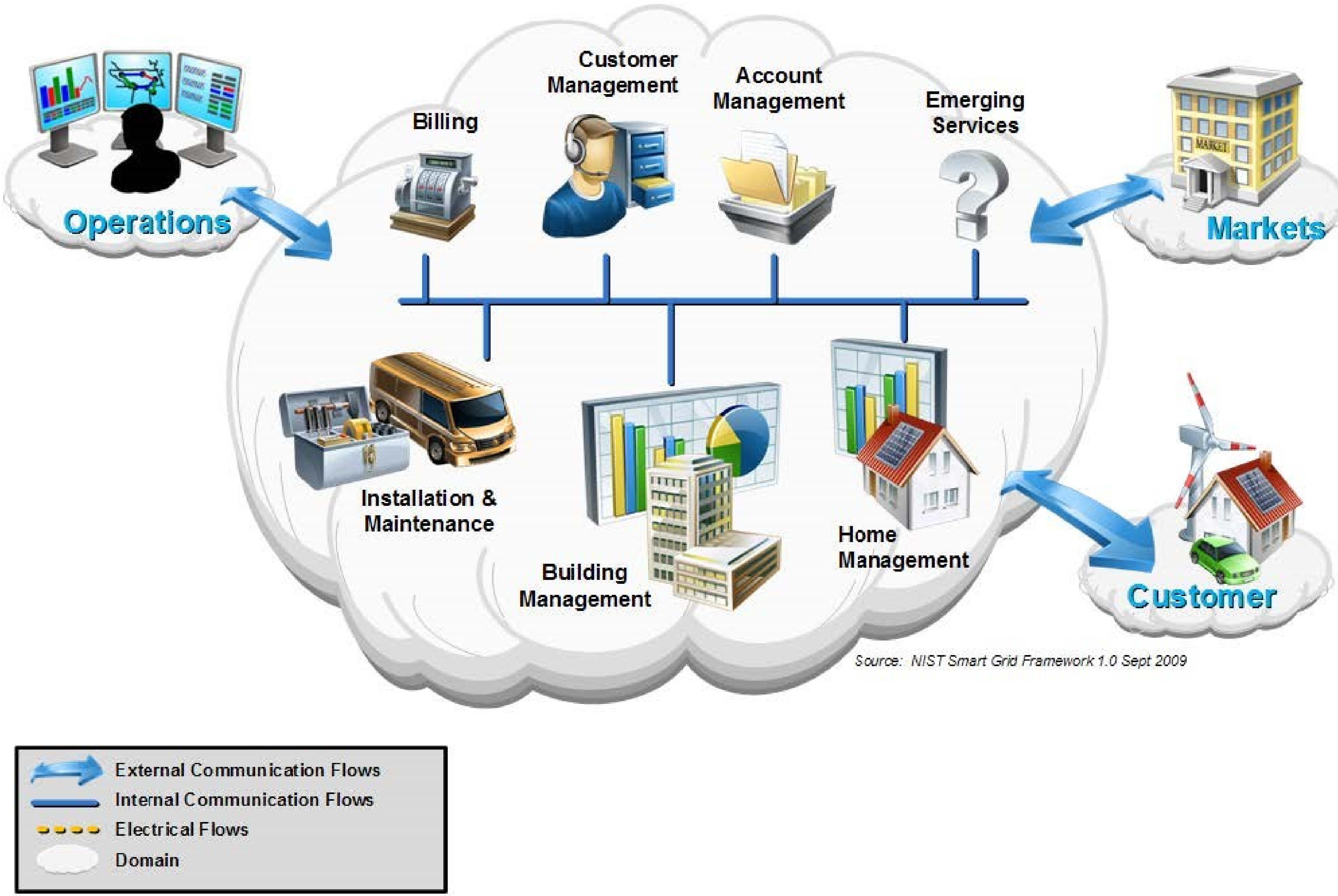
Service Provider
Operations
Distribution
Markets
Thermal Storage
Building / Commercial
Building Automation
Meter
Solar
Campus
Building Gateway
Multi-Dwelling
Distributed Wind
Co-Generation
Electric Vehicle
Automation
Industrial
Meter
Lighting
Solar Generation
Thermostat
Home
Meter
Automation
Appliances
Home Gateway (ESI)
Industrial Gateway
Sub-Metered Processes
Source: NIST Smart Grid Framework 1.0 Sept 2009
External Communication Flows
Internal Communication Flows
Electrical Flows
Domain

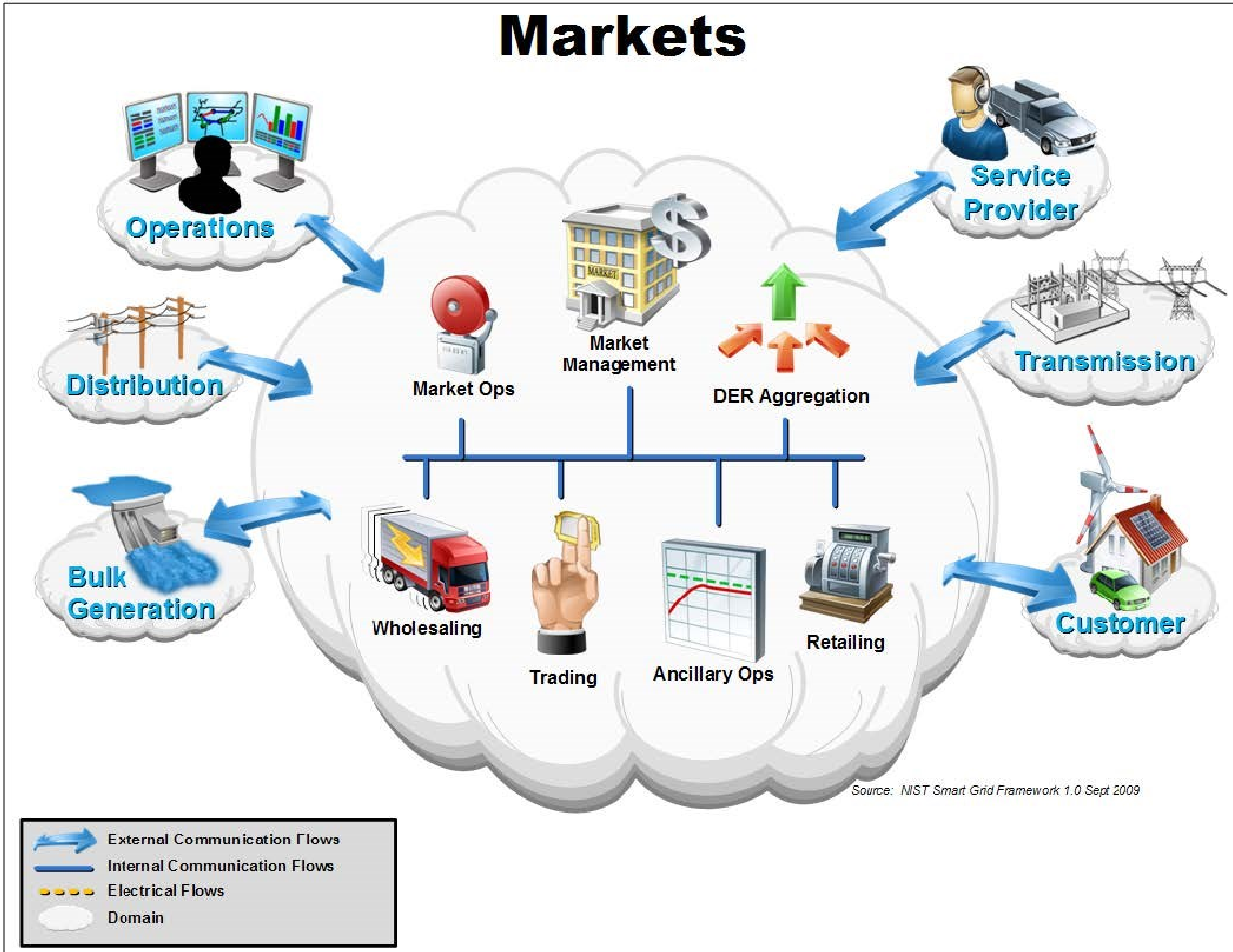
Operations



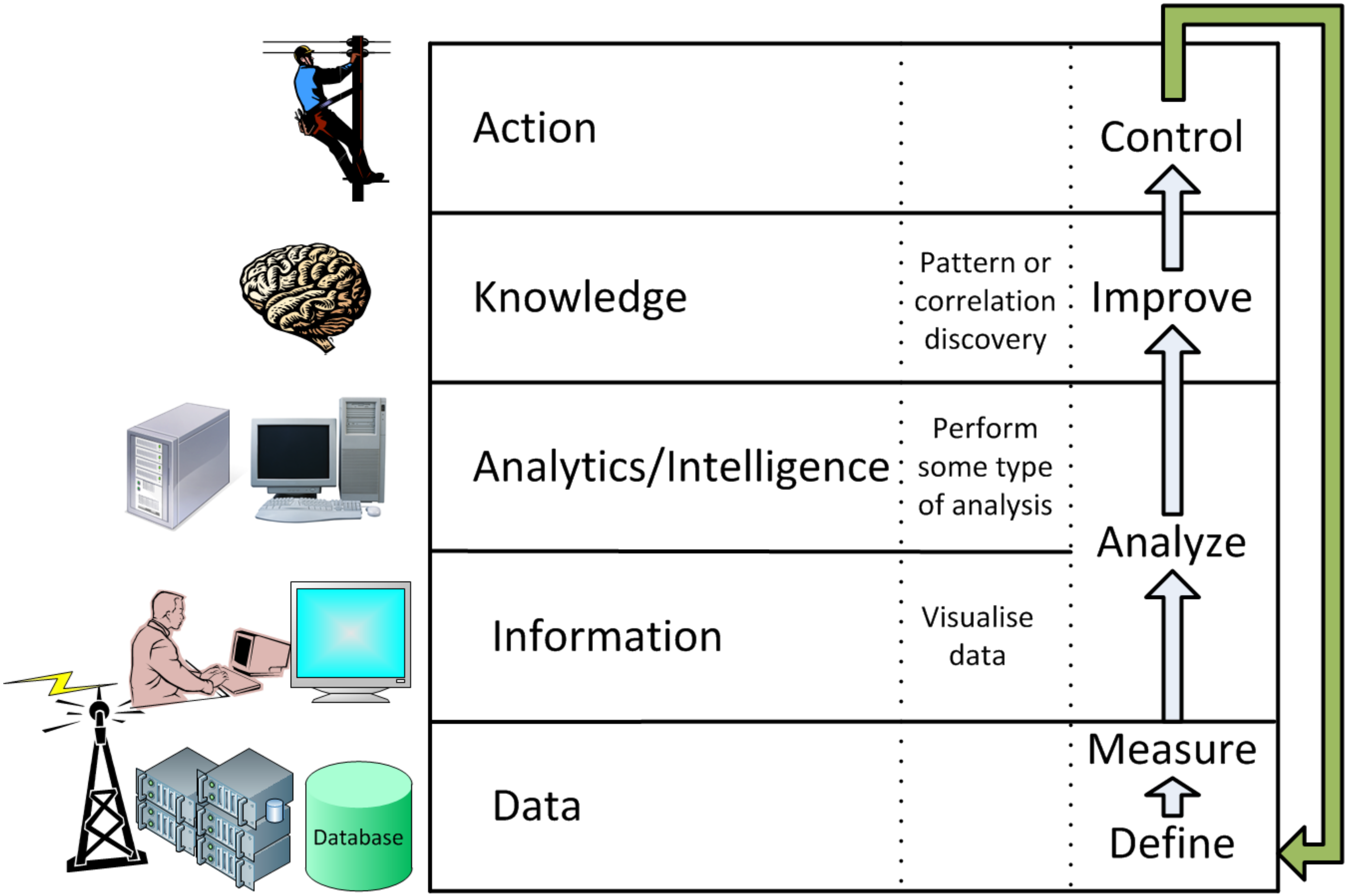
Source: NIST Smart Grid Framework 1.0 Sept 2009

