Risk-based security-constrained economic dispatch (RB-SCED)

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Motivation

SCED "security" criteria:

•Post-contingency emergency overload for each circuit k: $F_{max,k}$

•For each circuit k, if economic solution wants $F_k > F_{max,k}$, then

➔constrain $F = F_{max,k}$

We make two observations:

1.$F_{max,k}$ is not unique; we only know that as flows get higher, the likelihood of tripping (sag/touch, inadvertent relay) increases.

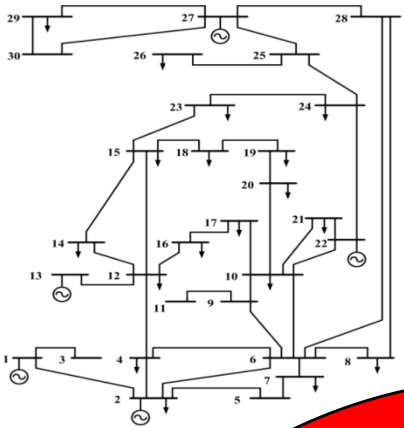
2.The approach controls "circuit security" not "system security" – as a result, a "SCED-secure" solution may be less secure than a "SCED-insecure" solution, as illustrated below:

<u>SCED-secure solution</u>:
20 contingencies each having 5 post-contingency flows between 90% and 100% of $F_{max,k}$

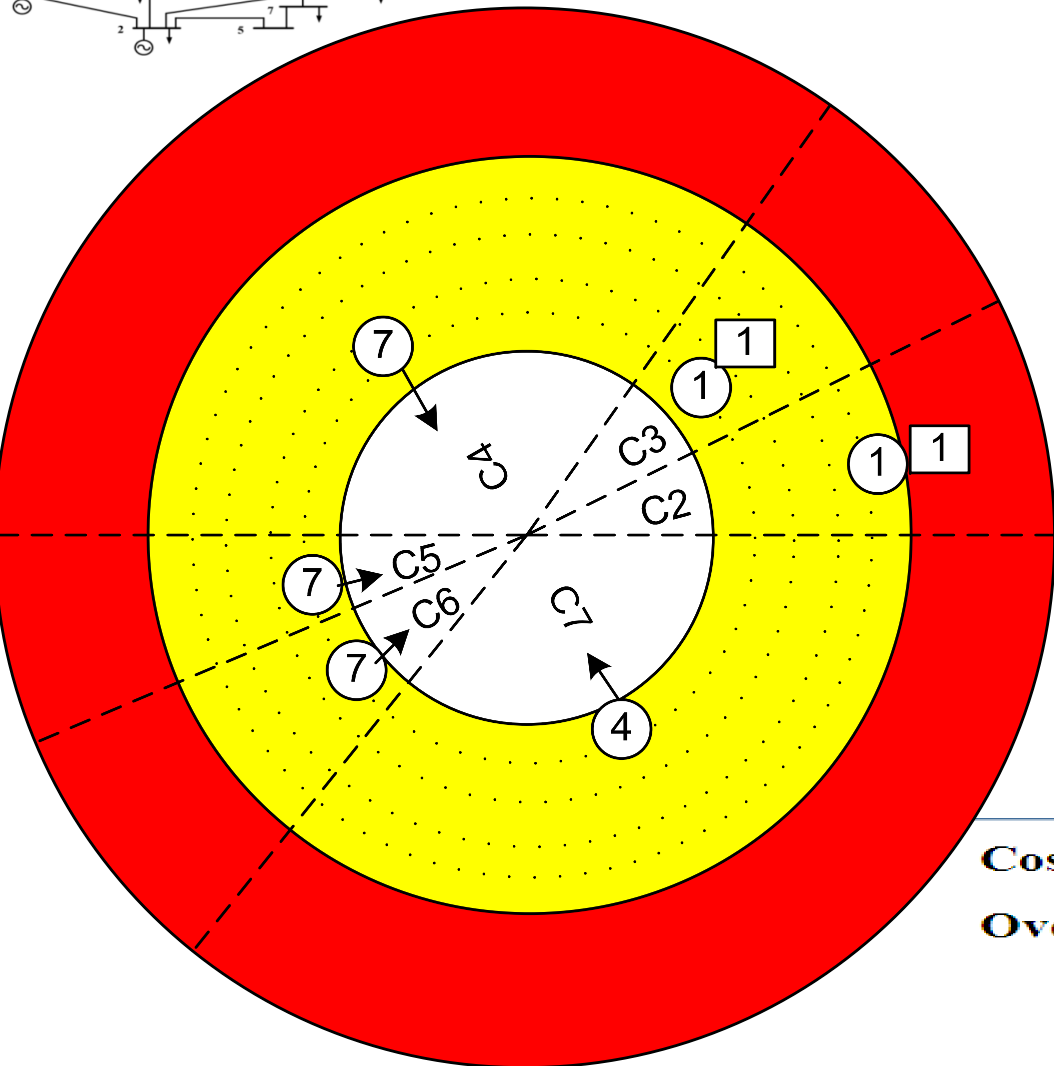
<u>SCED-insecure solution</u>:
1 contingencies having 1 post-contingency flow at 102% of $F_{max,k}$ and all other flows<80% of $F_{max,k}$.

