Valuating Infrastructure For a Self-Healing Grid

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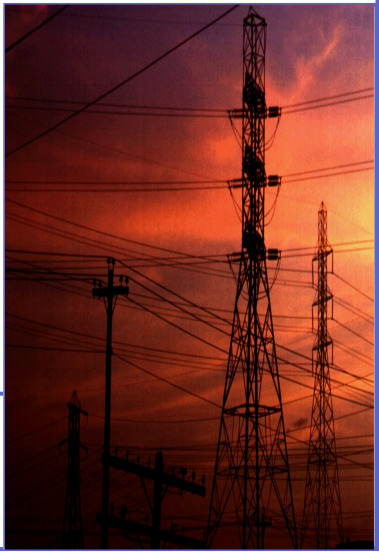

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Presented by:

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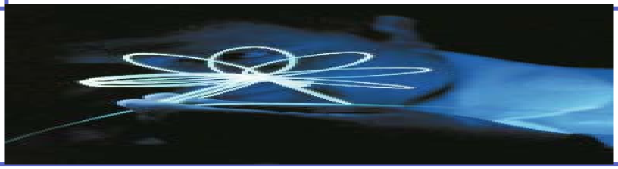

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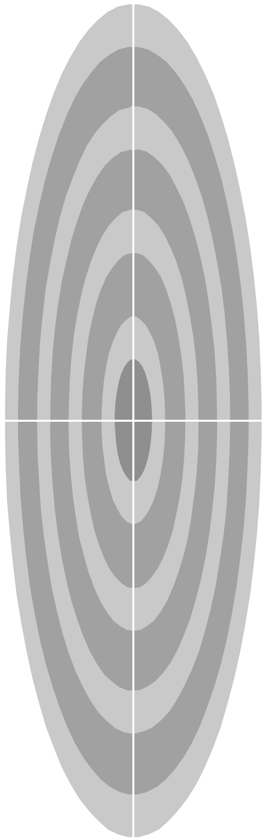
Overview

- **Vision**
- **Background**
  - **Architectural Framework**
  - **Analytical Framework**
- **Valuating**
  - **Cost Models**
  - **Benefit Models**
  - **Business Cases**
  - **Costs-Benefits Analysis**
- **Conclusion**

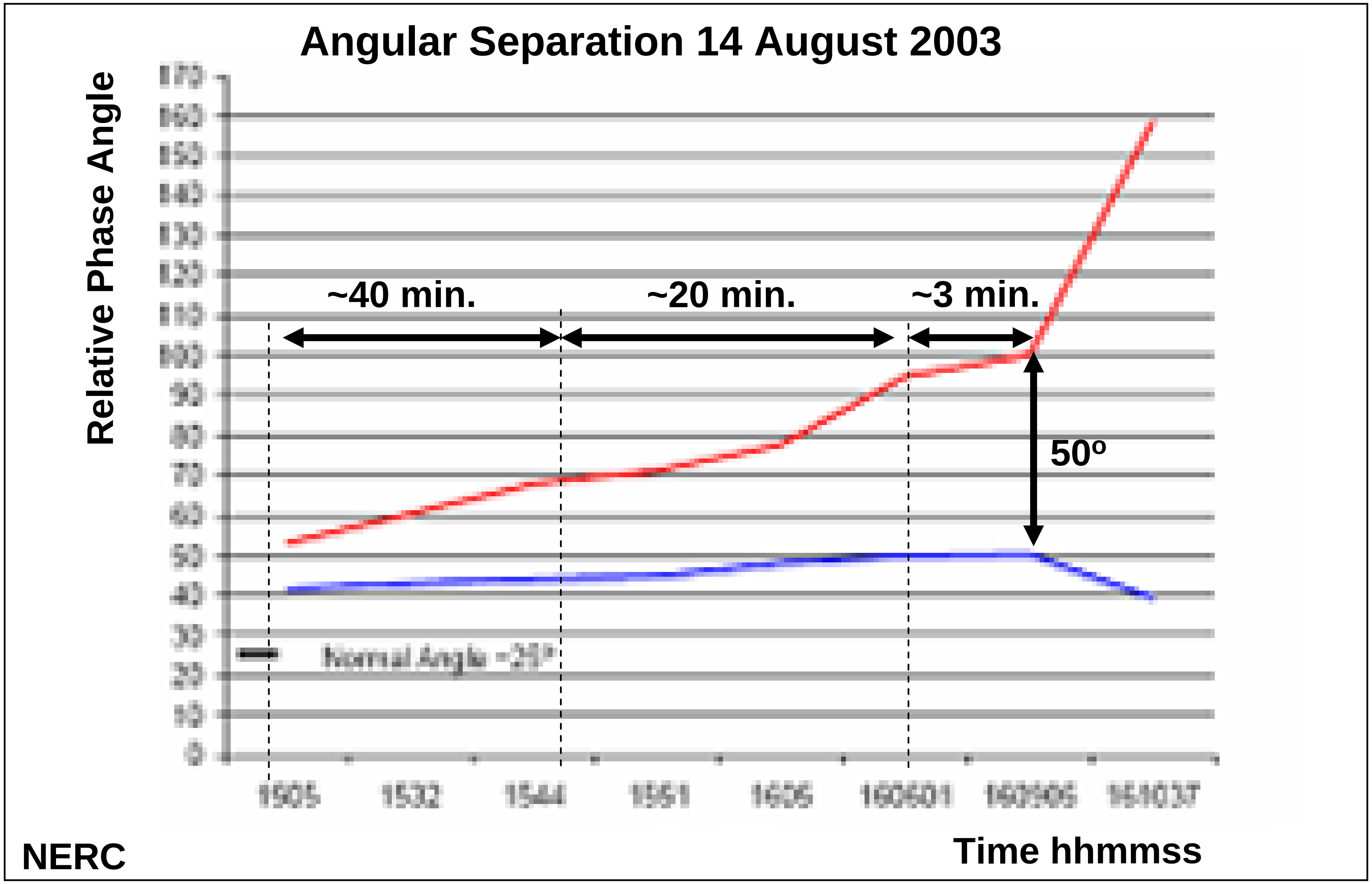


Background: Self-Healing Power Grid

- High reliability
- Non-stop service (or graceful/minimal degradation)
- Fail-proof control actions (no errors of omission or commission)
- Flexible responses to various disturbances and attacks
- Resource deployment to minimize impact of potential problems
- Minimum possible loss of service and time to restore service

