Emerging Technologies in Transmission Networks

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Nature of Transmission Network Disruptions

- Natural Events
- Human errors, hidden failures
- Failure of equipment (aging or neglect)
- Accidental failure (or deliberate destruction) of the monitoring and control infrastructure
- Malicious actions which deliberately seek and exploit system vulnerabilities (not likely, but quite possible)

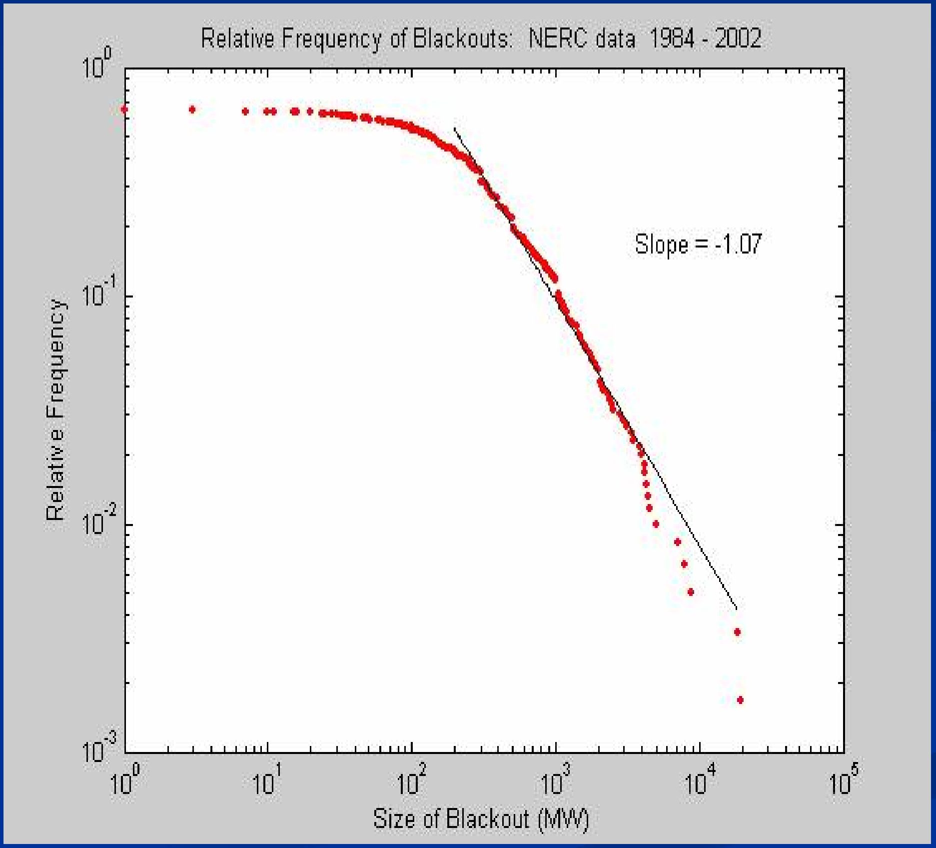
Cost of Failures

- Large amount of data on past failures: about 60 major disturbances per year, averaging 250 MW each
- Estimation of the cost to society is more than statistical analysis of size, frequency, duration and location
- No theoretical basis for estimating the cost of delivery (or non-delivery) of unit of energy
- Circumstances play a significant role; interpretations are highly subjective
- Metric: how much are customers willing to pay for emergency power supply? (According to surveys, 5-40 times the commercial cost of electricity is not uncommon)

Source: "Brittle Power: Energy Strategy for National Security", Amory and Hunter Lovins, 1982

Cost of Failures (cont.)

- Social costs: lost income, life, health, comfort, downstream economic consequences…
- New York 1977 Blackout cost estimates:
  - Riot damage (37 percent)
  - National economic costs (24 percent)
  - Various social and economic costs (39 percent)
  - Total: $310M (7 percent of then national GNP-day)
  - Higher estimates: $100/affected person ($1 Billion)
  - Today's blackouts cost much more



Source: "Brittle Power : Energy Strategy for National Security", Amory and Hunter Lovins, 1982

Assessment of Emerging Technologies for Energy Systems

- Market Infrastructure Analysis
- Performance Indices of the Candidate Technology
- Regulatory Barriers or Obstacles to Introduction
- Stage of Market Introduction

Market Infrastructure

- Potential for Large Scale Production
- Supply Chain Assessment
- Infrastructure Support for Design and Construction
- Ease of Use/Quality Control/Experience
- Support/Training Infrastructure
- Availability of Turnkey Solutions

Source: www.leonardo-energy.org

Performance Indices

- Integration in the Overall System
- Reliability (Dependability) of the Solutions
    - Operational Accuracy
    - MTBF / MTTR
- Economic Indicators (Cost Benefit Analysis)
- Complexity of Use

