Hsiao-Dong Chiang

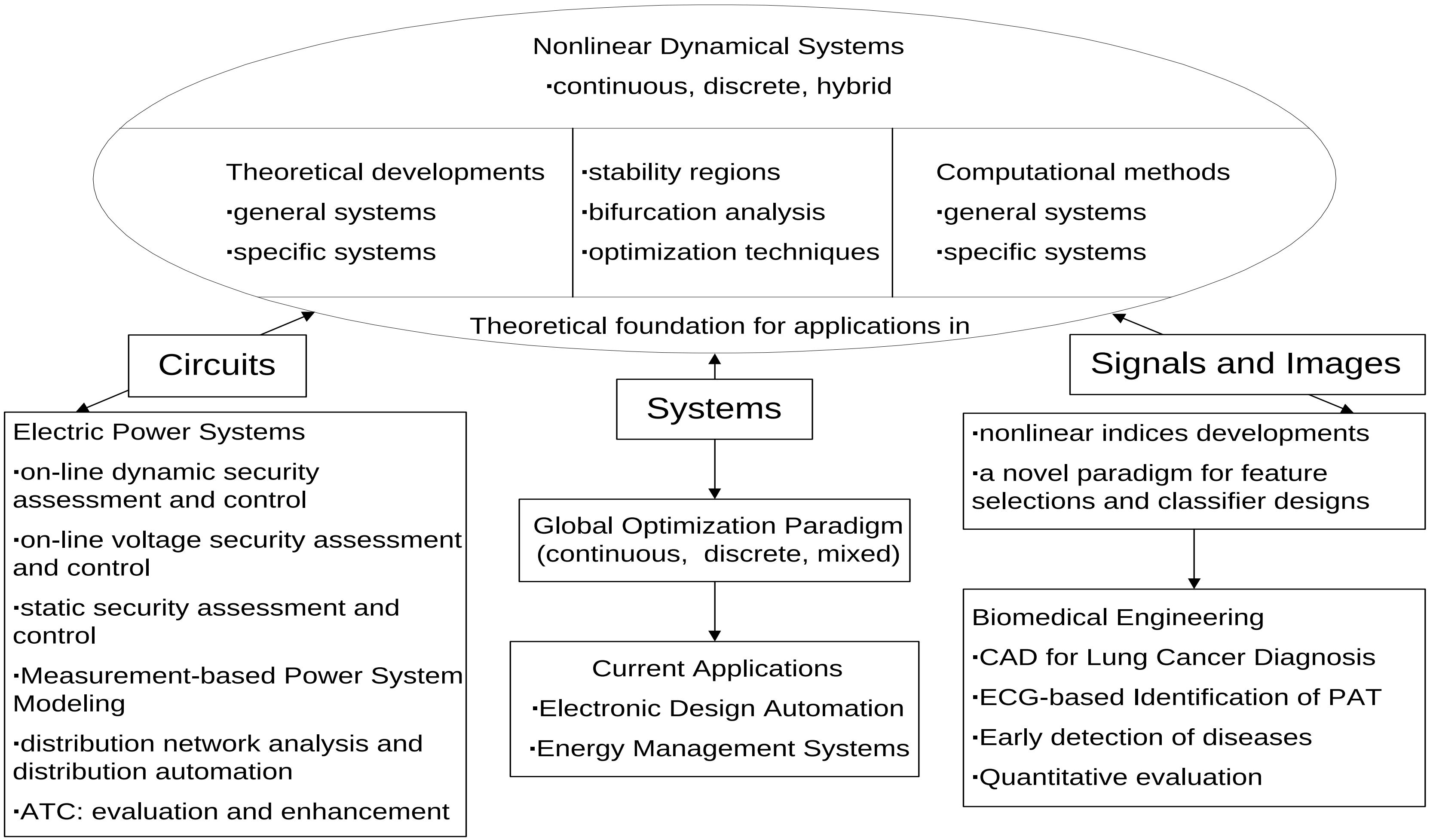
Professor, Electrical and Computer Engineering

Research areas: (i) Electric Power Systems,
(ii) Nonlinear Computation & Application in Circuits, systems, Signals and Images

- Modeling, analysis, stability and control of electric power systems (both transmission and distribution level)
- On-line Power system Security assessment and enhancement
- Smart Power Grids
- Nonlinear Systems Theory and Applications
- Global optimization and applications

Always search for excellence…

Research: Nonlinear System Theory, Computation and Applications in Electric Circuits, Systems, Signals and Images

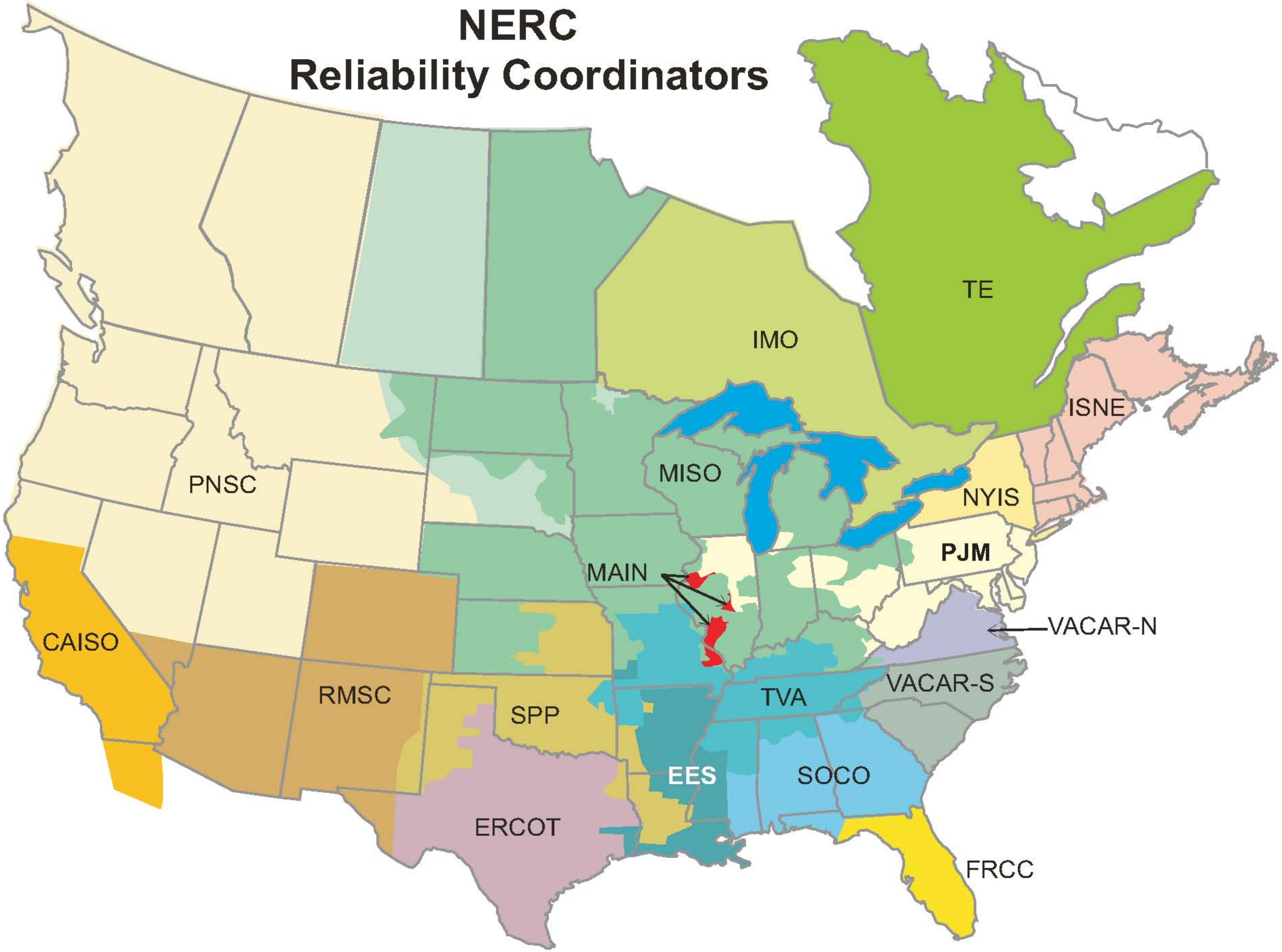


A (Smart) Real-time PMU-assisted Power Transfer Limitation Monitoring and Enhancement System

- Support Renewables on the Grid
- Exploring existing transmission infrastructure
- Enhance control room situational awareness and early warning system