- Instances of such features already exist
- They need to be ubiquitous

Background: Blackout Experiences

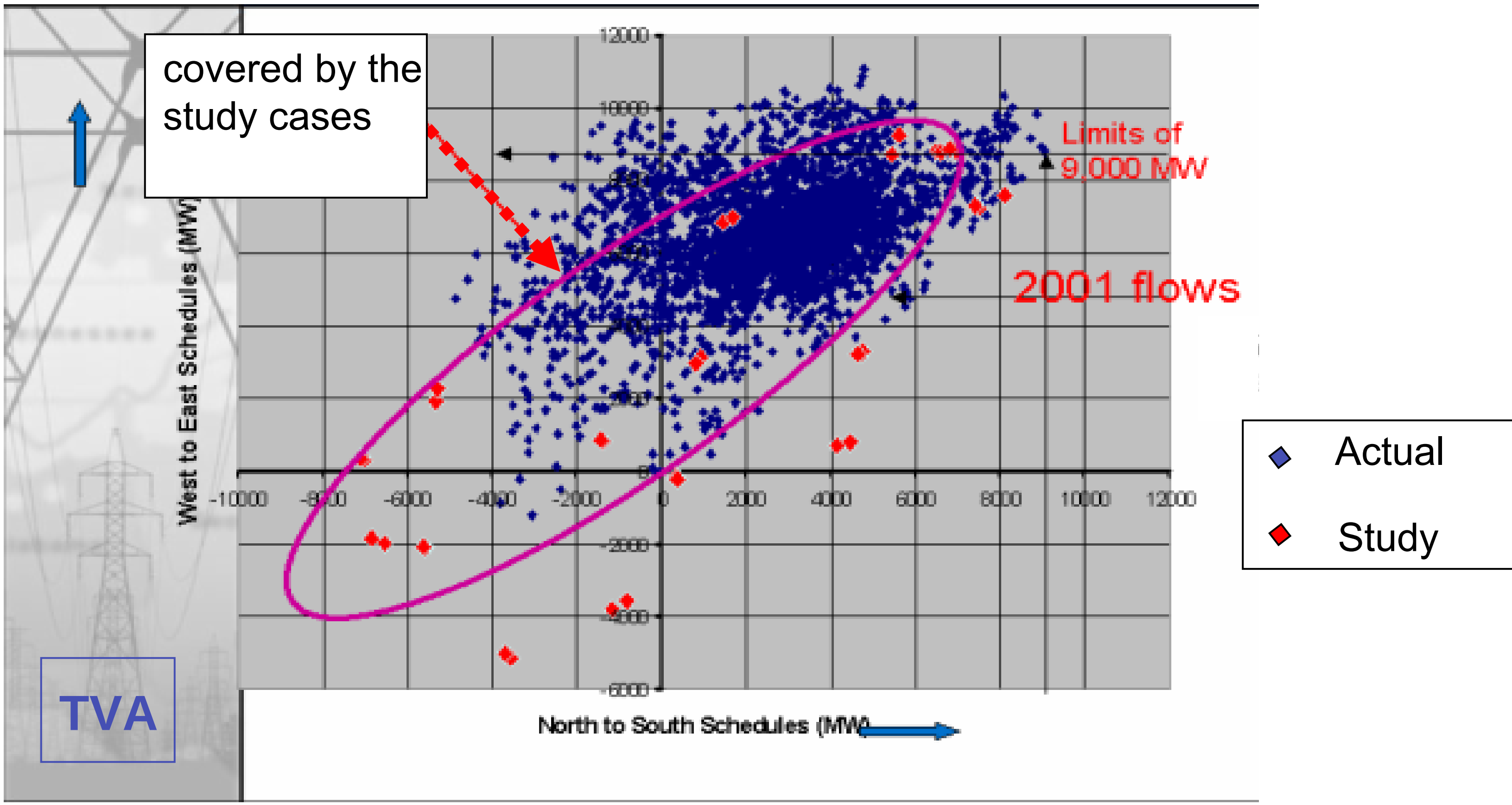


Cleveland

West Michigan (lower trajectory)

Background: Off-line Analyses May not Apply in Real-Time

- Transfer study cases vs. Actual Transfers



Background: Why Self-Healing?

- **Power system is operated much closer to its limits (more often!)**
- **Qualitatively a different operating environment (more touchy!)**
- **Larger foot-print (more pressure on the operator!)**
- **More volatility**
- **More data, more automation, more control (higher performance data processing!)**

Need a higher performance IT infrastructure

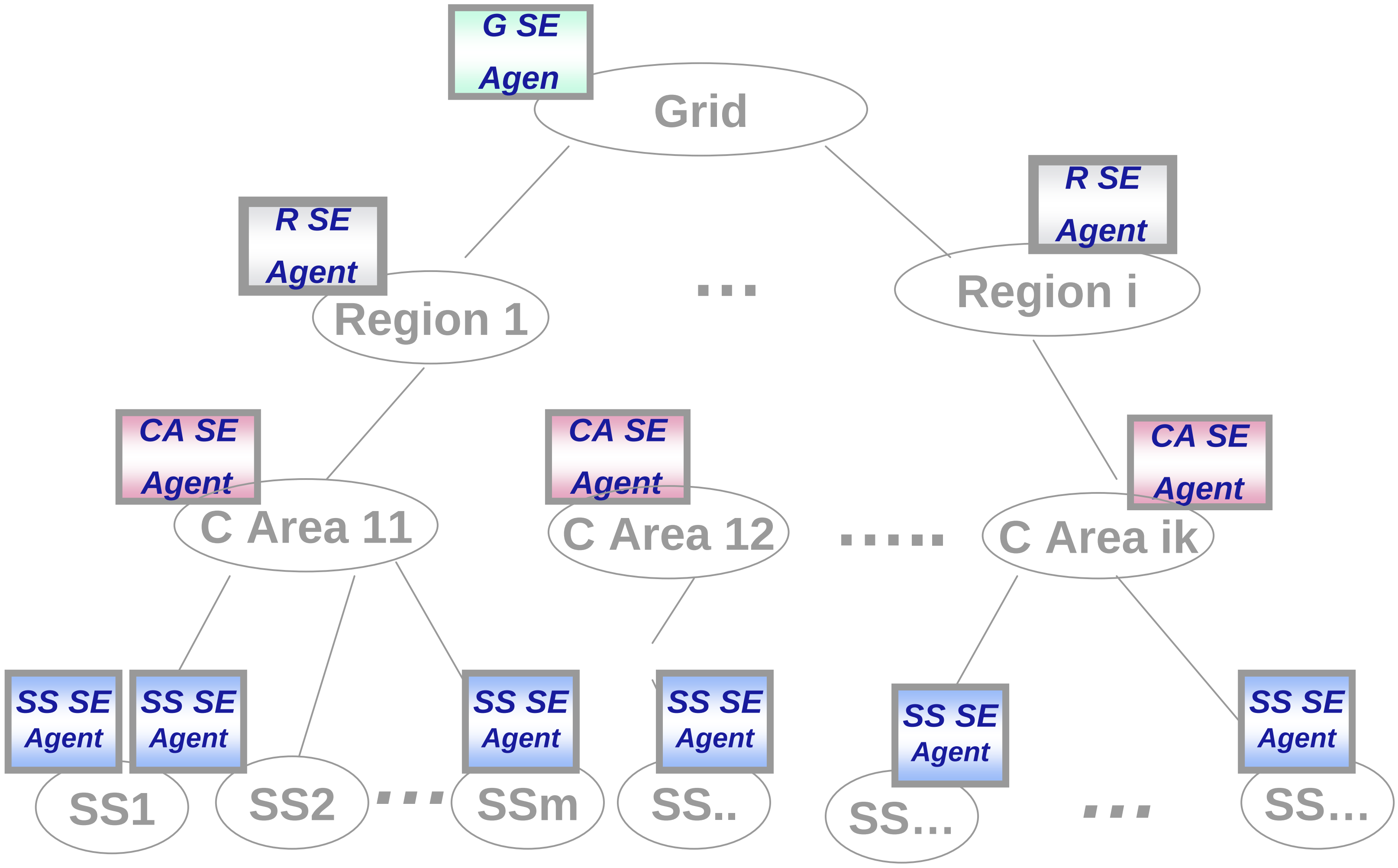
Background: Drivers of Architectural Innovation

