FULL AC NETWORK INTEGRATED CORE SOLVER : SUPEROPF FRAMEWORK

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Issues with Current Generation of Optimal Power Flow

- Current solvers are still not sufficiently robust
- Current solvers still can not correctly handle stability constraints
- Optimal power flow solution is NOT a global optimal solution
- Solvers only compute one (local) optimal solution while there are multiple local optimal solutions
- Each OPF solution corresponds to one location marginal pricing (which OPF solution is the right one ?)

Phase I: Robust AC OPF Solvers

1. (support industrial model) A commercial-grade core SuperOPF software supporting various industrial-grade power system models such as

(i) CIM-compliance; and

(ii) PSS/E data format

2. A multi-stage OPF solver with <u>adaptive homotopy-based Interior Point Method</u> for large-scale power systems (14,000-bus data)

Adaptive Homotopy-guided, Active-Set-Assisted Primal-Dual Interior Point OPF Solver (Patent pending, 2014)

1. Homotopy-based Methodology (continuation method + adaptive step-size)
2. Domain-knowledge-based
3. Active-set assisted
4. IPM method (core solver)

SuperOPF, PSSE & MATPOWER tests results (2014)

- 118-bus system

Solver	MIPS	FMINCON	KNITRO	IPOPT
Success Rate	69/101	101/101	101/101	101/101
Solver	TRANLM	PSSE	SuperOPF	
Success Rate	101/101	1001/1001	1001/1001	

- 3120-bus system

Solver	MIPS	FMINCON	KNITRO	IPOPT
Success Rate	1/101	1/101	36/101	1/101
Solver	TRANLM	PSSE	SuperOPF	
Success Rate	1/101	0/1001	1001/1001	

Results: Efficiency and Robustness (Analytical Jacobian matrices)

Effects of constraint analysis

Base case
Without constraint analysis
• Converged in 217 iterations • CPU time: 177 seconds • OPF loss: 3251.284MW
With constraint analysis
• Converged in 191 iterations • CPU time: 143 seconds • OPF loss: 3251.353MW

Robustness of our method

Loading Condition	One-Staged Scheme	Multi-Staged Scheme
1	Succeeded	Succeeded
2	Succeeded	Succeeded
3	Succeeded	Succeeded
4	Succeeded	Succeeded
5	Failed	Succeeded
6	Failed	Succeeded
7	Failed	Succeeded
8	Failed	Succeeded
9	Failed	Succeeded
10	Failed	Succeeded

Super-OPF (continuous and discrete variables)

Super-OPF Method

Stage I: OPF Constraint Analyzer → Stage II: Simple OPF w/o Thermal Limits → Stage III: Homotopy OPF w/ Active Thermal Limits → Stage IV: Sensitivity Analyzer for Discretization →

Input Data

$$
\begin{aligned}
\min \quad & f(V,\theta,t,\phi,b,P^G,Q^G) \\
s.t. \quad & P_i(V,\theta,t,\phi,b) + P_i^L - P_i^G = 0,\ i=1,\cdots,n_B \\
& Q_i(V,\theta,t,\phi,b) + Q_i^L - Q_i^G = 0,\ i=1,\cdots,n_B \\
& \underline{V}_i \le V_i \le \overline{V}_i,\ i=1,\cdots,n_B \\
& \underline{t}_i \le t_i \le \overline{t}_i,\ i=1,\cdots,n_T \\
& \underline{\phi}_i \le \phi_i \le \overline{\phi}_i,\ i=1,\cdots,n_P \\
& \underline{b}_i \le b_i \le \overline{b}_i,\ i=1,\cdots,n_S \\
& \underline{P}_j^G \le P_j^G \le \overline{P}_j^G,\ j=1,\cdots,n_G \\
& \underline{Q}_j^G \le Q_j^G \le \overline{Q}_j^G,\ j=1,\cdots,n_G
\end{aligned}
$$

OPF without thermal constraints

$$
\begin{aligned}
\min \quad & f(V,\theta,t,\phi,b,P^G,Q^G;\lambda) \\
s.t. \quad & P_i(V,\theta,t,\phi,b) + P_i^L - P_i^G = 0,\ i=1,\cdots,n_B \\
& Q_i(V,\theta,t,\phi,b) + Q_i^L - Q_i^G = 0,\ i=1,\cdots,n_B \\
& S_{ij}(V,\theta,t,\phi,b) \le \overline{S}_{ij} + \lambda\tilde{S}_{ij},\ (i,j)\in\mathcal{L}_\alpha \\
& S_{ji}(V,\theta,t,\phi,b) \le \overline{S}_{ij} + \lambda\tilde{S}_{ij},\ (i,j)\in\mathcal{L}_\alpha \\
& \underline{V}_i \le V_i \le \overline{V}_i,\ i=1,\cdots,n_B \\
& \underline{t}_i \le t_i \le \overline{t}_i,\ i=1,\cdots,n_T \\
& \underline{\phi}_i \le \phi_i \le \overline{\phi}_i,\ i=1,\cdots,n_P \\
& \underline{b}_i \le b_i \le \overline{b}_i,\ i=1,\cdots,n_S \\
& \underline{P}_j^G \le P_j^G \le \overline{P}_j^G,\ j=1,\cdots,n_G \\
& \underline{Q}_j^G \le Q_j^G \le \overline{Q}_j^G,\ j=1,\cdots,n_G
\end{aligned}
$$