Dr. Hsiao-Dong Chiang

NERC Reliability Coordinators



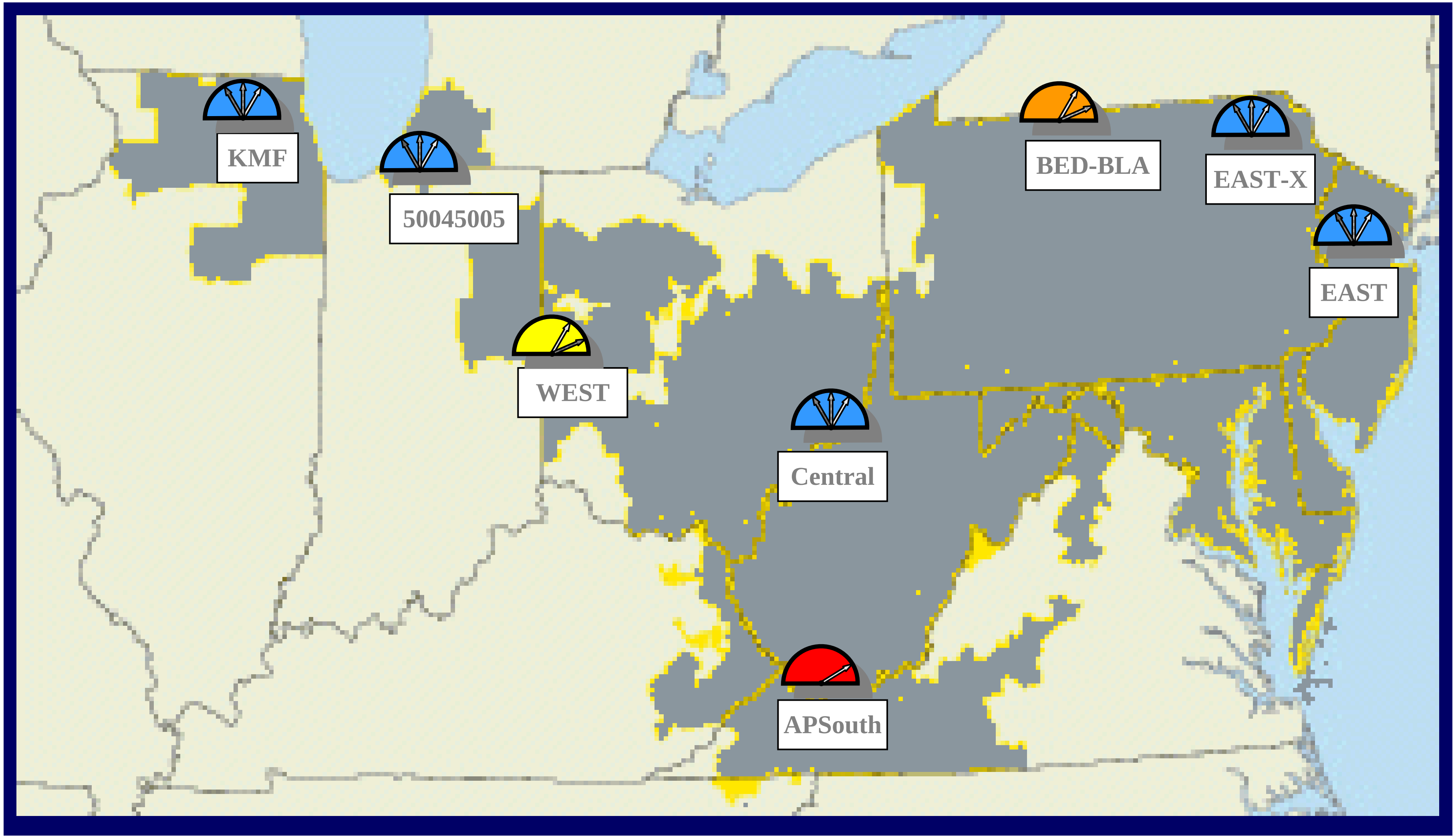
An Example

- NYISO’s Base-case power system (State estimation EMS using CIM-compliance format or PSSE format)

- Look-ahead scenario (proposed power transfer, look-ahead loads, look-ahead generation dispatch scheme, planned outage schedule)

- NYSIO’s On-line Available transfer capability monitoring system and (smart) enhancements (i.e. increase ATC)

Monitoring & Analysis (Base-Case) Main Window



ATC Monitoring and Enhancement Systems

Challenges and Opportunities

- N-1 criteria
- Real-time network model
- Real-time data
- Verification of model and data
- On-line computation capability
- On-line optimization technologies


Contingencies
Power System
Outage and Blackout

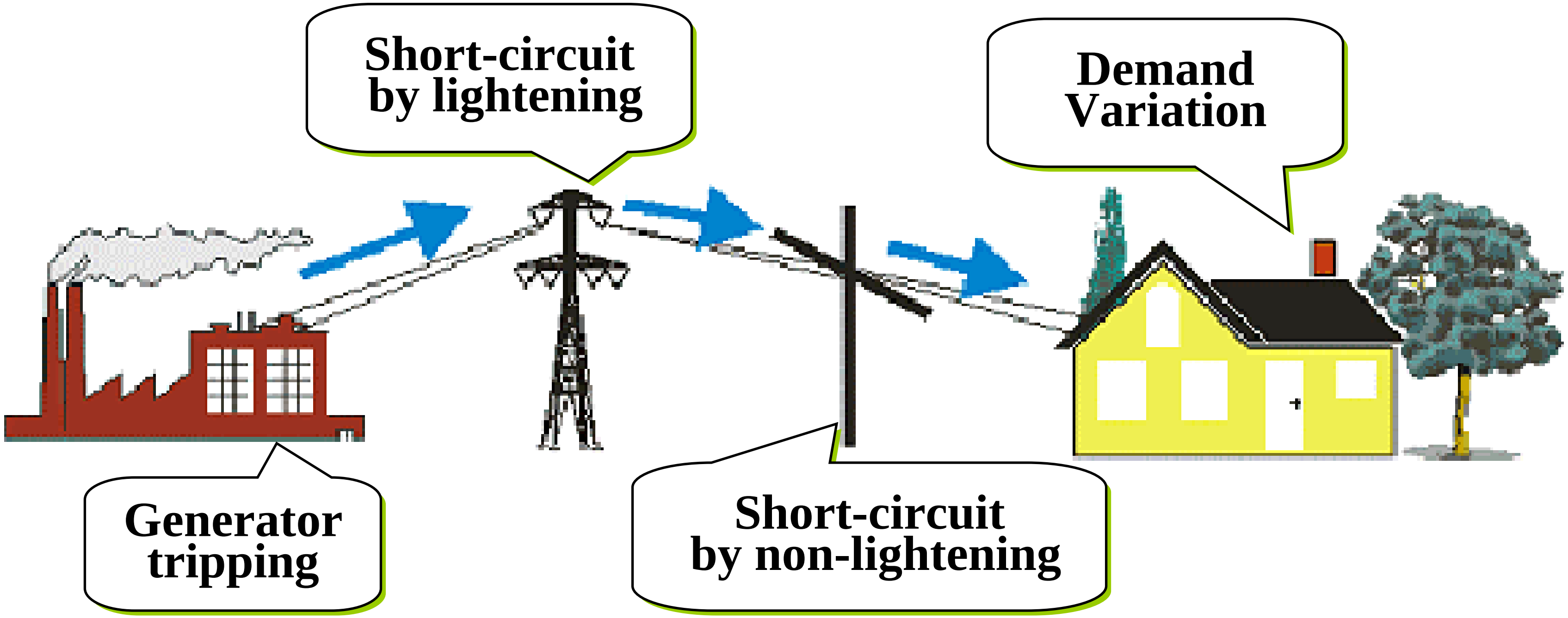
Mega-blackout of 2003

- Affected customers: 10 million in Ontario, Canada; 40 million in 8 U.S. states
- Affected area: about 9,300 square miles
- Financial loss: an estimated $6 billion.

Mega-blackout of 2003

- One important conclusion is the fact that the transmission network is the weakest link of the restructured power system.
- Impacts of major blackouts can be immense and very costly.

Contingencies



Contingencies cause limits on power systems

Hard Limits

Transient (angle) instability

Voltage instability

Soft Limits

Thermal-limit violation

Voltage-limit violation

Problem statements

Considerations (ATC monitoring systems)

1. ATC of the base-case power system
2. ATC of base-case + contingencies
3. Which ones will cause ATC's limitation ? (insecure contingencies)
4. Which ones will push the system near its limitations ? (critical contingencies)
5. Where are the weak buses, weak areas ?

Computational Challenges

On-Line Transient Stability Assessments Requires solving

- One contingency involves a set of 15,000 differential equations + 40,000 nonlinear algebraic equations
- Need to fast and accurately solve 3000 contingencies in 5 minutes
- Traditional time-domain-based approach can not meet this requirements

On-line TSA&C Requirements

- 12,000 plus buses in system model
- 1,300 generators
- 3000 contingencies

- 15-minute cycle for real-time EMS data
- 5 minutes in cycle allocated for contingency screening
- TEPCO-BCU screening performance target is 1.5 seconds to 2 seconds per contingency

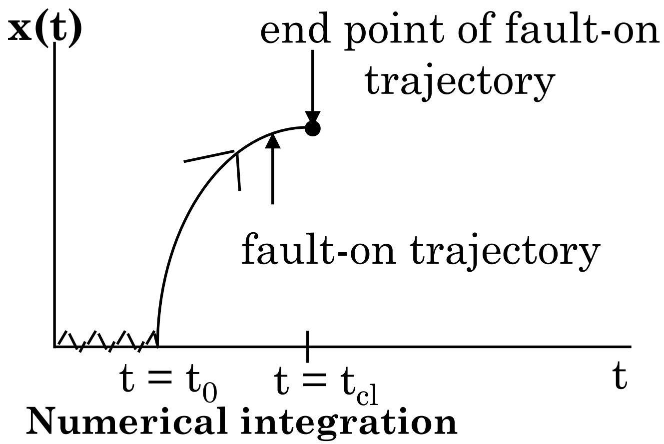
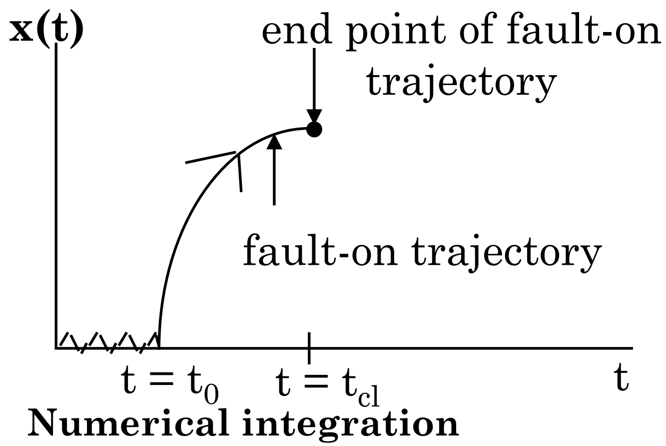
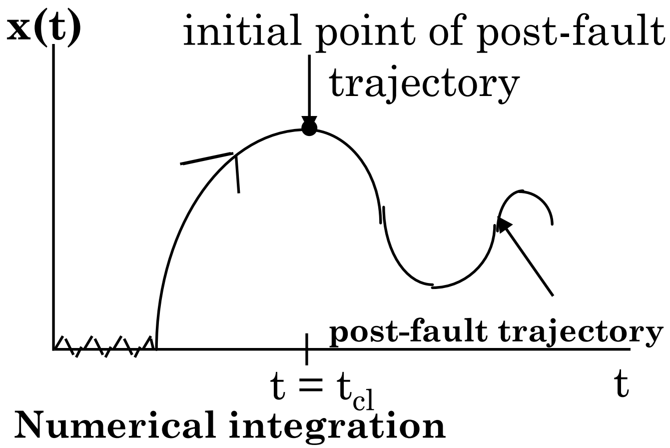
System Model for Each Contingency

$$\begin{cases} \dot{x}_1 = f_1(x,y) \\ \dot{x}_2 = f_2(x,y) \\ \vdots \\ \vdots \\ \vdots \\ \dot{x}_{15,000} = f_{15,000}(x,y) \end{cases}$$

$$\begin{cases} 0 = g_1(x,y) \\ 0 = g_2(x,y) \\ \vdots \\ \vdots \\ \vdots \\ \vdots \\ 0 = g_{40,000}(x,y) \end{cases}$$