- **Large blackouts involve:**
  - Cascading events within seconds
  - Aggravated by uncoordinated and unintelligent local actions
- **Prevention/Containment requires:**
  - Better monitoring
  - Coordinated response
  - Sub-second response
- **Centralized systems are too slow**
- **Distributed autonomous systems**
  - Existing RAS is an early example of distributed intelligence
- **Any number of operating entities (RTO/ISO, TO, etc.)**

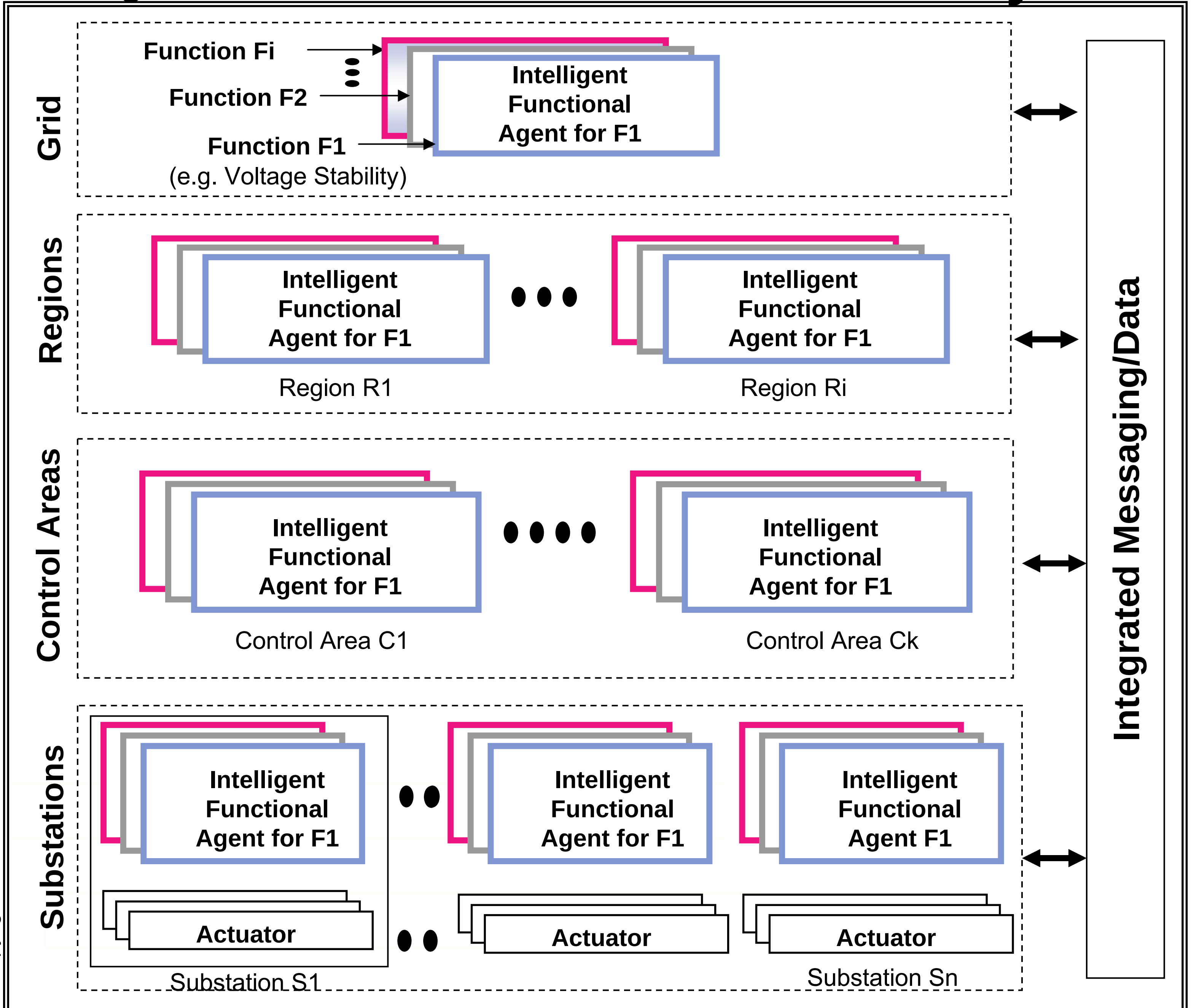
Background: Distributed Intelligent Agents

- **Distributed Agents afford:**
  - Fast response
- **Flexible framework for various strategies**
  - Distributed applications
  - Coordination
    - **Hierarchical**
    - **Temporal**
- **Reusable plug and play components**
- **Greater level of reliability**

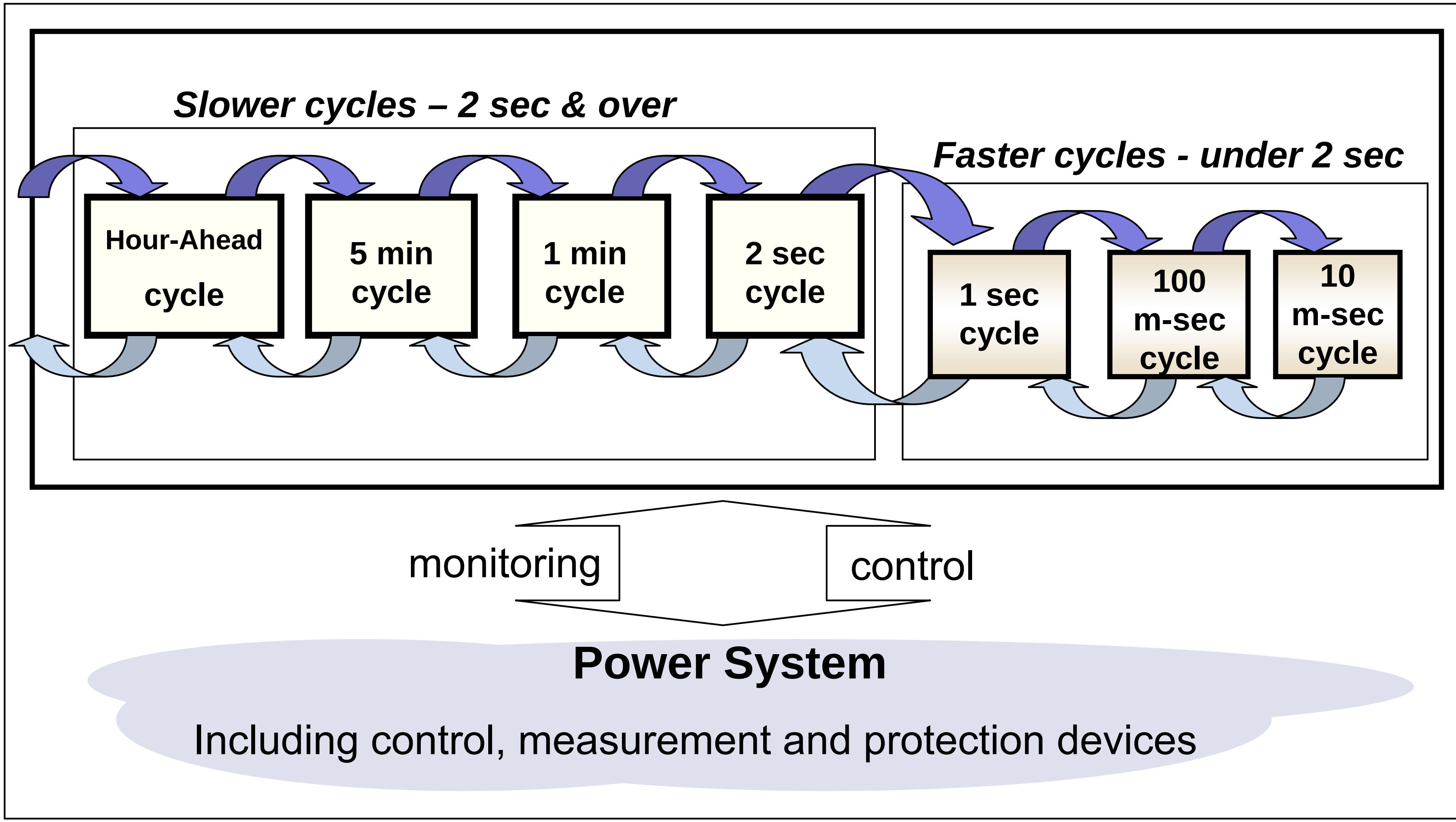
Distributed Agents - State Estimation Example