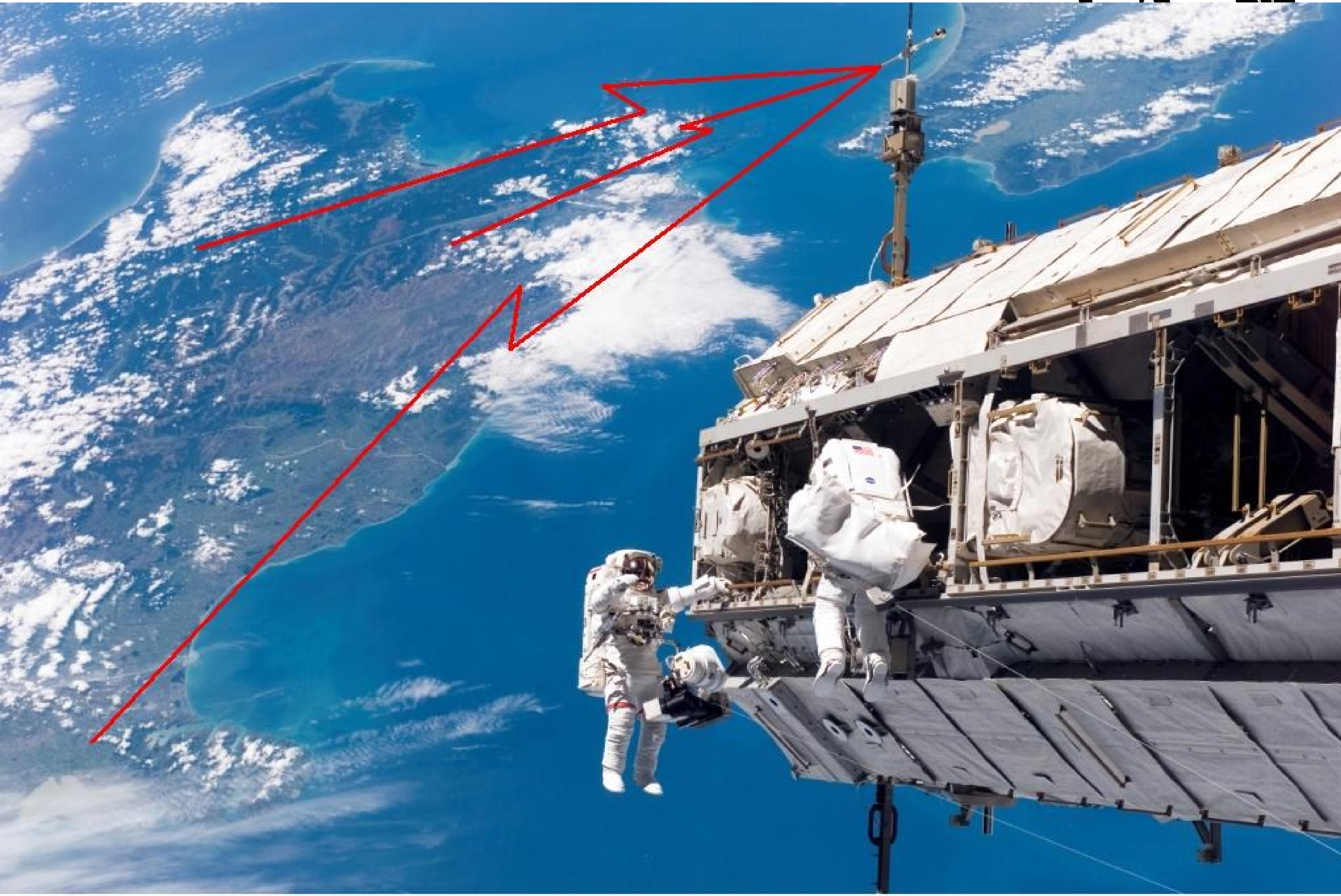
Service Provider




Markets
Operations
Distribution
Bulk Generation
Service Provider
Transmission
Customer
Market Ops
Market Management
DER Aggregation
Wholesaling
Trading
Ancillary Ops
Retailing
Source: NIST Smart Grid Framework 1.0 Sept 2009
External Communication Flows
Internal Communication Flows
Electrical Flows
Domain

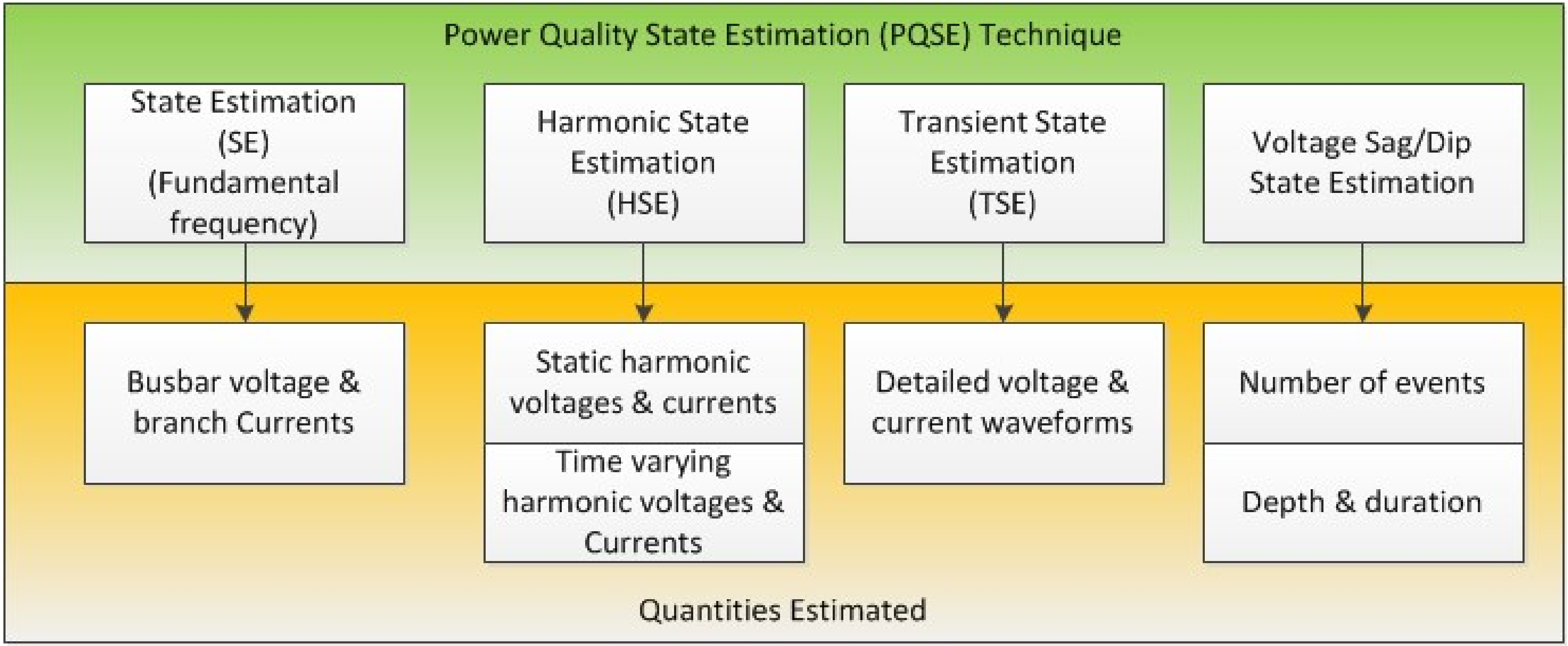
Back-office Applications





S116E05983

Example of Power Quality State Estimation (PQSE)



