IEEE ENERGY CON 2014-Invited Talk

Robust Power System Operation: Needs and Solutions

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May 15, 2014

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TEXAS A&M ENGINEERING EXPERIMENT STATION

Outline

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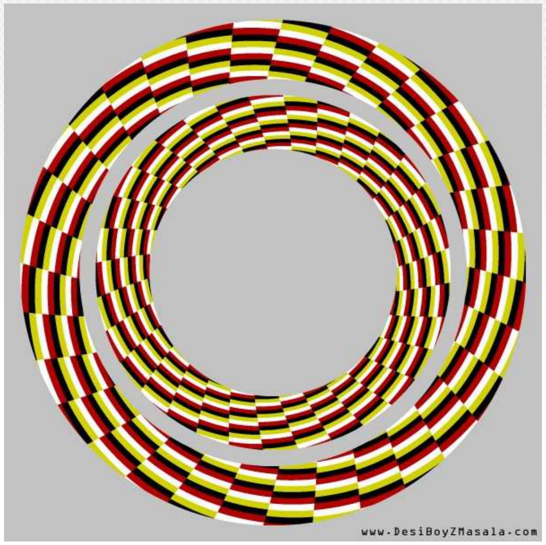

- The big picture and focus
- Status of legacy solution
- Automated assessment
- Mitigation approaches
- Use cases

Outline

The big picture

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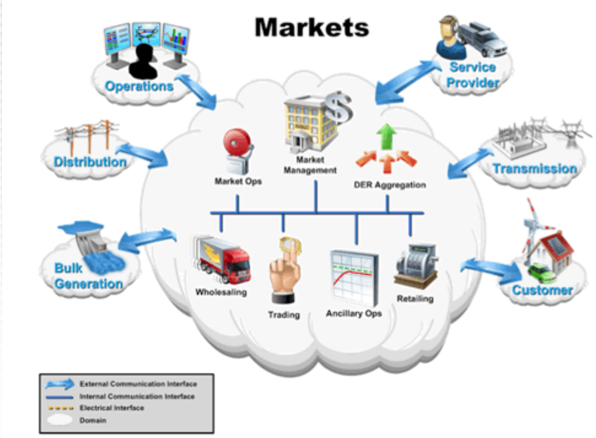
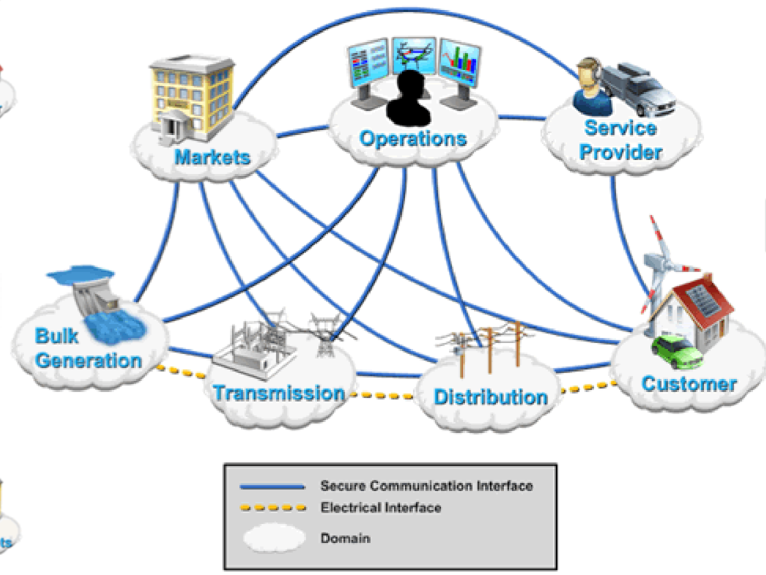
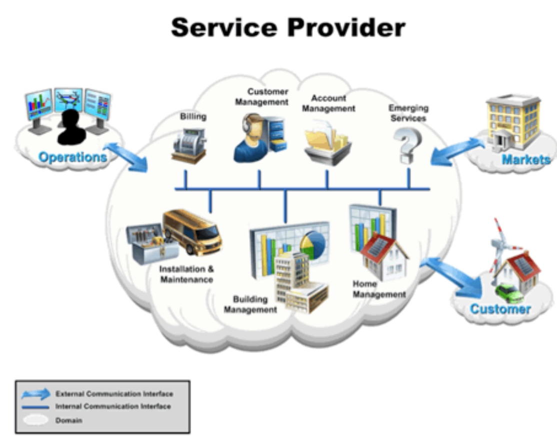
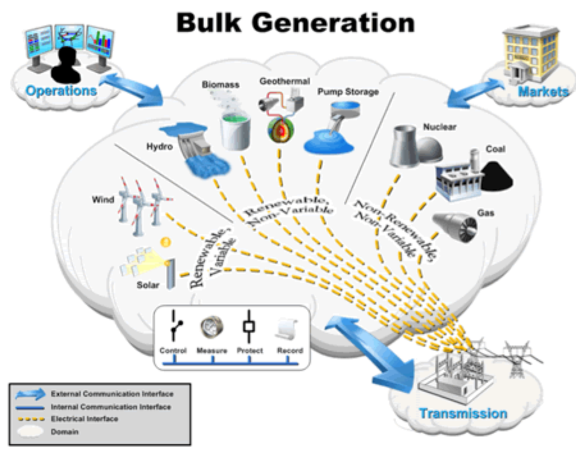
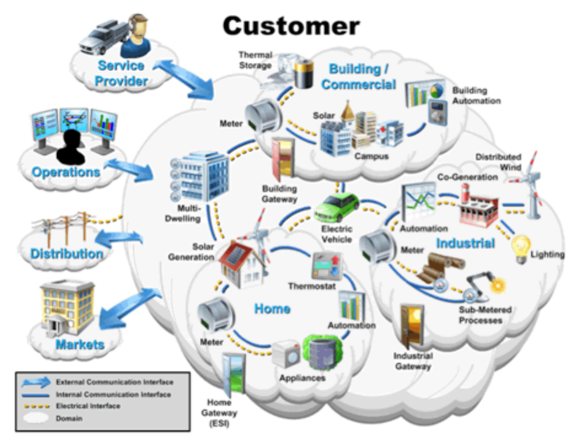


Infrastructure





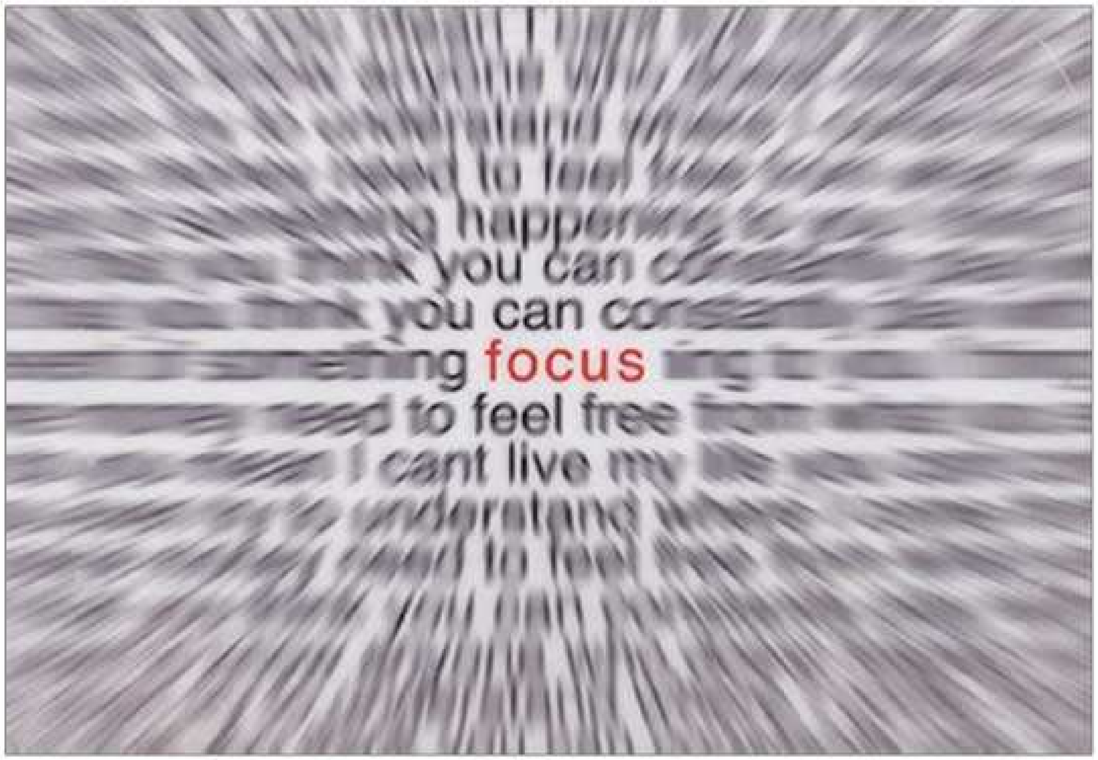




Disturbance classification

Disturbance Cause Impact/Action	Fault	Cascade	Operating condition	Malicious attack
Safety	De-energize, isolate			
System collapse		Arrest cascade		
Unwanted conditions			Correct conditions	
Intended Damage				Prevent intended damage

