New Security Tools for Real-Time Operation:
Risk-based security-constrained economic dispatch (RB-SCED)

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1. Project Objective: Develop Risk-based Security Assessment and Market functions

Provide new control-room software capabilities through:

BETTER SECURITY & ECONOMIC PERFORMANCE:
Identify a more secure operating condition at lower production costs

Function	Concept	Outcome
Risk-based security-constrained economic dispatch (RB-SCED)	**Achieve economic objective while managing *system* security +*circuit* security instead of only the latter.**	**• more secure operating conditions • lower costs**

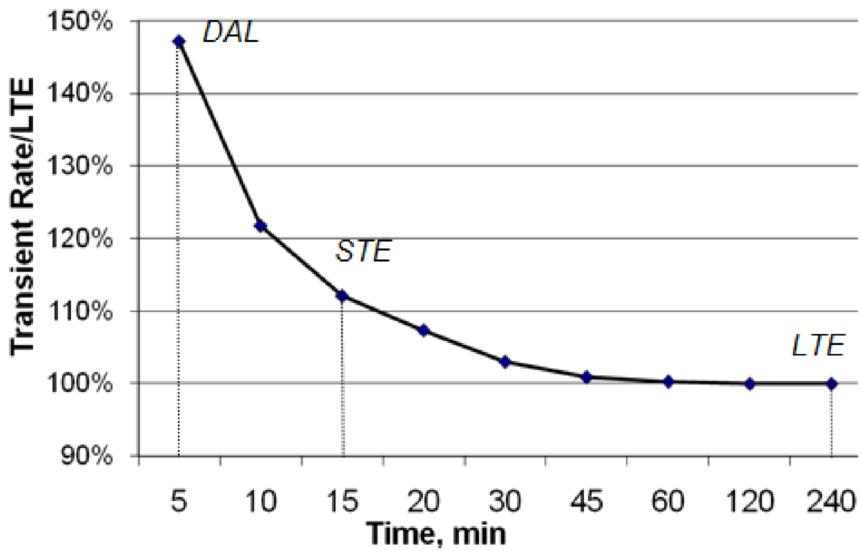
Risk Index

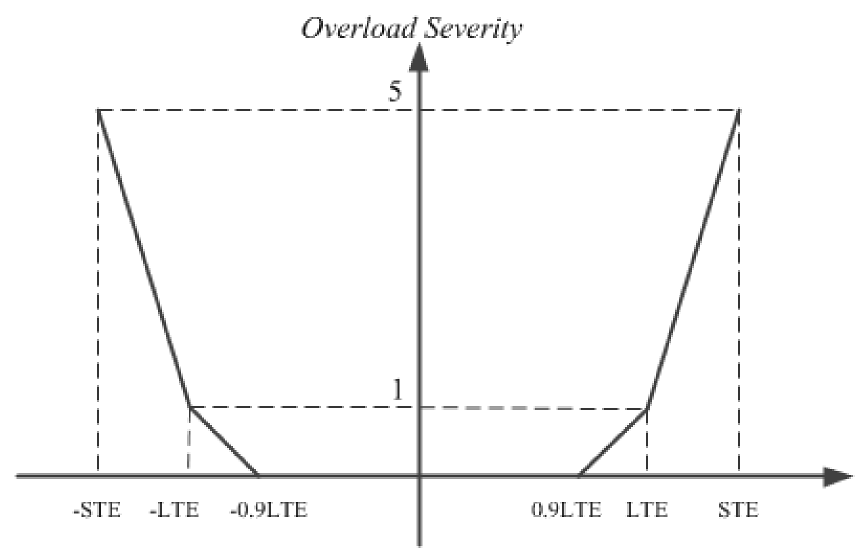
A weighted sum of normalized flows for the heavier-loaded circuits.

$$Risk = \sum_{k=1}^{n} \underbrace{\Pr_k}_{\text{Probability of contingency k}} \underbrace{\sum_{j=1, j \neq k}^{n} Sev_j(g_k(P_0))}_{\text{Severity of contingency k}}$$

Probability of contingency k

Severity of contingency k





Three emergency rates are defined *:

- Long Time Emergency (LTE) Rating, 4 *hrs*
- Short Time Emergency (STE) Rating, 15 *mins*
- Drastic Action Limit (DAL), *immediate action*

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*S. Maslennikov, E. Litvinov. "Adaptive Emergency Transmission Rates in Power System and Market Operation," *IEEE Trans. Power System*, May 2009.