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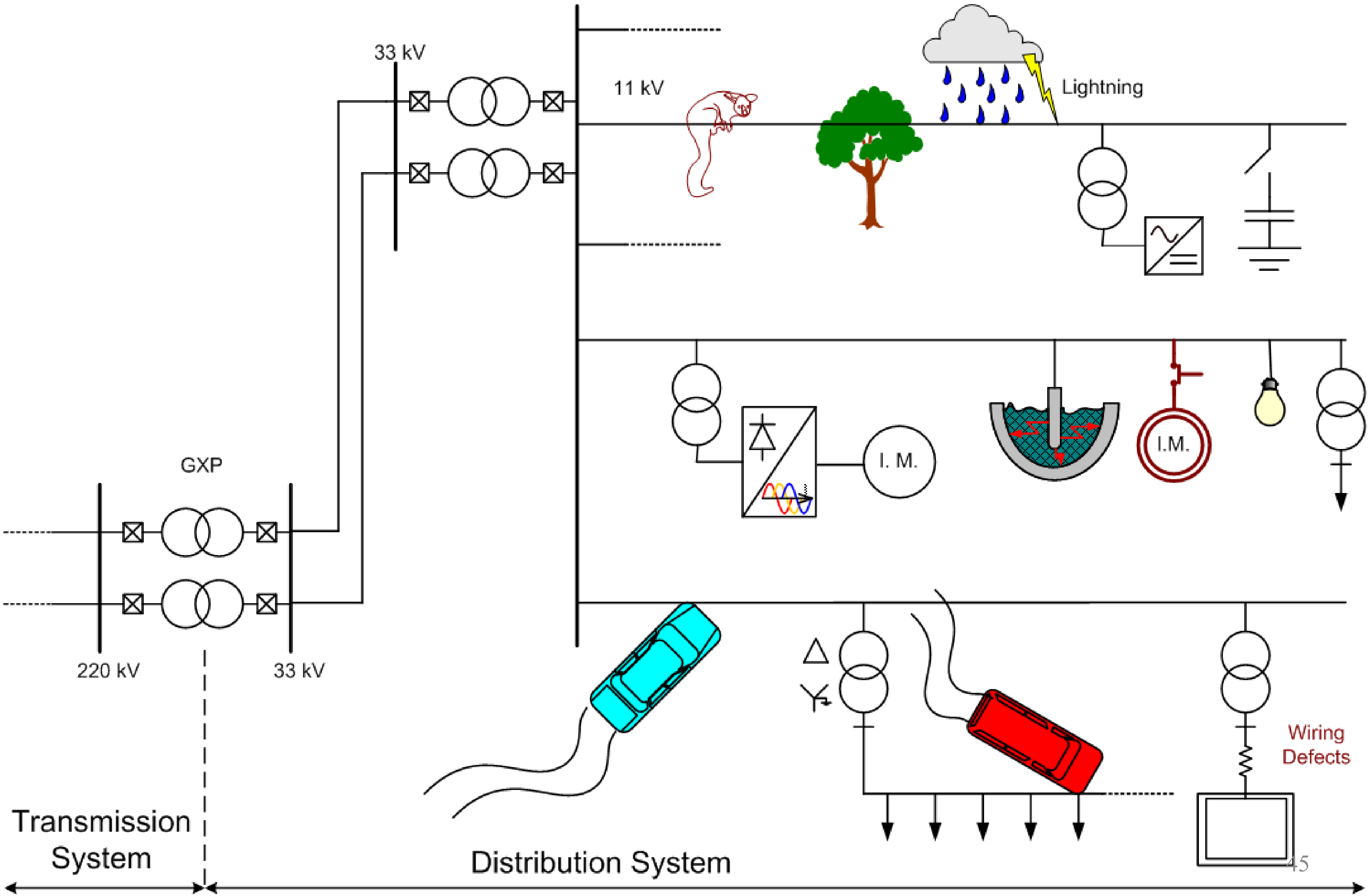
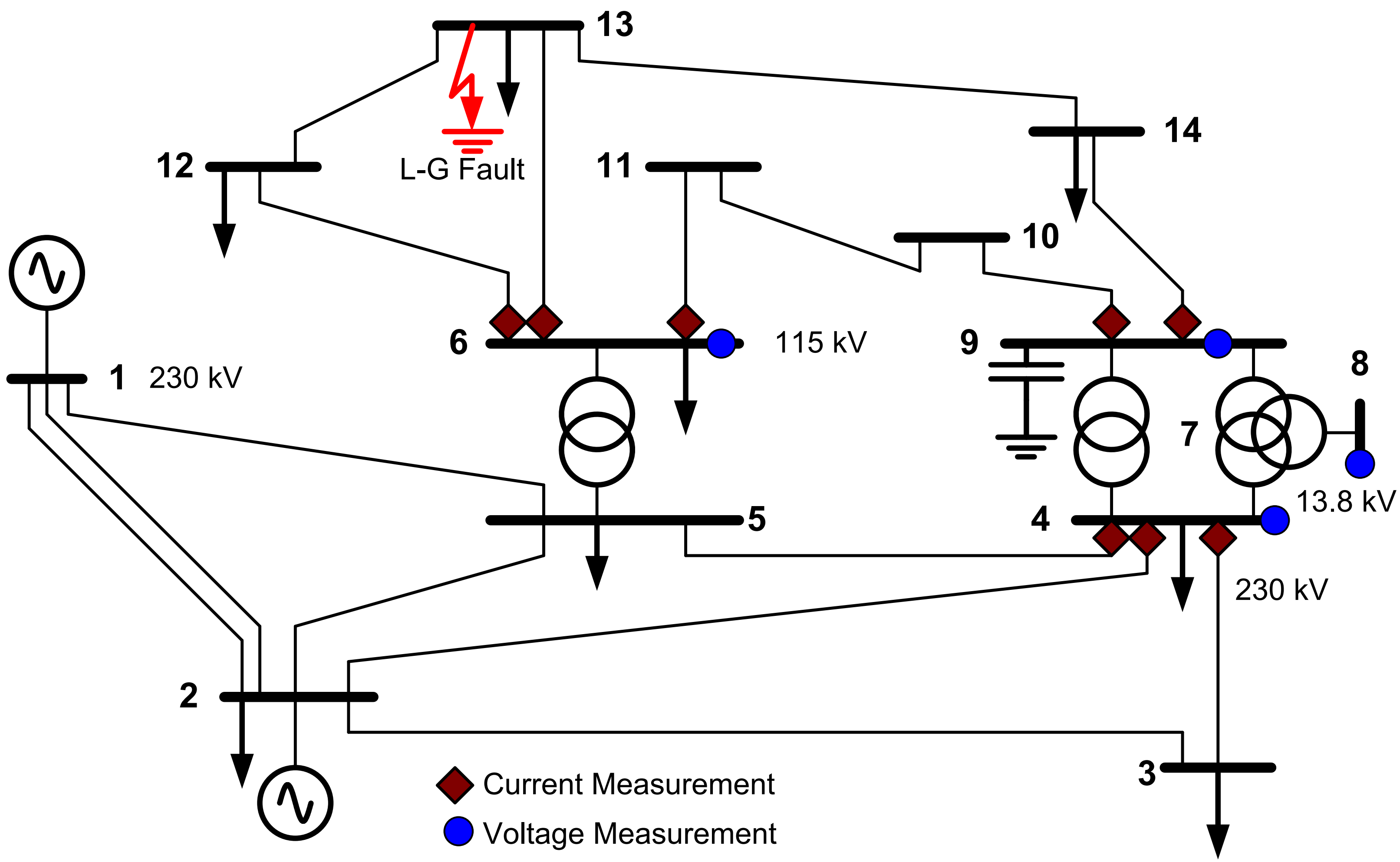
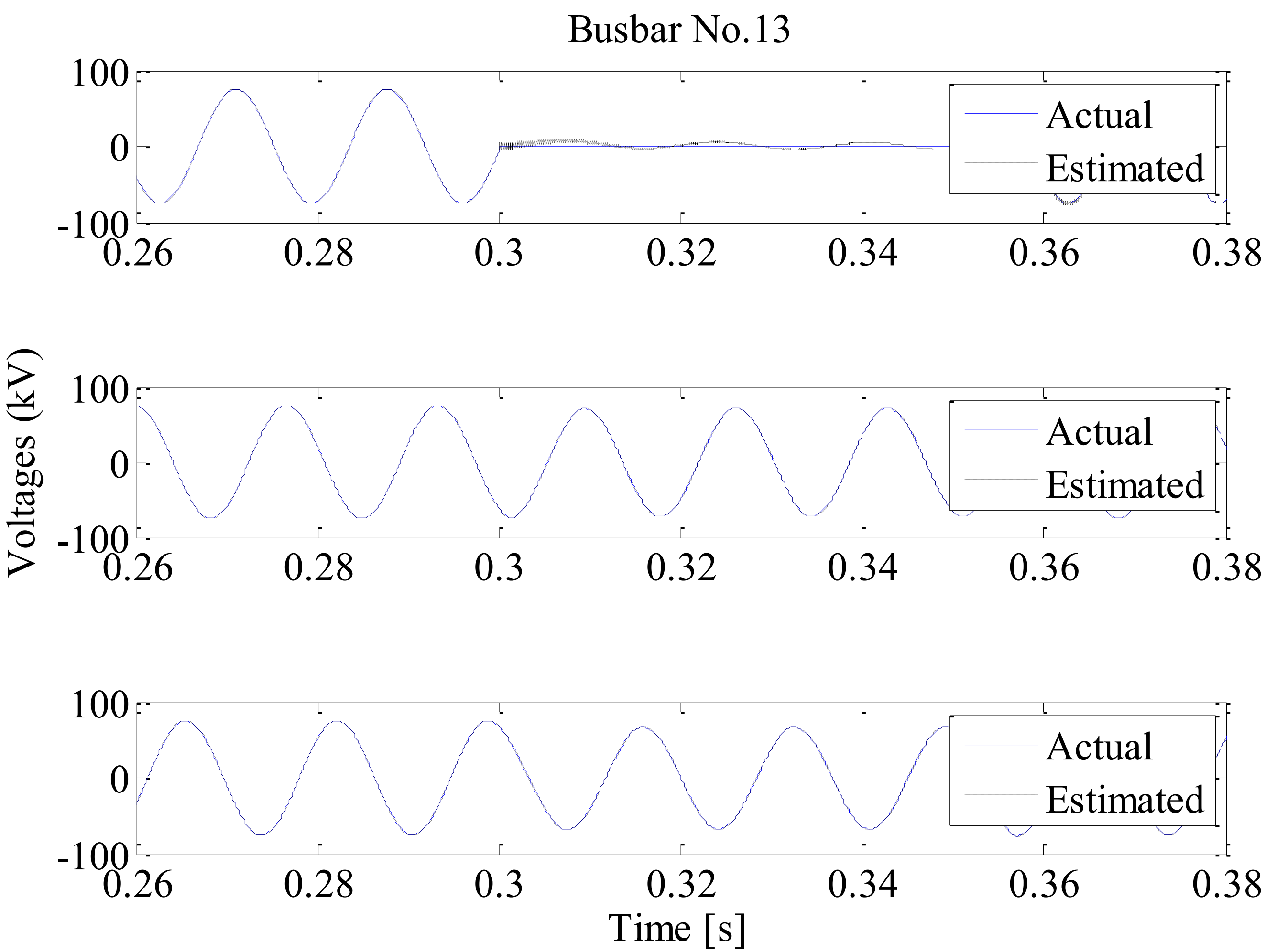


IEEE 14 Busbar Test System



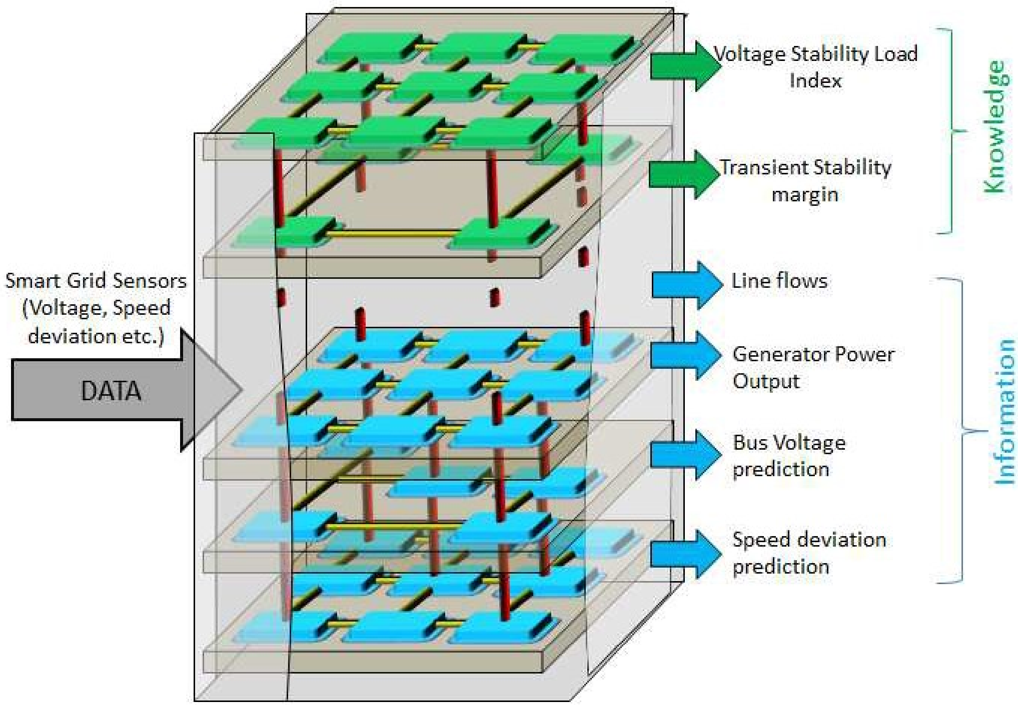
Estimation for Busbar 13



Situation Awareness

Situational awareness, aims to understand the current situation and closeness to boundaries and project how system states are going to evolve in the future.

This plays an important role in prevention or mitigation of cascading outages, or unwanted states such as inter-area oscillations.



Inter-Area Oscillations
(using phasor measurement units (PMUs) or synchrophasors)

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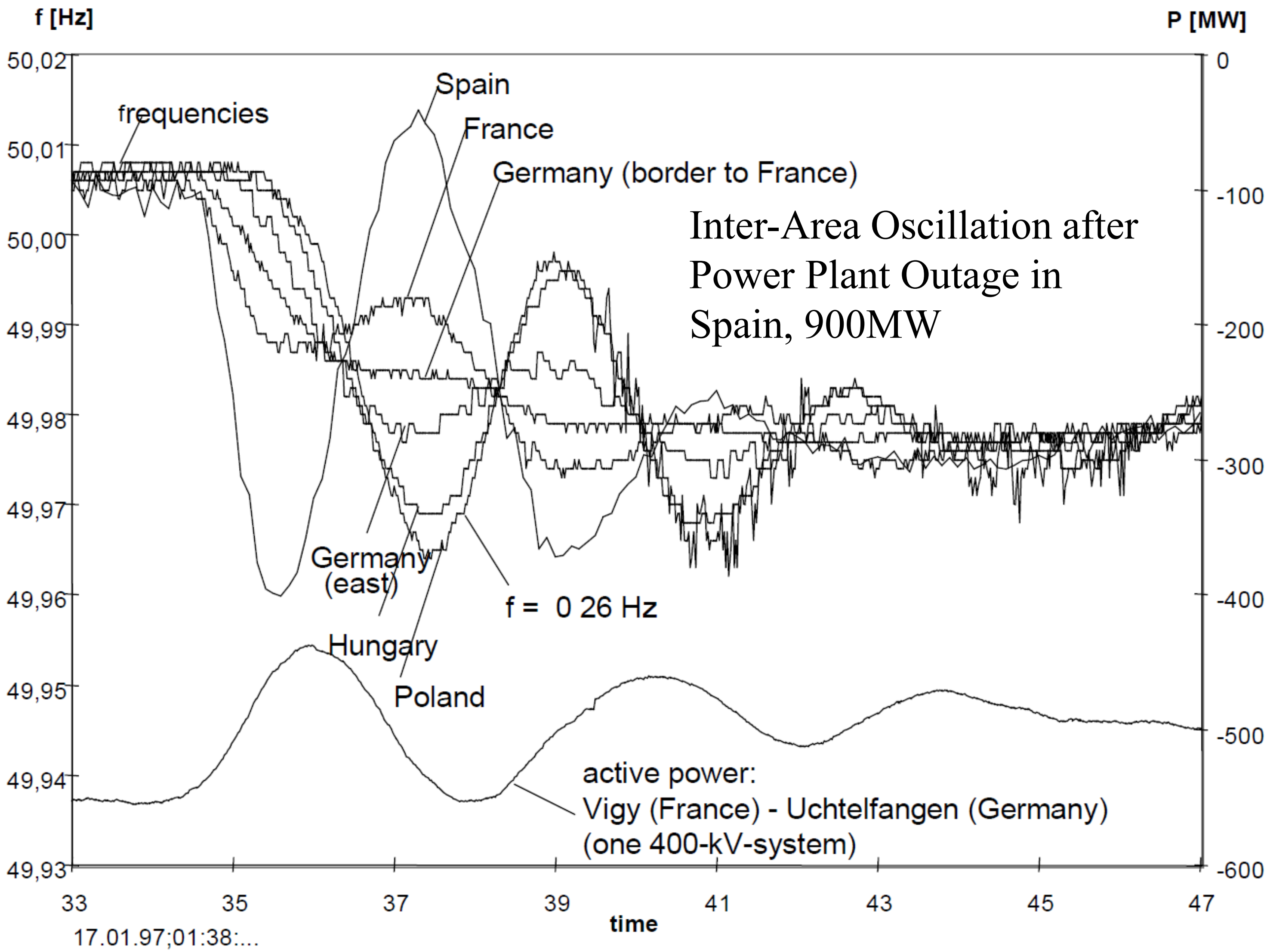