Outline



Expectations

- **Customer**
- **Asset Owner**
- **Market Operator**
- **Regulator**
- **Public**

Customer

Cost to customers: Transparent

Safety: No harm to humans and animals

Environment: No harm to ecosystem

Resiliency: Graceful degradation

Security: Awareness

Privacy: *Trustworthiness*

Continuity of service: Perfect Power

Reporting: *What went wrong*

Focus

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Asset Owner

Minimize damage to equipment

Reduce restoration time

Reduce inspection cost

Avoid collateral damage

Avoid loss of income

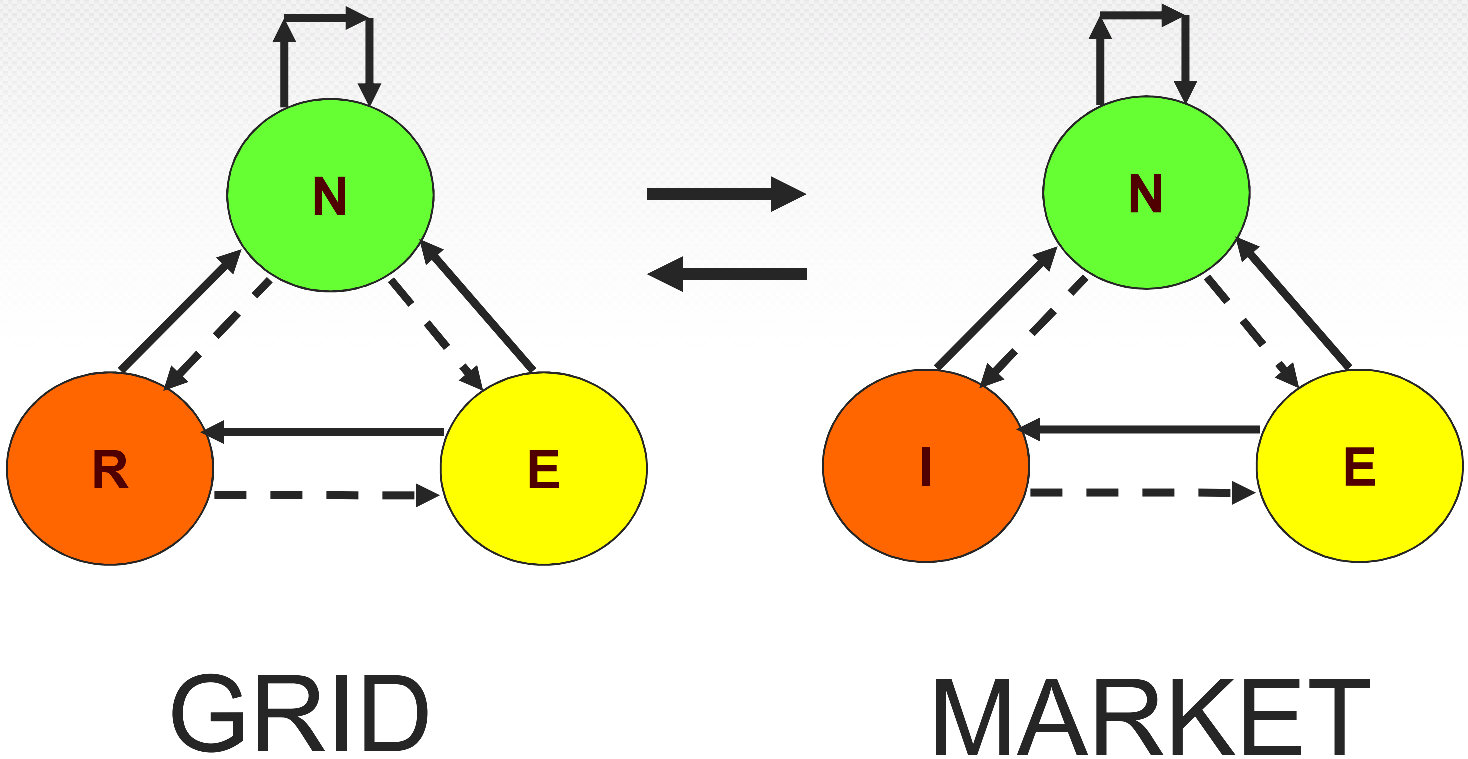
Decrease outage time

Avoid penalties

Improve image

Focus

Market Operator



Regulator

- Check whether utilities did their best
- Accommodate changes in regulation
- Make sure lessons are learned
- Confirm technical competence
- Maintain public confidence
- Avoid major disasters
- Provide transparency
- Keep statistics

Public

- Transparency across social groups
- Be informed what the reasons are
- Assure negligence is not a cause
- Public is not at-risk
- Avoid public unrest/riot
- Health is not affected
- Environment is not affected
- Media coverage is trustworthy
- Ubiquitous service

Outline

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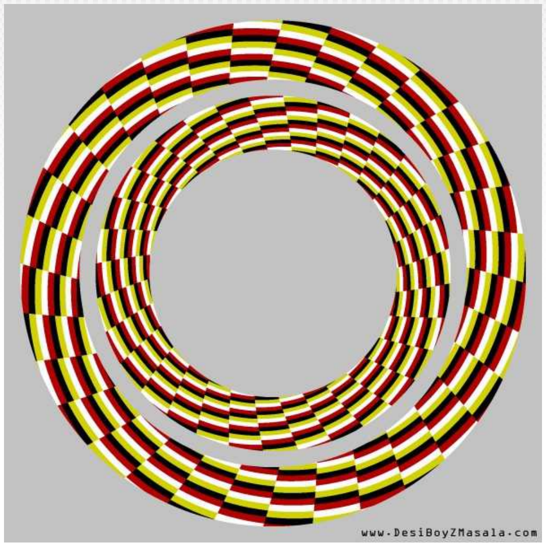