PRB-SCED: main concepts

Under PRB-SCED, the system is dispatched under normal conditions to:

Same as SCED

1. **Satisfy pre-contingency (normal) flow constraints**

Makes it more secure than SCED

2. **Lower post-contingency flows for circuits having post-contingency loadings above 90% of LTE flow limits**

3. **Satisfy post-contingency flow constraints**
   - **at LTE flow limits**
   - **at 105% of LTE flow limits**
   - **at 120% of LTE flow limits (STE)**

Makes it more economic than SCED

(2) and (3) together results in more secure & more economic operating conditions.

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2. Major technical objectives completed this year

PRB-SCED
CRB-SCED

Last year: developed/tested computational approach for preventive risk-based SCED (PRB-SCED). This year:

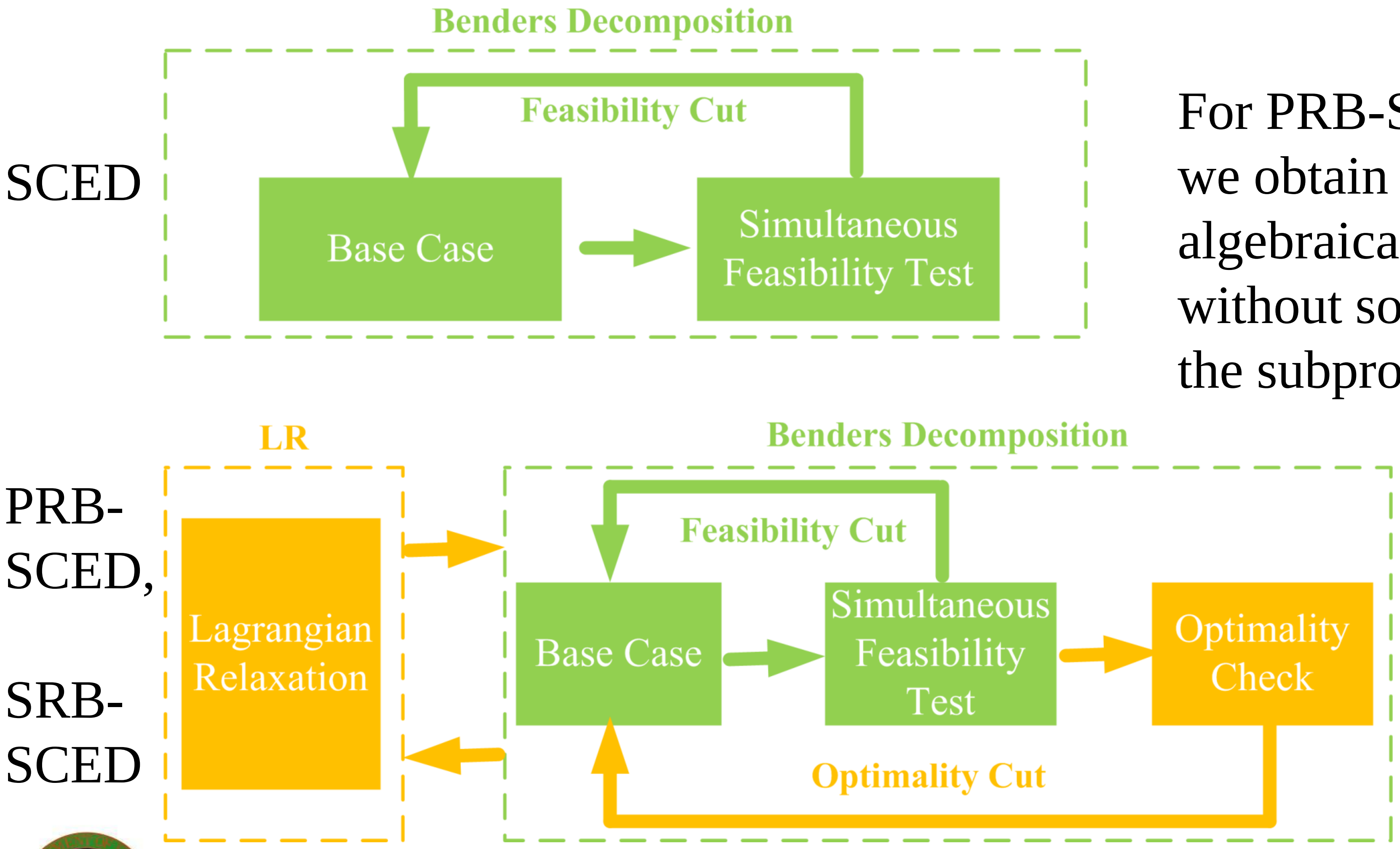
1. Developed computational approach for corrective risk-based SCED (CRB-SCED), and tested on IEEE 30-bus test system; improved computational approach for preventive RB-SCED (PRB-SCED)
2. Compared SCED, PRB-SCED, CRB-SCED on ISO-NE system;
   ➔Estimated annual savings in production costs for using PRB-SCED in ISO-NE system and throughout the US;
3. Developed approach for coordinating line limits & risk limit;
4. Identified steps necessary for implementing PRB-SCED at ISO-NE;