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Barriers & Risks

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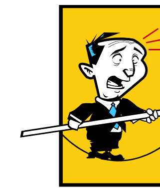
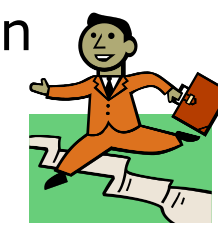


Difficulty in developing a realistic cost/benefit analysis, and hence business case, given the high level of uncertainty. → Difficult to finance the large-scale roll out of smart technologies. Risks are:

- Stranded assets with newer technologies becoming available.
- Under-performance due to uncertainty in being able to forecast the return on investment. Return can depend greatly on the resulting customers behaviour, which is hard to predict.
- Fragmented electricity industry results in benefits lying in several sectors (not shared).
- Although good (e.g. energy efficiency and promoting sustainability) may negatively impact revenue and incur other costs.



Trials

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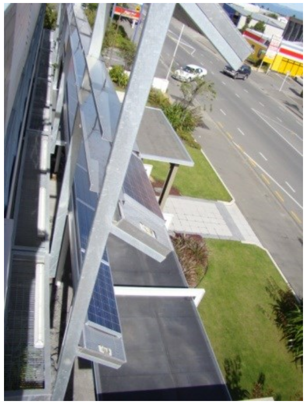
Many Electrical Network Businesses are trialing some of these technologies in order to understand how they will influence their system.



Electrical Network Businesses (ENBs) (a.k.a. Lines Companies)

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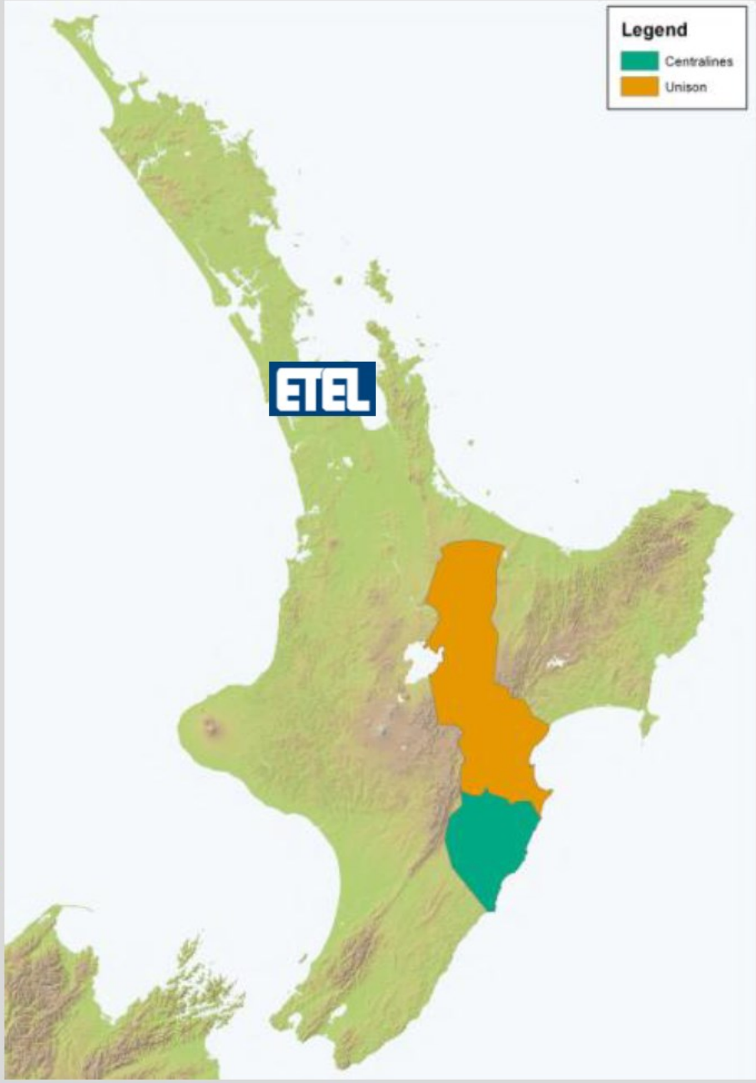
1. Network automation (has clearest cost/benefit)
2. Upgrade of communications systems
3. Reactive power support operated in real-time.
4. Fast switching transformers
5. Smart metering (issues over functionality and access to the data)
6. Distributed Generation (PV and micro-wind in rural)
7. Electric Vehicles
8. Communication and Data Collection
9. Dynamic rating of Cables and transformers
10. Energy efficient technologies (e.g. LED lighting)

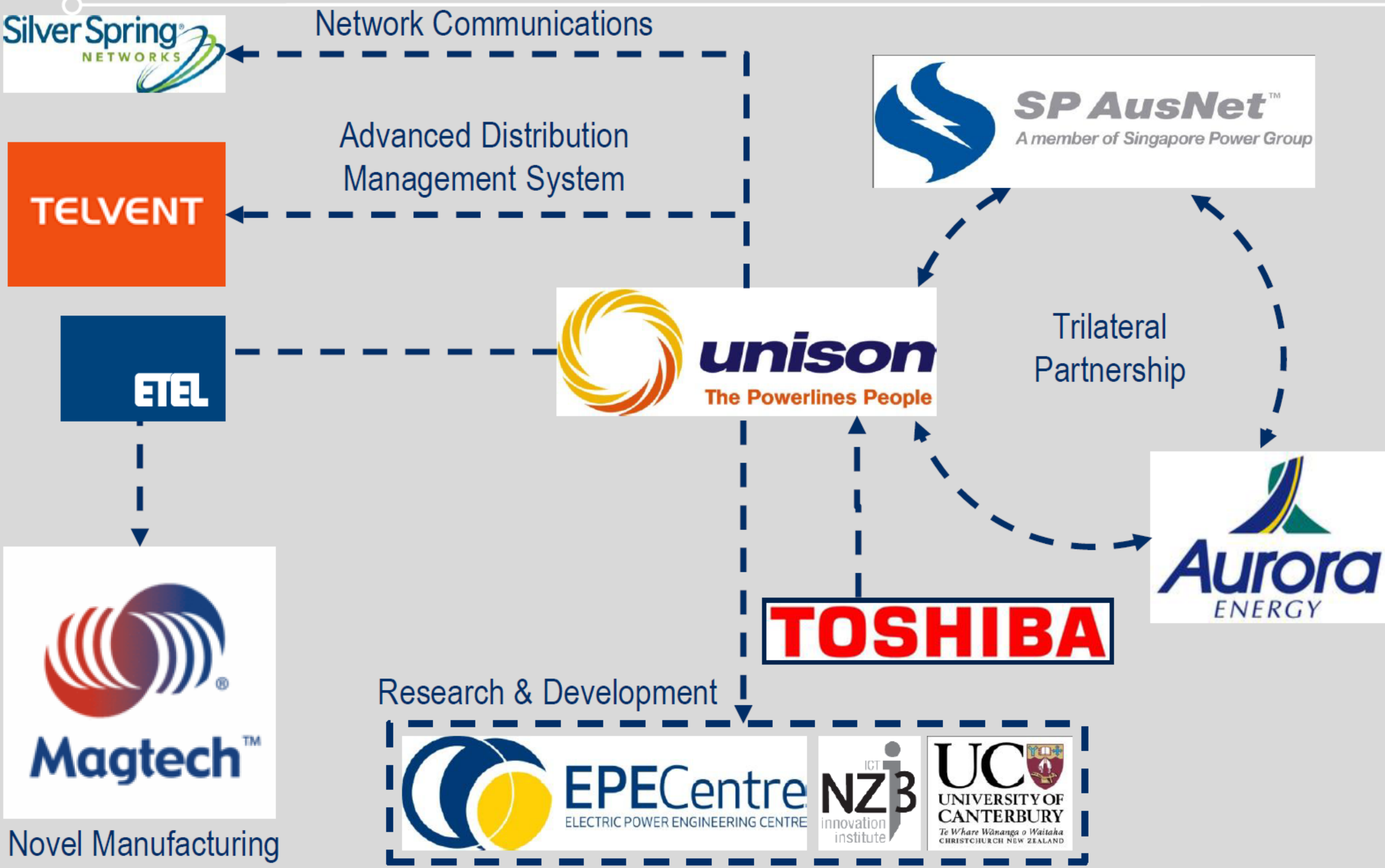
Unison: An Overview

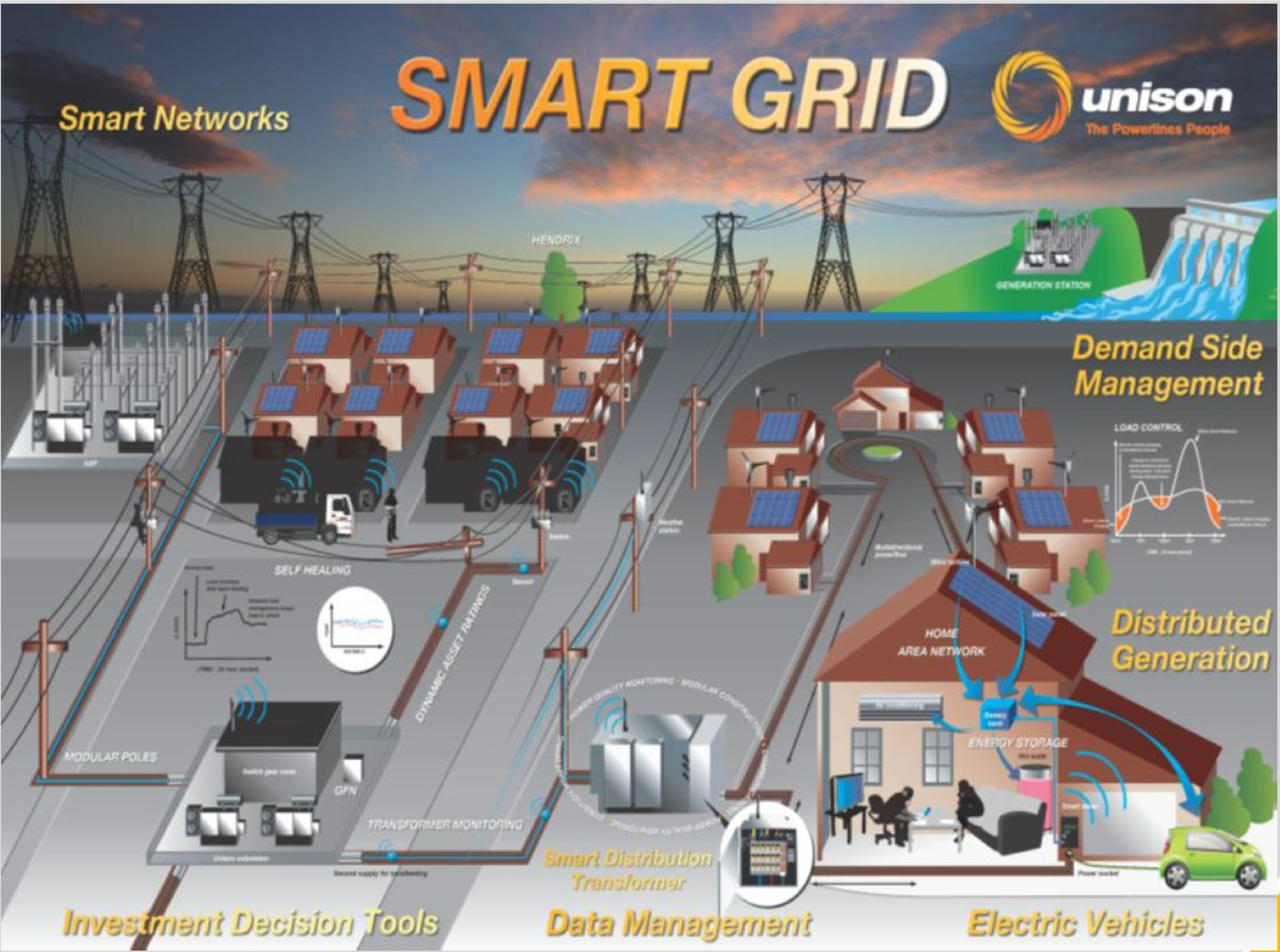
- Unison owns, manages and operates distribution networks in the Hawke's Bay, Taupo and Rotorua (including Centralines under management contract)
- 100% owned by the Hawke's Bay Power Consumers' Trust
- Serving approximately 109,000 consumers
- The Unison Group comprises,
  - Unison Networks Ltd
  - Unison Fibre Ltd
  - Unison Contracting Services Ltd
  - ETEL Ltd (Distribution Transformer Manufacturing Company)
  - Unison Insurance Ltd