Time-Domain Approach

- Speed: too slow for on-line applications
- Degree of Stability: no knowledge of degree of stability (critical contingencies vs highly stable contingencies)
- Control : do not provide information regarding how to derive effective control

<table>
<tr><th></th><th>Time-Domain Approach</th><th>Direct Methods (Energy Function)</th></tr>
<tr><td>Pre-Fault System</td><td>• (Pre-fault s.e.p.)</td><td>• (Pre-fault s.e.p.)</td></tr>
<tr><td>Fault-On System
$\dot{\mathbf{x}} = \mathbf{f}_F(x,y)$
$\mathbf{t_0 < t < t_{cl}}$</td><td>
</td><td>
</td></tr>
<tr><td>Post-Fault System
$\dot{\mathbf{x}} = \mathbf{f}(x,y)$
$\mathbf{t_{cl} < t < t_{\infty}}$</td><td>
</td><td>1. The post-fault trajectory x(t) is not required
2. If $v(x(t_{cl})) < v_{cr}$, x(t) is stable. Otherwise, x(t) may be unstable.

Direct stability assessment is based on an energy function and the associated critical energy</td></tr>
</table>

History of Direct Methods

- an active research topic in the last 60 years
- originally proposed by Magnusson in 1947 (in his Doctor Thesis)
- most R&D works were based on heuristic and dormant (DOE spent multi-million in 1970s)
- A popular topic of Doctor thesis
- EPRI spent about $10M in the 1980s and 1990s.

History of Direct Methods

- R&D between 1950s and 1980s were based on heuristics and did not work.
- EPRI spent about $10M in the 1980s and 1990s.
- Theoretical foundations were developed in 1987 by Chiang, Wu and Varaiya
- Practical methods, Controlling UEP method + BCU method, were developed in the 1990s.

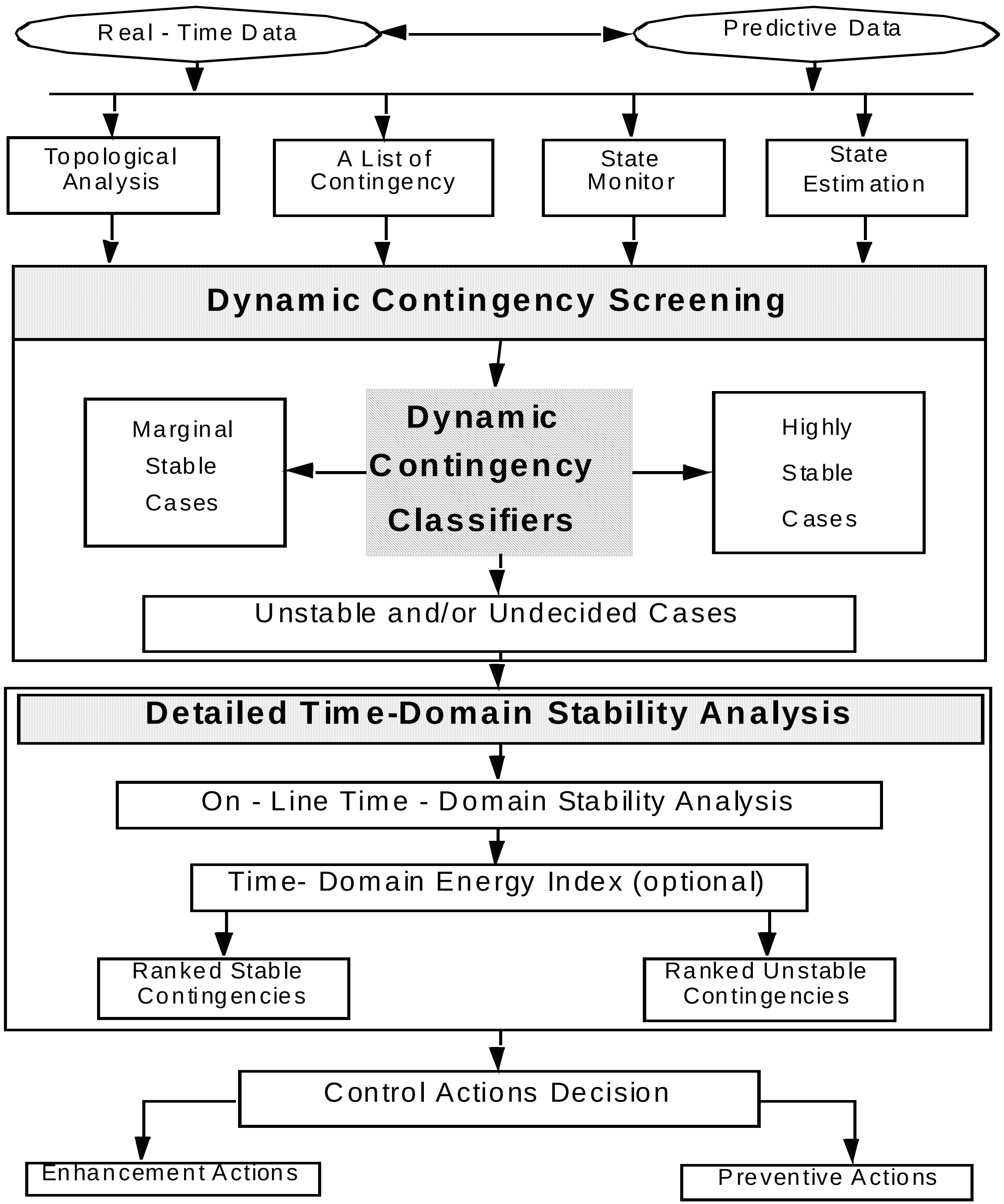
History of Direct Methods

- MOD (mode of disturbance) method (1970-1980s)
- PEBS method (by Kakimoto etc.)
- Acceleration machine method (Pavella etc.)
- Extended Equal Area Criteria (EEAC)
- Single-Machine-Equivalent-Bus (SIME)
- BCU method
- TEPCO-BCU method

Computational Challenges

On-Line TSA Requires solving

- One contingency involves a set of 15,000 differential equations + 40,000 nonlinear algebraic equations
- Need to fast and accurately solve 3000 contingencies in 5 minutes
- Traditional time-domain-based approach can not meet this requirements


Real - Time Data
Predictive Data
Topological Analysis
A List of Contingency
State Monitor
State Estimation
Dynamic Contingency Screening
Marginal Stable Cases
Dynamic Contingency Classifiers
Highly Stable Cases
Unstable and/or Undecided Cases
Detailed Time-Domain Stability Analysis
On - Line Time - Domain Stability Analysis
Time- Domain Energy Index (optional)
Ranked Stable Contingencies
Ranked Unstable Contingencies
Control Actions Decision
Enhancement Actions
Preventive Actions

TEPCO-BCU

- TEPCO-BCU is developed under this direction by integrating BCU method, improved BCU classifiers, and BCU-guide time domain method. The evaluation results indicate that TEPCO-BCU works well on several study power systems including a 15,000-bus test system.

Input Data

- Powerflow: is prepared using the real-time system snapshot and passed from EMS system.
- Dynamics: Dynamic data matches the real-time powerflow and passed from EMS system.

Key developments

- Theoretical Foundation
- Design of Solution Algorithm
- Numerical Methods
- Implementations (Computer Programs)
- Industrial User Interactions
- Practical system installations