Non-technical accomplishments:

- Interacted closely with ISO-NE, written 4 papers & submitted 2.
- Invited to present work at upcoming FERC conference;
- Excellent PhD student to enter workforce in next academic year.

2. Major technical objectives completed this year

CRB-SCED



For PRB-SCED, we obtain the cuts algebraically, without solving the subproblems

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2. Major technical objectives completed this year

CRB-SCED

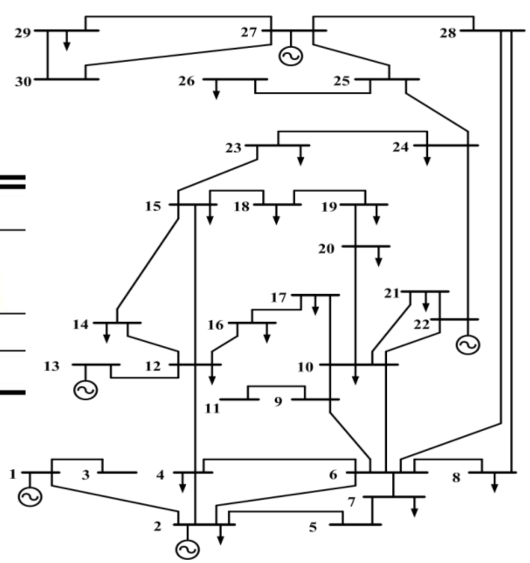
IEEE 30-bus system:

- 30 buses, 41 branches, 6 thermal units and 20 loads.
- 41 N-1 contingencies

- HSM: Highly secure mode
- ESM: Economic-secure mode
- HEM: Highly economic mode

Comparison of risk & costs between CSCOPF & CRB-SCOPF

Constraints	CSCED	CRB-SCED		
		HSM (K_C=1, K_R = 0.5)	ESM (K_C =1.05, K_R = 0.5)	HEM (K_C =1.20, K_R = 0.5)
Risk	0.1150	0.0575	0.0575	0.0575
Cost ($)	116207.5	125867.1	103475.1	102110.4