unison
The Powerlines People

Collaboration and Partnerships





SMART GRID
unison
The Powerlines People
Smart Networks
HENDRIX
GENERATION STATION
Demand Side Management
LOAD CONTROL
SELF HEALING
DYNAMIC ASSET RATINGS
HOME AREA NETWORK
Distributed Generation
ENERGY STORAGE
MODULAR POLES
GFN
TRANSFORMER MONITORING
Smart Distribution Transformer
Investment Decision Tools
Data Management
Electric Vehicles

Target

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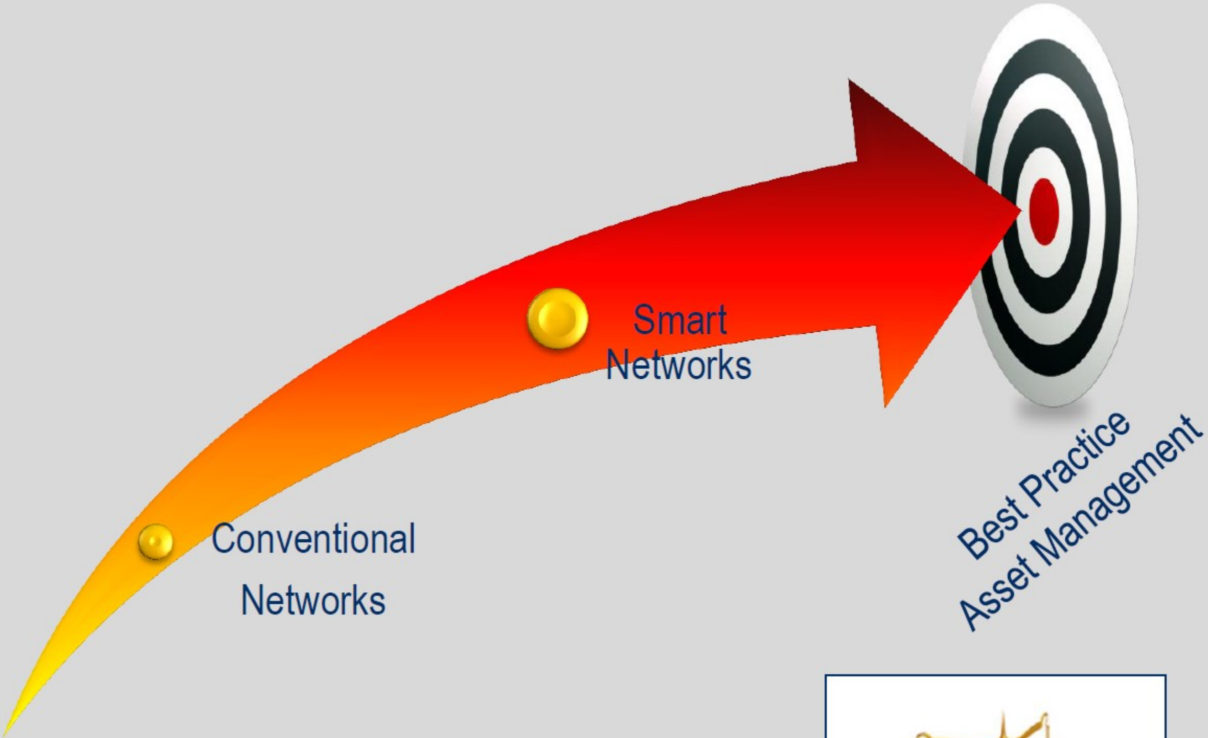
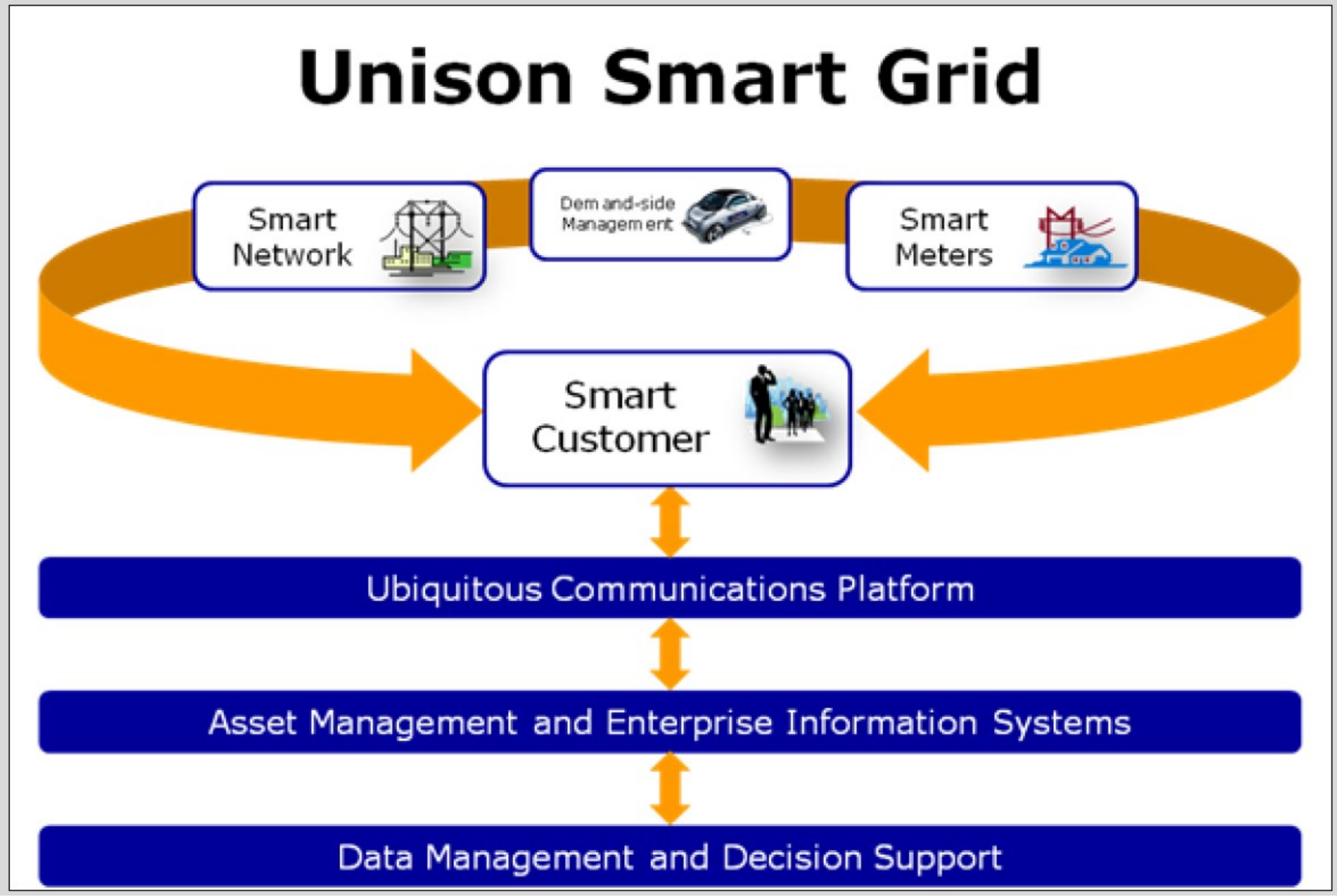


- Maximising Performance
- Minimising Cost
- Minimising Risk

PAS55, as benchmark

Unison's Smart Grid concept



Time-Frame

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Implementation

2011-2015

Expedited implementation of a smart network without adversely affecting core asset management values, while ensuring fiscal sustainability.

Optimisation

2016-2020

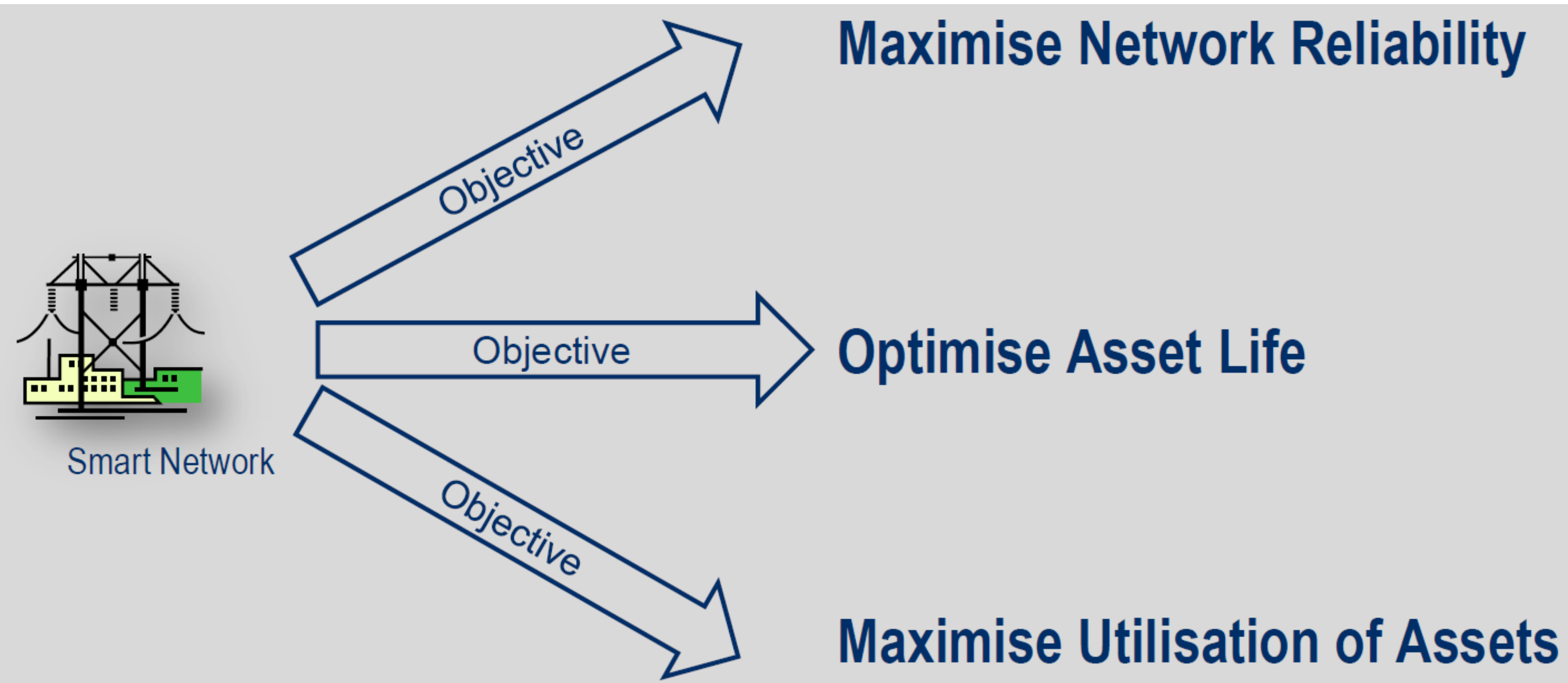
Realise in full the potential of the smart grid: increase the efficiency of expenditure on the network, improve quality of supply and enable Unison to become more sensitive to the changing needs of its customers.