OPF with active thermal constraints

OPF Result

$$
\begin{aligned}
S_y^f &= \frac{\partial f}{\partial y} - \left(\frac{\partial g}{\partial y}\right)^T \left[\left(\frac{\partial g}{\partial x}\right)^T\right]^{-1} \frac{\partial f}{\partial x} \\
S_y^h &= \frac{\partial h}{\partial y} - \frac{\partial h}{\partial x}\left(\frac{\partial g}{\partial x}\right)^{-1} \frac{\partial g}{\partial y}
\end{aligned}
$$

$$
\begin{aligned}
\Delta f_i^+ &= S_{d_i}^f (d_i^{j_i+1} - d_i^{j_i}) \\
\Delta f_i^- &= S_{d_i}^f (d_i^{j_i-1} - d_i^{j_i}) \\
\Delta h_{k_i}^+ &= S_{d_i}^{h_k} (d_i^{j_i+1} - d_i^{j_i}),\ \forall k=1,\cdots,n_h \\
\Delta f_{k_i}^- &= S_{d_i}^{h_k} (d_i^{j_i+1} - d_i^{j_i}),\ \forall k=1,\cdots,n_h
\end{aligned}
$$

$$
\begin{aligned}
\eta_i^+ &= w_f \Delta f_i^+ + \textstyle\sum_{k=1}^{n_h} w_h \max[0, h_k(\hat{x},\hat{y}) + \Delta h_{k_i}^+] \\
\eta_i^- &= w_f \Delta f_i^- + \textstyle\sum_{k=1}^{n_h} w_h \max[0, h_k(\hat{x},\hat{y}) + \Delta h_{k_i}^-]
\end{aligned}
$$

$$
\begin{aligned}
y_i^{j_i} &\leftarrow y_i^{j_i+1} \text{ if: } \eta_i^+ \le \eta_i^- \text{ and } \eta_i^+ \le \eta_{th} \text{ or} \\
y_i^{j_i} &\leftarrow y_i^{j_i-1} \text{ if: } \eta_i^- < \eta_i^+ \text{ and } \eta_i^- \le \eta_{th}.
\end{aligned}
$$

Sensitivity based adjustment

Super-OPF Dimensions

13183-Bus System

Stage I: OPF Constraint Analyzer → Stage II: Simple OPF w/o Thermal Limits → Stage III: Homotopy OPF w/ Active Thermal Limits → Stage IV: Sensitivity Analyzer for Discretization →

Input Data

System:
- Buses: 13183
- Loads: 9691
- Generators: 2304
- Branches: 18168
- Transformers: 1410
- Switched shunts: 1404

OPF Dimensions:
- Dimension of x: 31134
- Nonlinear equality constraints: 26366
- Nonlinear inequality constraints: 0
- Total equality constraints: 26367
- Total inequality constraints: 35902

OPF Dimensions:
- Dimension of x: 31134
- Nonlinear equality constraints: 26366
- Nonlinear inequality constraints: varying (<100)
- Total equality constraints: 26367
- Total inequality constraints: >35902 (varying)

System:
- Continuous variables: 28320
- Discrete variables: 2814

OPF Result

Challenges: Problem Formulations and Solvers

$$\min C(x)$$

Subject to: $h(x) = 0$

$g(x) \le 0$

However, security-constrained OPF can not be expressed as the above analytical form:

i. Power balance equations: $h(x) = 0$

ii. Voltage limit constraints: $\underline{x} \le x \le \overline{x}$

iii. Thermal limit constraints: $g(x) \le 0$

iv. Transient-stability constraints: ???

v. Voltage stability constraints: ???

Implications:
(i) It is not possible to represent them in explcit forms.
(ii) approximations are subject to incorrect stability assessment.

i. *Transient-stability constraints:* $h(x) = 0$

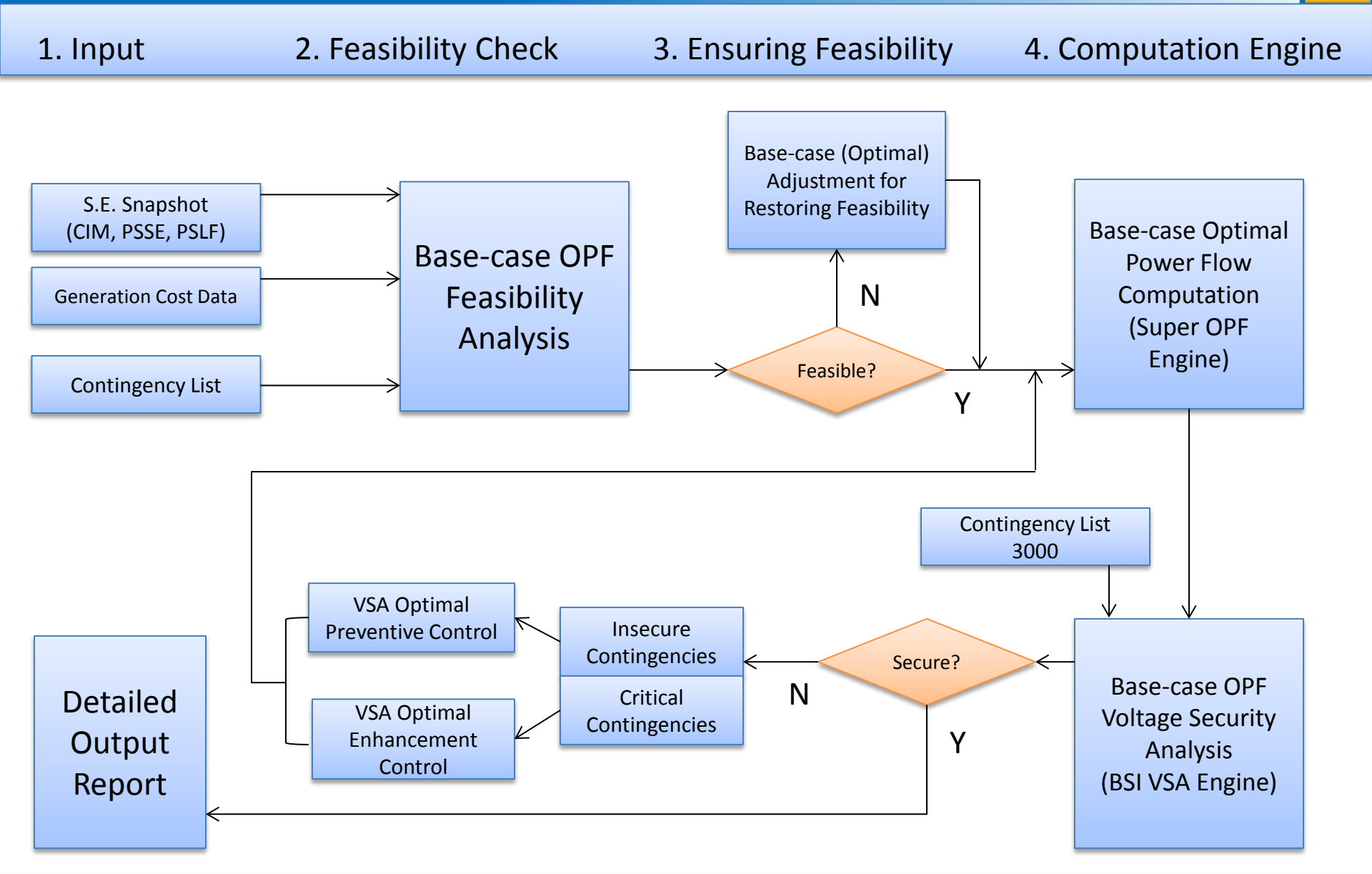
ii. *Voltage stability constraints:* $g(x) \leq 0$