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What is the status

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Future Electricity Grid

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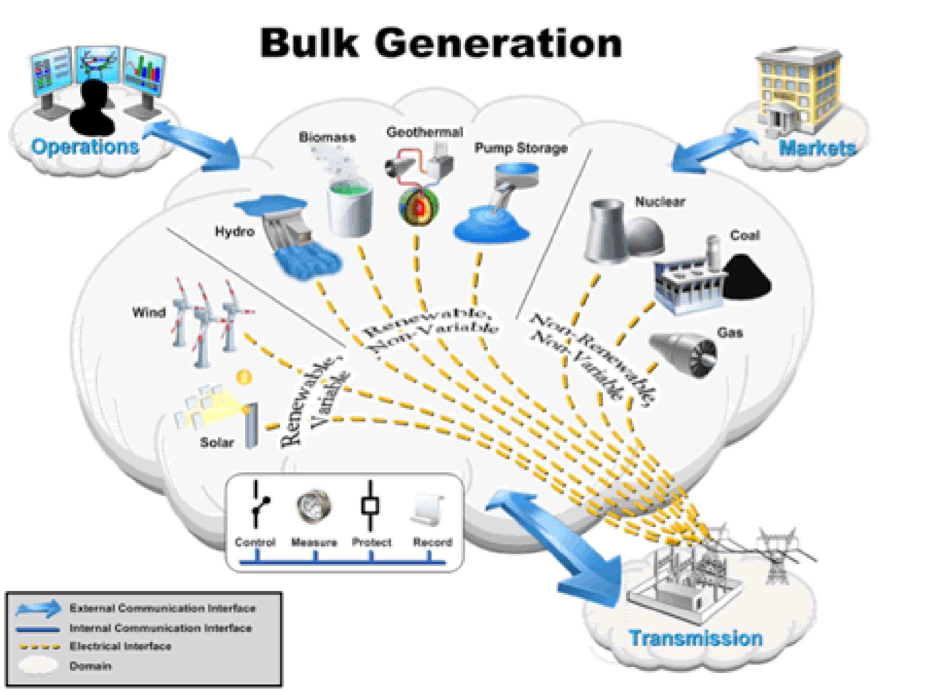
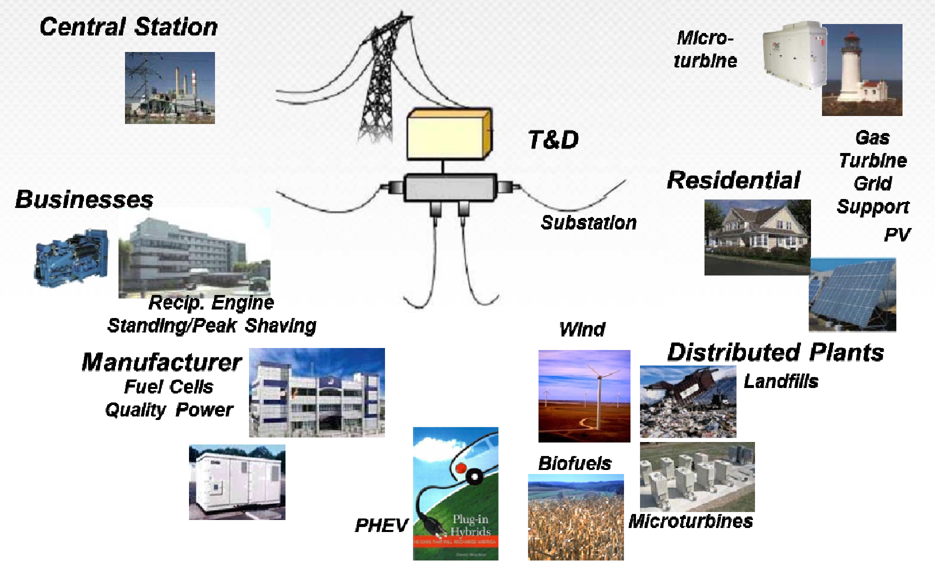
Generation

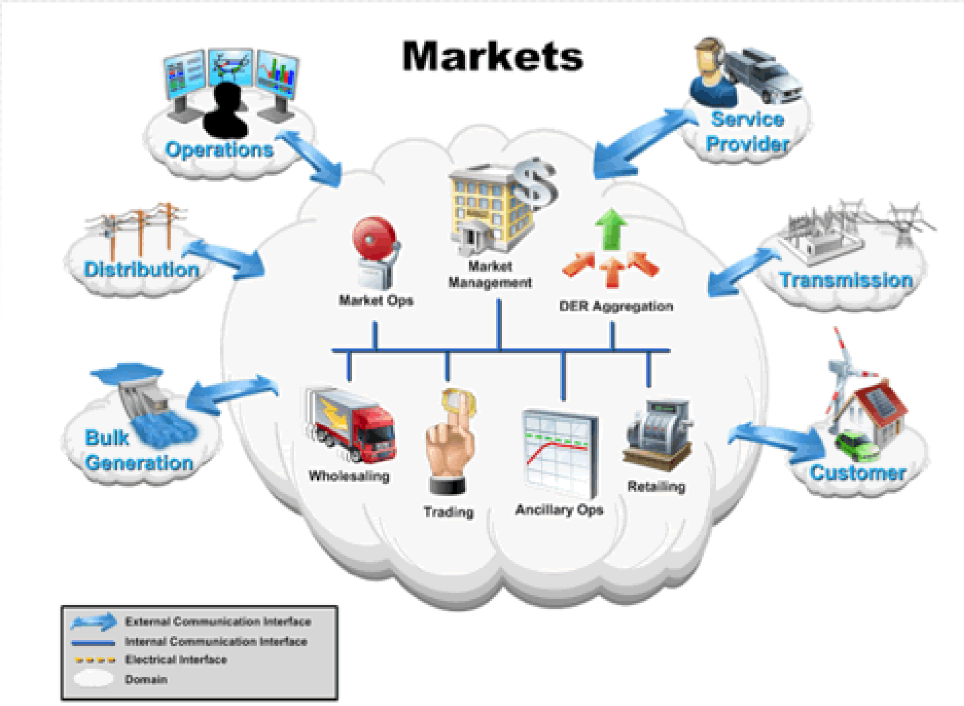




Operations

- Energy Management Systems, used by TOs and ISOs for 50 years are designed for normal operation
- Distribution Management Systems (DMS), used by distribution companies for 10 years are not mature yet
- Synchrophasor Wide-Area Measurement Systems (WAMS), primarily used by TO and ISOs over 5 years are still underutilized
- Smart Meter Systems (SMS) are used by utilities for 5 years but primarily for remote reading
- Intelligent (all-digital) substation automation (SA), used at T&D level for 15 years are still underutilized
- Digital protective relays (DPR) used at all voltage levels for 30 years are still mimicking legacy concept
- Power flow controllers (FACTs, SVCs, LTCs, Rectors, Capacitors), know for 30 years, are still pretty expensive