Key developments

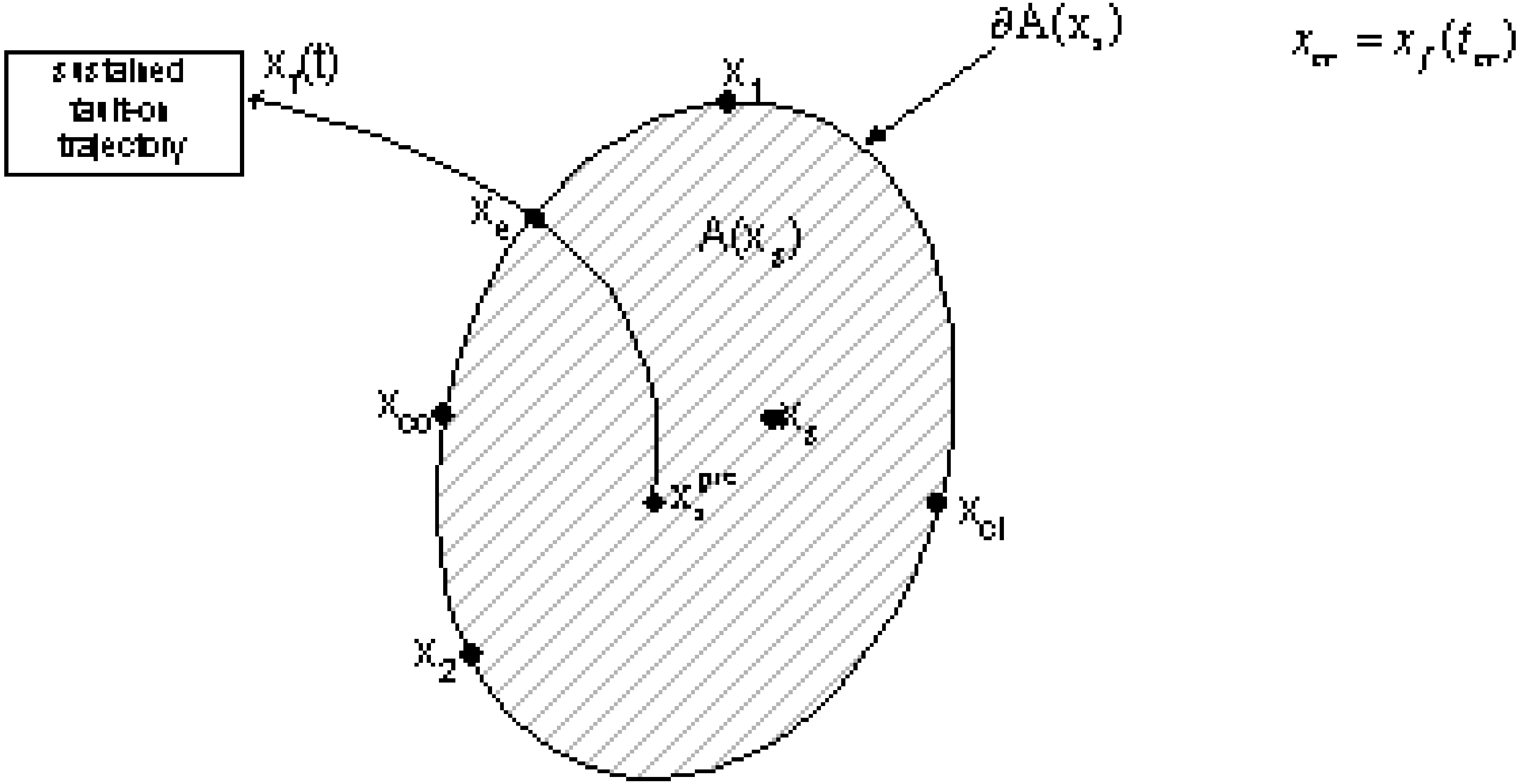
1. Theoretical Foundation (gain insights and build <u>belief</u>)

- Theory of stability boundary
- Energy Function Theory (extension of Lyapunov function function)
- Energy Functions for Transient Stability Models (non-existence of analytical energy function)

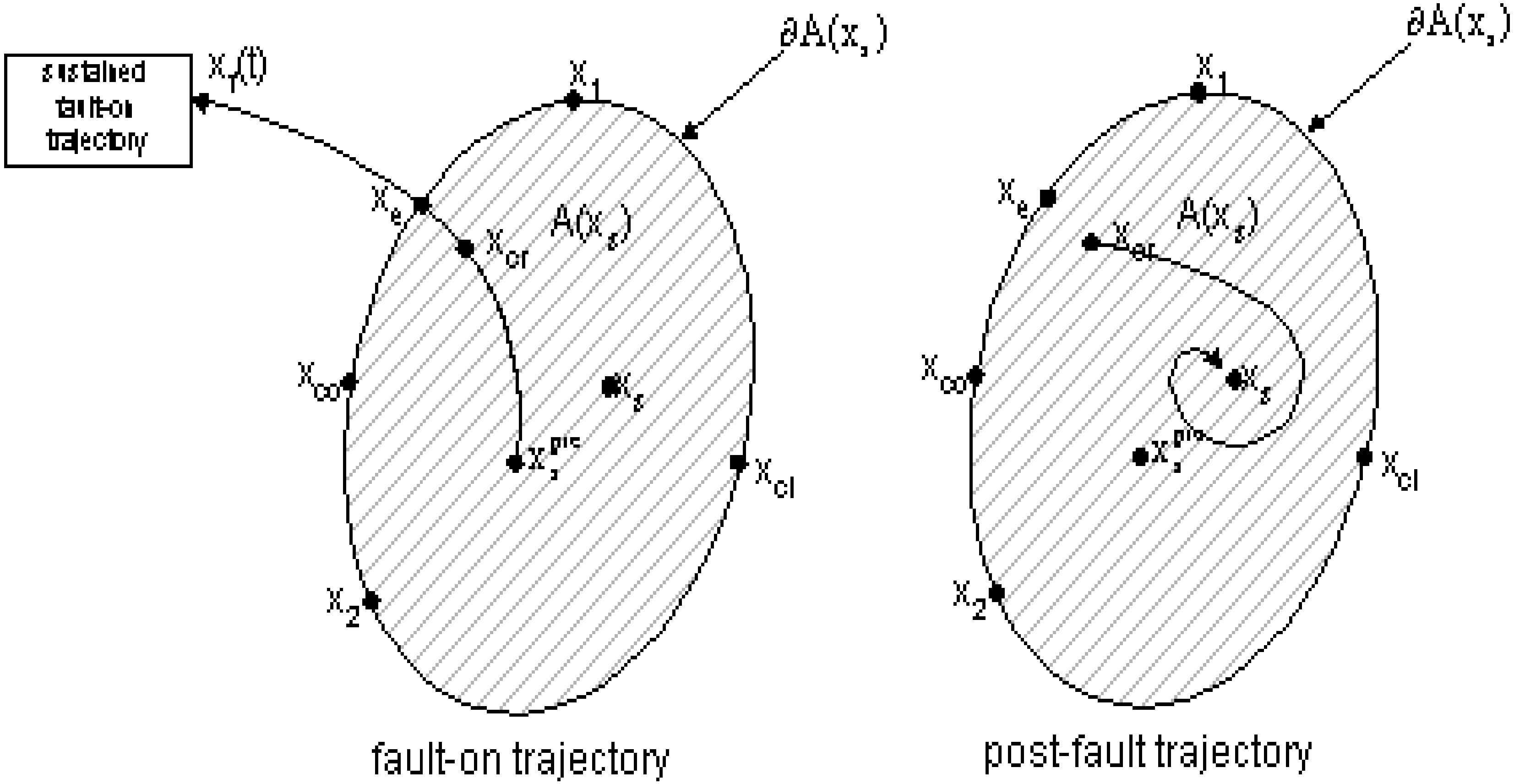
Key developments

1. Theoretical Foundation (gain insights and build belief)

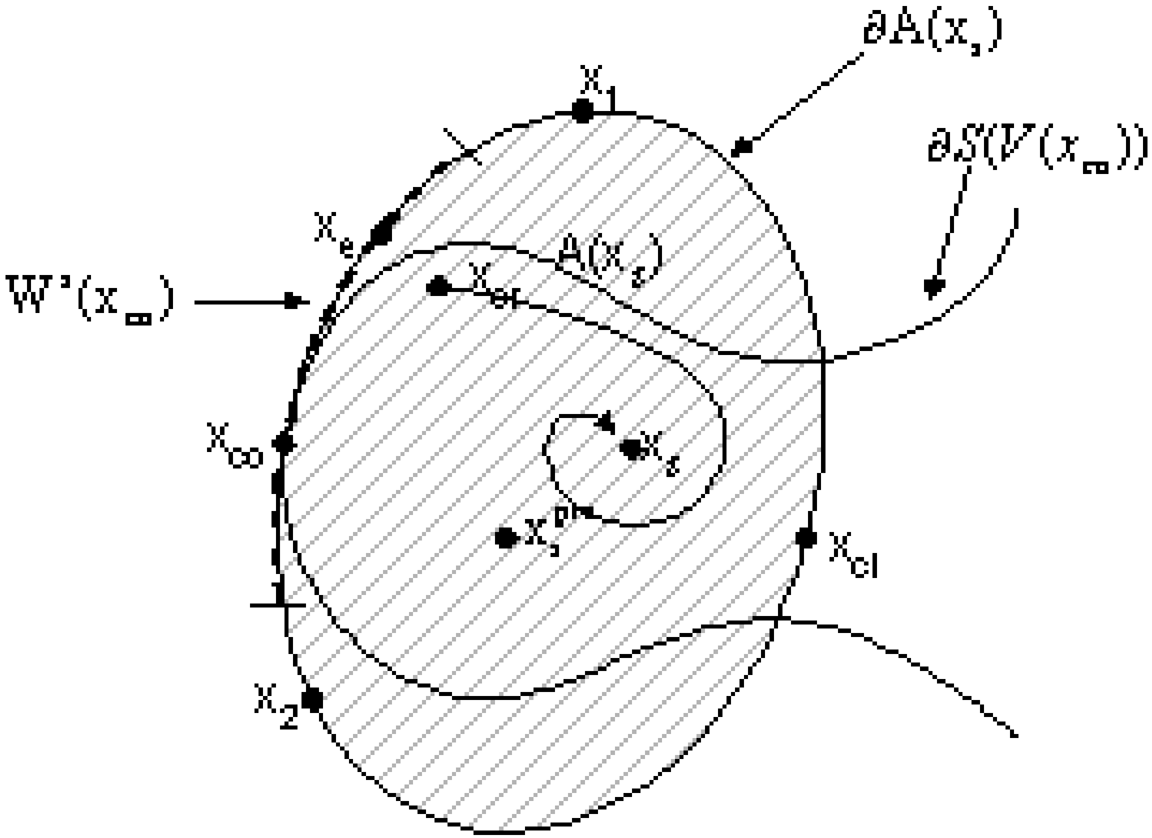
- Theoretical Foundations of Direct Methods
- CUEP method and Theoretical foundation
- Theoretical Foundation of BCU method