Stability Constraints Can not be explicitly dealt with

Making several recently proposed methods not applicable, such as

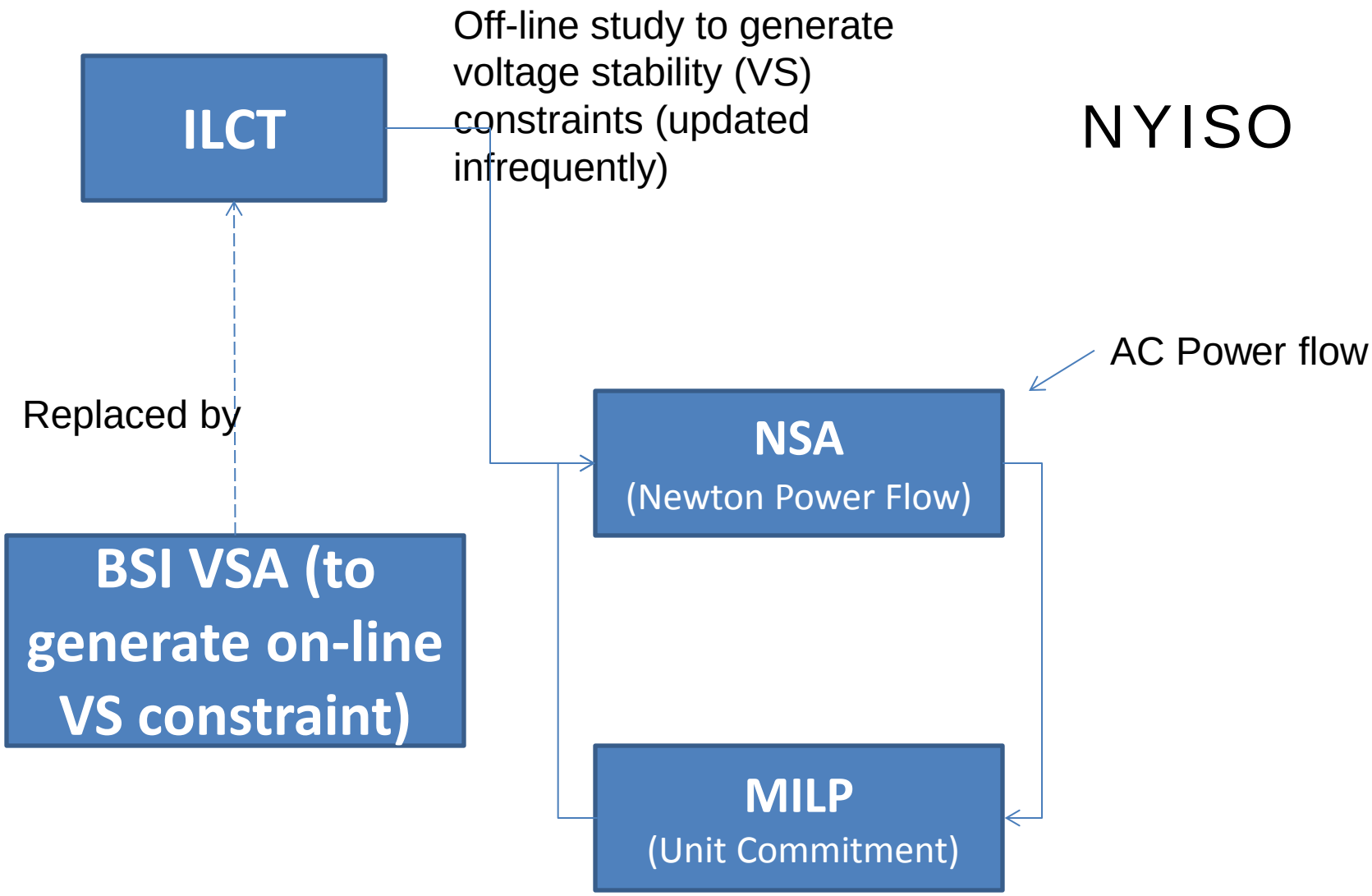
- J.Lavaei and S.Low, “Zero Duality Gap in Optimal Power Flow Problem,” IEEE Transactions on Power Systems, vol.27, no.1, pp. 92–107, February 2012.
- D.K. Molzahn, J.T. Holzer, and B.C. Lesieutre, and C.L. DeMarco, “Implementation of a Large-Scale Optimal Power Flow Solver Based on Semidefinite Programming,” *IEEE Transactions on Power Systems,* vol. 28, no. 4, pp. 3987-3998, November 2013.