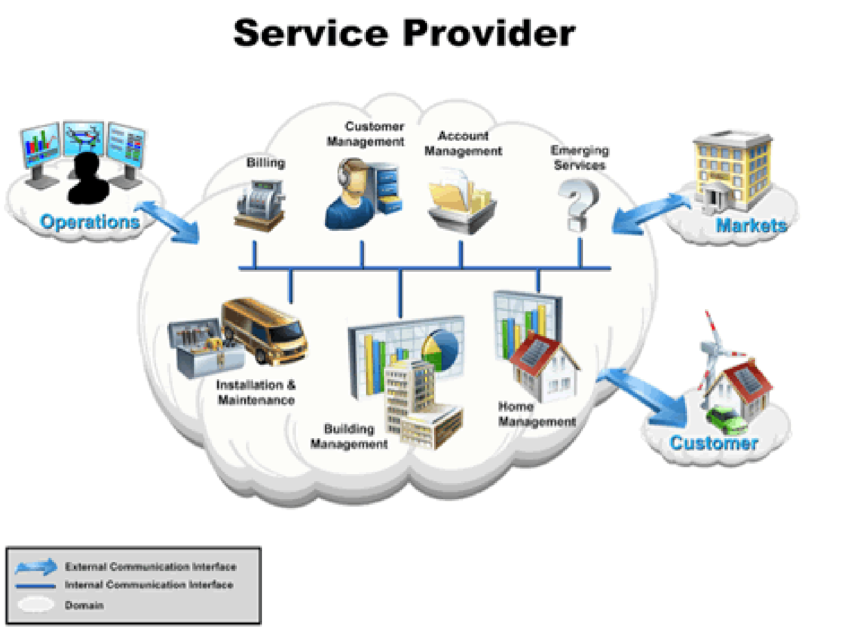
Markets

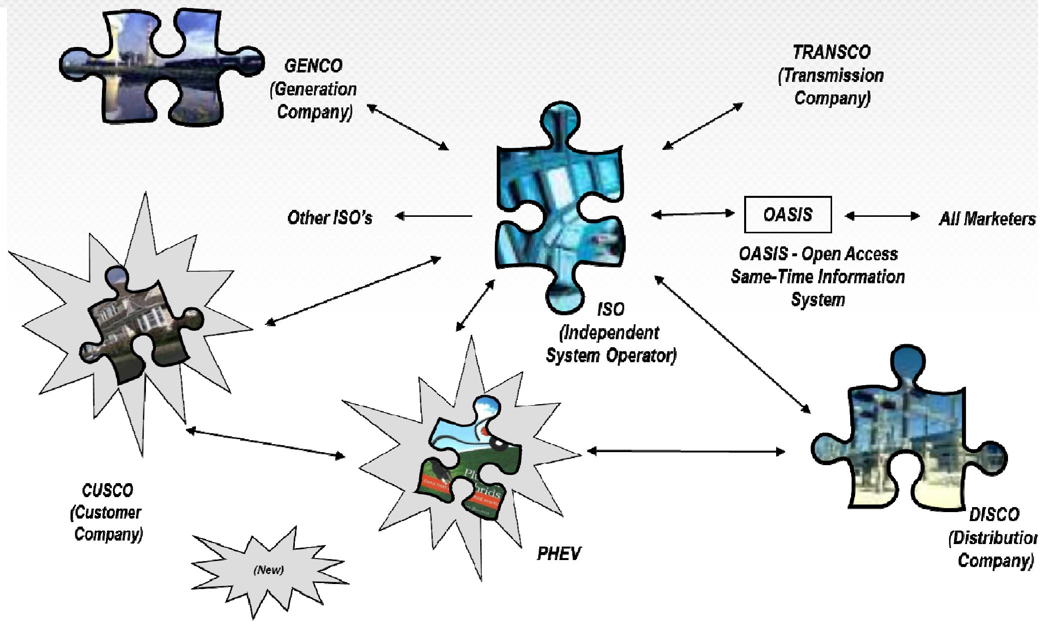


Type	Configuration	Market Parameters
Normal	All MPs Complete	Within limits
Emergency	All MPs Complete	One or more parameters violate the limits
Restorative	Structure incomplete	Within limits

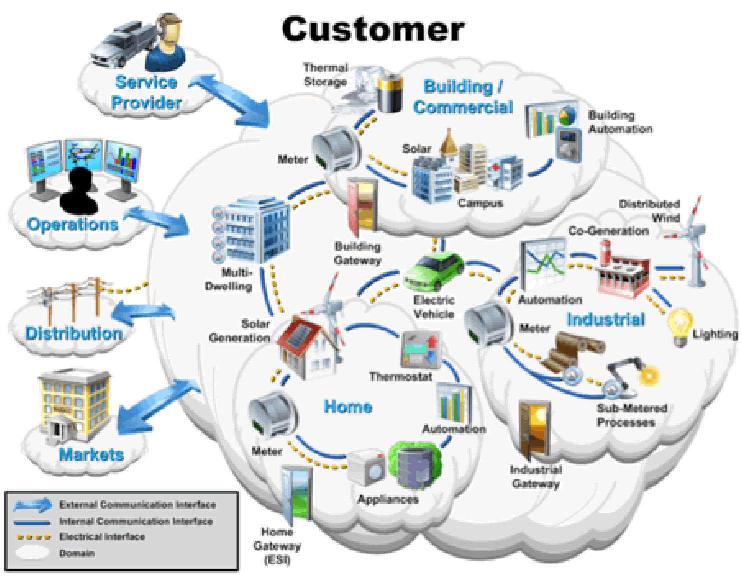
*MPs (Market Participants) include generator companies, transmission owners, load serving entities and other nonasset owners such as energy traders.

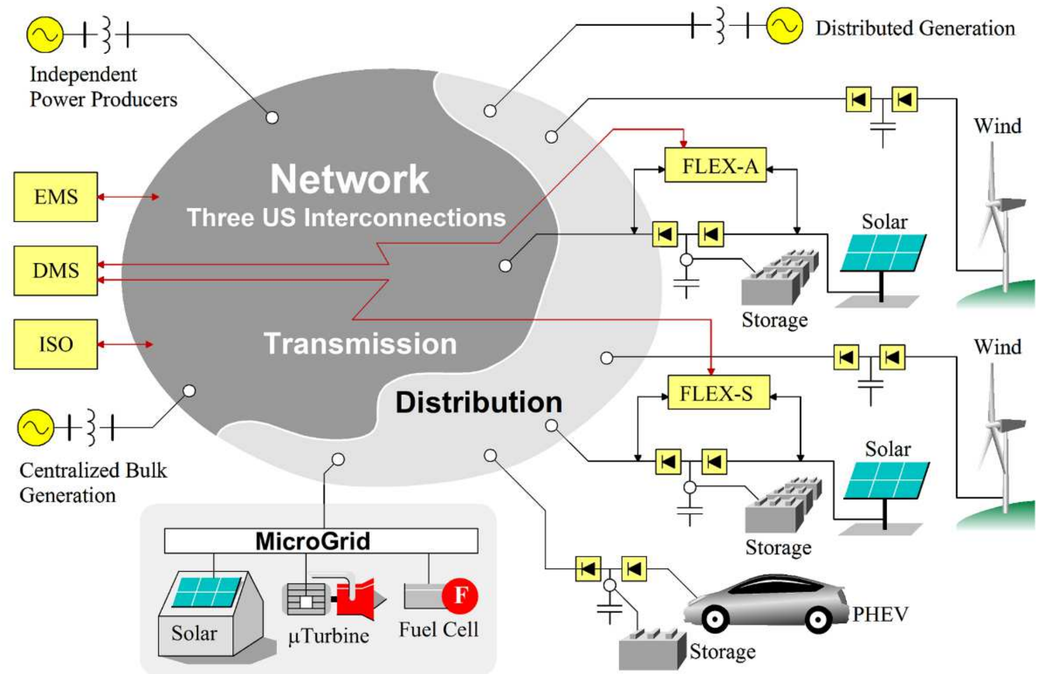
Service providers



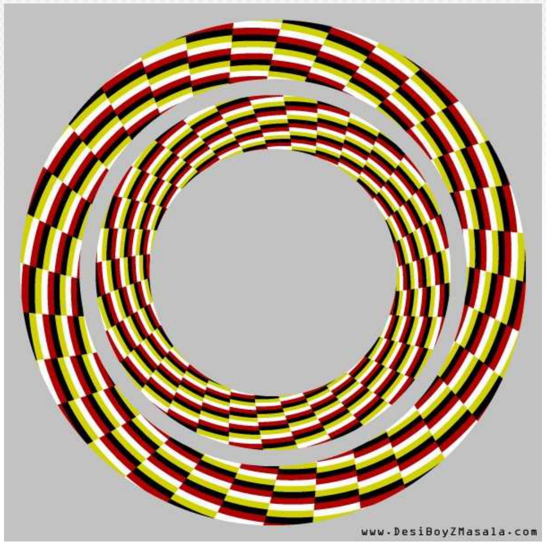


Customer


Customer
Service Provider
Operations
Distribution
Markets
Building / Commercial
Thermal Storage
Building Automation
Meter
Solar
Campus
Distributed Wind
Co-Generation
Multi-Dwelling
Building Gateway
Electric Vehicle
Automation
Industrial
Lighting
Solar Generation
Meter
Thermostat
Home
Automation
Sub-Metered Processes
Meter
Appliances
Industrial Gateway
Home Gateway (ESI)
External Communication Interface
Internal Communication Interface
Electrical Interface
Domain


Independent Power Producers
Distributed Generation
Network
Three US Interconnections
EMS
DMS
ISO
Transmission
Distribution
FLEX-A
FLEX-S
Wind
Solar
Storage
Wind
Solar
Storage
Centralized Bulk Generation
MicroGrid
Solar
µTurbine
Fuel Cell
PHEV
Storage

Outline



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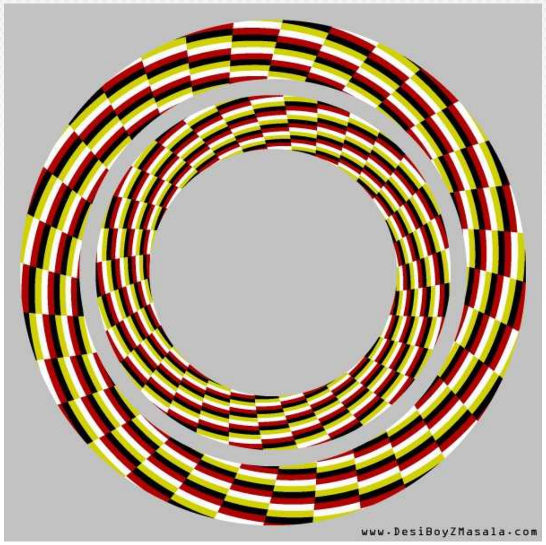
Tasks

- Detect and classify events
- Track status of power apparatus
- Track performance of control equipment
- Track environmental conditions
- Understand cause-effect
- Predict, correct, adapt