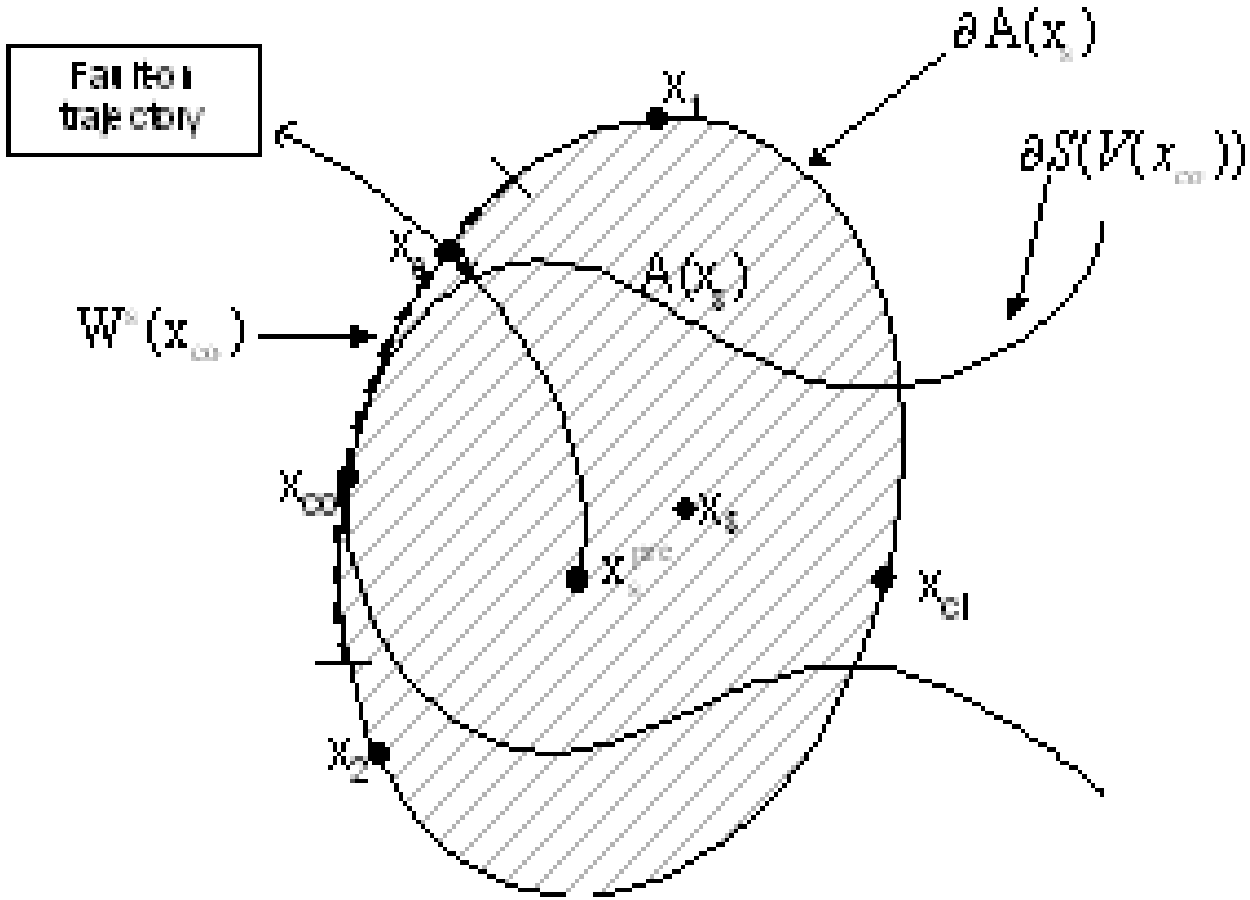
sustained fault-on trajectory moves toward the stability boundary intersects it at the exit point. The exit point lies on the stable manifold of the controlling UEP of the fault-on trajectory .



If the fault is cleared before the fault-on trajectory reaches the exit point, then the fault-clearing point must lie inside the stability region. Hence, the post-fault trajectory starting from the fault-clearing point must converge to the post-fault SEP .



The controlling UEP method approximates the relevant stability boundary, which in this case is the stable manifold of the controlling UEP, by the constant energy surface, which passes through the controlling UEP.



The only scenario in which the controlling UEP method gives conservative stability assessments is the situation where the fault is cleared when the fault-on trajectory lies between the connected constant energy surface and the relevant stability boundary which is highlighted in the figure.

Key developments

2. Design of Solution algorithms

- BCU method for computing CUEP
- BCU Classifiers
- High-yield BCU classifiers

Important Implications

- *CUEP method is the "must"*
- To directly compute CUEP of the original power system model is impossible.
- *Analytical results serve to explain why previous direct methods developed in the 1970s and 1980s did not work*
- *Analytical results provide directions for developing BCU method*
- *Do not pursue analytical energy functions*

Fundamentals of BCU Method

What: a boundary of stability region based controlling unstable equilibrium point method to compute the critical energy

Basic Ideas: Given a power system stability model (which admits an energy function), the BCU method computes the controlling u.e.p. of the original model via the controlling u.e.p. of a dimension-reduction system whose controlling u.e.p. can be easily, reliabily computed.

Fundamentals of the BCU Method

<u>Step 1</u>: *define an artificial, dimension-reduction system satisfying the static as well as dynamic properties.*

*(**how ?**) explores special properties of the underlying original model*

<u>Step 2</u>: *find the controlling u.e.p. of the dimension-reduction system*

*(**how?**) explores the special structure of the stability boundary and the energy function of the dimension-reduction system***.**

Fundamentals of the BCU Method

Step 3: *find the controlling u.e.p. of the original system.*

*(***How ?***) relates the controlling u.e.p. of the artificial system to the controlling u.e.p. of the original system with theoretical supports.*

Static and Dynamic Relationships

$$
\begin{aligned}
0 &= -\frac{\partial}{\partial u}U(u,w,x,y) + g_1(u,w,x,y)\\
0 &= -\frac{\partial}{\partial w}U(u,w,x,y) + g_2(u,w,x,y)\\
T\dot{x} &= -\frac{\partial}{\partial x}U(u,w,x,y) + g_3(u,w,x,y)\\
\dot{y} &= -\frac{\partial}{\partial y}U(u,w,x,y) + g_4(u,w,x,y)
\end{aligned}
$$

(Step 1)

$$
\begin{aligned}
\varepsilon_1\dot{u} &= -\frac{\partial}{\partial u}U(u,w,x,y) + g_1(u,w,x,y)\\
\varepsilon_2\dot{w} &= -\frac{\partial}{\partial w}U(u,w,x,y) + g_2(u,w,x,y)\\
T\dot{x} &= -\frac{\partial}{\partial x}U(u,w,x,y) + g_3(u,w,x,y)\\
\dot{y} &= -\frac{\partial}{\partial y}U(u,w,x,y) + g_4(u,w,x,y)
\end{aligned}
$$

(Step 2)

$$
\begin{aligned}
\varepsilon_1\dot{u} &= -\frac{\partial}{\partial u}U(u,w,x,y)\\
\varepsilon_2\dot{w} &= -\frac{\partial}{\partial w}U(u,w,x,y)\\
T\dot{x} &= -\frac{\partial}{\partial x}U(u,w,x,y)\\
\dot{y} &= -\frac{\partial}{\partial y}U(u,w,x,y)
\end{aligned}
$$

(Step 3)

$$
\begin{aligned}
\varepsilon_1\dot{u} &= -\frac{\partial}{\partial u}U(u,w,x,y)\\
\varepsilon_2\dot{w} &= -\frac{\partial}{\partial w}U(u,w,x,y)\\
T\dot{x} &= -\frac{\partial}{\partial x}U(u,w,x,y)\\
\dot{y} &= -\frac{\partial}{\partial y}U(u,w,x,y)\\
M\dot{z} &= -Dz
\end{aligned}
$$

(Step 4)

$$
\begin{aligned}
\varepsilon_1\dot{u} &= -\frac{\partial}{\partial u}U(u,w,x,y)\\
\varepsilon_2\dot{w} &= -\frac{\partial}{\partial w}U(u,w,x,y)\\
T\dot{x} &= -\frac{\partial}{\partial x}U(u,w,x,y)\\
\dot{y} &= (1-\lambda)z - \lambda\frac{\partial}{\partial y}U(u,w,x,y)\\
M\dot{z} &= -Dz - (1-\lambda)z - \lambda\frac{\partial}{\partial y}U(u,w,x,y)
\end{aligned}
$$

(Step 5)

$$
\begin{aligned}
\varepsilon_1\dot{u} &= -\frac{\partial}{\partial u}U(u,w,x,y)\\
\varepsilon_2\dot{w} &= -\frac{\partial}{\partial w}U(u,w,x,y)\\
T\dot{x} &= -\frac{\partial}{\partial x}U(u,w,x,y)\\
\dot{y} &= z\\
M\dot{z} &= -Dz - \frac{\partial}{\partial y}U(u,w,x,y)
\end{aligned}
$$

(Step 6)

$$
\begin{aligned}
\varepsilon_1\dot{u} &= -\frac{\partial}{\partial u}U(u,w,x,y) + g_1(u,w,x,y)\\
\varepsilon_2\dot{w} &= -\frac{\partial}{\partial w}U(u,w,x,y) + g_2(u,w,x,y)\\
T\dot{x} &= -\frac{\partial}{\partial x}U(u,w,x,y) + g_3(u,w,x,y)\\
\dot{y} &= z\\
M\dot{z} &= -Dz - \frac{\partial}{\partial y}U(u,w,x,y) + g_4(u,w,x,y)
\end{aligned}
$$

(Step 7)

$$
\begin{aligned}
0 &= -\frac{\partial}{\partial u}U(u,w,x,y) + g_1(u,w,x,y)\\
0 &= -\frac{\partial}{\partial w}U(u,w,x,y) + g_2(u,w,x,y)\\
T\dot{x} &= -\frac{\partial}{\partial x}U(u,w,x,y) + g_3(u,w,x,y)\\
\dot{y} &= z\\
M\dot{z} &= -Dz - \frac{\partial}{\partial y}U(u,w,x,y) + g_4(u,w,x,y)
\end{aligned}
$$

?