2. Major technical objectives completed this year

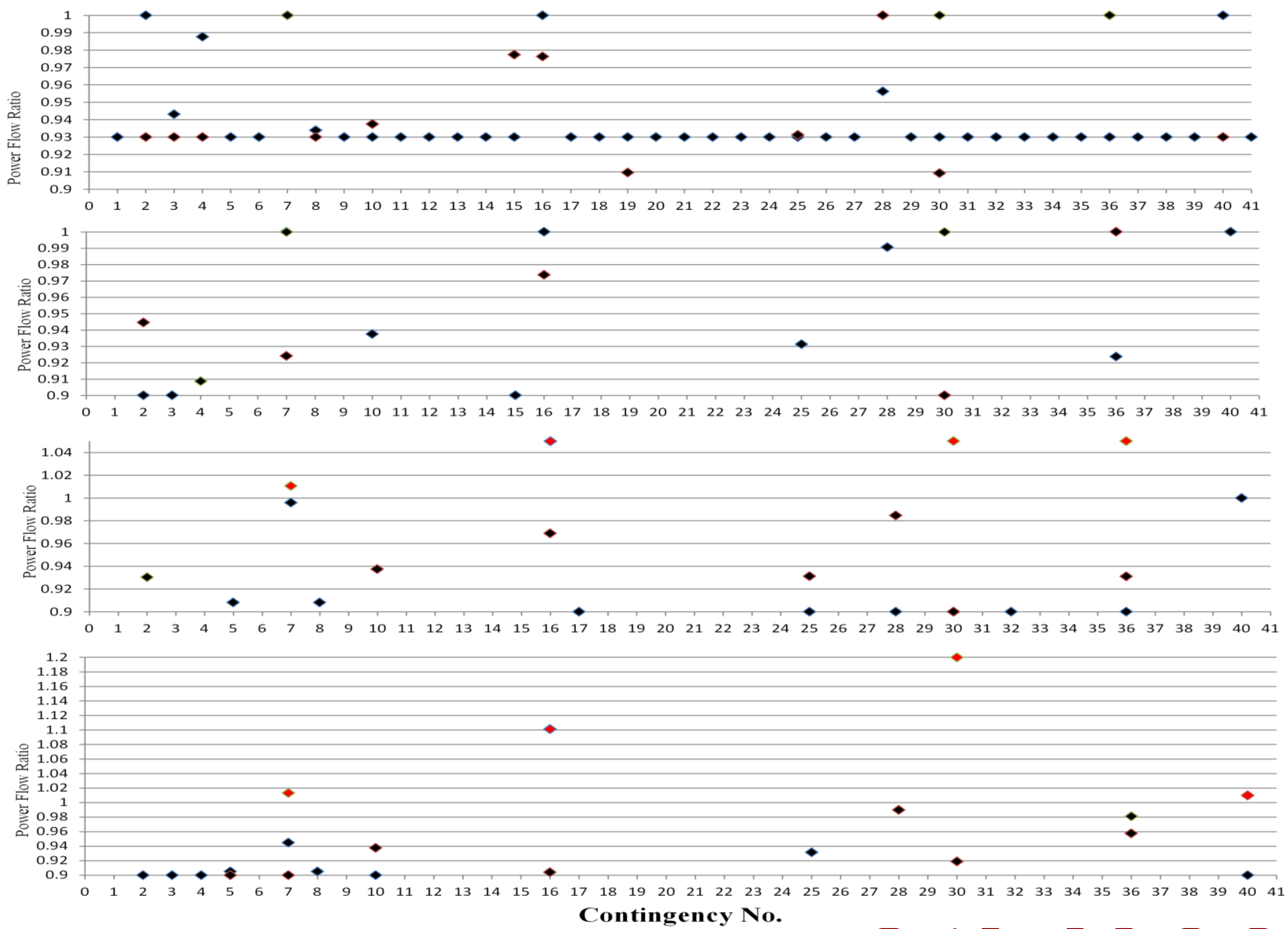
CRB-SCED

CSCED:

CRB-SCED: HSM

CRB-SCED: ESM

CRB-SCED: HEM



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2. Major technical objectives completed this year

SCED, RB-ED, PRB-SCED, CRB-SCED

- Compared SCED, RB-ED, PRB-SCED and CRB-SCED
- Illustrated on ISO-NE system

12,300 buses, 13,500 branches, Matlab, on 3.16GHz Intel Core 2 CPU; 4Gb RAM

SCED	RB-ED	RB-SCED: Preventive RB-SCED	RB-SCED: Corrective RB-SCED
$\min\left\{f(\underline{P}_0)\right\}$ $s.t.\ \underline{h}(\underline{P}_0)=\underline{0}$ $\underline{g}_{\min} \le \underline{g}(\underline{P}_0) \le \underline{g}_{\max}$ $\underline{g}'_{\min} \le \underline{g}_k(\underline{P}_0) \le \underline{g}'_{\max},$ $k=1,\ldots,NC$	$\min\left\{f(\underline{P}_0)\right\}$ $s.t.\ \underline{h}(\underline{P}_0)=\underline{0}$ $\underline{g}_{\min} \le \underline{g}(\underline{P}_0) \le \underline{g}_{\max}$ $0 \le Risk(\underline{g}_1(\underline{P}_0),\ldots\underline{g}_{NC}(\underline{P}_0)) \le K_R Risk_{\max}$	$\min\left\{f(\underline{P}_0)\right\}$ $s.t.\ \underline{h}(\underline{P}_0)=\underline{0}$ $\underline{g}_{\min} \le \underline{g}(\underline{P}_0) \le \underline{g}_{\max}$ $K_C\underline{g}'_{\min} \le \underline{g}_k(\underline{P}_0) \le K_C\underline{g}'_{\max},\ k=1,\ldots,NC$ $0 \le Risk(\underline{g}_1(\underline{P}_0),\ldots\underline{g}_{NC}(\underline{P}_0)) \le K_R Risk_{\max}$	$\min\left\{f(\underline{P}_0)\right\}$ $s.t.\ \underline{h}(\underline{P}_0)=\underline{0}$ $\underline{g}_{\min} \le \underline{g}(\underline{P}_0) \le \underline{g}_{\max}$ $K_C\underline{g}'_{\min} \le \underline{g}_k(\underline{P}_0) \le K_C\underline{g}'_{\max},\ k=1,\ldots,NC$ $\left\|\underline{P}_0-\underline{P}_k\right\| \le \Delta\underline{P}$ $0 \le Risk(\underline{g}_1(\underline{P}_0),\ldots\underline{g}_{NC}(\underline{P}_0)) \le K_R Risk_{\max}$