➔We want to modify SCED to ALSO control system security!

Results 1: SCED vs. RB-SCED



IEEE 30
bus system



Post-contingency flows represented by

Circles: SCED

Squares: RB-SCED

with distance to center equal to %flow:

White: $F_k < 0.9F_{max,k}$

Yellow: $0.9F_{max,} < F_k < F_{max,k}$

Red: $F_{max,k} < F_k$

Sectors: contingencies

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

Concepts

Provide new market/security software capabilities via:

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**

Concepts

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

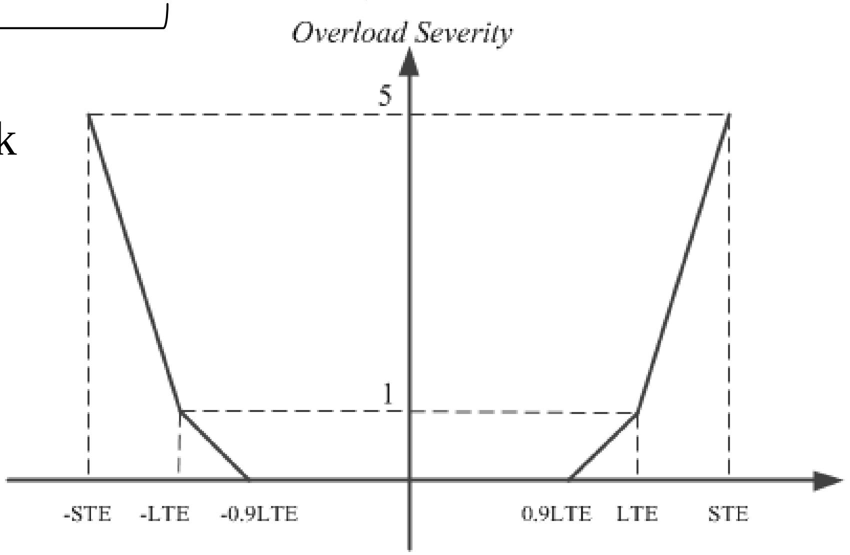
Severity of cct j for contingency k.

PF solution for contingency k.

$$Risk = \sum_{k=1}^{n} \Pr_k \sum_{j=1,\, j \neq k}^{n} Sev_j\left(g_k\left(P_0\right)\right)$$

Probability of contingency k

Severity of contingency k



Conceptually similar to adaptive emergency transmission rates in *S. Maslennikov, E. Litvinov. "Adaptive Emergency Transmission Rates in Power System and Market Operation," *IEEE Trans. Power System*, May 2009.

Concepts

Under RB-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
Makes it more economic than SCED	**•at 105% of LTE flow limits** **•at 120% of LTE flow limits (STE)**

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

Formulation and results 2

SCED

$$\min\left\{ f(\underline{P}_0)\right\}$$
$$s.t.\ \underline{h}(\underline{P}_0)=\underline{0}$$
$$\underline{g}_{\min} \le \underline{g}(\underline{P}_0) \le \underline{g}_{\max}$$
$$\underline{g}'_{\min} \le \underline{g}_k(\underline{P}_0) \le \underline{g}'_{\max},\quad k=1,\dots,NC$$