Outline



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Mitigation Approaches

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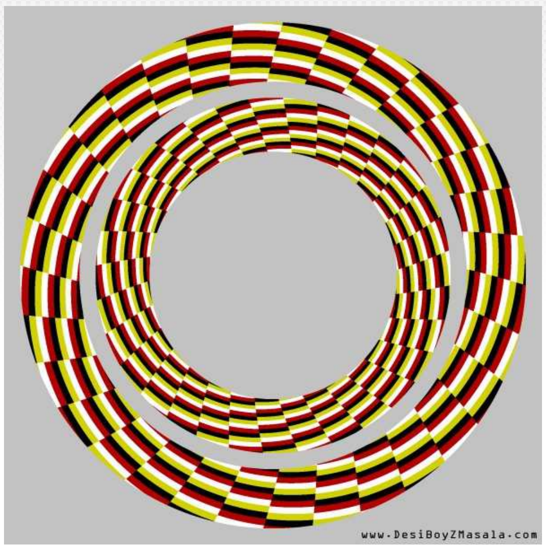
Tasks

- De-energize and isolate a faulted segment
- **Use flexible load as a resource**
- Monitor condition and reduce risk
- Switch topology
- Take SIPS decision on a fly
- Arrest cascade
- Anticipate and avoid failure

Outline



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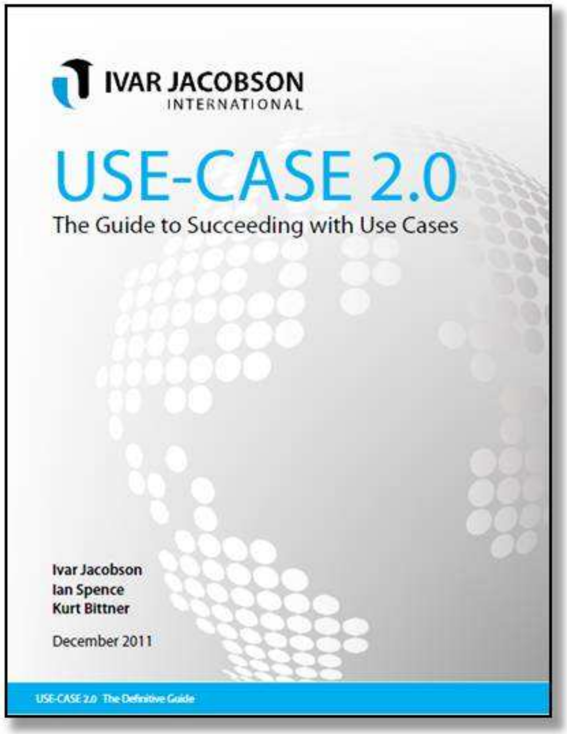
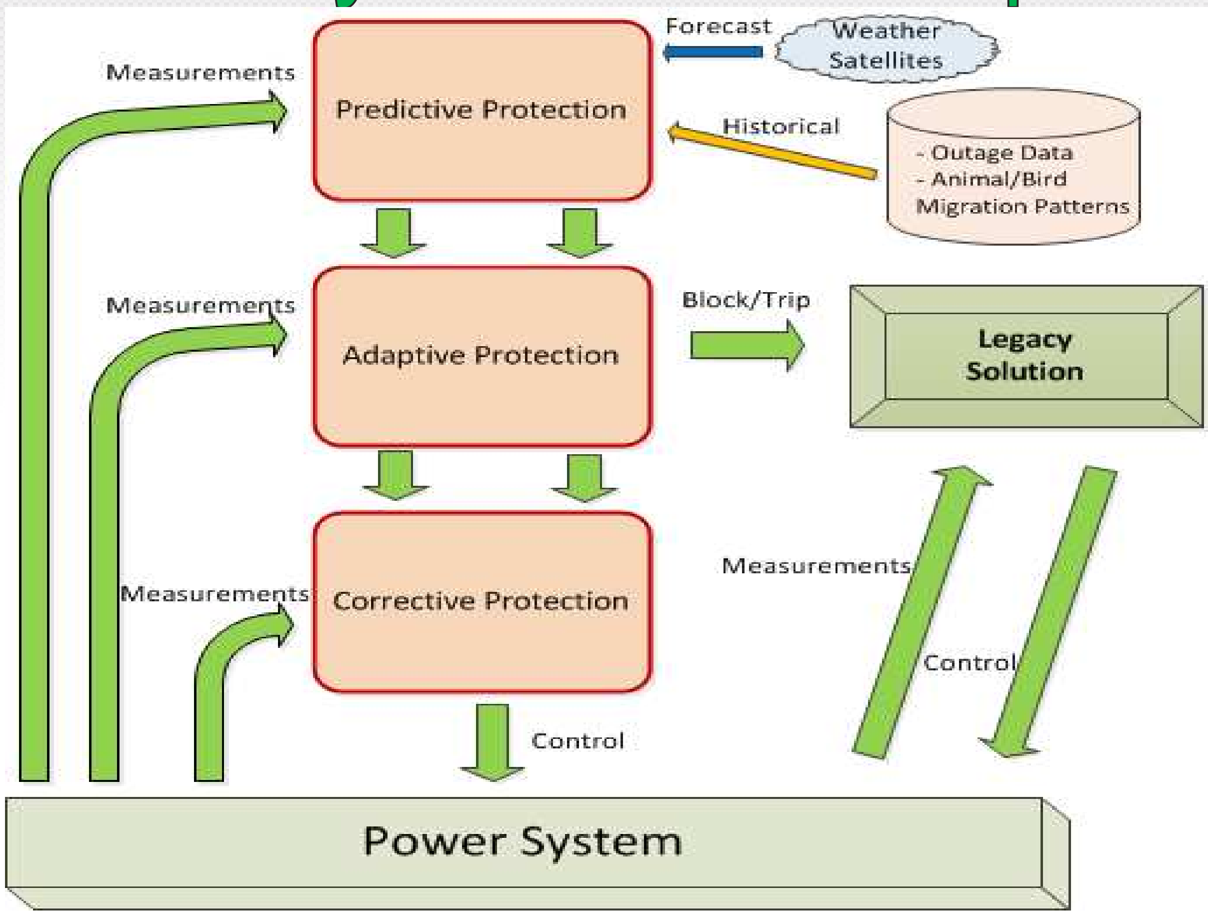
Examples

- Hierarchically coordinated protection
- Automated analysis of faults
- Economic alarms processor
- Detection of cascades
- Transmission line switching
- Use electrical vehicles in V2B
- Model-based fault location
- Risk-based CB assessment