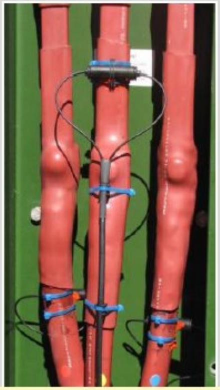
Integration

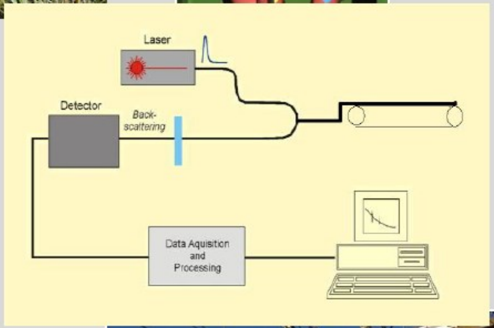
Beyond 2020

Achieve asset management excellence with an optimally tuned smart network. Manage network expenditure using tools that provide a direct nexus between expenditure (inputs) and performance (outputs).

Smart Grid managed according to lifecycle asset management principles


Maximise Network Reliability
Objective
Objective
Optimise Asset Life
Smart Network
Objective
Maximise Utilisation of Assets

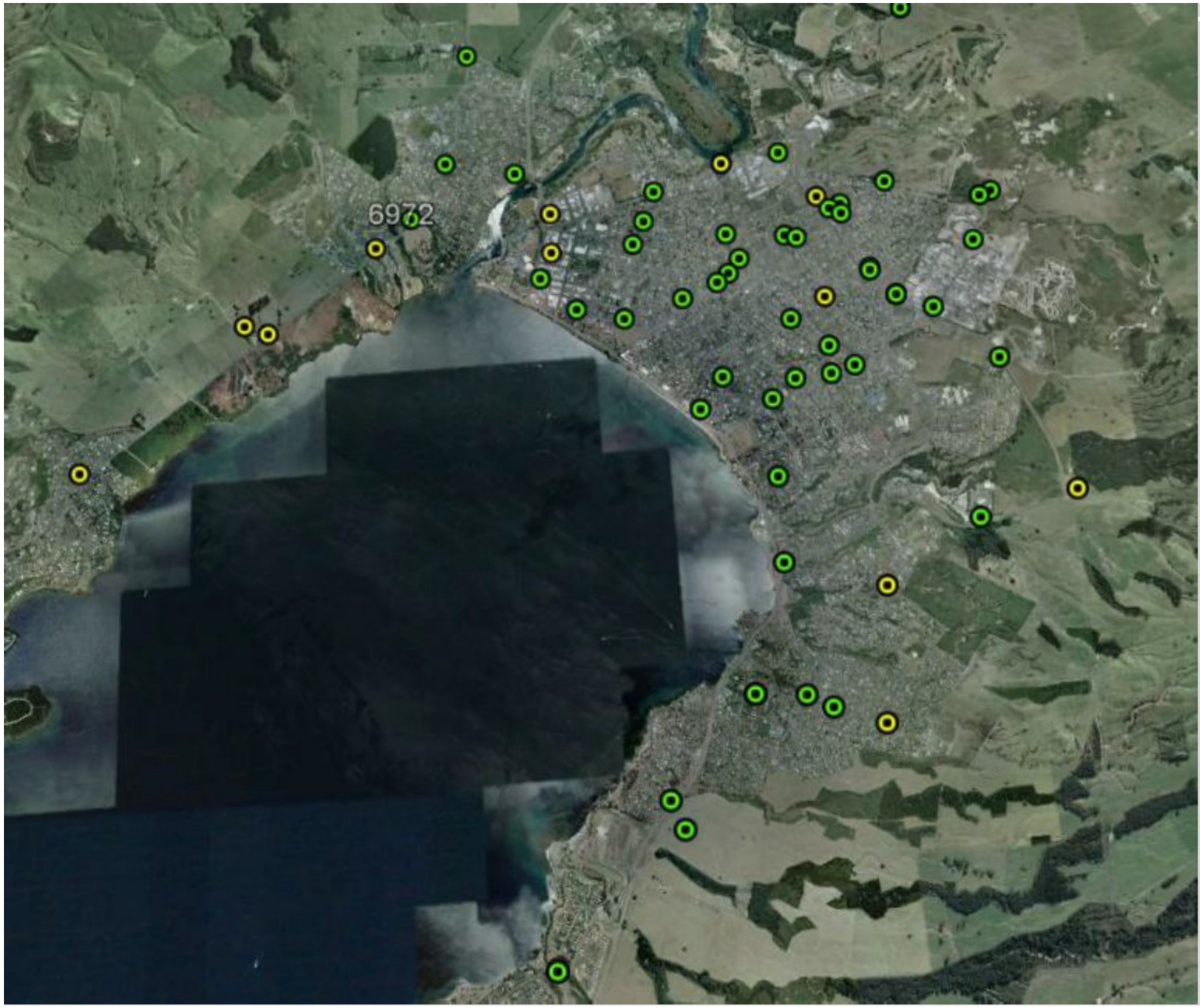



Laser
Detector
Back-scattering
Data Aquisition and Processing


Sensa

An Example - Self Healing technology

- Installed 40 automated switches in Taupo area
- Self-healing enabled in April 2014
- 9 Fast transfer schemes defers the replacement of 15 Power Transformers over next 10 years ($7.6million).



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Network Reliability benefits
Unison Historical SAIDI and SAIFI

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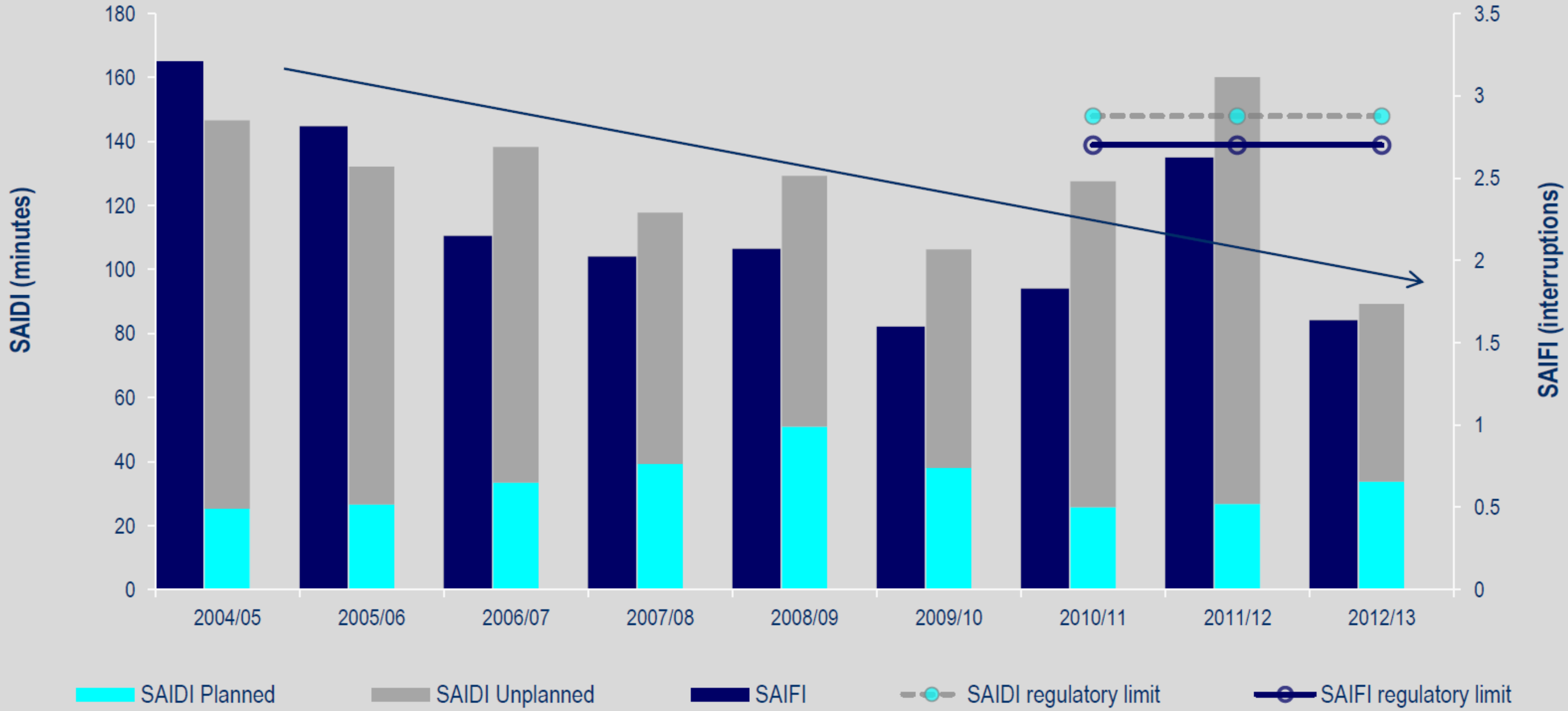


- Smart network technology resulted in a 24 SAIDI min saving in 2012/13
- Unison SAIDI minutes to reduce to 55 min p.a. post SG implementation

Communications

Regional Fibre Backbone

Currently: Urban Substations Enabling; High speed backhauling (DA AMI), Engineering Access (Event retrieval), VOIP, Security (cameras), Fast Protection, wireless connection to HQ

Future: Distribution Transformers?

Mesh Radio Network, enabler for:

Distribution Automation (DA)

MimoMax, enabler for:

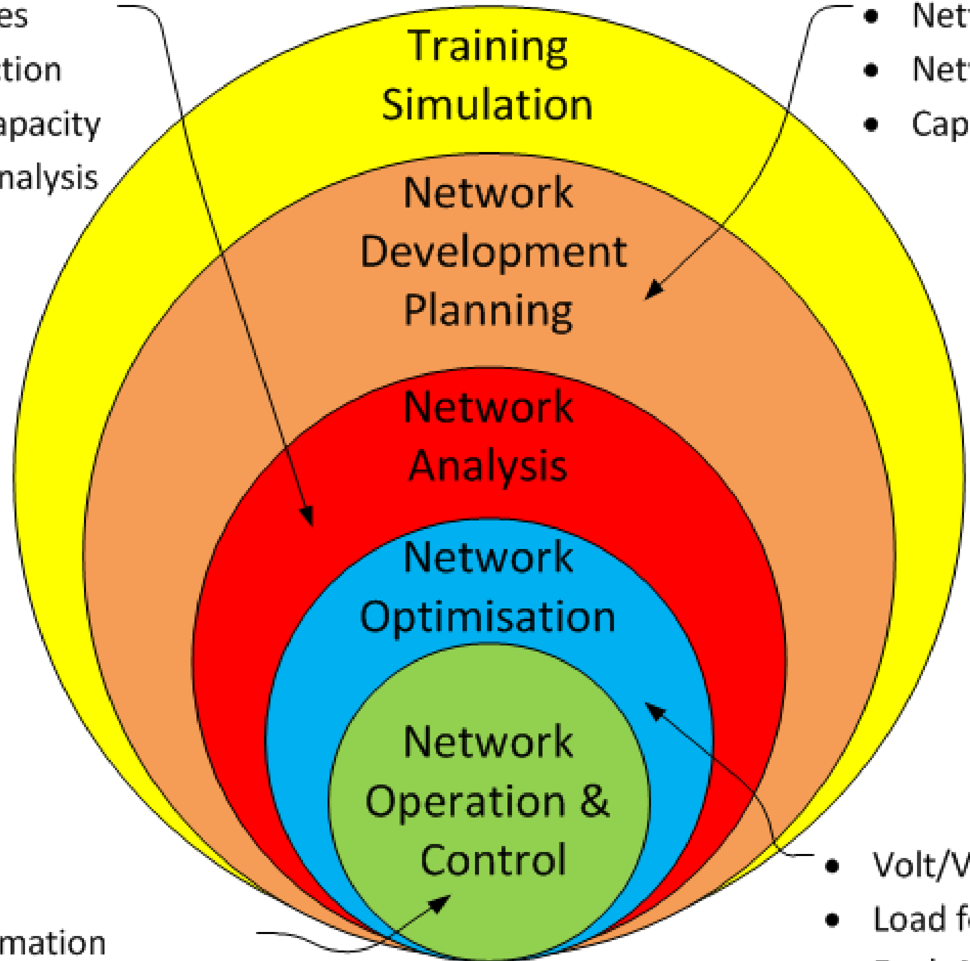
Rural Substations

Devices that require higher data speeds e.g. Reclosers

Asset Management / Information

- Energy Losses
- Fault Protection
- C.B./Fuse Capacity
- Harmonic Analysis

- Network Planning
- Network Scanner
- Capacitor Placement



- State Estimation
- Load-flow
- Fault Management
- Large Area restoration
- Switching Management