Constra.	**SCED**		**RB-ED**	**Preventive RB-SCED**			**Corrective RB-SCED**		
	Preventive	**Corrective**		**HSM** (K_C=1, K_R= 0.5)	**ESM** (K_C =1.05, K_R = 0.5)	**HEM** (K_C =1.20, K_R = 0.5)	**HSM** (K_C=1, K_R = 0.5)	**ESM** (K_C =1.05, K_R = 0.5)	**HEM** (K_C =1.20, K_R = 0.5)
Risk	18.2690	18.24	9.1345	9.1345	9.1345	9.1345	9.12	9.12	9.12
Cost($/hr)	684642.50	616172.1	605407.32	728899.10	610611.54	605542.08	678654.3	608672.2	593676.6

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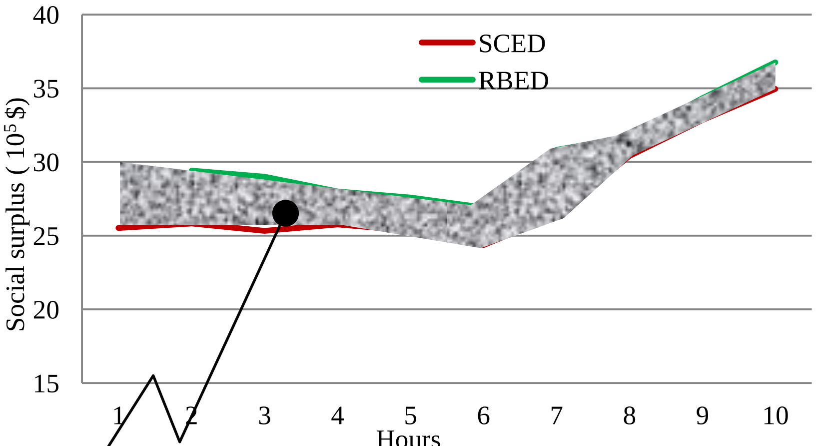
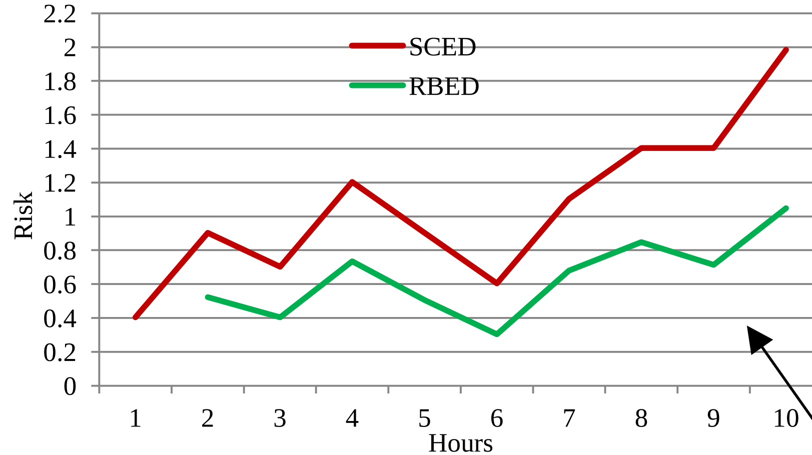
2. Major technical objectives completed this year

PRB-SCED

Comparing SCED, PRB-SCED on ISO-NE system for 10 sequential hrs

From EMS, 06/16/2010, 1 to 10 hours, computational time 20 minutes per case.