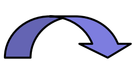


Background: Distributed Autonomous System

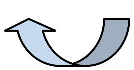


Background: Execution Cycles and Temporal Coordination





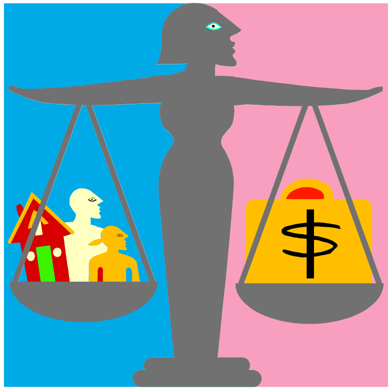
Forward plans, schedules, guidelines controls, messages



Feedback data, violations, alerts, messages

Valuation of Self-Healing Grid

- **Is the IT infrastructure financially feasible?**



Challenges of Valuation

- **Framework is broad and flexible**
  - Entire grid - All control levels, geographical areas, etc.
  - All analytical functions
  - All time scales - Milliseconds to hour
- **General systematic methodology**
  - Too many context dependent parameters
  - Subjectivity of size, existing infrastructure & solutions, costs, benefits
  - Too many cost factors - R&D, SW, devices, etc.
- **Meaningful business cases**
  - Too narrow - Not of interest
  - Too broad - Provides no specific guidelines

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Approach to Valuation

- No specific assumptions regarding power system
- Focus on IT - all cycles and all hierarchical levels
- Plug-and-play intelligent agents
  - Functionally generic and encompassing
  - Configurable to existing measurement and control capabilities
- Reasonable “upper bounds” on costs
- Reasonable “lower bounds” on Benefits
- Consider:
  - Incremental implementation
  - Shared benefits and costs
  - Existing SW & HW products

What are we costing?

- Software components/intelligent agents
- IT hardware
- System deployment and integration
- Control equipment (if absolutely needed)

- Not costed - Communication Connectivity

Cost Models: Software Components/Intelligent Agents

- **R&D / Prototype Costs**
  - Investigate/demonstrate innovative concepts and algorithms
  - One-time cost
- **Productization Costs**
  - Robustness, models, solutions, performance, visualization
  - Integration of R&D results to standardized modules
- **Shakedown Costs**
  - Database development, system configuration & integration
  - Maturity through multiple implementations for "plug-and-play" status:
    - Substation: 10 implementations
    - Zone/vicinity: 5 implementations
    - Control Area: 2 implementations

Cost Models: Software Components/Intelligent Agents

#	Level	Prototype / Productization (Person-Yrs)	Field Deployment - Shake-down - Later implementations
1	Substation	3 / 11	- 10% for the first 10 substations (13 person-months each) - 0.5% later (3 person-weeks each)
2	Zone/Vicinity	4 / 13	- 15% for the first 5 zones/vicinities (23 person-months each) - 3% later(5 person-months each)
3	Control Area	10 / 30	- 25% for the first 2 control areas (90 person-months each) -15% later (54 person-months each)
4	Region	2 / 8	- 25% for the first 2 regions (24 person-months each) - 15% later (14 person-months each)
5	Grid	2 / 5	- 25% for the first 2 grids (15 person-months each) - 15% later (9 person-months each)
	Total	21 / 67	Use above formulae for various systems

Cost Models: IT hardware

- **Measurements**
  - PMUs as representative
- **Communications**
  - Consider routers at all locations of the hierarchy
- **Computing**
  - Standard computing modules each with:
    - 2 CPUs (3.6 GHz or higher)

Costs Model – Typical HW Requirements and Costs

#	Level	PMU/PDC	Routers	SCM	Cost/Site
1	Substation	2 PMUs	3	3	$83 k
2	Zone/ Vicinity	2 PDCs	6	4	$135 k
3	Control Area	0	4	8	$100 k
4	Region	0	1	3	$33 k
5	Grid	0	2	4	$50 k

- 200 Substations, 20 Vicinity/Zones – per CA
- 20 Control Areas/ Region, 10 Regions/Grid
- Communications connectivity already exists
- Assume $15k/PMU, $22.5k/router and $7.5k/computer

Costs Model – System deployment and integration

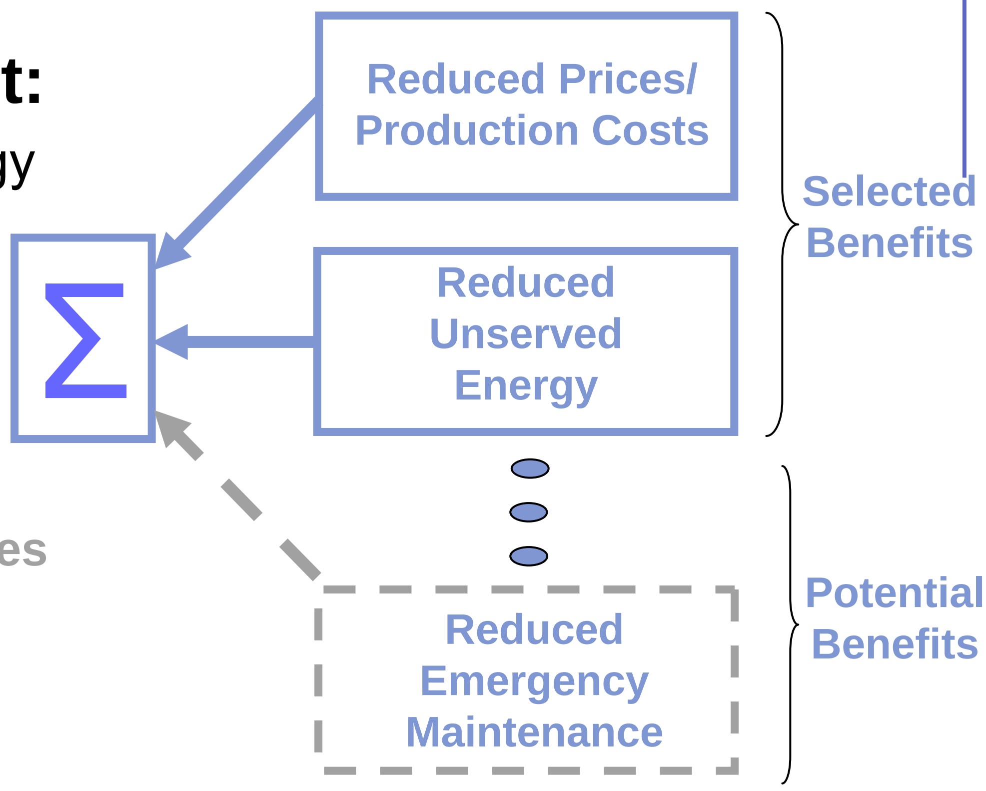
- Efforts for different levels and stages include:
  - DB development
  - Configuration
  - Integration
  - Field verification
  - etc.
- Cost roughly proportional to the number of substations
- Integration cost – system dependent
  - Typically 30% of total cost of SW deployment & HW