Super-OPF-VS (Voltage Stability) (Phase II)



Feedback Comments

- “explicitly include voltage stability constraints which would allow the solutions to more fully utilize existing capacity throughout electric power networks. This feature alone could be extremely valuable. “


ILCT
Off-line study to generate voltage stability (VS) constraints (updated infrequently)
NYISO
AC Power flow
Replaced by
NSA
(Newton Power Flow)
BSI VSA (to generate on-line VS constraint)
MILP
(Unit Commitment)

Super-OPF Contingency Analysis

A practical 6534-Bus System

Initial Power Flow from State Estimator → Super-OPF Solution → BSI VSA Preventive Control

1062 N-1 Contingencies

0	0	3010.028	-20.088	0	3010.028
1	21	-0.305	-0.305	3	0.000
2	34	-0.218	-0.218	6	0.000
3	691	-0.100	-0.100	17	0.000
4	8	-0.066	-0.066	1	0.000
5	35	-0.060	-0.060	5	0.000
6	24	-0.056	-0.056	2	0.000
7	36	-0.015	-0.015	4	0.000
8	639	1353.153	-9.031	12	2347.311
9	281	1884.894	-12.579	10	1397.252
10	282	1884.894	-12.579	11	1397.252
11	491	2715.639	-18.123	14	2481.276
12	492	2715.639	-18.123	13	2481.276
13	561	2716.463	-18.129	15	2485.825
14	521	2730.695	-18.224	16	2503.604
15	572	2789.834	-18.619	41	2789.834
16	864	2791.814	-18.632	42	2791.814
17	863	2791.814	-18.632	43	2791.814
18	628	2805.778	-18.725	44	2805.778
19	690	2807.721	-18.738	18	2619.026
20	684	2822.604	-18.837	47	2822.604

Load margin: 3010MW
Objective (loss): 2793.6MW
7 insecure contingencies

0	0	4840.000	-32.301	0	4840.000
1	21	-0.285	-0.285	3	0.000
2	34	-0.253	-0.253	5	0.000
3	35	-0.071	-0.071	4	0.000
4	8	-0.050	-0.050	1	0.000
5	24	-0.042	-0.042	2	0.000
6	561	4373.778	-29.189	16	4304.356
7	491	4386.839	-29.276	15	4284.000
8	492	4386.839	-29.276	14	4284.000
9	691	4404.315	-29.393	20	4404.315
10	521	4407.446	-29.414	17	4316.588
11	690	4437.187	-29.612	23	4437.187
12	281	4494.606	-29.996	18	4381.087
13	282	4494.606	-29.996	19	4381.087
14	639	4508.597	-30.089	21	4413.366
15	428	4544.092	-30.326	25	4483.436
16	432	4544.092	-30.326	26	4483.436
17	431	4544.092	-30.326	27	4483.436
18	430	4544.092	-30.326	28	4483.436
19	429	4544.092	-30.326	29	4483.436
20	501	4555.107	-30.399	30	4511.405

Load margin: 4840MW
Objective (loss): 1642.8MW
5 insecure contingencies

0	0	4840.161	-32.302	0	4840.161
1	561	4376.021	-29.204	23	4303.308
2	492	4389.094	-29.291	22	4282.792
3	491	4389.094	-29.291	21	4282.792
4	521	4409.681	-29.429	24	4315.462
5	690	4436.558	-29.608	25	4436.558
6	691	4509.283	-30.094	6	2244.418
7	431	4546.083	-30.339	26	4482.817
8	430	4546.083	-30.339	27	4482.817
9	429	4546.083	-30.339	28	4482.817
10	428	4546.083	-30.339	29	4482.817
11	432	4546.083	-30.339	30	4482.817
12	501	4556.994	-30.412	31	4510.822
13	509	4564.158	-30.460	32	4514.185
14	281	4571.971	-30.512	14	2416.908
15	282	4571.971	-30.512	15	2416.908
16	506	4577.873	-30.551	33	4534.745
17	662	4580.186	-30.567	38	4550.269
18	663	4580.186	-30.567	39	4550.269
19	456	4585.097	-30.599	34	4536.546
20	455	4585.097	-30.599	35	4536.546

Load margin: 4840MW
Objective (loss): 1674.6MW
No insecure contingency

Phase III was focused on the following enhancements

Topicss	Enhancements
Co-optimization over multiple scenario(functions)	(i) deal with multiple base-cases (i.e., co-optimize multiple base-cases)
Commercial-grade packages (applications)	(ii) deal with thermal limits and voltage limits under AC power flow models of a large set of contingencies.
Renewables (uncertainties)	(iii) deal with uncertainties of wind generations and other renewables

This phase is focused on the following enhancements

Topics	Enhancements
Co-optimization over multiple scenario(functions)	(vii) Engage utility companies to provide their assessment of and interest in adopting SuperOPF.
Commercial-grade packages (applications)	(viii) Engage utility companies to assist the development of SuperOPF.
Uncertainties in contingencies	(viiii) Co-optimized SuperOPF-Static + renewables + contingency package

SuperOPF Co-optimization

- Objective: minimizing the expected cost across all the scenarios

$$
\begin{aligned}
min \quad & f(x) = f_0(x_0) + \sum_{k=1}^{K} p_k[f_k(x_k) + c_k(x_k - x_0)] \\
s.t. \quad & h_0(x) = 0 \\
& g_0(x) \leq 0 \\
& \cdots\cdots \\
& h_K(x) = 0 \\
& g_K(x) \leq 0
\end{aligned}
$$

$x = (x_0, x_1, \cdots, x_K)$: optimization variables p_k: probability for k-th scenario

$x_i = (\Theta^k, V^k, T^k, S^k, B^k, P_G^k, Q_G^k)$: variables of the k-th scenario (0: base case)

$f_0(x_0)$: base case cost $f_k(x_k)$: k-th base cost (reserves, load shedding, etc)

$c_k(x_k - x_0)$: cost of scenario-induced deviations (from base-case)