RB-SCED

$$\min\left\{ f(\underline{P}_0)\right\}$$
$$s.t.\ \underline{h}(\underline{P}_0)=\underline{0}$$
$$\underline{g}_{\min} \le \underline{g}(\underline{P}_0) \le \underline{g}_{\max}$$
$$K_C\,\underline{g}'_{\min} \le \underline{g}_k(\underline{P}_0) \le K_C\,\underline{g}'_{\max},\ k=1,\dots,NC$$
$$0 \le Risk(\underline{g}_1(\underline{P}_0),\dots \underline{g}_{NC}(\underline{P}_0)) \le K_R Risk_{\max}$$

Constra.	SCED: Preventive
Risk	18.2690
Cost($/hr)	684642.50

RB-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	9.1345	9.1345	9.1345
Cost($/hr)	728899.10	610611.54	605542.08

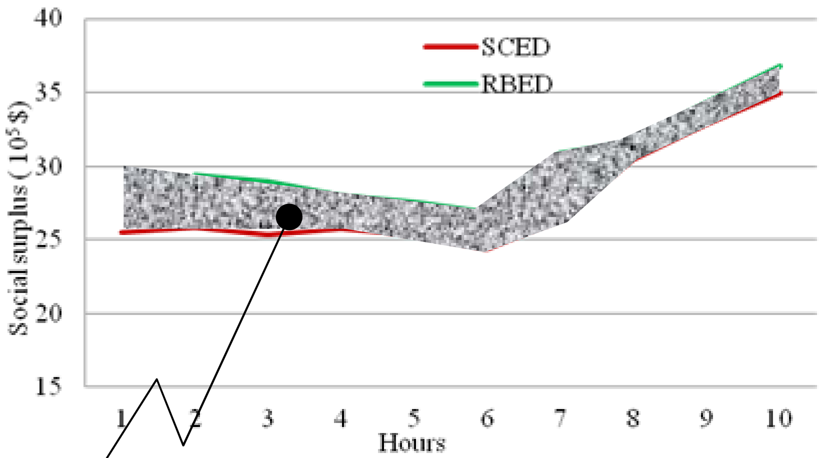
Illustrated on ISO-NE system

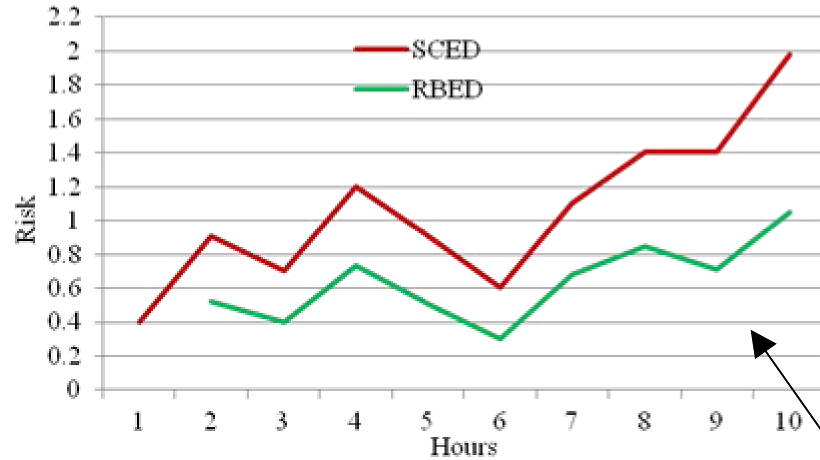
12,300 buses, 13,500 branches, Matlab, on 3.16GHz Intel Core 2 CPU; 4Gb RAM

Results 3: economic significance

Comparing SCED & RB-SCED on ISO-NE system for 10 sequential hrs

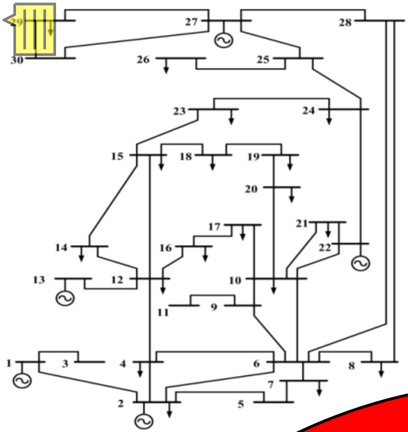
From EMS, 06/16/2010, 1 to 10 hours, computational time 20 minutes per case.