4/22/96 HDC

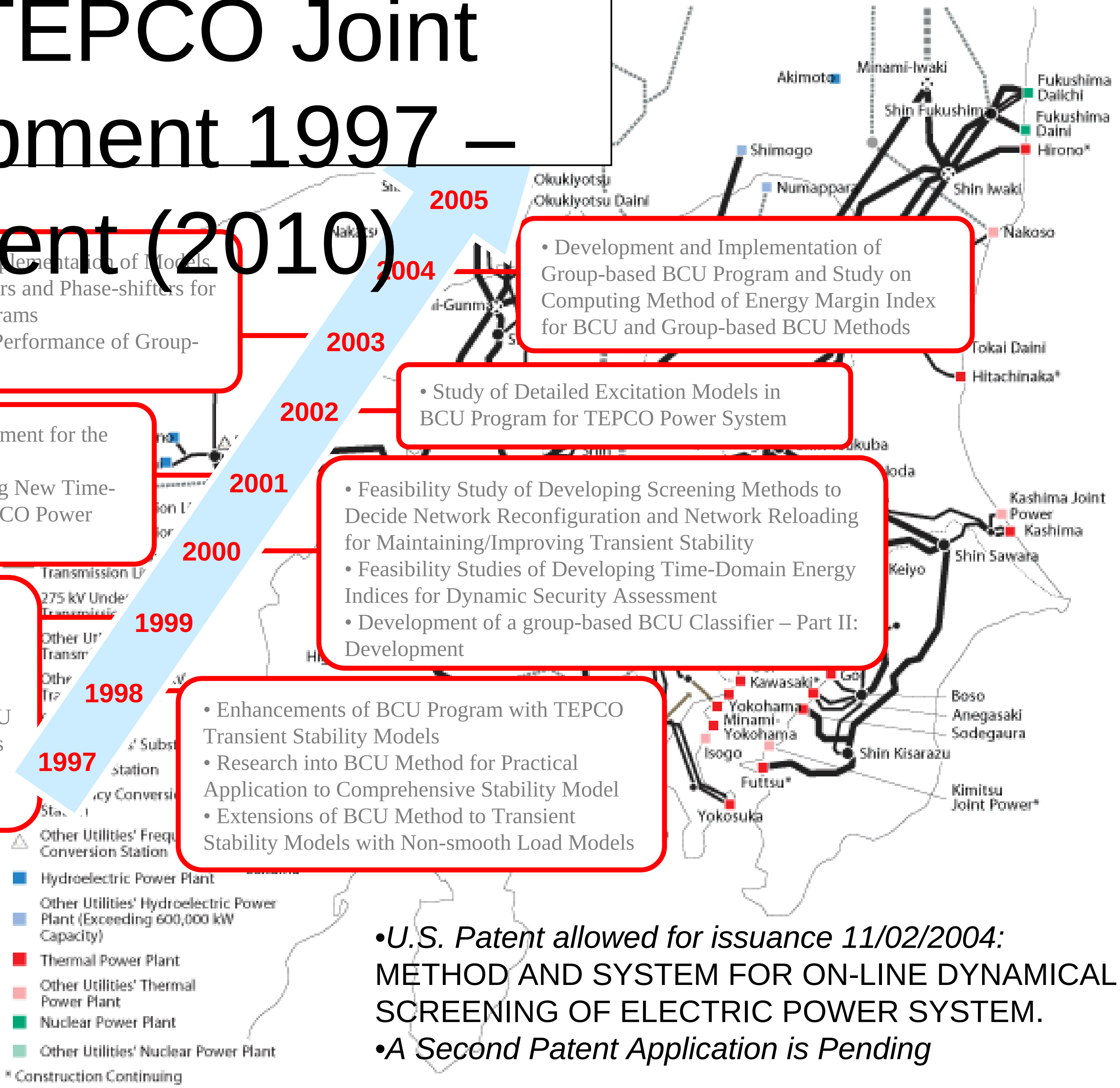
Spirits of BCU Method

- Explores the special structure of the underlying model so as to define an artificial, reduced-state model which captures all the equilibrium points on the stability boundary of the original model, and then
- Computes the controlling u.e.p. of the original model via computing the controlling u.e.p. of the reduced-state, which can be efficiently computed without resorting to an iterative time-domain procedure.

Challenges for Practical Applications of Direct Methods

Challenges	Descriptions	Possible Solutions
Modeling (I)	Models admitting energy functions	Development of a systematic way to construct energy functions
Modeling (II)	Post-fault system needs to be an autonomous system	The fault-sequence must be specified
Condition (I)	Existence of post-fault s.e.p.	Computation and verification
Condition (II)	The pre-fault s.e.p. lies inside the stability region of the post-fault s.e.p.	Computation and verification
Scenario	Requires the initial condition of the post-fault system	Inherent problem (numerical integration of fault-on system)
Accuracy (I)	Non-existence of analytical energy functions for general transient stability models	Numerical energy function
Accuracy (II)	Direct methods, except the controlling u.e.p. method, give either conservative or over-estimate stability assessments	Controlling u.e.p. method
Accuracy (III)	Controlling u.e.p.method always gives conservative stability assessments	Further development
Controlling u.e.p. (I)	**1.** Various definitions of controlling u.e.p. **2.** The controlling u.e.p. is the first u.e.p. whose stable manifold is hit by the fault-on trajectory (at the exit point)	BCU method uses the precise definition of controlling u.e.p.
Controlling u.e.p. (II)	**1.** The computation of the exit point usually requires the bruce force time-domain approach **2.** The existing methods proposed to compute the controlling u.e.p. based on the original power system models usually fail	BCU method and its improvements
Function	Applicable for only first-swing stability analysis	**1.** Use transient stability model valid for multi-swing stability analysis **2.** Controlling u.e.p. method

BSI &TEPCO Joint Development 1997 – Present (2010)



1997
- Development of a Group-based BCU Method – Part I: Research
- Development of Improved BCU Classifier for TEPCO Incorporated Analytical System
- Study of the Applicability of Improved BCU Classifiers for Multi-swing Stability Analysis
- Continual Development of BCU Classifiers (Version 2)

1998
- Enhancements of BCU Program with TEPCO Transient Stability Models
- Research into BCU Method for Practical Application to Comprehensive Stability Model
- Extensions of BCU Method to Transient Stability Models with Non-smooth Load Models

1999

2000
- Feasibility Study of Developing Screening Methods to Decide Network Reconfiguration and Network Reloading for Maintaining/Improving Transient Stability
- Feasibility Studies of Developing Time-Domain Energy Indices for Dynamic Security Assessment
- Development of a group-based BCU Classifier – Part II: Development

2001
- Study of the precision improvement for the Group-based BCU Method
- Feasibility Study of Developing New Time-Domain Energy Indices for TEPCO Power System

2002
- Study of Detailed Excitation Models in BCU Program for TEPCO Power System

2003
- Development and Implementation of Models of Generator Controllers and Phase-shifters for BCU and GBCU Programs
- Improvement in the Performance of Group-based BCU Programs

2004
- Development and Implementation of Group-based BCU Program and Study on Computing Method of Energy Margin Index for BCU and Group-based BCU Methods

2005

•*U.S. Patent allowed for issuance 11/02/2004:*
METHOD AND SYSTEM FOR ON-LINE DYNAMICAL SCREENING OF ELECTRIC POWER SYSTEM.
•*A Second Patent Application is Pending*

LEARN HOW TO IMPLEMENT BCU METHODS FOR FAST DIRECT STABILITY ASSESSMENTS OF ELECTRIC POWER SYSTEMS

Electric power providers around the world rely on stability analysis programs to help ensure uninterrupted service to their customers. These programs are typically based on step-by-step numerical integrations of power system stability models to simulate system dynamic behaviors. Unfortunately, this off-line practice is inadequate to deal with current operating environments. For years, direct methods have held the promise of providing real-time stability assessments; however, these methods have presented several challenges and limitations.

This book addresses these challenges and limitations with the BCU methods developed by author Hsiao-Dong Chiang. To date, BCU methods have been adopted by twelve major utility companies in Asia and North America. In addition, BCU methods are the only direct methods adopted by the Electric Power Research Institute in its latest version of DIRECT 4.0.

Everything you need to take full advantage of BCU methods is provided, including:

- Theoretical foundations of direct methods
- Theoretical foundations of energy functions
- BCU methods and their theoretical foundations
- Group-based BCU method and its applications
- Numerical studies on industrial models and data

Armed with a solid foundation in the underlying theory of direct methods, energy functions, and BCU methods, you'll discover how to efficiently solve complex practical problems in stability analysis. Most chapters begin with an introduction and end with concluding remarks, making it easy for you to implement these tested and proven methods that will help you avoid costly and dangerous power outages.

HSIAO-DONG CHIANG, PhD, a Fellow of IEEE, is Professor of Electrical and Computer Engineering at Cornell University. Dr. Chiang is the Founder of Bigwood Systems, Inc. and Global Optimal Technology, Inc. as well as the Co-founder of Intelicis Corporation. Dr. Chiang's research and development activities range from fundamental theory development to practical system installations. He and his group at Cornell have published more than 300 refereed journal and conference papers. Professor Chiang's research focuses on nonlinear system theory and nonlinear computations and their practical applications to electric circuits, systems, signals, and images. He was awarded ten US patents and four patents from overseas countries.

