Newton Energy Group

Grid Locational Reliability Analyzer (GLORA)*

A software tool for the locational probabilistic reliability assessment of large bulk electrical systems

FERC Technical Conference
27-29th June 2016

Evgeniy (John) Goldis

Alex Rudkevich

Alex Beylin

Andrei Kharchenko (FOM Instituut voorAtoom en Molecuul Fysica)

Russ Philbrick (Polaris Systems Optimization)

*Partial funding from DOE Phase I SBIR Grant, Award No. DE-SC0013099

Outline

- Benefits of Locational Reliability Assessment
- The Reliability Dispatch Problem and LSRPs
- Traditional Reliability Metrics
- Marginal Reliability Analysis and Nodal Metrics
- Computational Challenges
- Addressing Challenges with Variance Reduction, Parallelization and GPUs
- Example of Reliability Prices for ISO-NE test case

Why Locational Reliability Matters

- Jointly evaluate the reliability benefit of generation and transmission
- Analyze energy deliverability of transmission constrained resources
- Value DERs’ impact on reliability where location is important
- Value locational load shedding for addressing reliability needs

Generalized Reliability Dispatch OPF (RD SCOPF)

$$\min \mathrm{v}' u(t,w)$$

Minimize product of locational VOLL and unserved energy across all stochastic scenarios *w*

$$1'[p(\mathrm{t},\mathrm{w}) + u(t,w) - L(t,w)] = 0$$

Energy balance

$$\underline{F}(t,w) \le \Psi(t,w)[p(t,w) + u(t,w) - L(t,w)] \le \underline{F}(t,w)$$

Line flows with stochastic limits

$$\underline{S}(t,w)X \le p(t,w) \le \bar{S}(t,w)X$$

Generation limits where *X* is the capacity and $0 \le \underline{S}(t,w) \le \bar{S}(t,w) \le 1$

$$0 \le u(t,w) \le l(t,w)$$

Unserved energy is non-negative and cannot exceed load shedding limits

RD SCOPF and Reliability Prices

- Consider the feasibility analysis of the power system performed under many thousand random scenarios and over time
- This analysis factors in full network representation as well as generator and transmission outages
- In each instance, feasibility is analyzed by minimizing VOLL x Unserved Load at all locations. If this indicator is 0, the system is feasible. If the system is infeasible the minimal non-zero cost is determined
- In this instance of this reliability dispatch we compute Locational Marginal Prices
- We will call these prices Locational Stochastic Reliability Prices (LSRPs)

Standard Reliability Metrics

$$LOLP_a(t) = \Pr\{LS_a(t,\omega) > 0\}$$

$$LOLH_a(per) = \sum_{h \in per} \Pr\{LS_a(h,\omega) > 0\}$$

$$EUE_a(per) = \sum_{t \in per} \mathbf{E}[LS_a(t,\omega)]$$

Standard definitions of loss of load and unserved energy metrics for a given area *a* and time period *per* in terms of load shed (LS)

LOLH = Expected number of hours per year of loss of load

EUE = Expected unserved energy

Marginal Analysis

Expected Locational Marginal Unserved Energy (kW) is the reduction in unserved energy per 1 kW change in load

$$MEUE_n = \sum_t \frac{\Delta EUE_{system}(t)}{\Delta Load_n(t)}$$

In an unconstrained system MEUE = (1kW*LOLH) / 1kW = LOLH.

Similarly $\dfrac{\Delta EUE(h)}{\Delta Load\ (h)} = LOLP(h)$

Assuming a constant VOLL, In the RD SCOPF we minimize VOLL*UnservedEnergy
Evaluating $\mathbf{E}[LSRP_n(t,\omega)]$ is equivalent to $MEUE_n(t) * VOLL$

$$E[LSRP_n(t,\omega))] = E\left[\frac{\Delta[\mathrm{v}' u(t,\omega)]}{\Delta L_n(t,\omega)}\right]$$

We can tie these concepts back to the capacity market where at equilibrium CONE is equated to LOLH*VOLL (in an unconstrained system)

$$LRP_n = \sum_t \mathbf{E}[LSRP_n(t,\omega)]$$

If LRP > CONE => Build the Generator

Generation Deliverability and Transmission Metrics

Deliverable Generation Capacity at Time of Scarcity (DGTS):

The deliverability of the generator at the time of scarcity with respect to a specific area, *a* (or system)

$$DGCTS_{gen->a}(t) = \mathbf{E}[p_{gen}(t,\omega) \mid LS_a(t,\omega) > 0]$$

At time of scarcity, all available generators should be at max. If not, deliverability is constrained