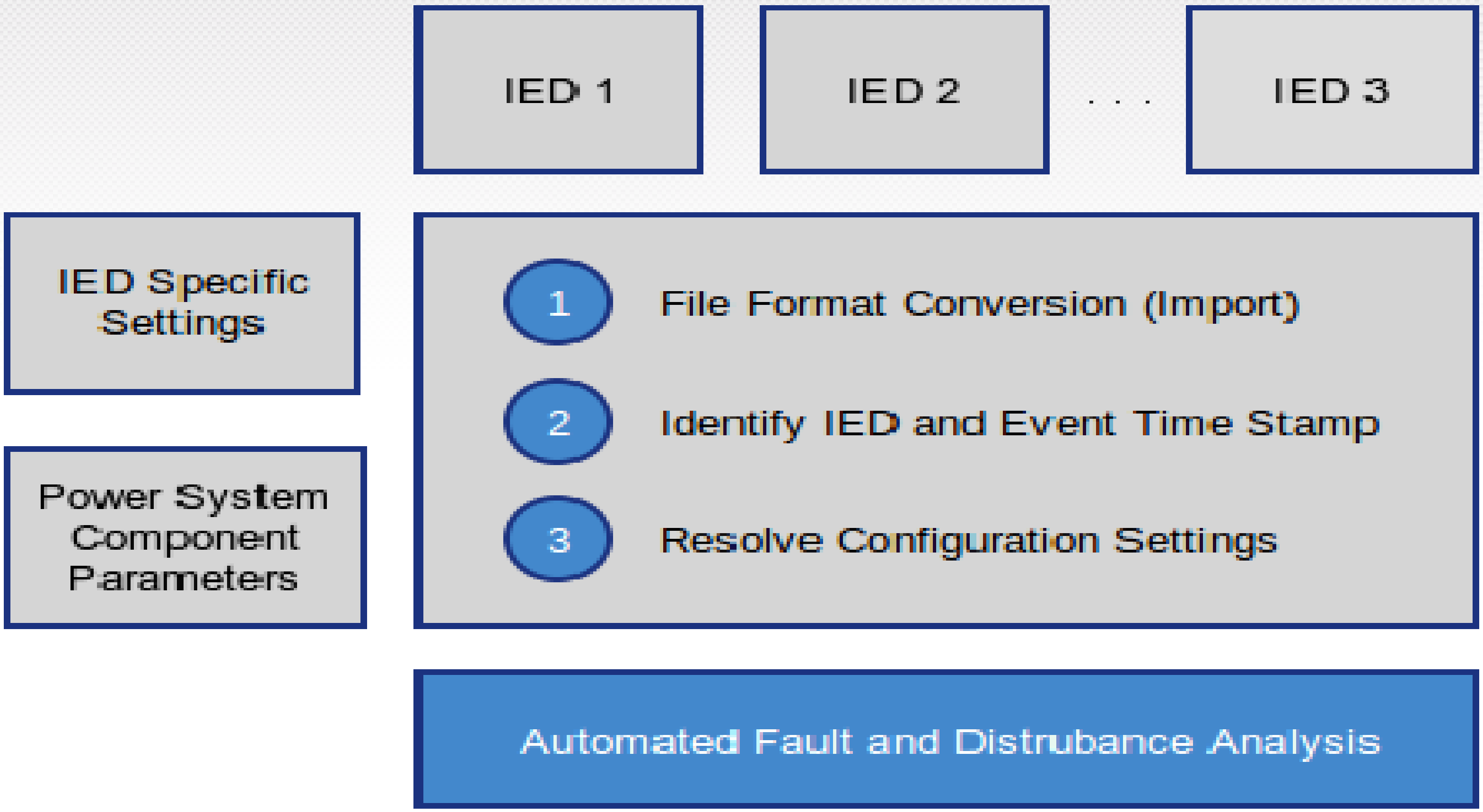
M. Kezunovic, J.D. McCalley, and T.J. Overbye, "Smart Grids and Beyond: Achieving the Full Potential of Electricity Systems," Proceedings of the IEEE, Vol.100, Special Centennial Issue, pp.1329-1341, May 13 2012.

Hierarchically coordinated protection



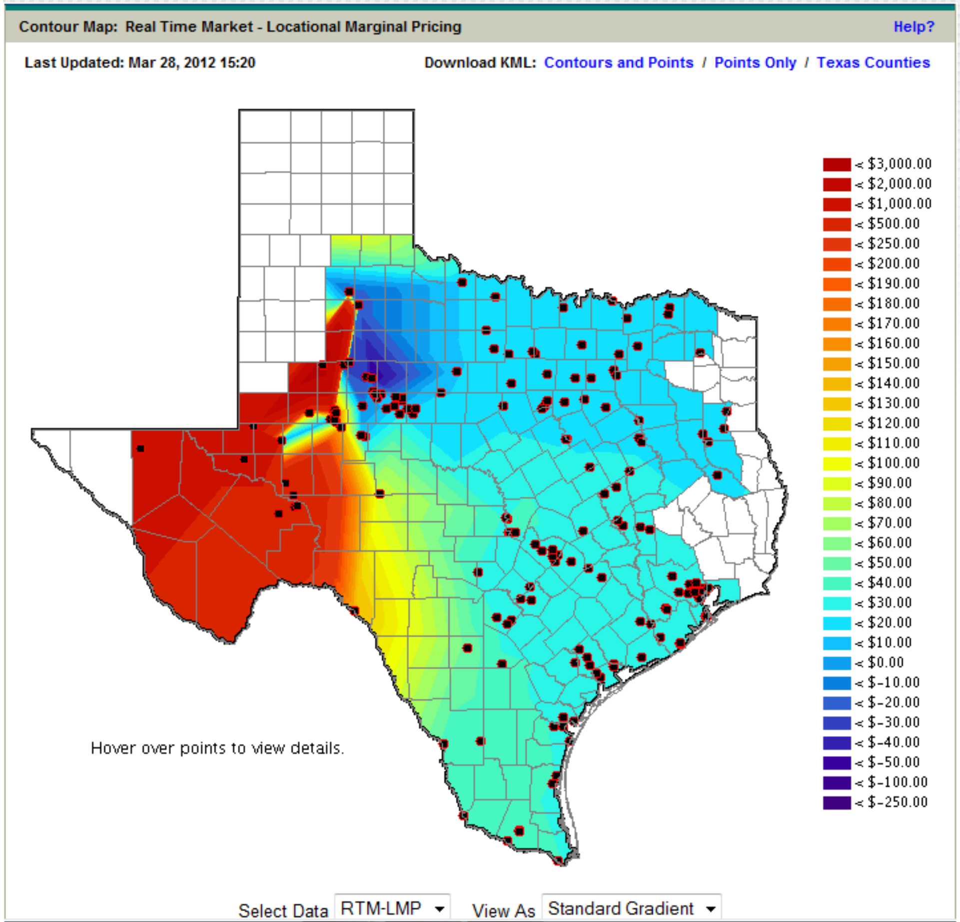
M. Kezunovic, B. Matic Cuka, "Hierarchical Coordinated Protection With High Penetration of Smart Grid Renewable Resources (2.3)," PSerc/DOE Workshop, Madison, WI, May 2013.

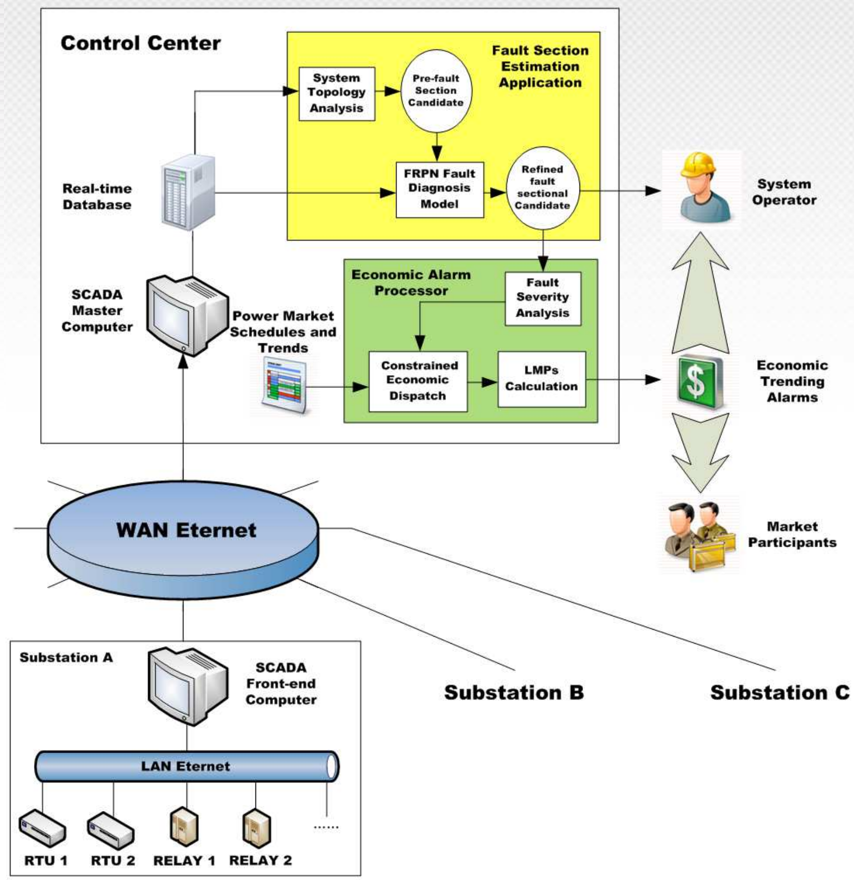
Automated analysis of faults



T. Popovic, M. Kezunovic, B. Krstajic, "Smart Grid Data Analytics for Digital Protective Relay Event Recordings," Information Systems Frontiers, Springer, June 2013.