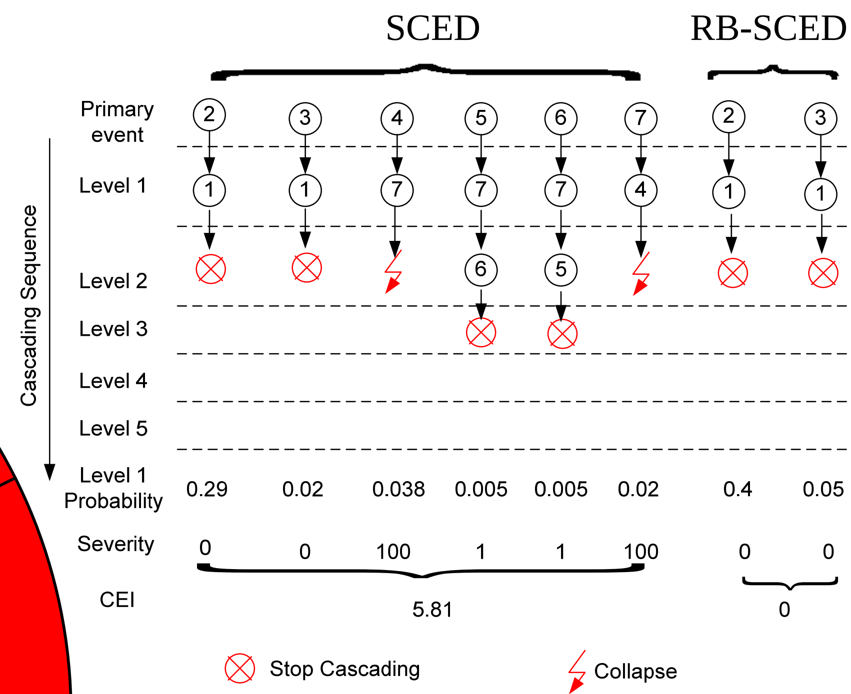


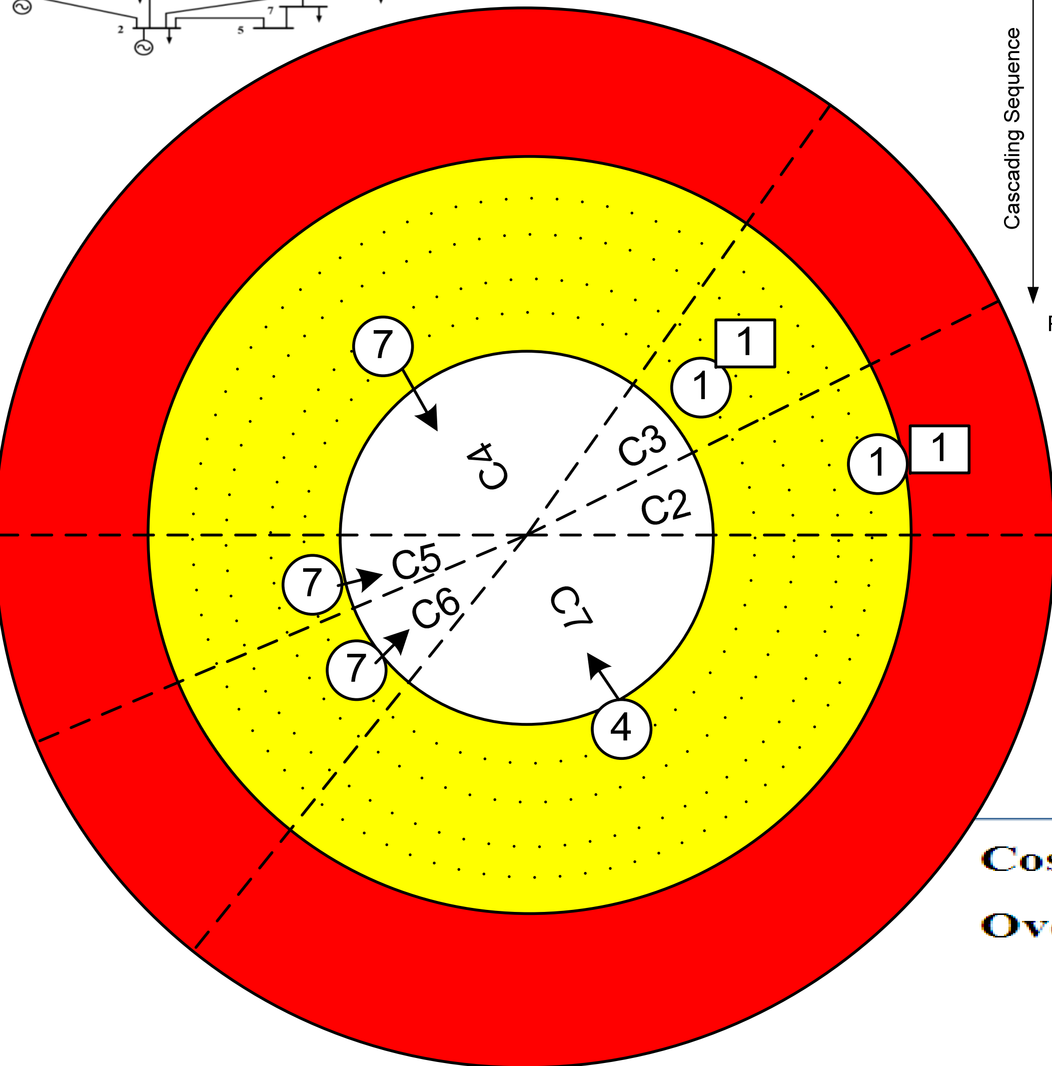
- Area=ISO-NE savings over 10 hrs=$2M (assume 0 during other 14 hrs)
- Annual cost saving: $2.0M×5×52=$520M/yr (assume 0 for weekend)
- ISO-NE is 3% of nation ➔ Annual national savings=$520M÷(.03)=$17B/yr
- It will be more if CRB-SCED is used. And it is more secure!