- Area=ISO-NE savings over 10 hrs=$2M (assume 0 during other 14 hrs)
- Annual cost saving: $2.0M×5×52=$520M/yr (assume 0 for weekend)
- ISO-NE is 3% of nation ➔ Annual national savings=$520M÷(.03)=$17B/yr
- It will be more if CRB-SCED is used. And it is more secure!

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2. Major technical objectives completed this year

PRB-SCED

Risk and “N-1 criteria” can be coordinated to enhance both economy and security.

$$\min\left\{ f(\underline{P_0}) \right\}$$

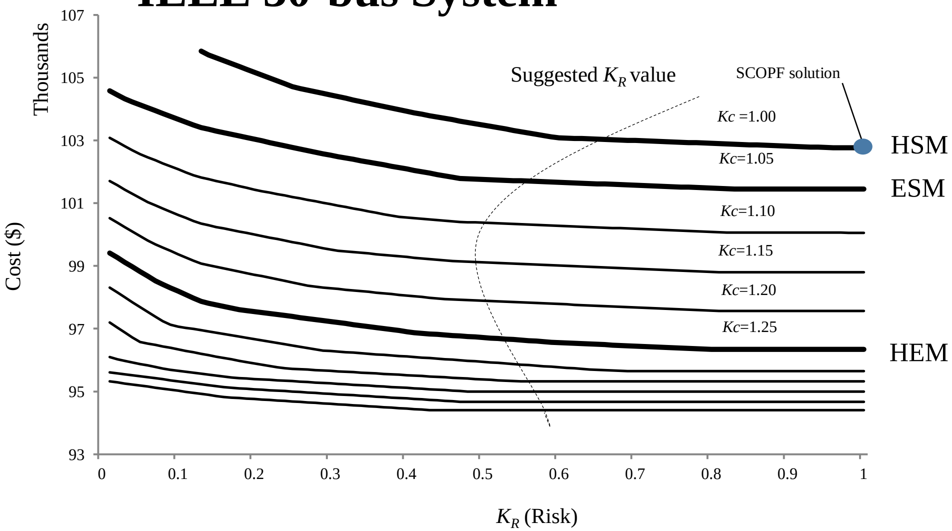
$$s.t.\ \underline{h}(\underline{P_0}) = \underline{0}$$

$$\underline{g}_{\min} \le \underline{g}(\underline{P_0}) \le \underline{g}_{\max}$$

$$K_C\, \underline{g}'_{\min} \le \underline{g}_k(\underline{P_0}) \le K_C\, \underline{g}'_{\max},\ k = 1, \ldots, NC$$

$$0 \le Risk(\underline{g}_1(\underline{P_0}), \ldots \underline{g}_{NC}(\underline{P_0})) \le K_R Risk_{\max}$$

IEEE 30-bus System



How to choose K_C and K_R?

- K_C can be chosen based on rules of when to use HSM (bad weather, stressed), ESM (normal weather & stress), and HEM (normal weather, unstressed).
- Or K_C can be chosen based on the criteria that the amount of allowable overload, (K_C*Limit-Limit) should be less than the amount of post-contingency shift that can be obtained on that circuit, Ramp*ΔT*GSF

$$K_C < \frac{\text{Ramp} * \Delta T * GSF + \text{Limit}}{\text{Limit}}$$

\- K_R is chosen at a “breakpoint” - the minimum value that does not result in significant cost increase

3. Deliverables/schedule for activities to be completed under FY12 funding

SCED, RB-ED, PRB-SCED, CRB-SCED

June 1~ July 31	Explore Risk-based LMPs	At ISU
Aug.1~ Aug.31	Finish a paper for *IEEE Trans. Power System* titled 'Modeling Risk in LMP calculation'	At ISU, travel to ISO-NE for running software
Sep.1~ Sep.30	Compare PRB-SCED to SCED for losses and cascading overload	
Oct.1~ Oct.30	Compare PRB-SCED to SCED for voltage collapse	
Nov.1~ Nov.31	Derive conditions for which PRB-SCED is guaranteed to outperform SCED.	
Dec.1~ Dec.31	▪ Result analysis, document work ▪ Write white paper justifying RBOPF approach and describe its benefits	Follow-on work, at ISU

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4. Risk factors affecting timely completion of planned activities/movement thru RD&D cycle

Risk Factors	How we are addressing them
Non-technical	**Non-technical**
Will FERC accept it?	We present it at upcoming FERC conference
Will operators feel comfortable with it?	Keep it simple to operators
Technical and non-technical	**Technical and non-technical**
What effect will it have on LMPs?	We are studying this now.
Technical	**Technical**
Will computing time be low enough?	We are close, faster CPU, vendor codes help
Can we give convincing evidence that system is truly more secure?	Working with ISONE now testing voltage stability

RB-SCOPF

The 2012 voltage and cascading testing on ISO-NE data, and interaction with FERC, should position us to engage with Alstom.