SuperOPF Co-optimization

Four types of scenarios

Type-1 scenario: Base case

$$\begin{aligned} &\min && f(x) \\ &s.t. && P_i(x) + P_{Di} - P_{Gi} = 0 \qquad 1 \le i \le n_B \\ & && Q_i(x) + Q_{Di} - Q_{Gi} = 0 \\ & && S_k = \sqrt{P_{ij}^2(x) + Q_{ij}^2(x)} \le S_k^{max} \qquad (i,j) \in L \\ & && x^{min} \le x \le x^{max} \end{aligned}$$

n_B: the number of buses L: the set of branches

Type-2 scenario: Base case + contingency

$$\begin{aligned} &\min && f(x) \\ &s.t. && P_i(x) + P_{Di} - P_{Gi} = 0 \qquad 1 \le i \le n_B \\ & && Q_i(x) + Q_{Di} - Q_{Gi} = 0 \\ & && S_k = \sqrt{P_{ij}^2(x) + Q_{ij}^2(x)} \le S_k^{max} \qquad (i,j) \in \hat{L} \\ & && x^{min} \le x \le x^{max} \end{aligned}$$

$\hat{L}$: L excludes contingent branches

Type 3 scenario: Base case + renewable energy

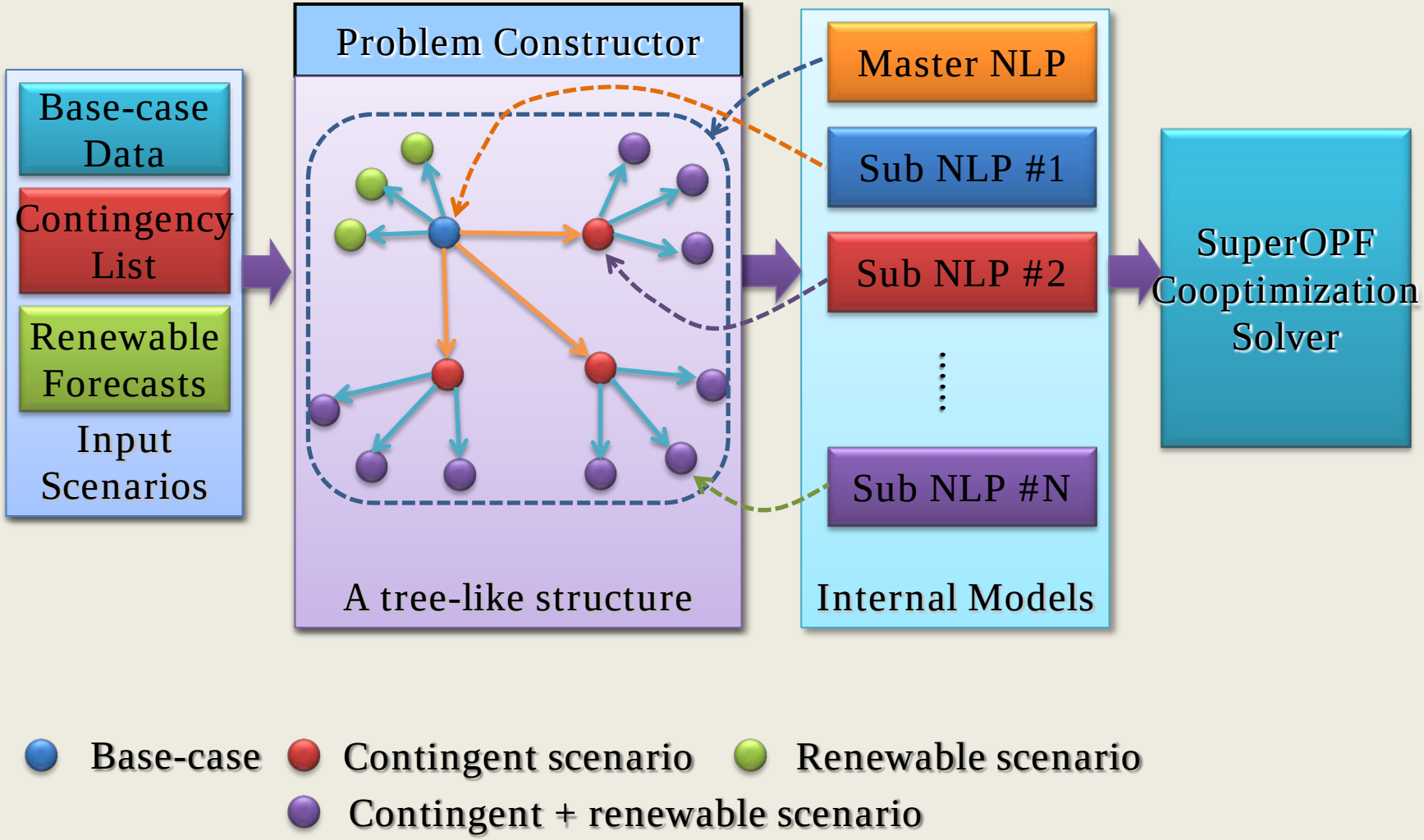
$$\begin{aligned} &\min && f(x) \\ &s.t. && P_i(x) + \hat{P}_{Di} - P_{Gi} = 0 \qquad 1 \le i \le n_B \\ & && Q_i(x) + \hat{Q}_{Di} - Q_{Gi} = 0 \\ & && S_k = \sqrt{P_{ij}^2(x) + Q_{ij}^2(x)} \le S_k^{max} \qquad (i,j) \in L \\ & && x^{min} \le x \le x^{max} \end{aligned}$$

Type 4 scenario: Base case + renewable energy + contingency

$$\begin{aligned} &\min && f(x) \\ &s.t. && P_i(x) + \hat{P}_{Di} - P_{Gi} = 0 \qquad 1 \le i \le n_B \\ & && Q_i(x) + \hat{Q}_{Di} - Q_{Gi} = 0 \\ & && S_k = \sqrt{P_{ij}^2(x) + Q_{ij}^2(x)} \le S_k^{max} \qquad (i,j) \in \hat{L} \\ & && x^{min} \le x \le x^{max} \end{aligned}$$