Results 4: Is it really more secure?



IEEE 30 bus system





	SCED	RB-SCED
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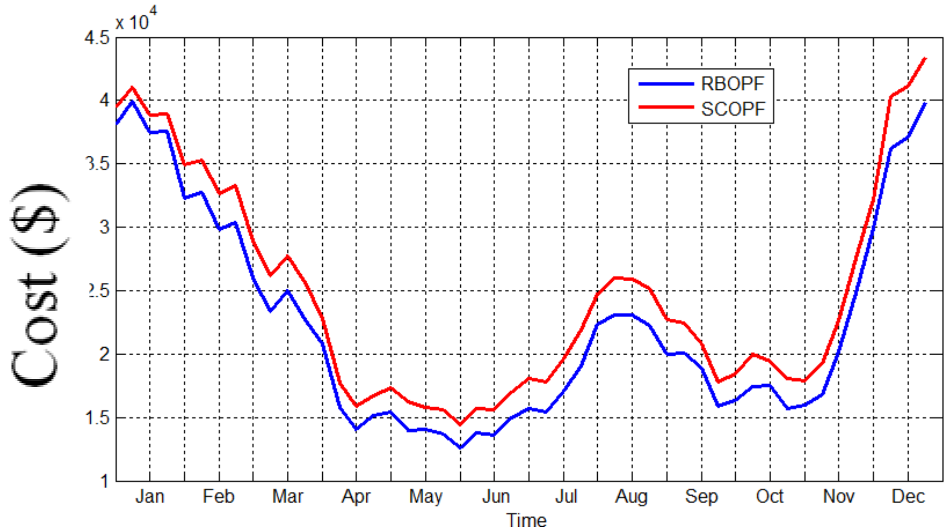
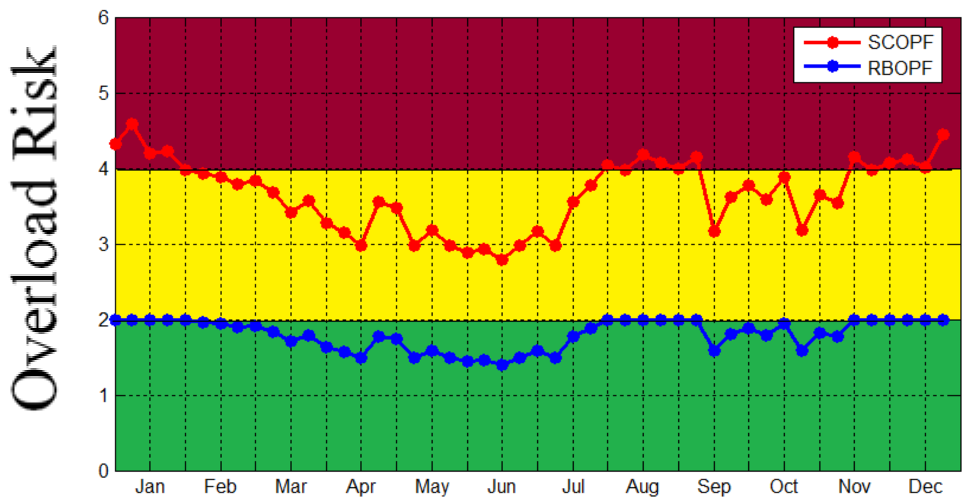
Overload Risk	1.51	0.84

Results 4: Is it really more secure?