Extra Slides Follow

Summary of activities for PhD student Qin Wang

SCED, RB-ED, PRB-SCED, CRB-SCED

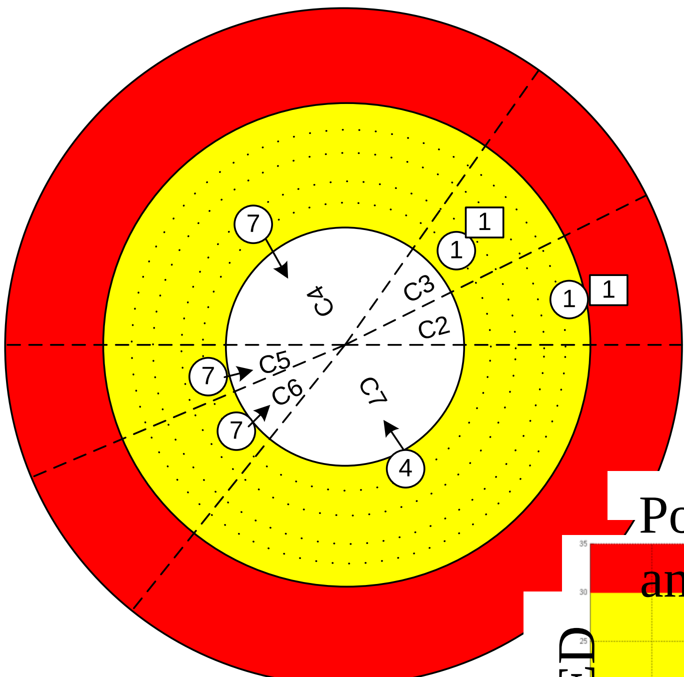
Date	Events
6/2009	Arrive at ISU, begin research
6/2010-8/2010	Summer intern at ISO-NE, exchanged ideas with industry, formed big picture for solving PRB-SCOPF
9/2010- 3/2011	Designed solver for PRB-SCOPF
4/2011	Passed qualifying exam (becomes PhD candidate)
5/2011- 8/2011	Designed solver for CRB-SCOPF
9/2011- 12/2011	Fall intern at ISO-NE, developed, tested software for PRB-SCED solver, brought it closer to industrial application.
1/2012-3/2012	Developed, tested software for CRB-SCED
3/2012	Passed preliminary exam (research proposal accepted)
4/2012- 5/2011	Developed coordination method for risk and "N-1" criteria
5/2012- present	Developing/exploring risk-based LMPs
1/2013-6/2013	Final defense (graduation)