Source: www.leonardo-energy.org

Example: Industry Experience with SIPS

- Motivation: "*Industry Experience with Special Protection Schemes*" *IEEE/CIGRE Special Report*, P. Anderson, B.K. LeReverend, *IEEE Transactions on Power Systems*, Vol. 11, No. 3, Aug. 1996, pp. 1166-1179
- 2004: System Protection SC of the IEEE PSRC started an initiative to update the industry experience on SPS and SIPS
- Medium: a survey, which would attempt to attract a wide response from the industry worldwide

System Studies Done Prior to Deploying the SIPS

- Planning criteria
- Types of planning studies
- Real-time operational studies
- Protection and control coordination studies
- Coordination with other Protection and Control systems
- Types of protective relaying technology used
- Existence of standards for SIPS applications

Architecture Issues

- **Hardware Description and Outage Detection**
  - Outage detection Method
  - Questions on use of programmable logic controllers
- **Scheme Architecture**
  - Objective: decision making
  - Redundancy needs/implementation - Both telecommunication and hardware
  - Redundancy philosophy
  - Questions on use of the voting schemes
  - Questions about control: event based, or response based
  - Questions on Breaker Failure
  - Performance requirements:
    - Throughput timing: entire scheme
    - Throughput timing of the controller

Measurements and Communication

- **Data acquisition and related tools**
  - Measured Quantities
  - Time synchronization requirements
  - Use of SMART SIPS / Intelligent SIPS
  - Blocking (by the scheme) of any automatic reclosing
  - Restoration Issues and Planned Mechanisms
- **Communication, Networking, and Data Exchange**
  - Architecture of the communication
  - Communication medium and protocols
  - Information about shared communication (with other applications)
  - Impact of communication failure on reliability index and availability
  - Cyber security implementation and protection features
  - Operability of the scheme with a communication channel failure
  - Control Area Visibility

SIPS: Implementation

- **Arming methodology**

- **Implementation issues**
  - Multi-functionality of the scheme
  - Design: Centralized or Distributed Architecture
  - Availability of event reconstruction or system playback capability
  - Description of event records and their availability within the organization

SIPS: Testing, Reliability and Cost

- **Testing Considerations**
  - Testing procedures
  - Periodicity of testing
  - Maintenance issues
- **Cost Considerations**
  - Approximate cost
  - System information (infrastructure)