Cost Models: Control Equipment

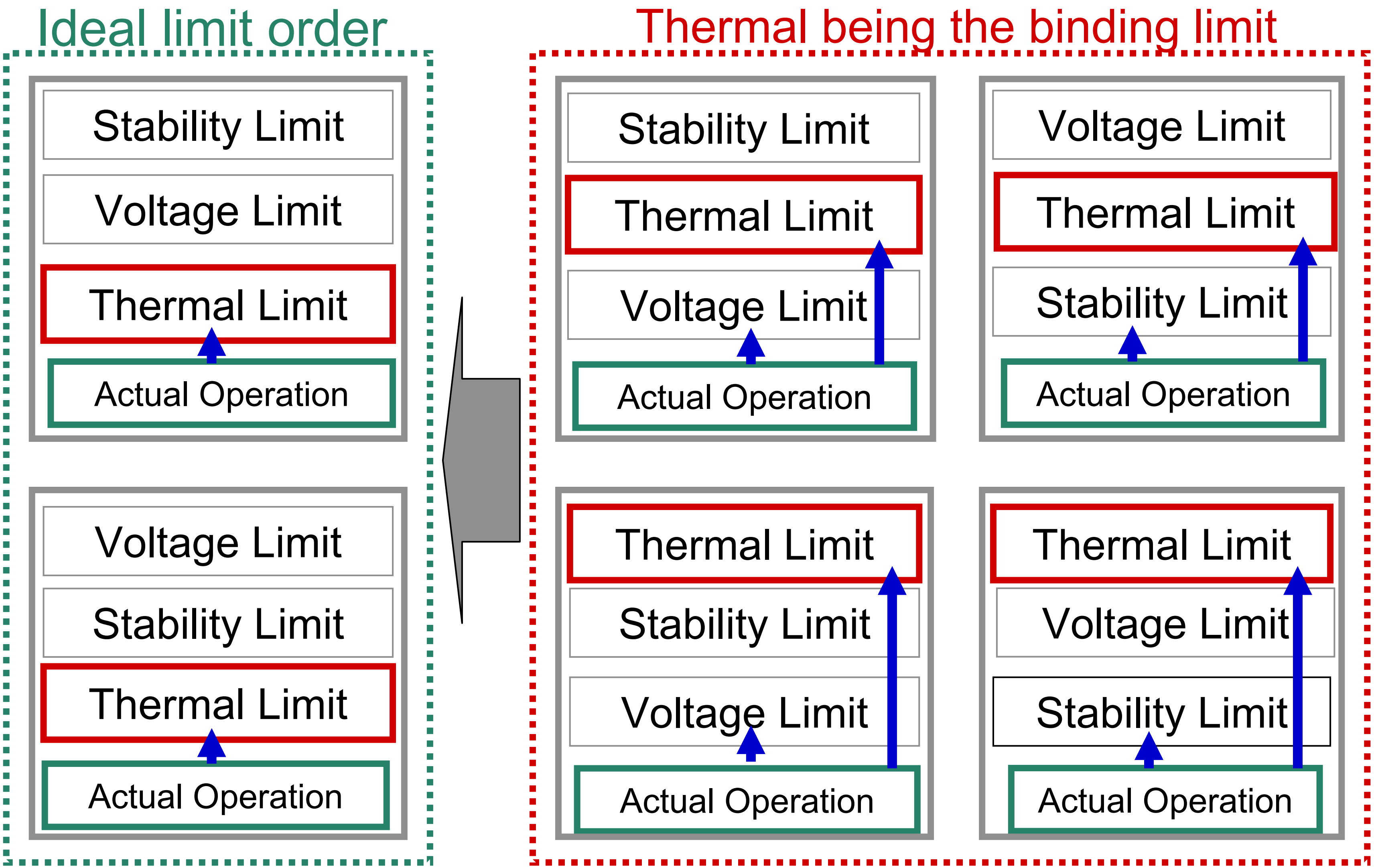
- **Where absolutely necessary**
- **Consider shunt FACTS devices as representative**
- **Potentially about 10% of transmission system supplied reactive requirements through FACTS**
  - Translates to 4 MVAr per 100 MW peak load
  - Costed at $50k/MVAr

Benefits Model – Which benefits?

- **Limit improvement:**
  - Improved market prices/production costs
- **Blackout containment:**
  - Reduced unserved energy
- **Possible others:**
  - Reduction of emergency maintenance costs
  - Deferral of capital expenses
  - Improved power quality
  - Etc.

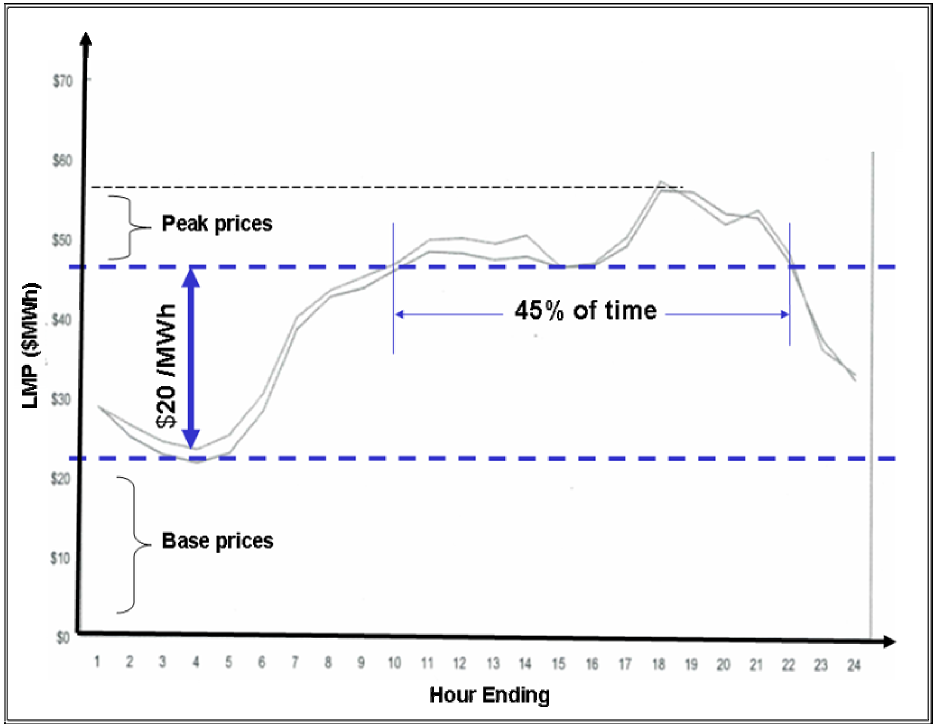


Benefits Models - Limit Improvements



Limit Improvements – Less Expensive MWh

- Estimated price differential
  - Gas CC vs Coal
  - Typically $20/MWh
- Estimated effective hours/year
  - Capacity factor of CC
  - Typically 45%
- Possible Limit Improvement
  - Transfer limit
  - 1% of base load
  - Analytically justified