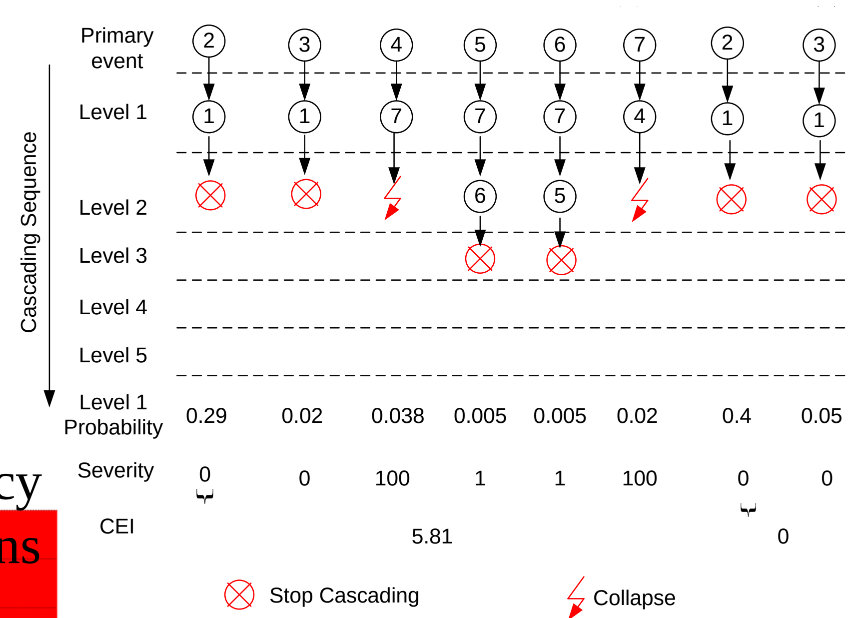
SCED vs. RB-ED

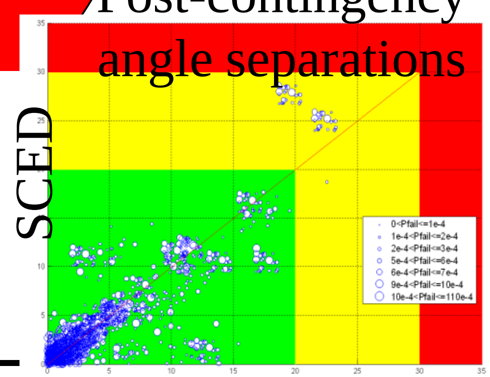
SCED	RB-ED
$\min_{x_0,\ldots,x_{NC},u_0} \; f_0(x_0,u_0)$ $s.t. \; g_k(x_k,u_0)=0 \quad k=0,\ldots,NC$ $h_k(x_k,u_0)\le h_k^{max} \quad k=0,\ldots,NC$	$\min_{x_0,\ldots,x_{NC},u_0} \; f_0(x_0,u_0)$ $s.t. \; g_k(x_k,u_0)=0 \quad k=0,\ldots,NC$ $h_0(x_0,u_0)\le h_0^{max}$ $\sum_{k=0}^{NC} Risk_k(Pr_k,x_k)\le Risk_{max}$

IEEE 30 bus system

	SCED	RB-ED
Cost($)	451,383	446,420
Overload Risk	1.51	0.84







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Deliverables/schedule for activities to be completed under FY12 funding

PRB-SCOPF

- Risk-based LMP

SCED:

$$LMP = Energy + Loss + Congestion$$

$$\begin{aligned} &\text{Min} \sum_{i=1}^{N} c \times P_i \\ &s.t. \sum_{i=1}^{N} (P_i - D_i) = Loss, && \lambda \\ &\sum_{i=1}^{N} GSF_{k,i} \times (P_i - D_i) \le Limit_k, && \tau \\ &\qquad for\ k \in all\ lines \\ &P_i^{\min} \le P_i \le P_i^{\max}, \quad for\ all\ i && \mu \end{aligned}$$

Will see how $\frac{\partial L}{\partial D}$ changes.

RB-SCED:

$$LMP = Energy + Loss^* + Congestion^* + Risk$$

$$\begin{aligned} &\text{Min} \sum_{i=1}^{N} c \times P_i \\ &s.t. \sum_{i=1}^{N} (P_i - D_i) = Loss, && \lambda \\ &\sum_{i=1}^{N} GSF_{k,i} \times (P_i - D_i) \le Limit_k, && \tau \\ &\qquad for\ k \in all\ lines \\ &P_i^{\min} \le P_i \le P_i^{\max}, \quad for\ all\ i && \mu \\ &\sum_{k=0}^{NC} Pr_k \sum_{l=1}^{NL} Sev_{l,k} \le K_R \times Risk_{max}, && \gamma \end{aligned}$$

- The meaning of the risk component
  - A price signal to reflect the system's overall risk
- Market simulation
  - How will RB-SCED change the market efficiency (social surplus)

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Deliverables/schedule for activities to be completed under FY12 funding

HSET-TDS

- Use of new integration schemes: We worked on a variable time step, high-order scheme HH4, ➔ very good for large time steps. But slow for small time steps which have to be taken when there are fast transients. So, we are now investigating a variable order variable time step method called the Variable Order Variable Coefficient Backward Differentiation Formula.
- Use of fast linear solvers: We have implemented several successfully, and have had particular success regarding use of SUNDIALS.
- Use of parallelized computing: We have not had good success here, mainly because it requires machines and significant IT support. I have therefore established a working relationship with researchers at Lawrence Livermore National Laboratory.
- Overall speedups have been less than expected.