- Volt/VAR
- Load forecasting
- Fault Management
- Load Management
- Energy Storage

Research & Development Programme

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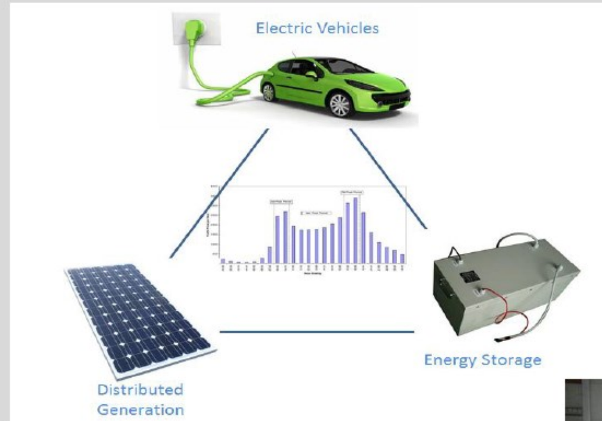
Drivers:
- Increase Asset Utilisation
- Optimise Asset Life
- Enhance Power Quality

Example Projects:
- UAV/Data Collection
- Asset Intelligence (Condition Assessment, Remaining Life)
- LIDAR integration

Examples

Installing Solar Panels (Voltage/PQ Impact)

- High efficiency panel (20.1%) from Sunpower
- Investigate impact on Network
- 20kW generation at Unison HQ (63 panels)



Buying Electric vehicle (Investment Impact)

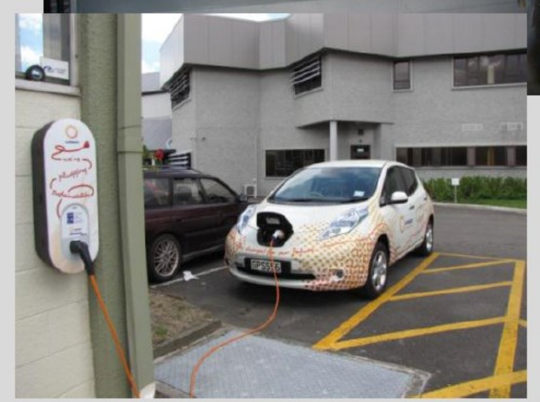
- Nissan leaf
- Investigate impact on Network
- Investigate Vehicle to Grid concept

Installing Battery Storage (Mitigation)

- Li-ion battery to demonstrate load shaving
- Lighter and longer lasting than lead-acid batteries

Developing a Control Hub (Load & Voltage Management)

- Amplify benefits by co-ordinating the above technologies
- Algorithms to dynamically control the technologies based on:
  - Load
  - Pricing signals
  - Power Quality



ASSET INTELLIGENCE

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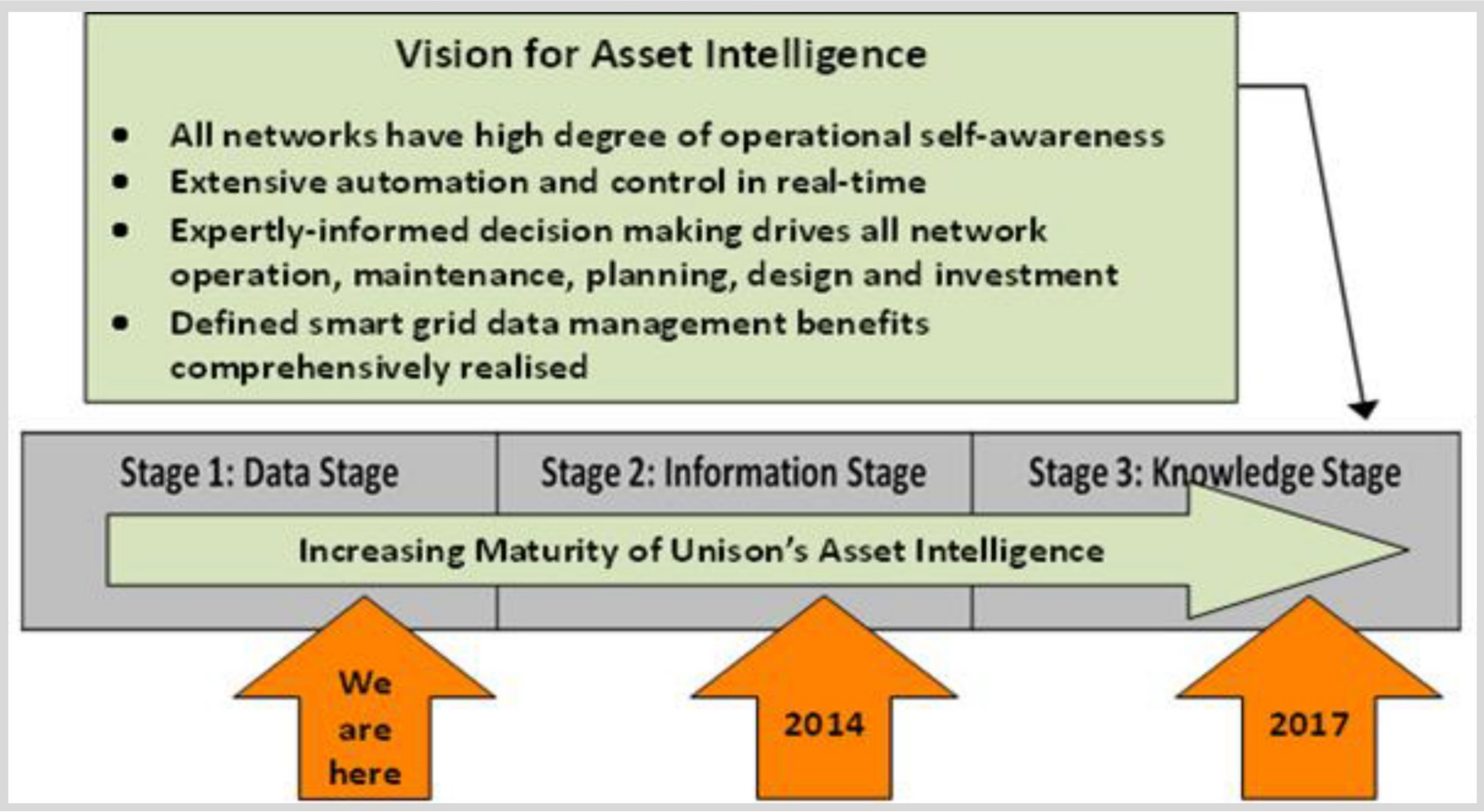
ASSET INTELLIGENCE in the context of a **smart grid:**

- "is the establishment of a **computational framework** ensuring that well-chosen **data streams** collected by smart network assets are **optimally utilised**"
- Purpose : To materialise the **stated benefits of the smart grid initiative** in full at minimum cost

Enhanced asset capacity (rating)	0.25
Extended asset life	0.2
Optimisation of planned maintenance	0.15

Unison's Vision for Asset Intelligence



All supporting and enabling **Life Cycle Asset Management**

Asset of the Future should:

- Have complete and independent **'situational awareness'**
- Be able to tell the Control Room **how much load it can carry,** in real time ('dynamic rating')
- Be able to **self-diagnose condition and 'asset health'**
- Be able to tell Asset Managers and Planners:
  - What it's **remaining life expectancy** is
  - If it is at risk of **incipient failure**
  - If it is **operating sub-optimally, needs maintenance, exactly what and when maintenance is needed** (e.g. 'I will need an oil change next week')

Algorithm Class: Priorities for Asset Intelligence

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1. Dynamic Rating

(a) Be able to tell the Control Room **how much it can carry and for how long**, in real-time.

(b) Provide additional information for Asset Managers and Planners

2. Asset Analytics

3. Power Quality

Algorithm Class: Priorities for Asset Intelligence

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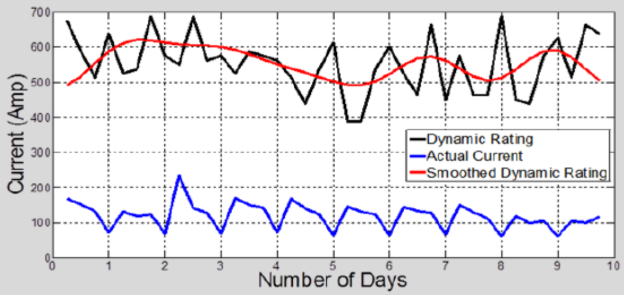
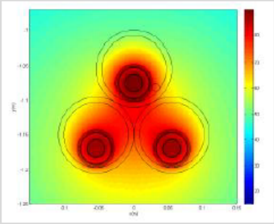
Algorithm Classes:

1. Dynamic rating
2. Asset Health Analytics
3. Power Quality

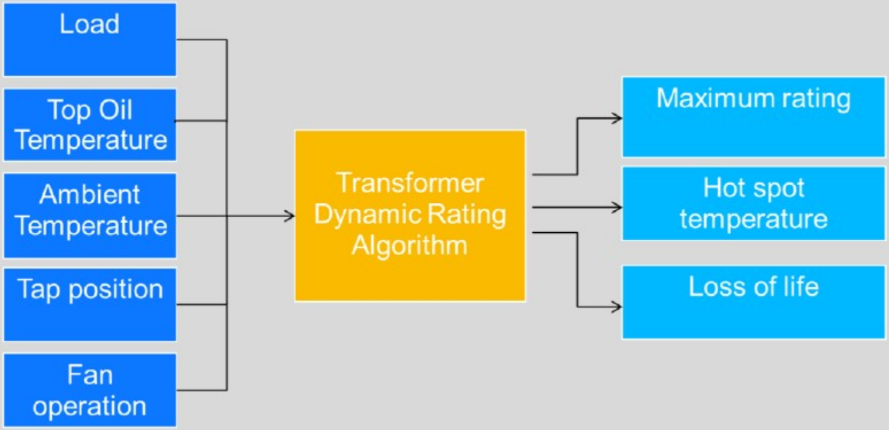
- Power transformers
  - Distribution transformers
- 33 kV lines
  - 11 kV lines