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Direct Methods for Stability Analysis of Electric Power Systems
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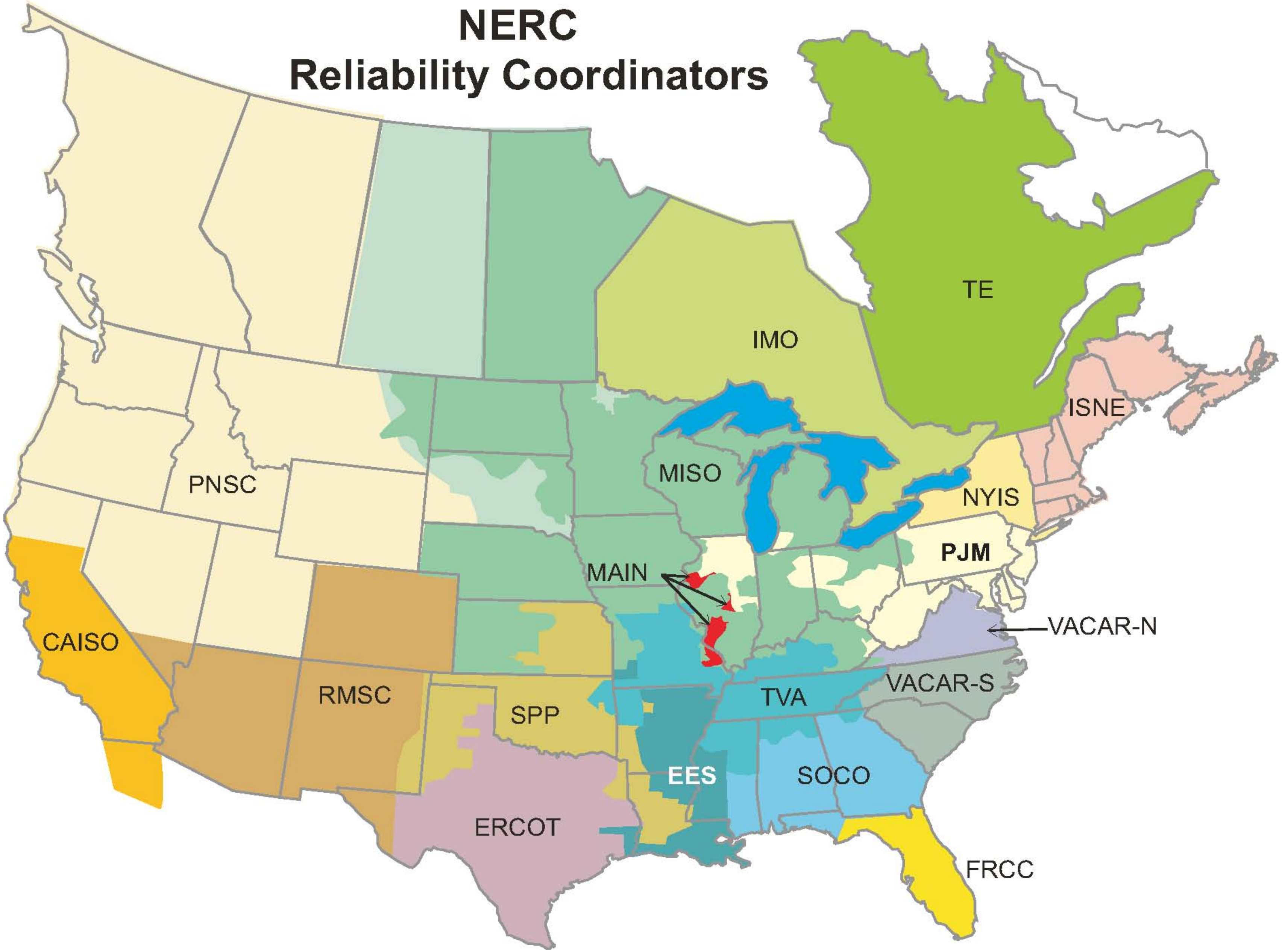
Theoretical Foundation, BCU Methodologies and Applications

HSIAO-DONG CHIANG

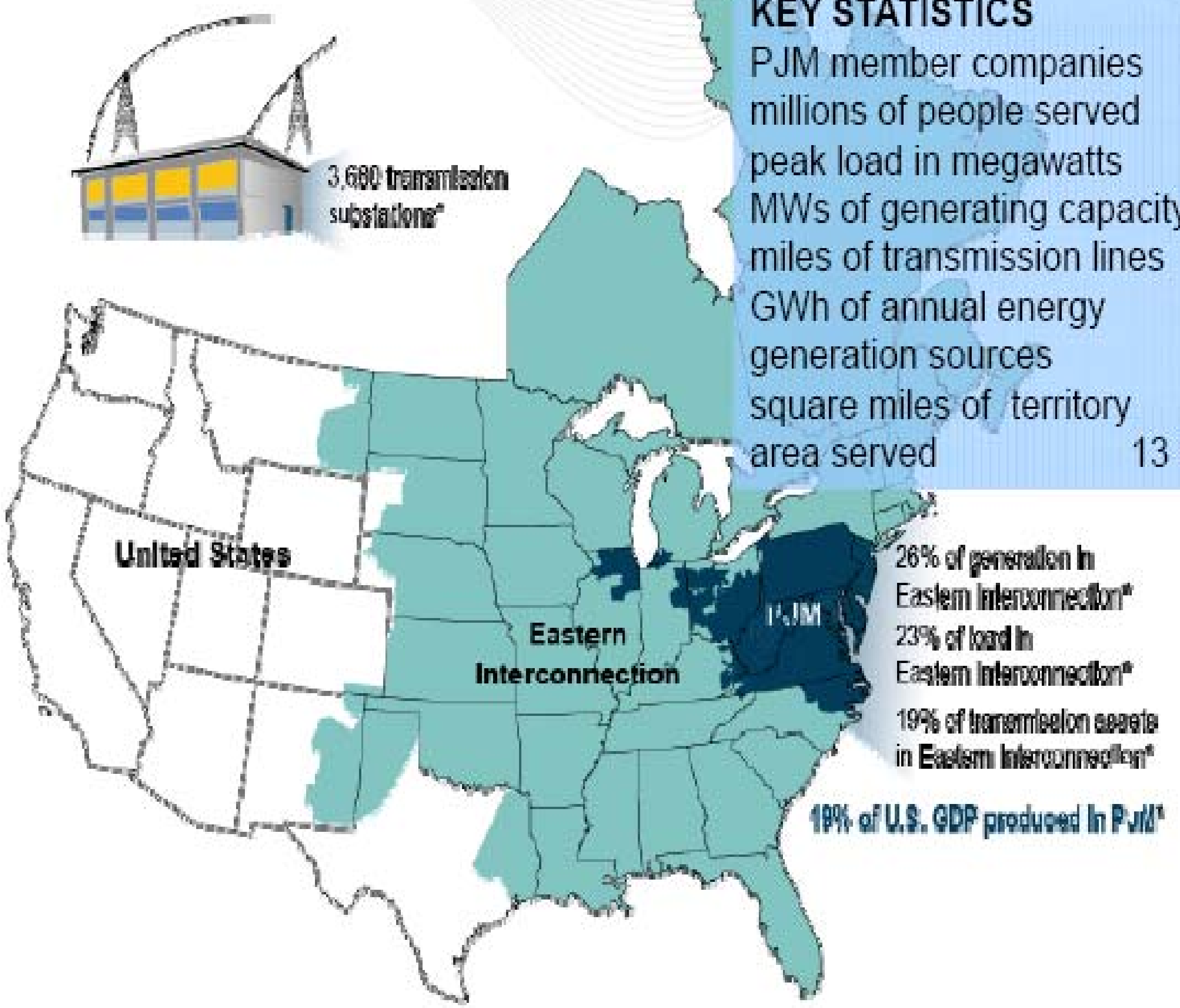
WILEY

NERC
Reliability Coordinators

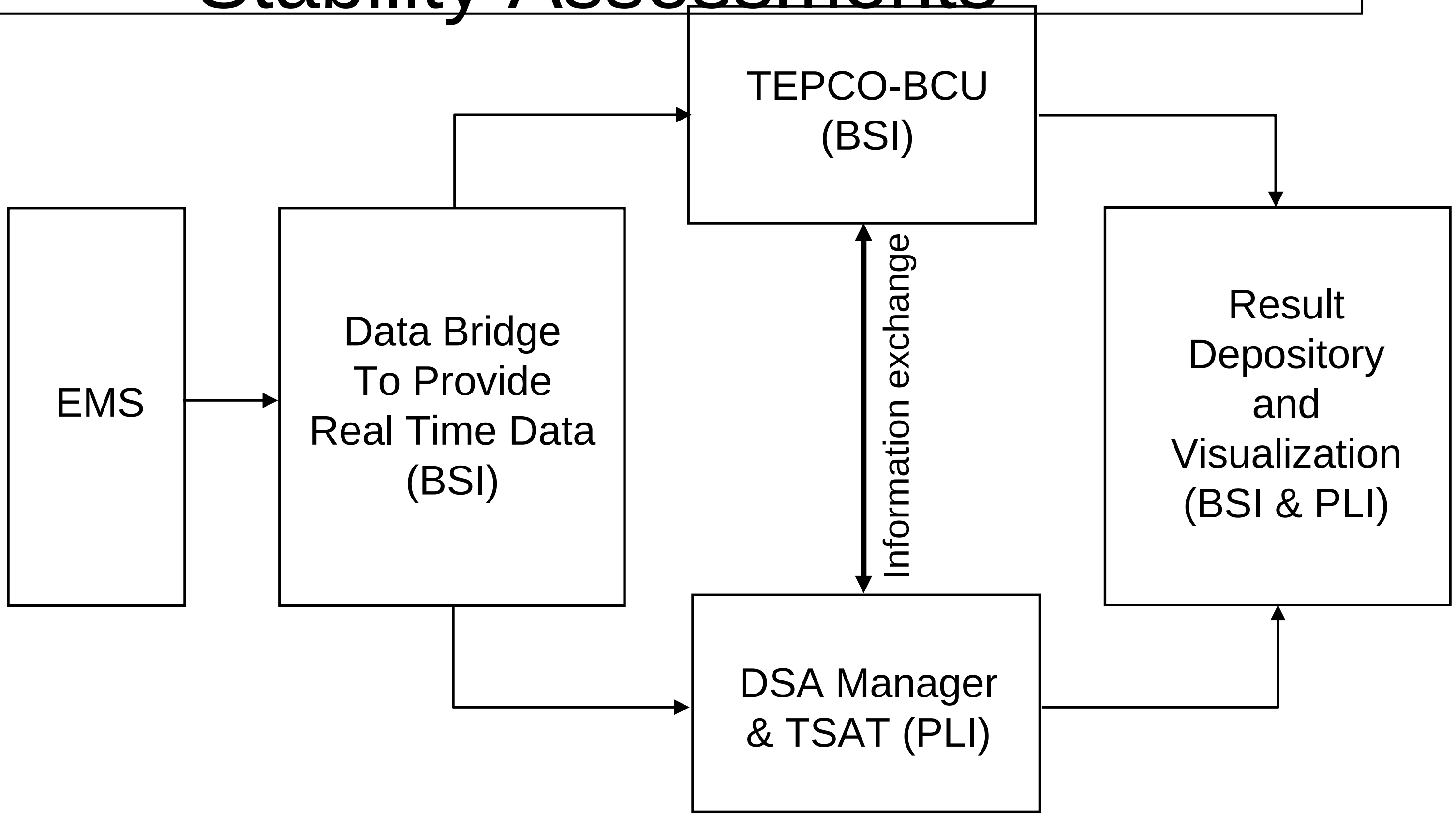


PJM as Part of the Eastern Interconnection

KEY STATISTICS	
PJM member companies	400+
millions of people served	51
peak load in megawatts	145,000
MWs of generating capacity	165,738
miles of transmission lines	56,070
GWh of annual energy	700,000
generation sources	1,082
square miles of territory	164,260
area served	13 states + DC