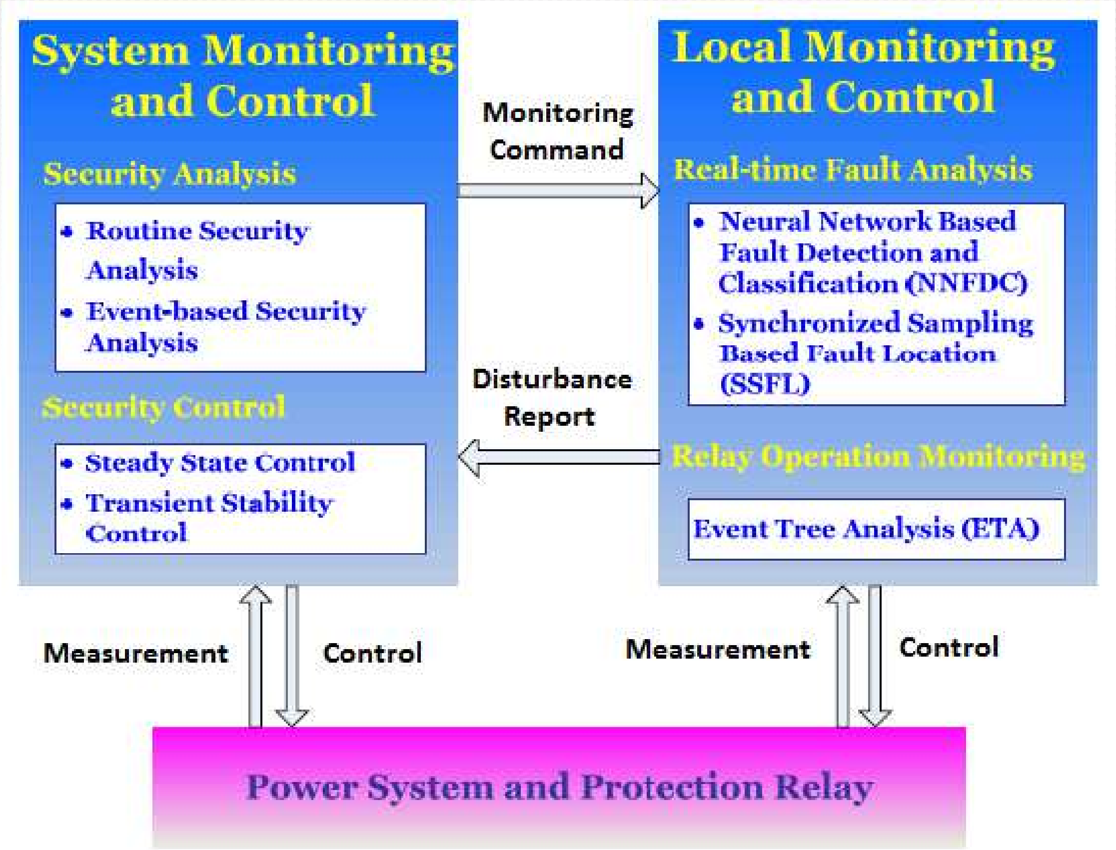
Economic Alarm Processor





Y. Guan, M. Kezunovic, "Contingency-based Nodal Market Operation Using Intelligent Economic Alarm Processor", IEEE Trans on Smart Grid, IEEE Trans on Smart Grid, vol.4, no.1, pp.540-548, 2013

Detection of cascades



H. Song, M. Kezunovic, "A New Analysis Method for Early Detection and Prevention of Cascading Events," Electric Power Systems Research, Vol. 77, Issue 8, Pages 1132-1142, June 2007.

Examples

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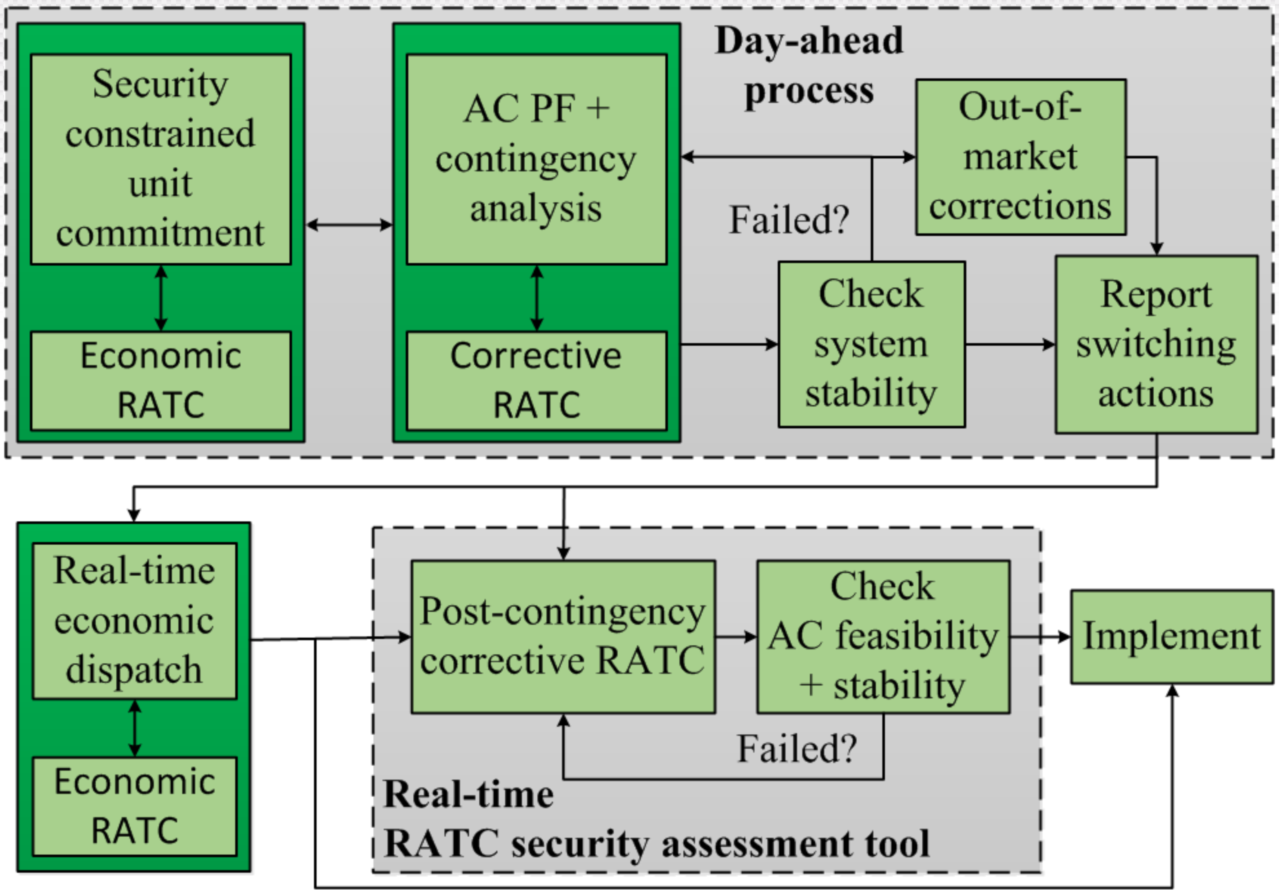
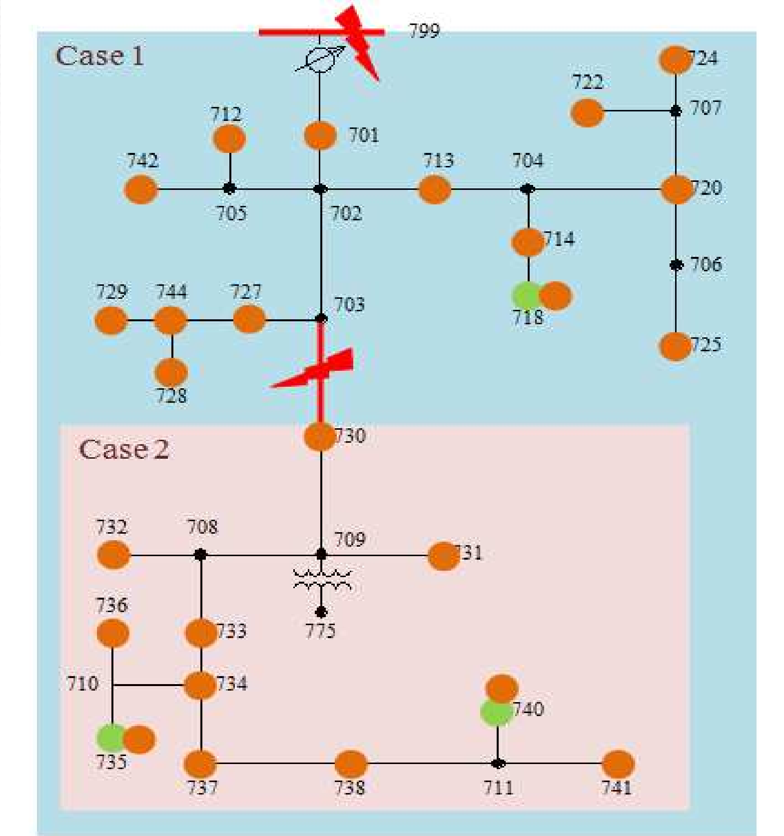
Transmission Line Switching



M. Kezunovic, T. Popovic, G. Gurrala, P. Dehghanian, A. Esmaeilian, M. Tasdighi, "Reliable Implementation of Robust Adaptive Topology Control," HICCS - Hawaii International Conference on System Science, Manoa, Hawai, January 2014.