Reliability Limiting Hours (RLH) for Transmission Constraints

$$RLH^{pos}_{constr}(per) = \mathbf{E}[\sum_{t \in per} sign(\bar{\mu}_{const}(t,\omega))]$$

$$RLH^{neg}_{constr}(per) = \mathbf{E}[\sum_{t \in per} sign(\underline{\mu}_{const}(t,\omega))]$$

$\bar{\mu}$, $\underline{\mu}$ are non-zero only when a constraint is binding during a scarcity event

Transmission Reliability Rent (TRR)

$$TRR_{branch}(t,\omega) = f_{branch}(t,\omega)[LSRP_{branch.to}(t,\omega) - LSRP_{branch.from}(t,\omega)]$$

If $\mathbf{E}[\Sigma_t TRR_{branch}(t,\omega)] > $ Cost to build the branch => Build the branch

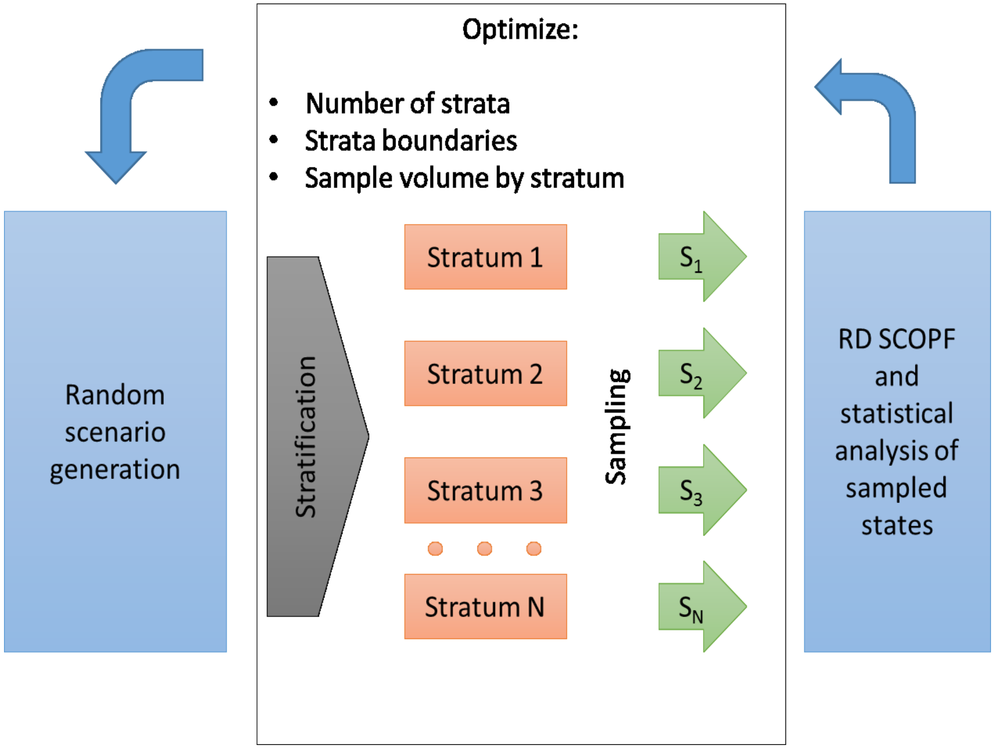
Challenges

- Real power systems designed for "1 day in 10 years" reliability standards: 1 in 10 year-long scenarios will have load shedding events
- Rough estimates:
  - Estimating probability of 1/10 with precision of at least 1/100, $O(1000)$ Monte Carlo scenarios will be needed
  - Each scenario will span through 8760 hourly time-steps and solve SCOPF in each time step – overall $O(10^7)$ SCOPF solutions
  - For a system the size of PJM with over 7000 contingencies to monitor, each SCOPF could take 0.05 – 0.1 hour and $O(10^7)$ SCOPF solutions would require between 0.5 to 1 million processor-hours

3 Steps to a Tractable Solution

- Stratified Sampling and Variance Reduction
- Parallelize OPFs
- Security Constraint Analysis on GPUs