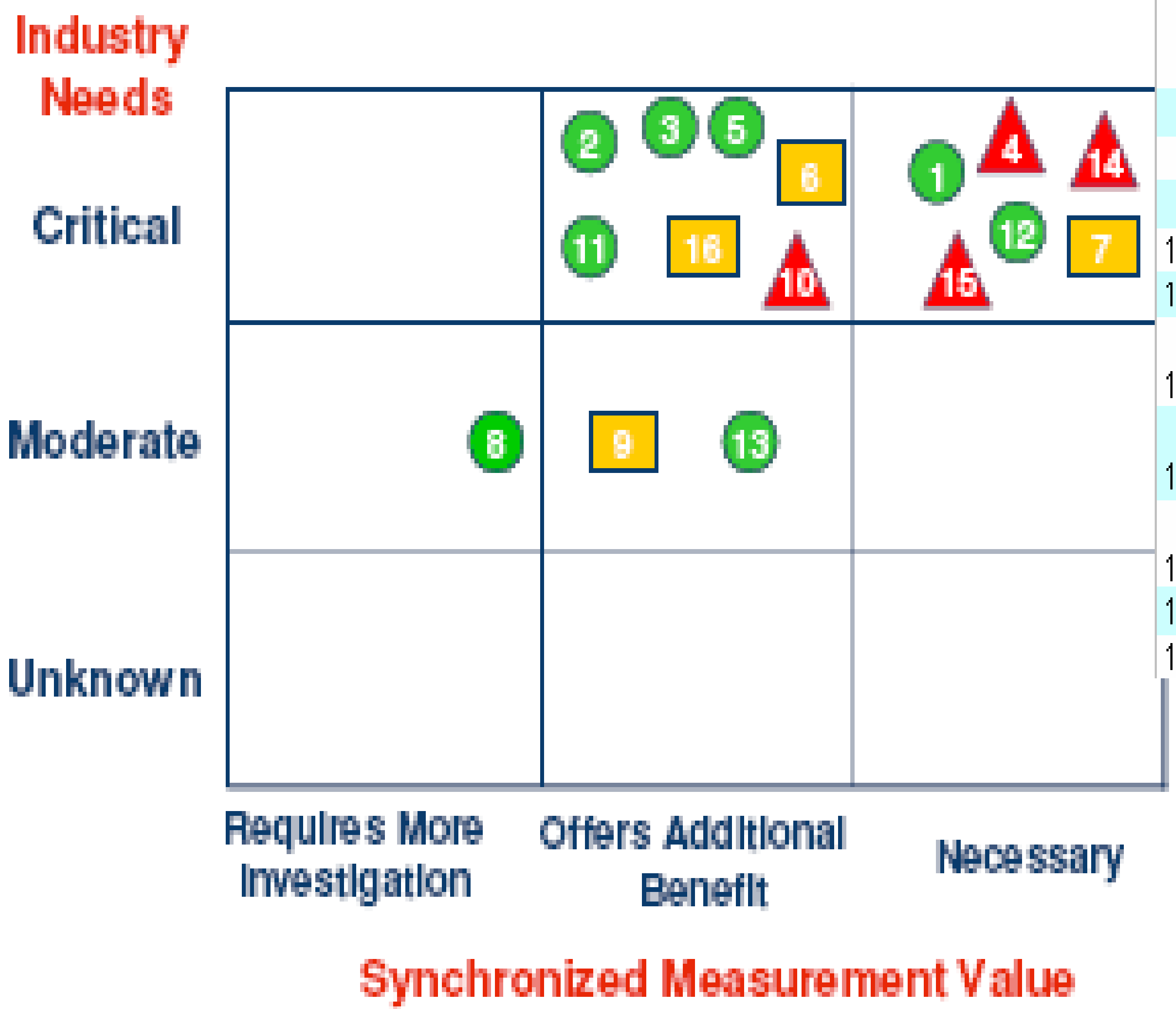
SIPS: Summary

- Advanced analytical techniques are becoming available for various types of SIPS applications
- Traditional scheme requirements evolve towards SIPS
- Fast changing operating conditions in power systems and quickly changing enabling technologies for power system control and protection
- Industry is changing quickly and adapting to the conditions imposed by new business practices
- Survey: should provide valuable information to industry practitioners and researchers alike about the trends and experiences in system protection

Sample of ET in TD

- High-Speed Monitoring and Systemwide Communication and Control
- System Integrity Protection Schemes (SIPS)
- Advanced Algorithms and IED for Control
- Power Electronics (FACTS, smart sensors)
- Custom Power Systems/Devices
- Sensor Networks for Diagnostics
- High Temperature Superconductivity (HTS)

Industry Needs vs. Synchronized Measurement Values



1	Angle/Freq. Monitoring
2	Voltage Stability Monitoring
3	Thermal Overload Monitoring
4	Real-Time Control
5	State Estimation (Improvement)
6	State Estimation (boundary conditions)
7	State Measurement (linear)
8	WA stabilization (WA-PSS)
9	Adaptive Protection
10	Congestion Management
11	Power-system Restoration
12	Post-mortem Analysis (incl. Compliance Monitoring)
13	Model Benchmarking; Parameter Estimation (Steady-State)
14	Model Benchmarking; Parameter Estimation (Dynamic)
15	Planned Power-System Separation
16	DG/IPP applications

Economic Analysis Process

Identify Areas for Analysis → Analyze Opportunities for Improvement → Identify Stakeholders → Estimate Deployment Plan and Costs → Perform Financial Analysis

Identify Areas for Analysis

Steps

1. List the major functions, activities, processes that Synchronized Measurements might help with
2. Identify the current performance of each function, activity, process, ...
3. Identify existing use of PMU in the industry and experience in enhancing planning and operations.
4. Identify government mandates, if any.

Analyze Opportunities for Improvement

Steps

1. Delineate benefits of PMU to specific activities in your organization
2. Quantify the benefits as (a) direct revenue, (b) avoided cost.
3. Identify needed equipment to achieve the benefits
4. Prioritize the benefits

Identify Stakeholders

Steps

1. Identify benefits of PMU to personnel from departments within the organization
2. Articulate benefits of PMU to identified stakeholders in the organization
3. Identify of benefits of PMUs to stakeholders outside the organization

Estimate Deployment Plan and Costs

Steps

1. Estimate capital costs
2. Estimate variable costs
3. Form alternatives
4. Sketch deployment plans

Perform Financial Analysis

Steps

1. Form projection of quantified benefits
2. Form projection of capital investment and annual expenses
3. Evaluate project alternatives

Control Technologies

- Statistical Learning Theory
- Data Mining for Dynamical Systems
- Biologically Inspired Control Architectures
- Integration of Control and System Health Mgt.
- Nonlinear Control Theory
- Modeling of Economic (Sub)systems
- Complex Adaptive Systems

Problem Environment

- High dimensionality, abundance of data
- Issues: modeling accuracy, measurement errors, sensing and actuation delays
- Problem solutions may be intractable in terms of their scaling properties (multi-scale decompositions are a logical option)
- Objective measures of success (accuracy, speed, stability) require substantial computational complexity

Conclusions

- Activities of ETCC and PES Technical Committees in identifying and assessing emerging technologies are important
- IEEE can greatly support/facilitate/provide feedback/enable standards introduction in support of emerging technologies
- Operational reality of transmission networks requires (or will soon require) support of a number of emerging (or soon to be emerging) technologies