$\hat{P}_D, \hat{Q}_D$: equivalent loads with renewable energies

SuperOPF Co-optimization

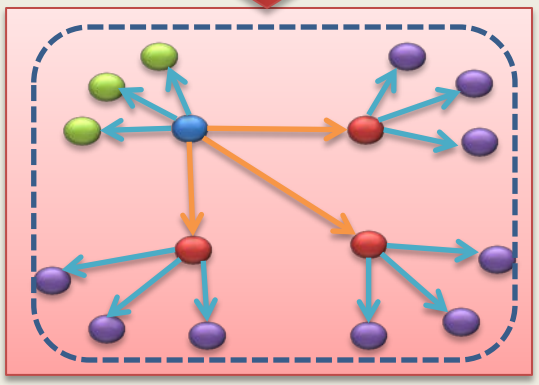


SuperOPF Co-optimization

Base Case → Contingencies + Renewable Energy Forecasts → Internal Combinatorial Scenarios K=(M+1)*(N+1) → SuperOPF Co-optimization

$$\begin{aligned} \min \quad & f_0(P_0) \\ s.t \quad & h_0(x) = 0 \\ & g_0(x) \le 0 \end{aligned}$$

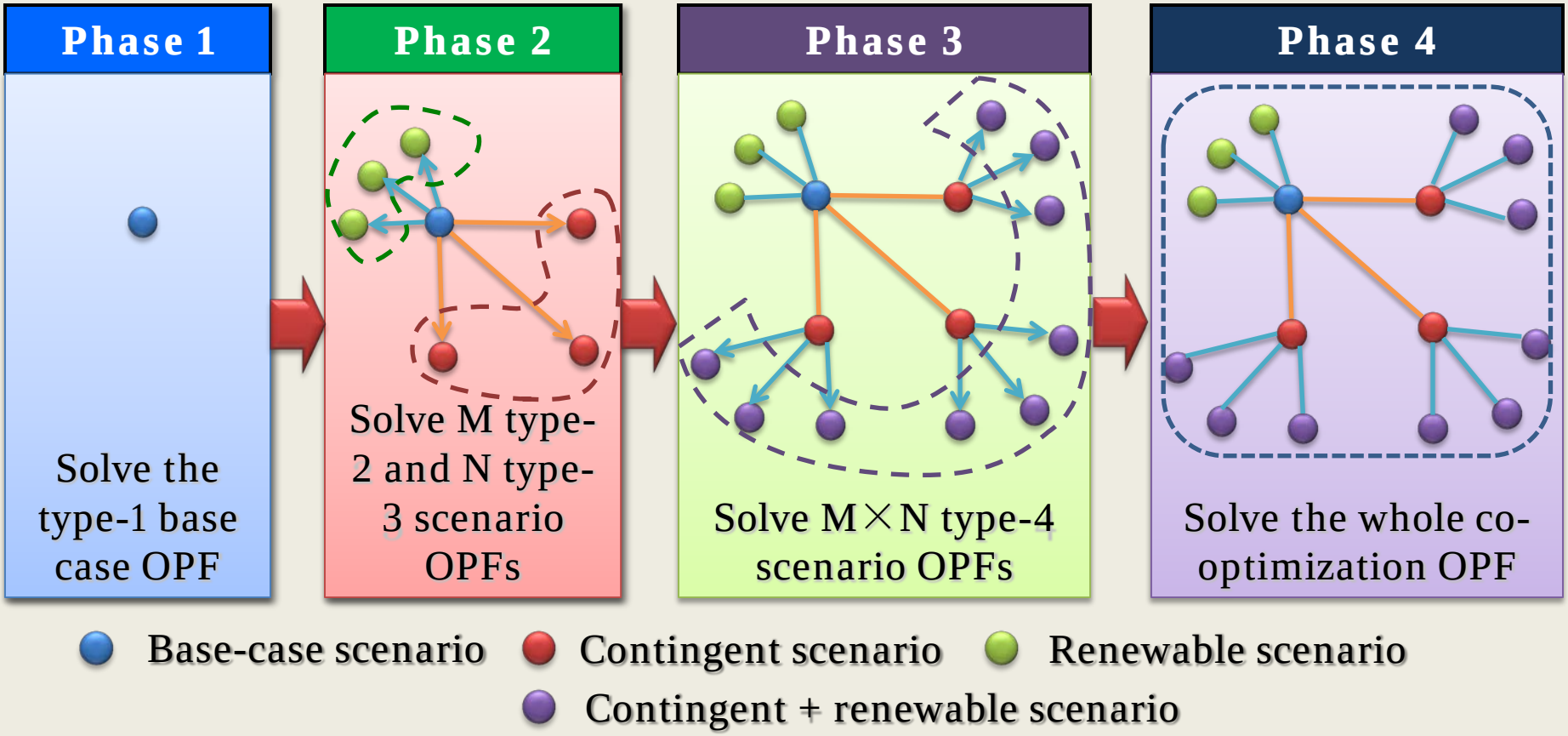
M: # of contingencies
N: # of renewable energy forecasts



$$\begin{aligned} \min \quad & f(x) = f_0(x_0) + \sum_{k=1}^{K} p_k[f_k(x_k) + c_k(x_k - x_0)] \\ s.t. \quad & h_0(x) = 0 \\ & g_0(x) \le 0 \\ & \cdots\cdots \\ & h_K(x) = 0 \\ & g_K(x) \le 0 \end{aligned}$$

Multi-phase Approach

- A multi-phase scheme is developed in which base case OPF solutions are used as initial points for solving scenario problems. A combination of all sub-problem solutions is used as the initial point for the entire co-optimization problem.