Weighted Average LMPs for PJM Market - 2004

Limit Improvements - Industry Statistics for Parameters

#	Description	Range in Industry Statistics	Sources	Value used in this project
1	LMP Differentials	$0-$438 /MWh	Delmarva Study, NYISO real-time LMP's PJM State of the Market	$20/MWh
2	Hours with high LMP's (>$45/MWh)	45% = 3942hrs /Yr	PJM State of the Market Report	3942 hrs/Yr
3	Base load MW at Low LMP's ($0-$25)/MWh	80% of average load	PJM State of the Market Report	80% of average load
4	Average MW affected	0-1136 MW 1888 MW /TLR Event	Delmarva study, TLR report	1% of base load for 45% of the hours = ~ 31.5 Sys.Hrs/Yr

Limit Improvement - Validation of Model

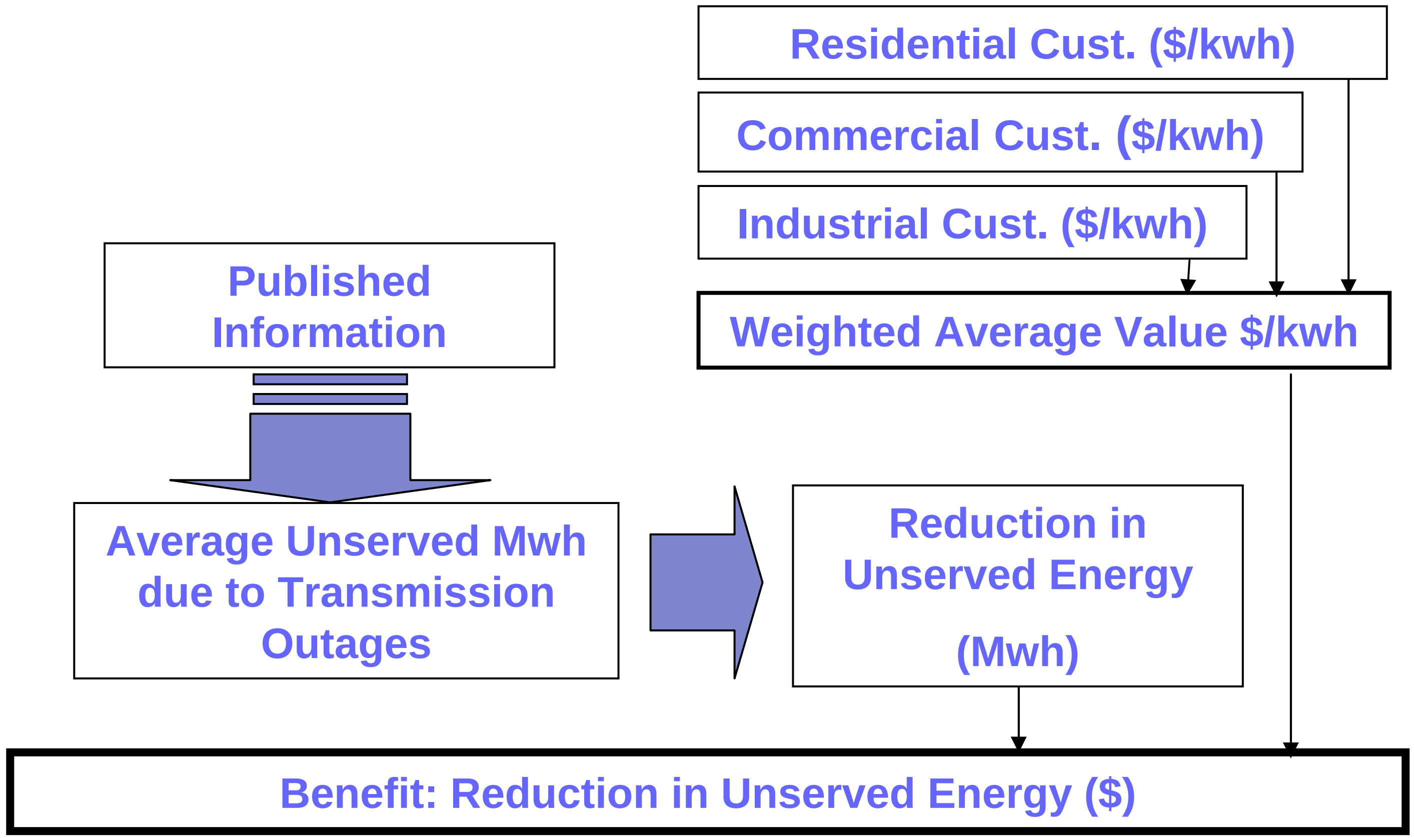
Model: Entire US

Description	Value
Effective congested hours (45%)	3942 hr/Yr
1% of base load for entire U.S.	3,560 MW
Potential Impact	14,034 GWh/Yr

Industry:

#	Description	GWh/Yr
1	**Congested GWh in Top 20 paths in Eastern Grid** (National Transmission Grid Study Report)	**107,470**
2	**Congested GWh in Top 20 paths in Western Grid** (National Transmission Grid Study Report)	**38,548**
3	**Energy schedules cut by TLR's (Eastern Grid - actual)** (NERC TLR data)	**3,468**

Benefits Models - Unserved Energy



Unserved Energy - Parameters for Valuating

#	Description	Range	Sources	Value used
1	Service interruptions due to transmission problems ignoring major disturbances	4-22 System-minutes per year	- PG&E, Reliability Indices Report submitted to CPUC (10 year history) - TVA - NERC/DAWG Database (Year 2002)	10 sys.min. per year
2	Interruptions due to major disturbances due to transmission problems	0-133 System-minutes per year	- PG&E, Reliability Indices Report submitted to CPUC (10 year history).	20 sys.min. per year
3	Fraction of the above that could be avoided	-------	- Analytically justified	10%
4	Value of unserved energy	$1,000-$361,000 /MWh	PG&E, Ontario Hydro, SCE and other studies – adjusted for inflation	$24,000/MWh

Benefit Models: Unserved Energy Value ($/MWh)

Sector	PG&E 1990 $/MWh	PJM Inflation . Factor	2004 $/MWh
Residential	4,640	1.42	6,590
Commercial	31,630	1.42	44,910
Industrial	10,770	1.42	15,290
Agricultural	3,670	1.42	5,210
Weighted	16,930	1.42	24,040

Source:
PG&E report (1990) quoted in PJM white-paper (2004) on
"Future PJM Capacity Adequacy Construct- The Reliability Pricing Model"