The GLORA Approach – Stratify and Sample

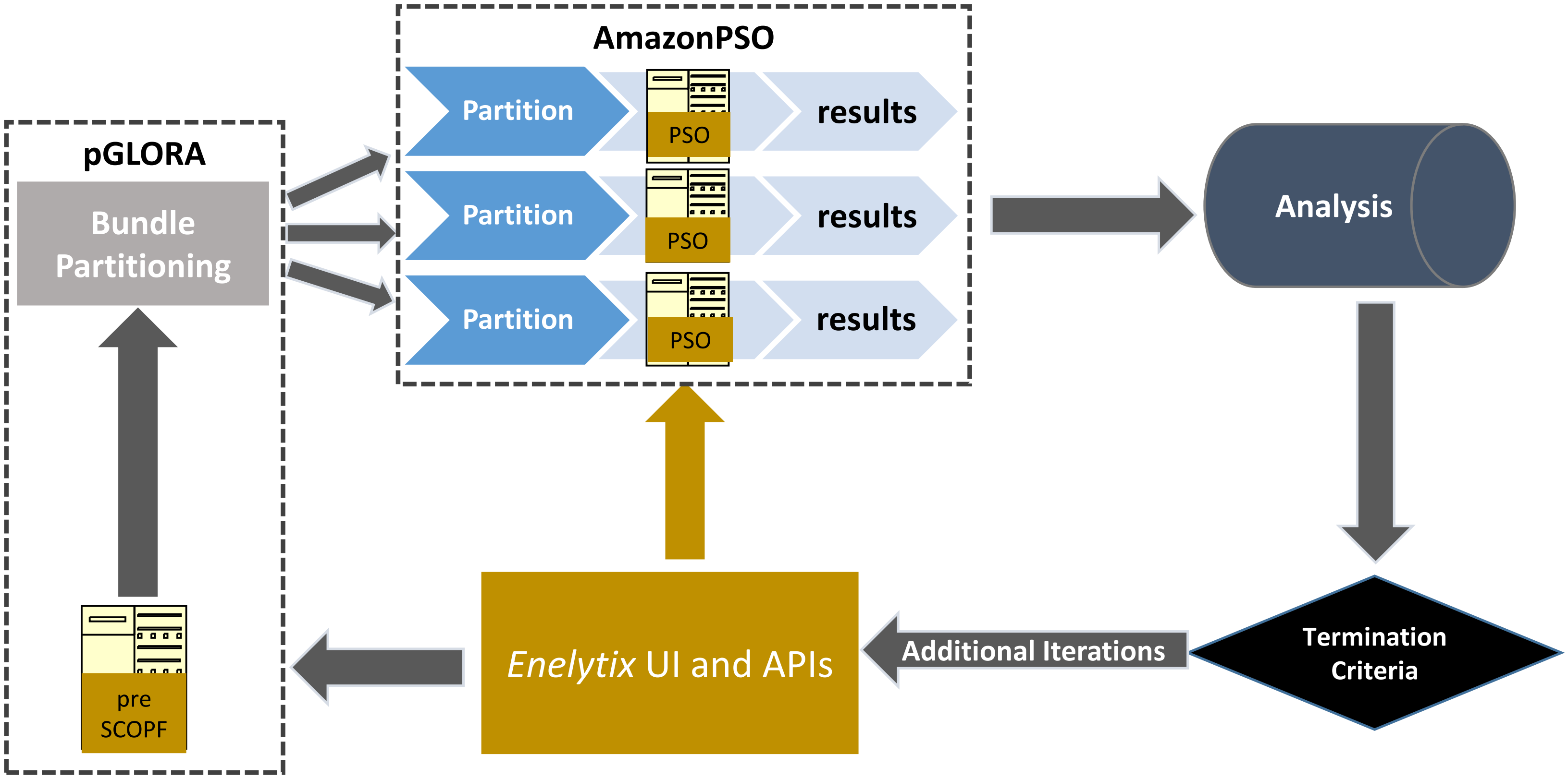


Stratification and Sampling

- Design strata such that a given system state falls into only 1 strata.
  - Reserve Margin Index for strata *i* between $\alpha_i$and α_{i+1}
- Calculate probability that a random state will fall into each strata
  - Fast Monte-Carlo sampling using asymptotic formulas for computing probabilities for the tail of the distribution function (rare events)