Numerical Simulations

- Two practical large-scale systems
  - a 6534-bus system
  - A 13183-bus system

- Simulation environment:
  - 2.6GHz quad-core Intel i7-3720QM processor (Turbo boost to 3.6GHz), 16GB 1600MHz DDR3 RAM, Mac OSX 10.8.4, GCC 4.8.1

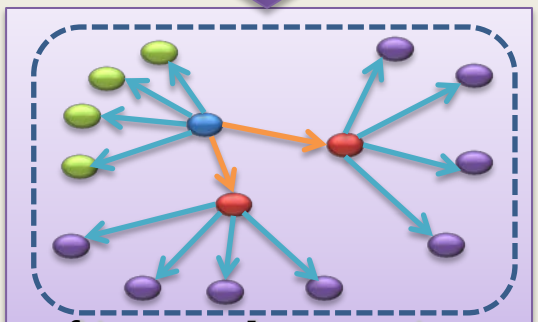
Co-optimization Results on a 6500-bus System

Base Case → Contingencies + Renewable Energy Forecasts → Internal Combinatorial Scenarios → SuperOPF Co-optimization

System:

Buses: 6534
Loads: 2901
Generators: 1903
Branches: 8295
Transformers: 294
Switchable shunts: 520

# of contingencies: 2
# of renewable forecasts: 4



# of internal scenarios: 15

- # of optimization variables: 226,215;
- # of constraints: 287,360 (equality: 181,260; inequality: 106,100);
- # of Hessian non-zeros: 3,190,566

Co-optimization Results on CAISO System

Sub-problem	Scenario	*p*	F(x)	# of Iters	CPU Time (sec)	Sub-problem	Scenario	*p*	F(x)	# of Iters	CPU Time (sec)
	Initial PF		80.418985			9	Base case + Renewable 2 + Contingency 2	0.573%	21.076384	79	10.38
1	Base case		21.085284	80	10.48	10	Base case + Renewable 3	1.28%	21.089217	77	10.11
2	Base case + Contingency 1	10%	21.106819	79	10.52	11	Base case + Renewable 3 + Contingency 1	0.128%	21.110689	74	9.70
3	Base case + Contingency 2	10%	21.085464	78	10.32	12	Base case + Renewable 3 + Contingency 2	0.128%	21.089421	77	10.09
4	Base case + Renewable 1	3.04%	21.172620	79	10.46	13	Base case + Renewable 4	5.60%	21.218402	75	9.88
5	Base case + Renewable 1 + Contingency 1	0.304 %	21.194469	80	10.43	14	Base case + Renewable 4 + Contingency 1	0.560%	21.240219	78	10.31
6	Base case + Renewable 1 + Contingency 2	0.304 %	21.173087	80	10.58	15	Base case + Renewable 4 + Contingency 2	0.560%	21.218608	76	10.26
7	Base case + Renewable 2	5.73%	21. 076129	83	10.92	Cooptimization problem			21.129602	310	2281.02 (i.e. 38 min.
8	Base case + Renewable 2 + Contingency 1	0.573%	21. 097419	82	10.85						

Proposed Requirements for Scenario Reduction Schemes

(reliability measure) identify all representative scenarios that properly maintain important information of stochastic variables.

(efficiency measure) the retain important information with the least number of scenarios.

(*speed and robust measure*) It should be fast and robust to operating conditions

Scenario Reduction Techniques

- Forward selection and backward reduction are the most used scenario reduction technique.
- These methods all focus on :

"distance" between the selected scenario set and the original scenario set. They are problem-independent.

Our Proposed Scenario Reduction Scheme for Voltage Stability

- Problem-dependent

Application-Oriented Scheme

Voltage Stability Analysis Under a large number of scenarios

Stage I: Cluster Scheme (input space)

Stage II: Screening and Ranking Scheme (effect, output space)

Stage III: Detailed Analysis (effect, output space)

Voltage Stability Analysis Under Uncertainty (Cluster + Screening + ranking + detailed analysis)

In comparison with Monte Carlo method (Scenario : 5000)

IEEE 118-bus Test System	
(Renewables at 1, 7, 40, 78, 117)	Weibull distribution

Reduction Ratio	Accuracy(%)	Missing Scenarios
99.08%	100%	0

Scenarios	5000
Stage I & II	Reduce to 46 scenarios
Stage III	Reduce to 17 scenarios

Voltage Stability Analysis Under Uncertainty (Cluster + Screening + ranking + detailed analysis)

Poland 3120-bus	
(23, 68, 69, 70, 261, 263, 1393, 1395, 1398, 3100, 3101, and 3102)	Weibull distribution

Reduction Ratio	Accuracy(%)	Critical Missing Scenarios
98.52%	100%	0

Scenarios	5000
Stage I & II	Reduce to 74 scenarios
Stage III	Reduce to 29 scenarios

Scenario Reduction Scheme for OPF (a challenging one)

- Problem-dependent

Application-Oriented Scheme

Under a large number of scenarios

Stage I: Cluster Scheme (input space)

Stage II: Screening and Ranking Scheme (effect, output space)

Stage III: Detailed Analysis (effect, output space)

CONCLUSION

SuperOPF

is an

advanced & comprehensive

ACOPF solver

needed by modern power systems.

Innovation prevails!

Commercialization of the SuperOPF Framework:

Comments on SuperOPF from Targeted Early Adopters in the Electric Utility Industry

Industry Participation Component of Phase 3 Work

Objective

Convince RTOs/ISOs, Reliability Coordinators, Balancing Authorities and Transmission Owners that the way to characterize operational risk is to move to the SuperOPF stochastic co-optimization formulation

1.

- Identify Industry partner organizations and key individuals in each that will support this technology transition and the role they are willing to play

2.

- Identify applications, functionality, hurdles to overcome and the best path forward.

TVA Contacts

Key Contacts

Josh Shultz

Operations

Tom Cain

Planning

TVA Observations

- Help addressing NERC requirements
- Dynamic stability constraints with contingency

- Static stability constraints with contingency
- Setting voltage schedules
- Minimizing number of controls for reliability
- Co-optimizing transfer capability and generation dispatch to provide proven cost-benefit
- Help limit exposure to weak adjoining networks (500kv/161kv transition)
- Currently in discussions with TVA, regarding Voltage Scheduling Study using SuperOPF

- Co-optimization of MW and MVAR is a unique and valuable capability
- Scenario co-optimization
- Peak Load Reduction

PJM Contacts

Key Contacts

Jianzhong Tong

Operations

Biagio Pinto

Outage Analysis Technology

Jeremy Lin

Interregional Planning

Byoungkon Choi

Transmission Planning

PJM Observations

- Look-ahead (short–term up to 4 hours) for renewables using co-optimization
- Application to the day-ahead to address renewable intermittency and pre-planning of reserve generation