Business Case – Model for Full Scale Implementation

- A reasonably large control area embedded in an interconnection

#	Description	Value
1	Peak load	20,000 MW
2	Average load	12,500 MW
3	Base load	10,000 MW
5	Substations	200
6	Vicinities/zones	20

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Full Scale Implementation – Total Deployment Cost

#	Description	Cost ($K)
1	**SW Deployment Subtotal**	**11,400**
2	**IT Hardware**	**19,400**
3	**System Integration** **(30% of SW & HW)**	**9,240**
	Deployment Total	**40,040**

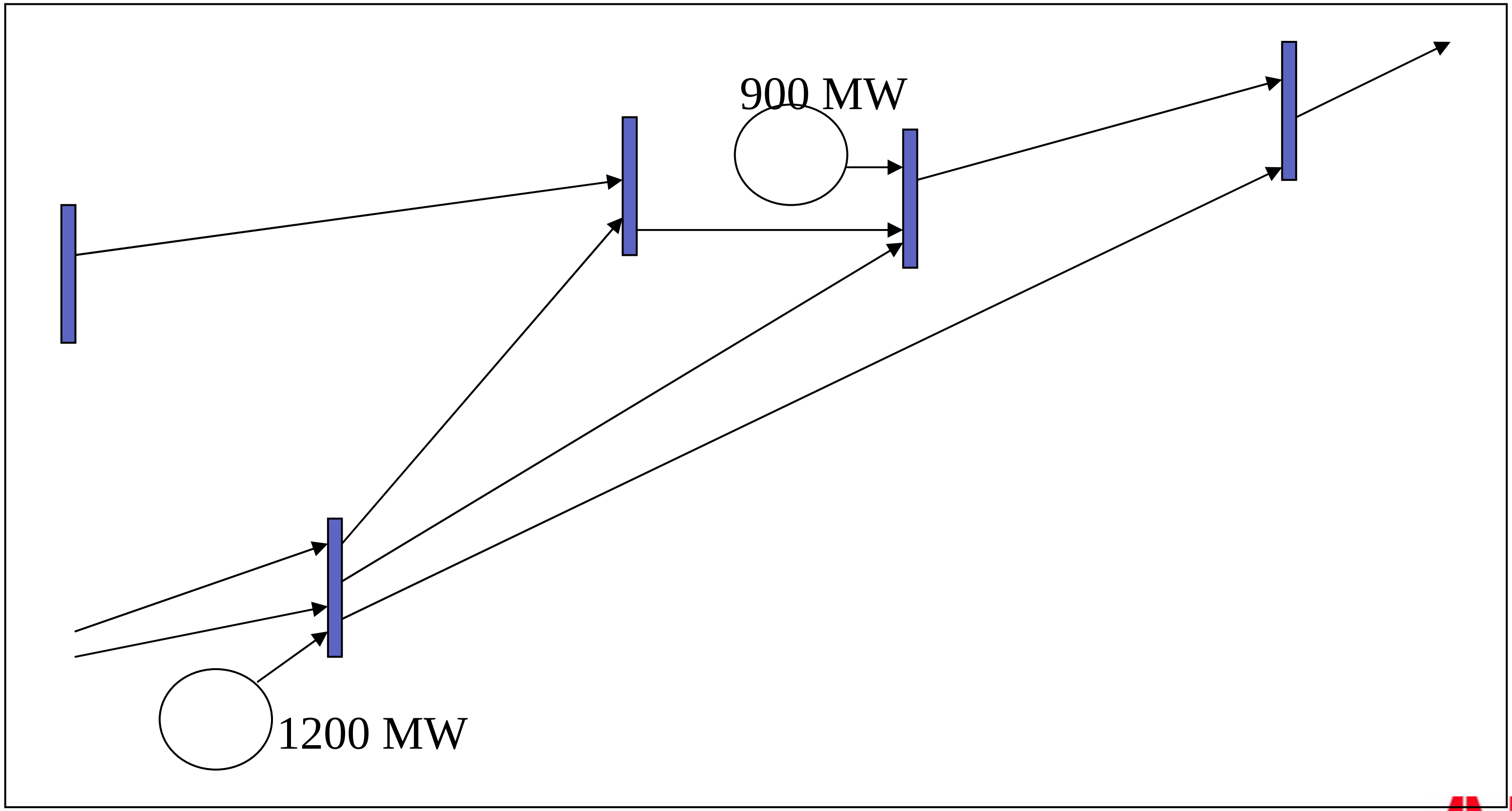
Full Scale Implementation – Costs and Benefits Summary

Item	K$
SW + HW + Integration	40,040
Control Equipment	N/A
Total Costs	40,040
Limit improvement benefit	39,420
Avoided unserved energy benefit	75,000
Total Benefits	114,420

- SW implementation cost includes deployment at 200 substations, 20 vicinities, and the control area as well as interfaces with region and grid
- **The SW development cost of $34 M to be distributed/licensed**

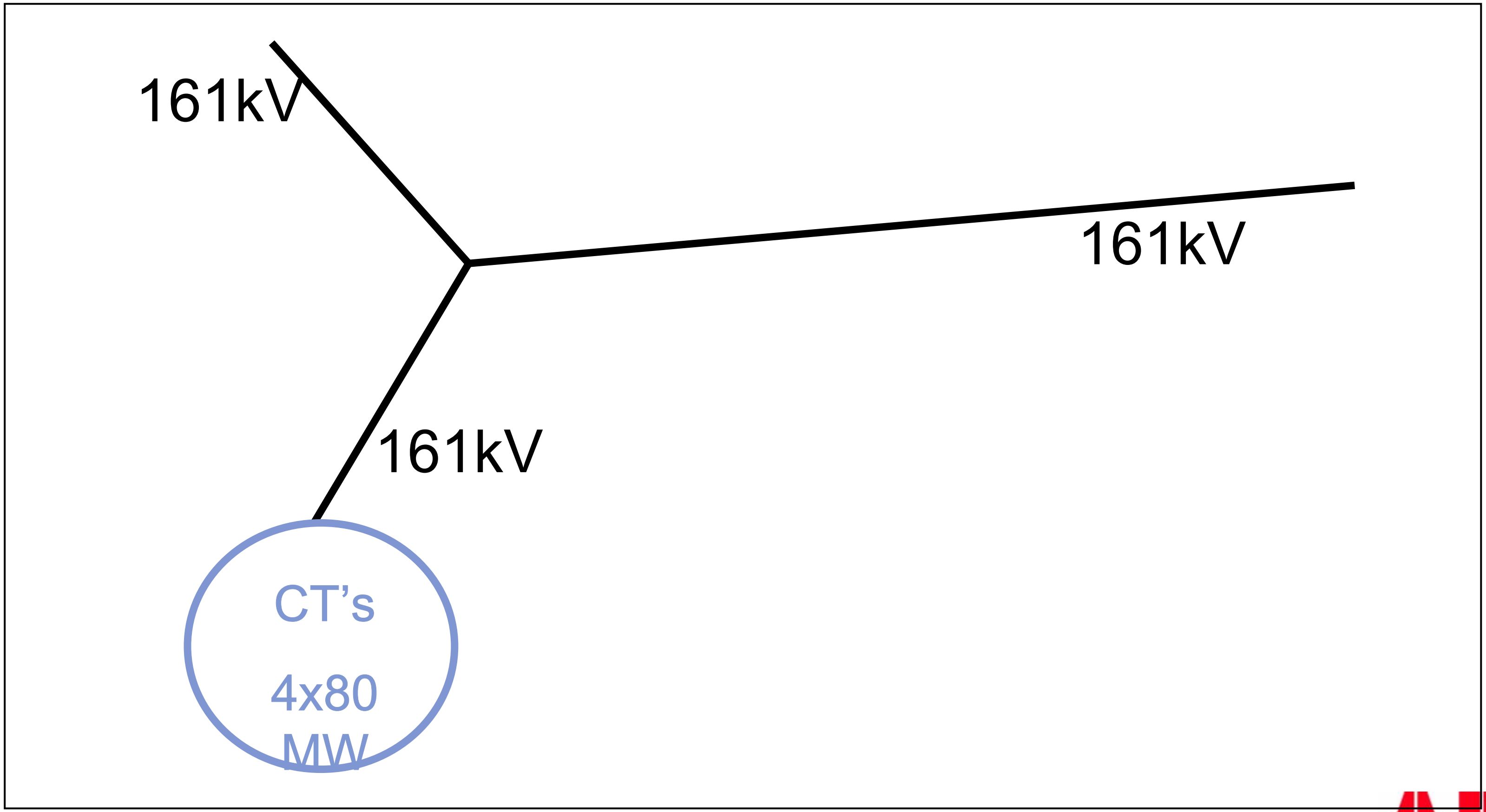
Partial Implementation Problem 1 - EHV Outage Stresses HV System