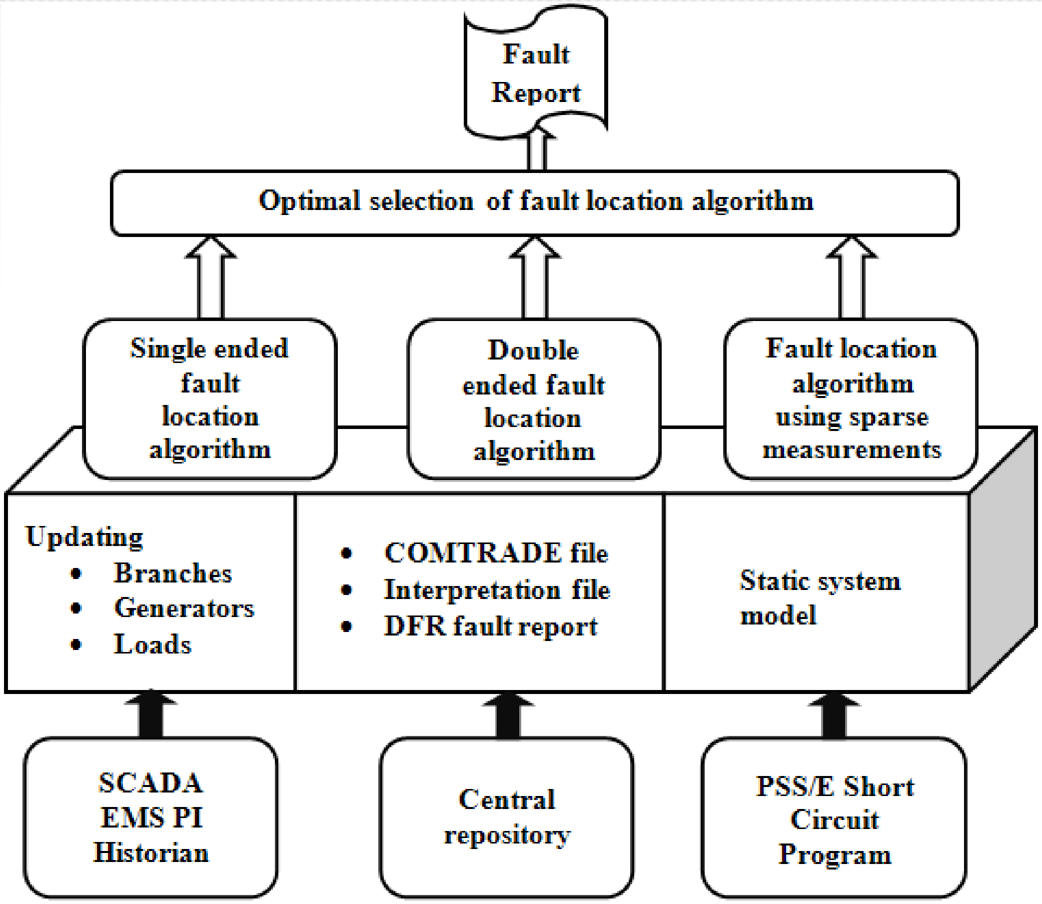
Use of electrical vehicles in V2B

Auto Model	Battery Type	Capacity (minimum)	Range	Charging Time
Chevy Volt	Lithium Ion	16 kWh	40 miles	6-6.5 hours (240V)
Nissan Leaf	Lithium Ion	24 kWh	73 miles	7 hours (240V) 30 minutes (quick charger)



C. Pang, P. Dutta, M. Kezunovic, "BEVs/PHEVs as Dispersed Energy Storage for V2B Uses in the Smart Grid," IEEE Transactions on Smart Grid, Special Issue on Transportation Electrification and Vehicle-to-Grid Applications, Vol. 3, No. 1, pp 473-482, March 2012.

Model-based fault location



M. Kezunovic, "Smart Fault Location for Smart Grids," IEEE Transactions on Smart Grid, Vol 2., No. 1, pp 61-69, March, 2011

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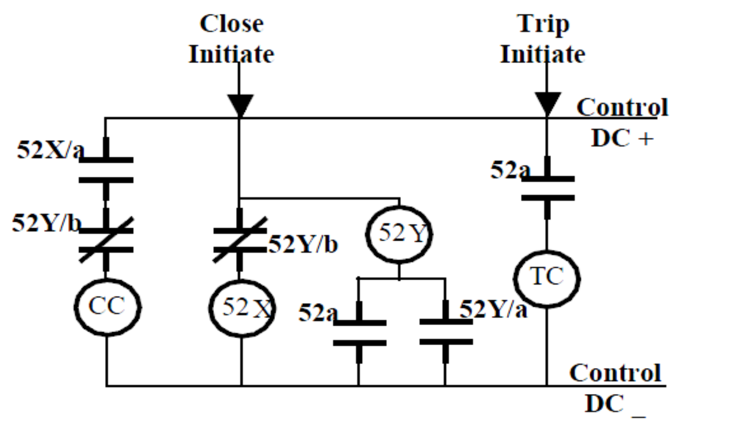
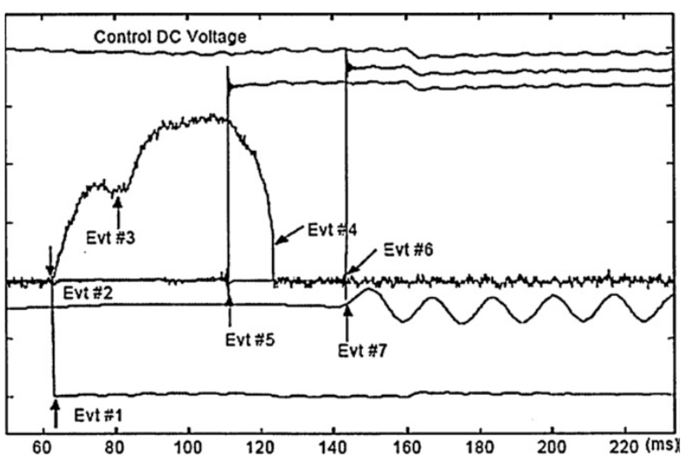
Risk-based CB assessment





Event	Event Description	Signal Parameter
1	Trip of close operation is initiated	t_1
2	Trip coil current picks up	t_2
3	Trip coil current dips after saturation	t_3
4	Trip coil current drops off	t_4
5	B contact breaks or makes (a change of status from low to high or vice verse)	t_5
6	A contact breaks or makes	t_6
7	Phase current breaks or makes	t_7

M. Kezunovic, Z. Ren, G. Latisko, D.R. Sevcik, J. Lucey, W. Cook, E. Koch, "Automated Monitoring and Analysis of Circuit Breaker Operation,"IEEE Transactions on Power Delivery, Vol. 20, No. 3, pp 1910-1918, July 2005

Conclusions

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- Maintaining robustness of power system operation under varying operating and fault conditions is a challenge going forward
- Advanced concepts such as predictive, adaptive and corrective control, as well as model and data based techniques will have to be used
- High level of automation is needed, which also demands the use of Big data, edge processing, high performance computing, flexible load, etc.
- Concepts have also to change in the use and design of monitoring, control and protection systems in the future

Contact

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Thank you!

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