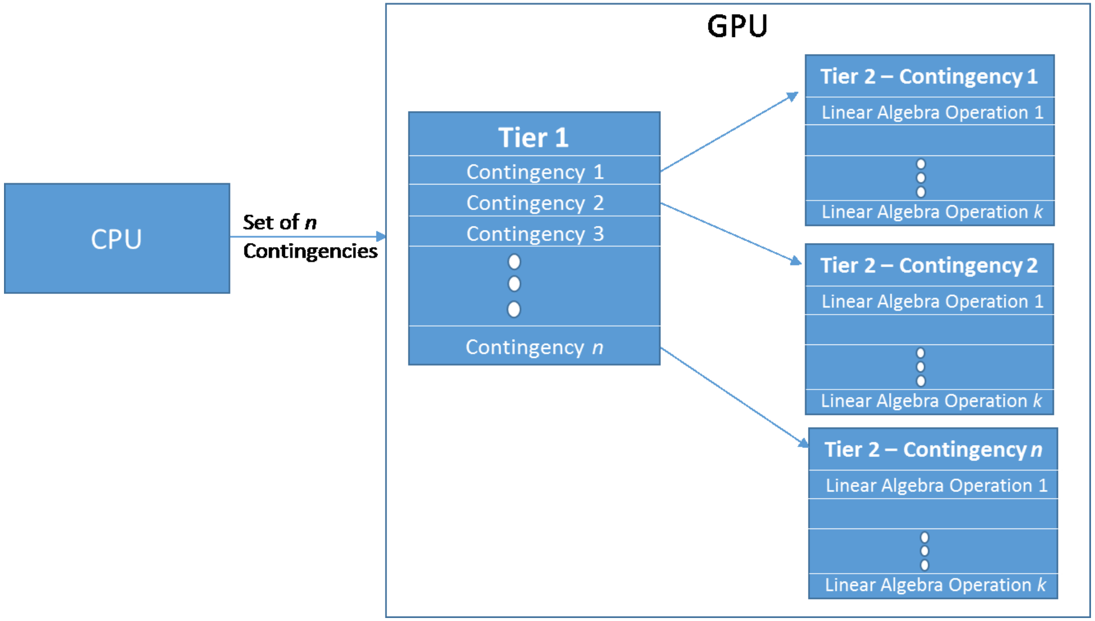
Parallelized OPFs

Leverage existing cloud-based Enelytix platform with PSO engine to run RD OPFs in parallel



Key GLORA Specific Components of Enelytix

Security Constraints Analysis on the GPU

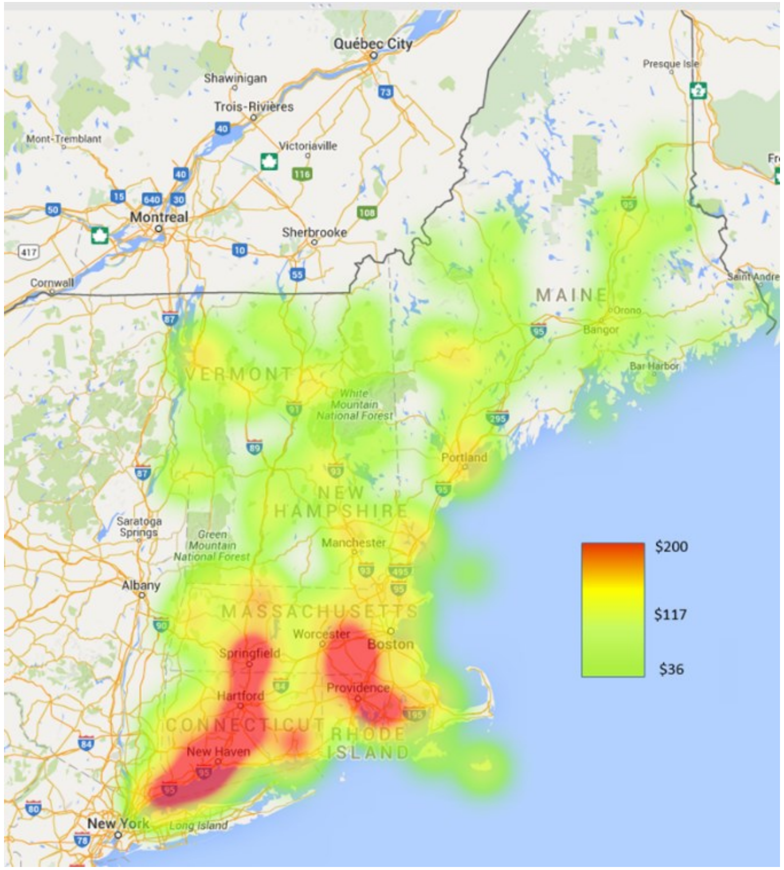


This two-tier algorithm (dynamic parallelism) breaks each contingency in Tier 1 into a set of parallelizable linear algebra operations (Tier 2)

Relies on PSO's Open Library Implementation to pass optimization results to an external component

Delivers an order of magnitude performance improvement compared to CPU-based SC Analysis

Reliability Prices For ISO-NE Test Case



Simulations were performed for Sep 2016 through Aug 2017

Reliability prices shown in this Figure are measured in $/kW-year and range between $36/kW-year and approximately $200/kW-year, i.e. they vary by a factor of more than 5.

This diversity in reliability indices confirm the importance of locational reliability assessment

Dataset for ISO-NE model assembled from FERC 715 network model, CELT report, SNL Financial, NEG assumptions, NREL, EIA, EPA and other public sources

Conclusions

Summary of Benefits from Locational Reliability Assessment

- Jointly evaluate and compare contribution of generation and transmission assets toward resource adequacy
- Determine deliverability of generation during times of scarcity
- Properly capture locational reliability impacts of load shedding and distributed resources

Illustrative Monte Carlo simulations using New England data confirm significant locational differences in nodal resource adequacy indices

Questions

For additional Information on GLORA contact

John Goldis

jgold@negll.com

Alex Rudkevich

arudkevich@negll.com