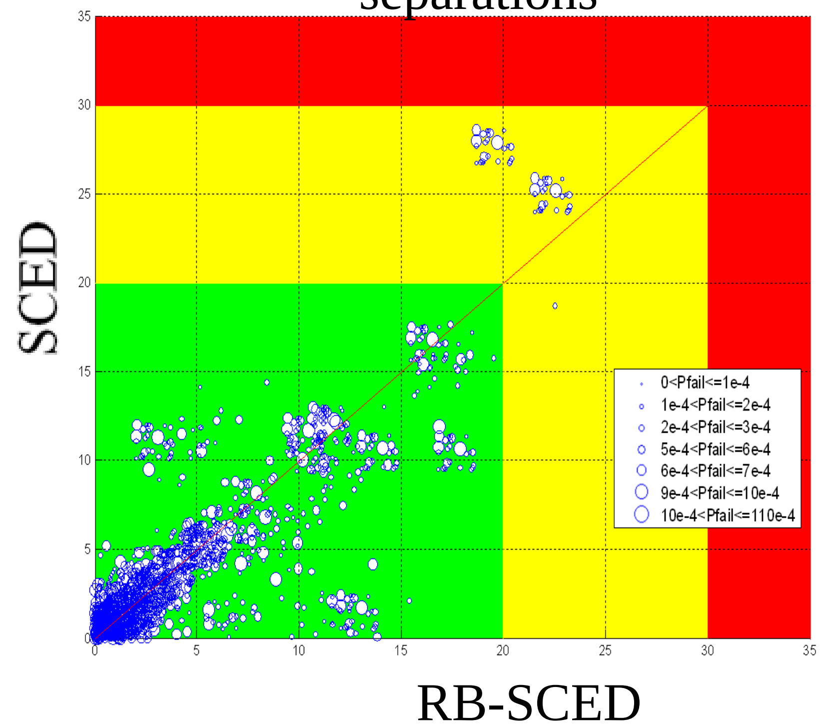




Time→

Done on EMP60 Test System

Post-contingency angle separations



We are planning to compare SCED and RB-SCED solutions for voltage instability studies on the ISO-NE system.

Effects on LMPs

SCED:

$$LMP = Energy + Loss + Congestion$$

$$\begin{aligned}
&\text{Min} \quad \sum_{i=1}^{NG} c_i \times P_i \\
&s.t. \sum_{i=1}^{NG} P_i - \sum_{i=1}^{NG} D_i = Loss, && \lambda_1 \\
&\sum_{i=1}^{NG} GSF_{l-i}(P_i - D_i) \le Limit_l \text{ , for } l \in all\ lines, && \mu_1 \\
&P_i^{\min} \le P_i \le P_i^{\max} \text{, for all } i. && \gamma_1
\end{aligned}$$

RB-SCED:

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

$$\begin{aligned}
&\text{Min} \quad \sum_{i=1}^{NG} c_i \times P_i \\
&s.t. \sum_{i=1}^{NG} P_i - \sum_{i=1}^{NG} D_i = Loss, && \lambda_2 \\
&\sum_{i=1}^{NG} GSF_{l-i}(P_i - D_i) \le K_C Limit_l \text{ , for } l \in all\ lines, && \mu_2 \\
&P_i^{\min} \le P_i \le P_i^{\max} \text{, for all } i, && \gamma_2 \\
&\sum_{k=1}^{NC} Pr_k \sum_{l=1}^{NL} Sev_l^k \le K_R \times Risk_{max}. && \tau
\end{aligned}$$

The risk component of the LMP provides a price signal that incentivizes market participants to improve system risk.

The risk component may be positive or negative.

LMPs from RB-SCED should be lower than LMPs from SCED if $K_C > 1$.

➔We are studying this now.

Conclusions

RB-SCED has potential to significantly enhance efficiencies of US real-time electricity markets

while simultaneously increasing security levels and providing operators with a “lever” to more effectively control their power system.

The approach will not require changes in market structure.

Although it requires some additional R&D, it is very close to being ready for commercialization.