When one of the EHV lines is out for maintenance, the contingent outage of another EHV line places severe stress on the underlying HV system.



Partial Implementation Problem 2 - Voltage Collapse

When one line is down due to maintenance or forced outage, the (N-1) reliability criterion is not met. The underlying sub-transmission system will be subject to voltage collapse if another line fails.

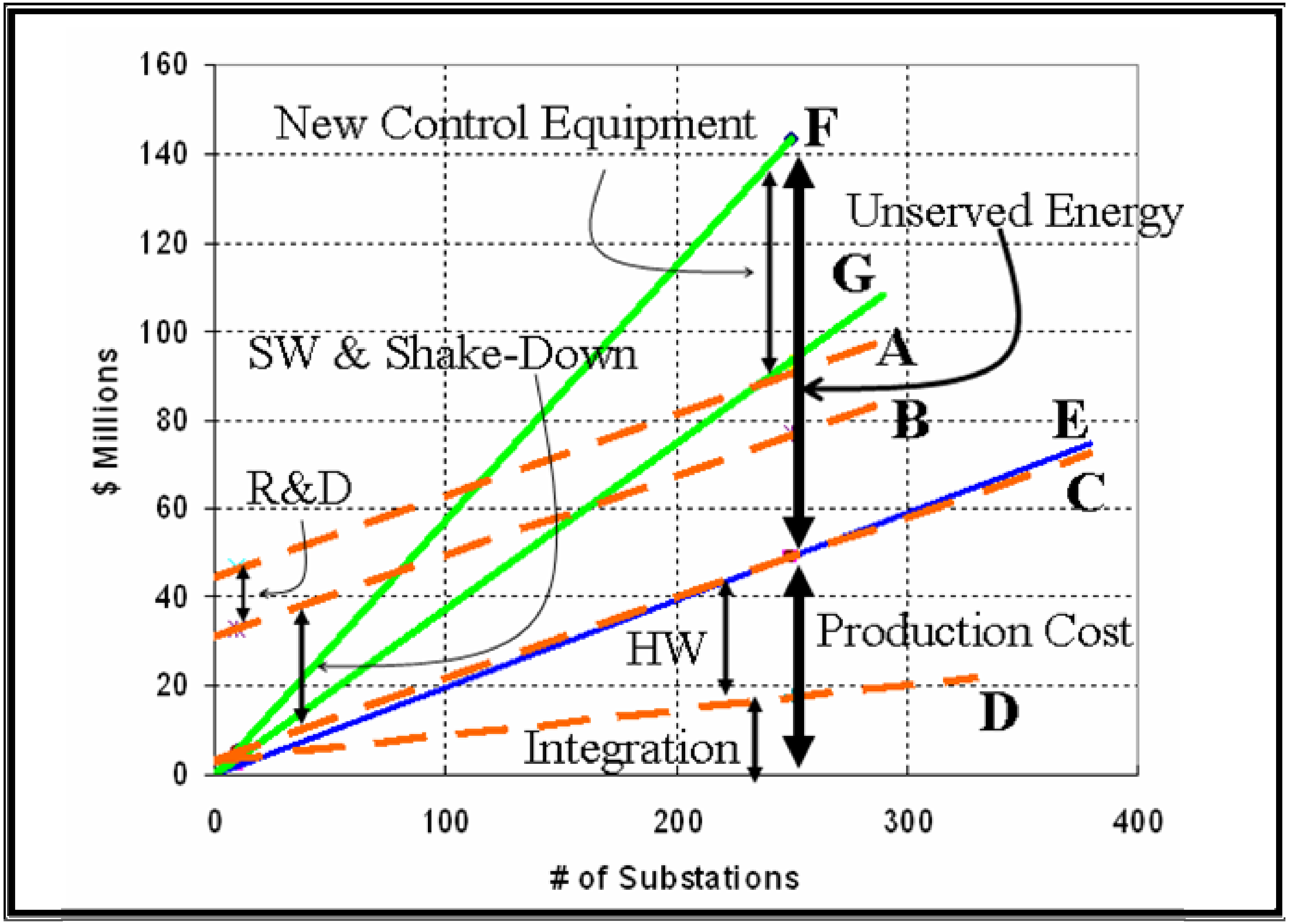


Partial Implementation Problems - Costs and Benefits

#	Description	Amount ($K)
1	**Problem 1**	
1.1	Cost (at 3 substations)	~ 400
1.2	Total Benefits	~ 60,000
1.3	**Benefit / Cost**	**~149**
2	**Problem 2**	
2.1	Cost (at 3 substations)	~ 400
2.2	Total Benefits	2,660
2.3	**Benefit / Cost**	**~6.67**

- All software and hardware has matured in prior implementations.
- Only interfaces necessary for the two specific problems are included

Empirical Models – Costs and Benefits



Conclusions

- **Systematic and general methodology to translate broad scope into quantifiable costs and benefits**
  - **Identification of significant cost components**
  - **Identification of financially significant benefits**
  - **Scalable framework of models to assess reasonable “upper bounds” on costs and “lower bounds” on benefits for localized or system-wide implementations**
  - **Validation of the models against industry statistics.**
  - **Analytical justification of model parameters.**
  - **Development of an empirical model to facilitate feasibility analysis**

Conclusions

- **Inevitable grid-wide penetration of self-healing capabilities:**
  - **First implementation would substantially bring down the “entry barrier” for the remaining utilities to a level comparable to traditional control centers**
  - **Steady decline of cost of computing power**
  - **Value of benefits continue to increase as the economy and quality of life become more dependent on a reliable power grid**
  - **For the entire U.S. , benefits (billions of $) would far exceed initial R&D costs of $65M**
- **The above conclusion remains valid and unaffected by any reasonable changes in the specific values of the parameters used in the calculations.**