High-level Overview
Solution for PJM on-line Transient Stability Assessments



Data Bridge contains common fixed data for both TEPCO-BCU/TSAT and local data required only by TEPCO-BCU or TSAT

PJM Evaluation Results

- (1) **Reliability measure**: TEPCO-BCU consistently gave conservative stability assessments for each contingency during the three-month evaluation time. TEPCO-BCU did not give over-estimated stability assessment for any contingency.

PJM Evaluation Results

- For a total of 5.29 million contingencies, TEPCO-BCU captures all the unstable contingencies.

Table 1.Reliability Measure

Total No. of contingency	Percentage of capturing unstable contingencies
5293691	100%

Speed:

- TEPCO-BCU consumes a total of 717575 CPU seconds. Hence, on average, TEPCO-BCU consumes about 1.3556 second for each contingency.

Table 2. Speed Assessment

Total No. of contingency	Computation Time	Time/per contingency
5293691	717575 seconds	**1.3556 second**

Screening measure:

- Depending on the loading conditions and network topologies, the screening rate ranges from 92% to 99.5%

Table 3. Screening Percentage Assessment

Total No. of contingency	Percentage Range
5293691	92% to 99.5 %

A summary

- The overall performance indicates that TEPCO-BCU is an excellent screening tool These unstable contingencies exhibit first-swing instability as well as multi-swing instability.

Table 4. Overall performance of TEPCO-BCU for on-line dynamic contingency screening

Reliability measure	Screening measurement	Computation speed	on-line computation
100%	**92% to 99.5%**	1.3 second	Yes

Concluding Remarks

- A comprehensive evaluation study of the TEPCO-BCU package in a real time environment as a screening tool for on-line transient stability assessment has been presented.
- TEPCO-BCU package is an excellent dynamic contingency screening tool for on-line transient stability analysis of large-scale power systems.

Concluding Remarks

This evaluation study represents the largest practical application of the stability region theory and its estimation of relevant stability region behind the BCU methodology in terms of the size of the study system which is a 14,000-bus power system dynamic model with a total of 5.3 million contingencies.

Concluding Remarks

This confirms our belief that theory-based solution methods can lead to practical applications in large-scale nonlinear systems.

	Dynamic Security Assessment	CPFLOW Transient-Stability ATC Evaluation	Minimum-Number Preventive Control
TEPCO-BCU	Very Good	Very Good	Excellent
Time-Domain Simulations	Good	Not Good	No Such Capability

	Minimum-Cost Preventive Control	Minimum-Number Enhancement Control	Minimum-Cost Enhancement Control
TEPCO-BCU	**Excellent**	**Excellent**	**Excellent**
Time-Domain Simulations	**No Such Capability**	**No Such Capability**	**No Such Capability**

Improving transient stability

Stability Assessment

unsatisfactory stability

Want to increase stability of vulnerable stable cases?

Enhancement controls

Increase CCT (or enlarge stability region)

Crucial information for controls

- Degree of stability or instability
- Useful information for deriving enhancement/preventive controls

What if the system is <u>unstable</u> ?

Preventive controls

Final CCT must meet the requirement

Control Developments

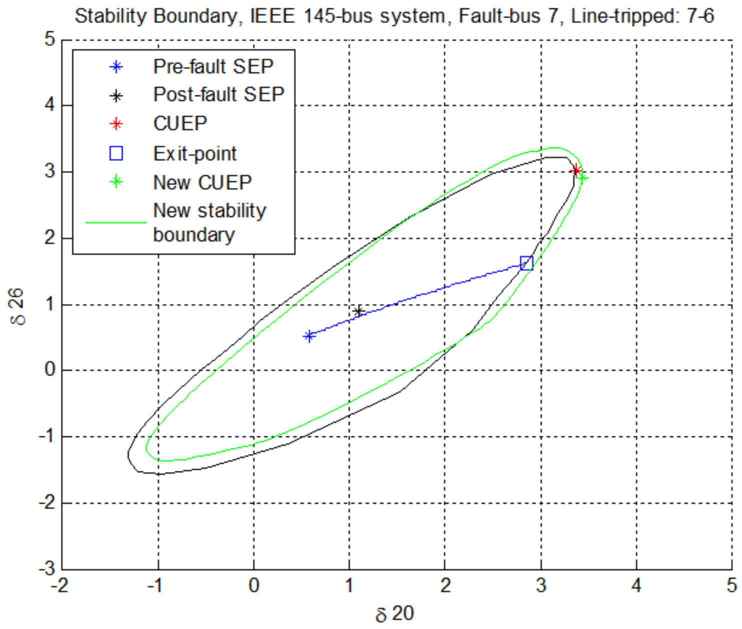
1. Preventive control (against all insecure contingencies)
2. Enhancement control (to increase load margins for critical contingencies)

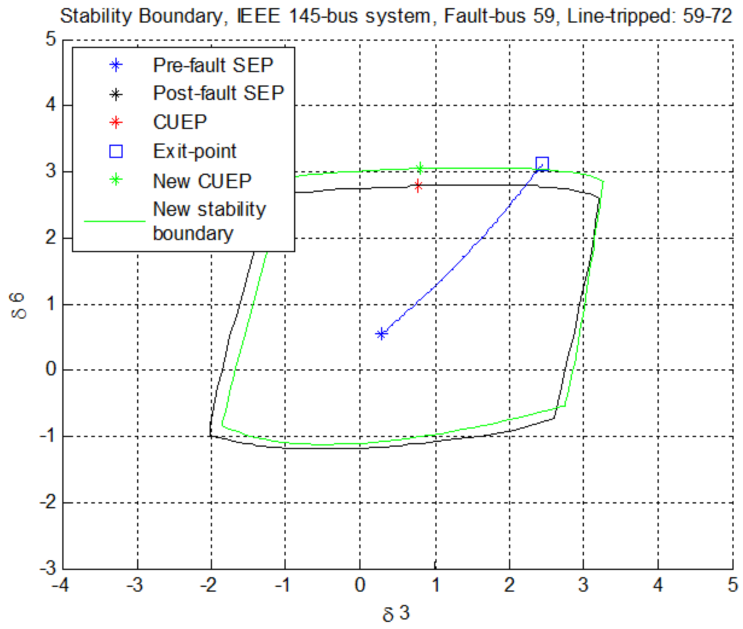
Improved CCT’s on IEEE145

Scheme: Minimal # of control (Rank 1- Rank 50 pair MW Shift)
Single contingency

Contingency #	Fault- bus: fault-line	Original CCT	Maximum CCT after enhancement controls	% Improvement
1	7: 7, 6	0.16103	0.48921	203.8 %
2	59: 59, 72	0.25914	0.43190	66.67 %
3	112: 112, 69	0.27209	6.0462	2122.13%
4	91: 91, 75	0.29763	0.53721	80.5%
5	6: 6, 1	0.17822	4.39887	2368.22%
6	12: 12, 14	0.33291	0.53222	59.87%
7	6: 6, 10	0.26490	3.29890	1145.34%
8	33: 33, 49	0.21777	0.41671	91.35%
9	69: 69, 32	0.13749	0.31002	125.49%
10	105: 105, 73	0.19812	0.26773	35.14%
11	59: 59, 103	0.23701	5.67811	2295.726%
12	66: 66, 8	0.30105	2.33595	675.93%

Effects on stability boundary





- Relevant stability boundaries can be stretched to increase stability and critical clearing times.

Enhancement control results on Structure-Preserving Models (DAE)

Contingency #	Fault- bus: fault-line	Original CCT	Maximum CCT after enhancement controls	% Improvement
1	7: 7, 6	0.1539	0.5211	238.5965 %
2	59: 59, 72	0.2633	0.4592	74.40182 %
3	112: 112, 69	0.2631	8.3104	3058.647 %
4	91: 91, 75	0.301	0.6271	108.3389 %
5	6: 6, 1	0.1667	4.4899	2593.401 %
6	12: 12, 14	0.3209	0.5936	84.97974 %
7	6: 6, 10	0.2713	4.296	1483.487 %
8	33: 33, 49	0.2007	0.4371	117.7877 %
9	69: 69, 32	0.1408	0.3532	150.8523 %
10	105: 105, 73	0.2021	0.2935	45.22514 %
11	59: 59, 103	0.2442	5.798	2274.283 %
12	66: 66, 8	0.3135	2.4021	666.2201 %

The enhancement control scheme is also effective on SP model

My Belief

solving practical problems efficiently and reliably can be accomplished through

- a thorough understanding of the underlying theory, in conjunction with
- exploring the features of the practical problem under study