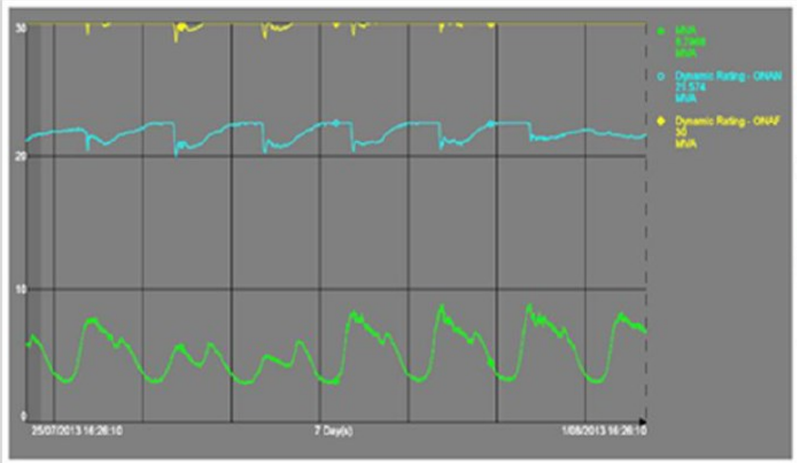


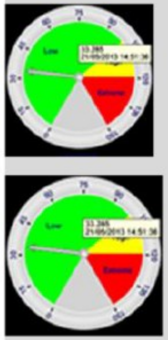
- 33 kV cables
  - 11 kV cables

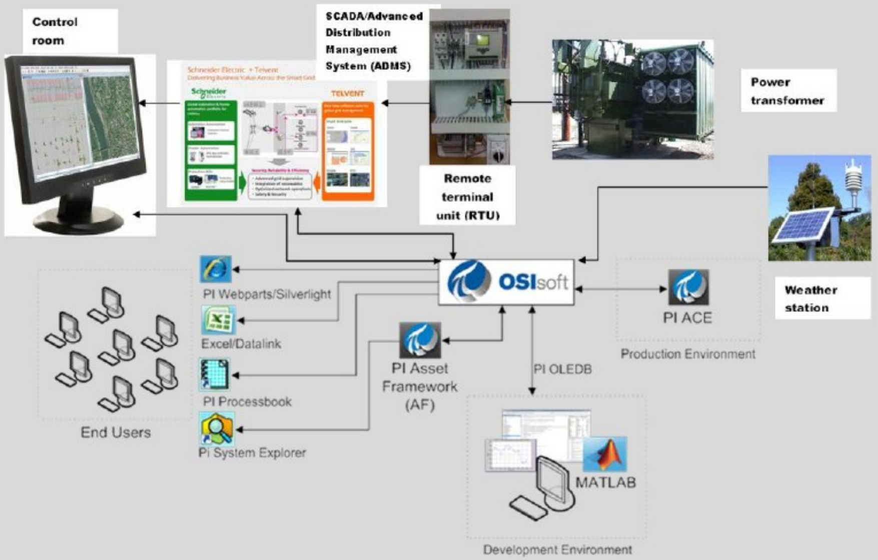


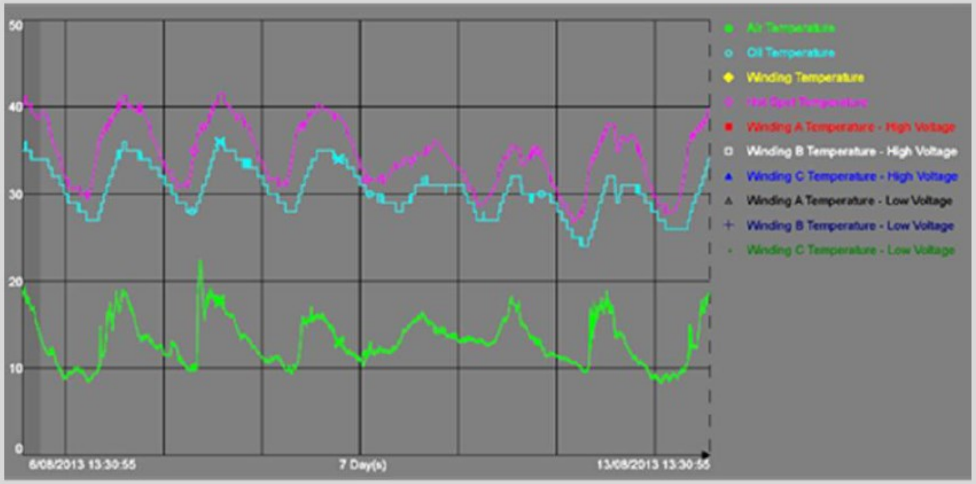
Dynamic Power Transformer Rating











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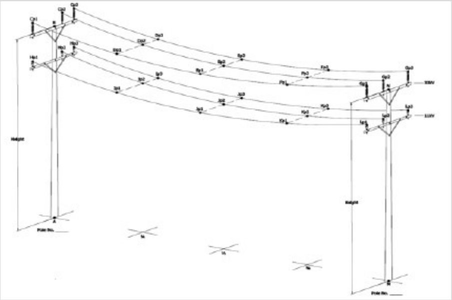
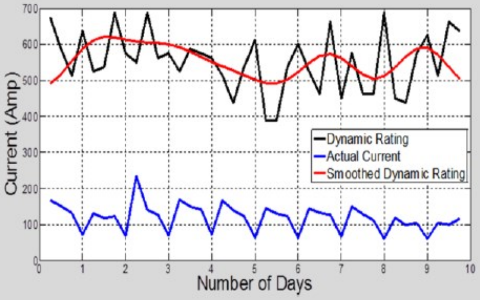
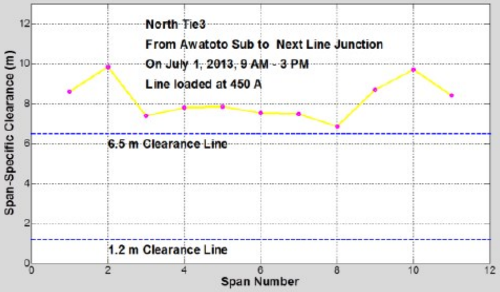
Overhead Lines Rating

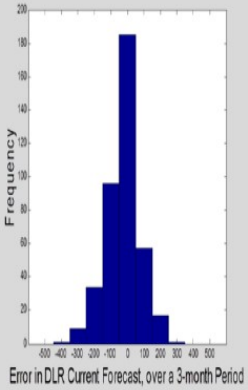


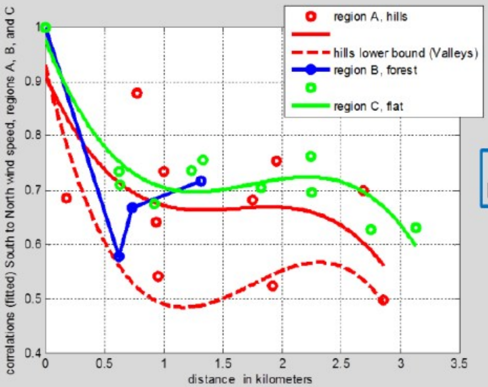
$$mc\frac{dT_{av}}{dt} = P_J + P_S - P_R - P_C$$

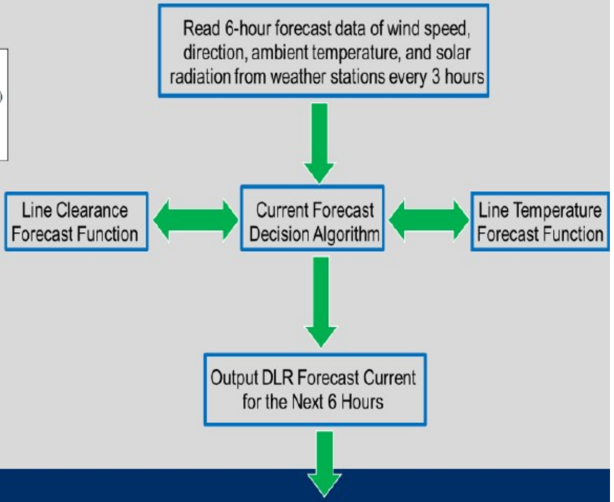
Where P_J is the I^2R or "Joule" heating, P_S is the solar heat gain, P_R is the radiative heat loss P_C is the convective heat loss, m is the conductor mass per unit length, and c is the specific heat capacity.











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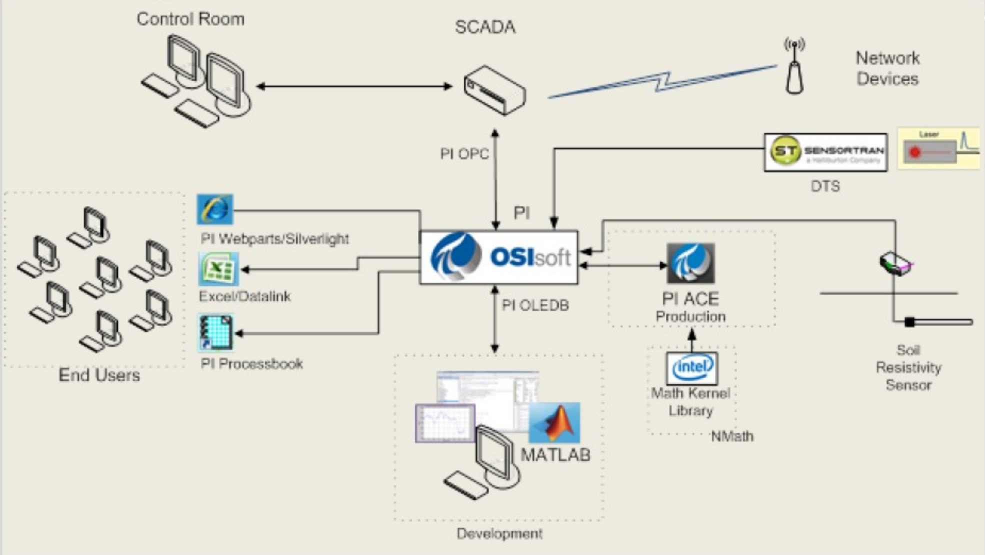
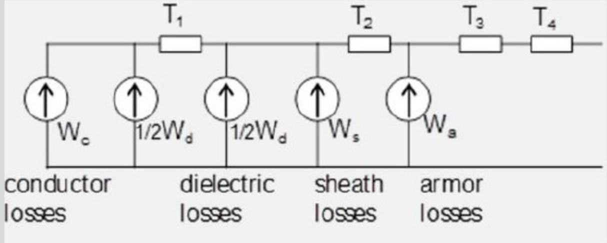
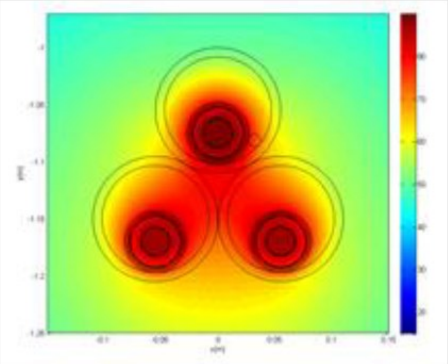
Underground Cable Rating



Heat equation with internal heat generation

$$\frac{\partial^2\theta}{\partial x^2}+\frac{\partial^2\theta}{\partial y^2}+W_{\text{int}}\,\rho=\frac{1}{\delta}\frac{\partial\theta}{\partial t}$$





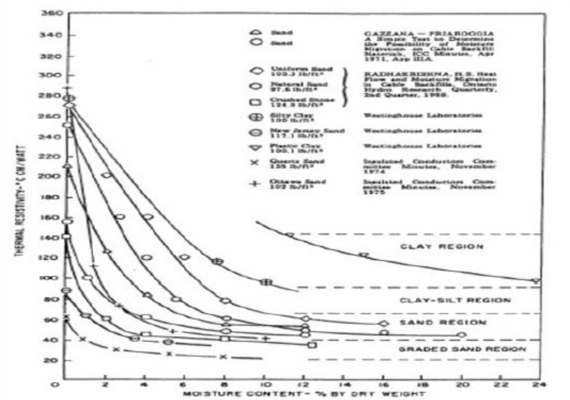
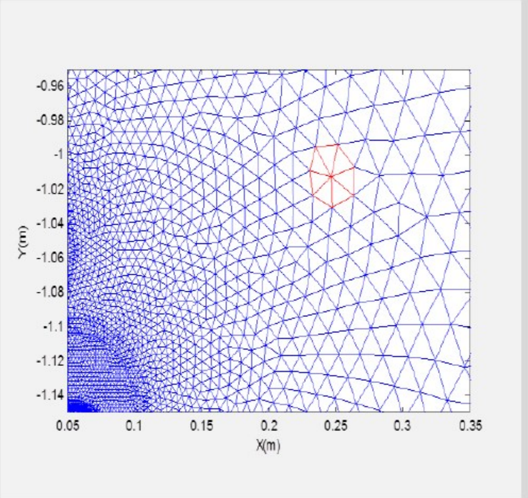


Figure 3—Thermal Property Characteristics of Soils



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- National Institute of Standards and Technology (NIST), USA

References:

[1] A. Lapthorn, Smart Grids in a New Zealand Context, University of Canterbury/MBIE, 2012

[2] P. Behrens, Monitoring mechanisms for tracking the progress towards a smarter grid in New Zealand, NERI/MBIE, August 2013


Questions?