Power Market & Operations

- Static & Dynamic stability constraints with contingency

Operations & Planning

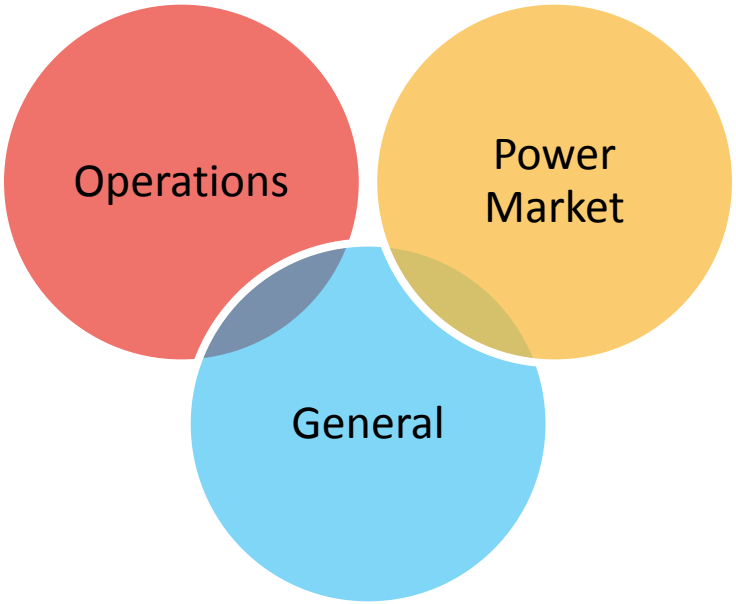
ISO-NE Contacts

Key Contacts

Eugene Litvinov	Director-Business Architecture and Technology
Xiaochuan Luo	
Tongxin Zheng	

ISO-NE Observations

- Control actions should be accounted for in the optimization
- Setting transfer limits based on margins to limits (thermal, voltage, stability)
- Cost of operating the market under SuperOPF must be considered and compared to DC-OPF



- This SuperOPF AC formulation is the most accurate
- Operation of the system with huge margins may change in future; there is opportunity for Super OPF, if results are high quality, accurate, and the solver is robust
- A proven SuperOPF would serve as an industry benchmark for markets

- ISO-NE would like to see a study done to assess SuperOPF the impact on the operation of the market
- ISO-NE is currently co-funding a study with BSI to compare SuperOPF to ISO-NE Production Software

CAISO Contacts

Key Contacts

Mark Rothleder

Vice President of Market Quality and Renewable Integration

Khaled Abdul-Rahman

Director, Power Systems and Smart Grid Technology Development

CAISO Observations

Operations

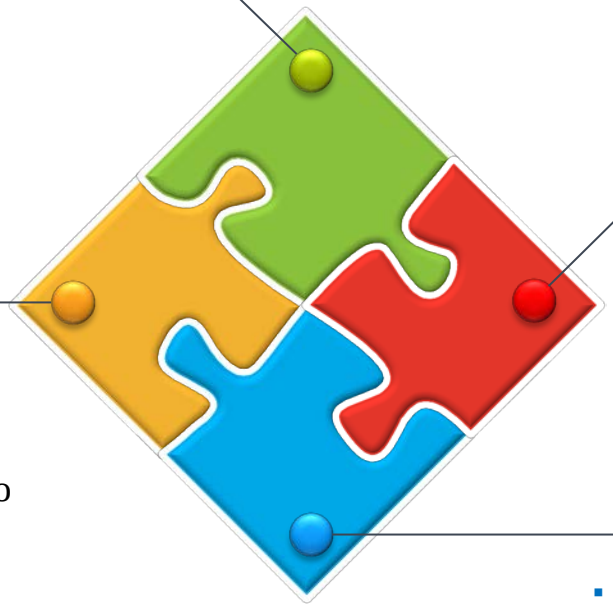
- State Estimation Improvements

Planning & Operations

- Static & Dynamic stability constraints with contingency

Power Market & Operations

- Non-linear OPF needed for the CAISO power market
- SuperOPF with handling voltage stability as a constraint is of value to the power market
- Ramp Constraints in model
- Co-optimization of worst scenarios especially with renewables,
- Inclusion of AGC response into SuperOPF to deal with renewable integration
- Require good real-time performance



General

- Operational Reserve requirements with renewables

Innovation prevails! BSI

2014 Project Title: Study of Co-optimization Stochastic SuperOPF Applications in the CAISO System

Theme: Co-optimization Stochastic SuperOPF-renewables

Project Overview

- Study the impact of co-optimization in improving key challenges in the CAISO system using the commercial-grade SuperOPF tool
- CAISO is our partner for the project offering in-kind services including:
  - Technical expertise
  - Data analysis
  - Testing
  - Results review
  - Evaluations of the work and overall concepts

Study at CAISO: Primary Objectives

- Co-optimize the objective function and the updated worst scenario for voltage stability
- Co-optimize the objective function, operational reserve and renewable energy. In addition, the ramp rate of renewable energy should be included

Study at CAISO: Secondary Objectives

- Handle the ramp constraints of generation
- Handle constraints needed for LMP calculations and required outputs for the power market

Project Deliverables

- Demonstration using CAISO data – SuperOPF software which can co-optimize the objective function and the updated worst scenario for voltage stability
- Demonstration using CAISO data – SuperOPF software which can co-optimize the objective function, operational reserve and the renewable energies with the inclusion the ramp rate of renewable energy.
- Demonstration using CAISO data – SuperOPF software equipped with the ramp constraints of generations
- Demonstration using CAISO data – Super-OPF software which can handle constraints needed for LMP calculations and outputs required for the power market

Project Deliverables (2)

- Regular meetings with CAISO (including 2 face-to-face meetings)
- Quarterly Progress Reports
- Compiled reports of CAISO feedback
- Users' manual for the commercial-grade Co-optimization SuperOPF software.
- Design manual for the commercial-grade Co-optimization SuperOPF software
- Project final report

Thank you