Risken för effektbrist i det nordiska kraftsystemet

Ett inledande diskussionsseminarium:

Tidiga forskningsresultat från flera delprojekt

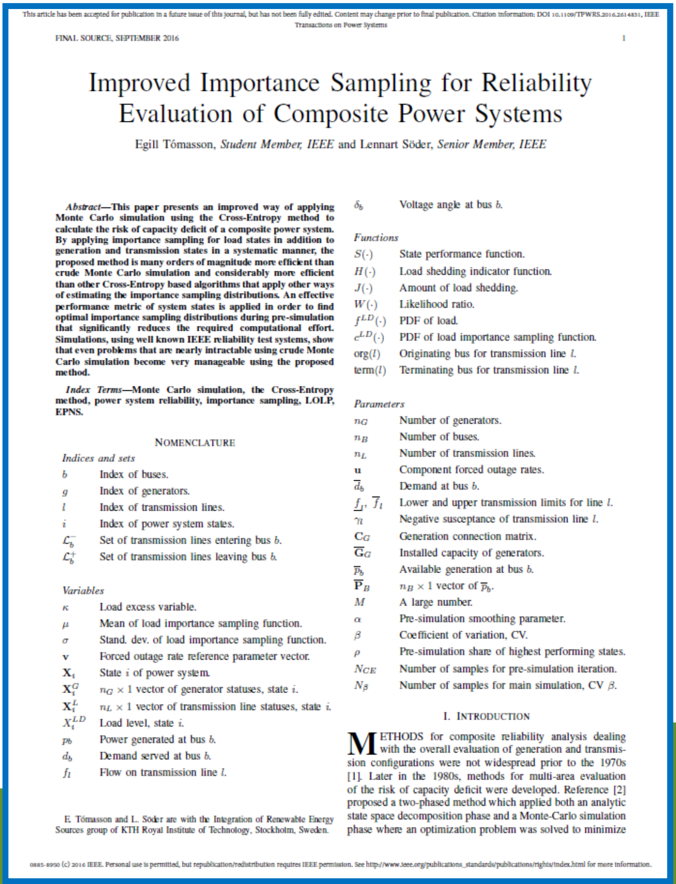
23 maj 2017, Clarion Hotel Sign, Stockholm

Professor Lennart Söder

Handling of risk of capacity deficit in Multi-area systems

1. **Methods for estimation of risk of capacity deficit**: **Egill Tomasson**, Svenska Kraftnät, (2015-2020).

Consider multi-area system and correlations etc



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Improved Importance Sampling for Reliability Evaluation of Composite Power Systems

Egill Tómasson, *Student Member, IEEE* and Lennart Söder, *Senior Member, IEEE*

***Abstract*—This paper presents an improved way of applying Monte Carlo simulation using the Cross-Entropy method to calculate the risk of capacity deficit of a composite power system. By applying importance sampling for load states in addition to generation and transmission states in a systematic manner, the proposed method is many orders of magnitude more efficient than crude Monte Carlo simulation and considerably more efficient than other Cross-Entropy based algorithms that apply other ways of estimating the importance sampling distributions. An effective performance metric of system states is applied in order to find optimal importance sampling distributions during pre-simulation that significantly reduces the required computational effort. Simulations, using well known IEEE reliability test systems, show that even problems that are nearly intractable using crude Monte Carlo simulation become very manageable using the proposed method.**

***Index Terms*—Monte Carlo simulation, the Cross-Entropy method, power system reliability, importance sampling, LOLP, EPNS.**

NOMENCLATURE

Indices and sets

b Index of buses.
g Index of generators.
l Index of transmission lines.
i Index of power system states.
$\mathcal{L}_b^-$ Set of transmission lines entering bus b.
$\mathcal{L}_b^+$ Set of transmission lines leaving bus b.

Variables

κ Load excess variable.
μ Mean of load importance sampling function.
σ Stand. dev. of load importance sampling function.
$\mathbf{v}$ Forced outage rate reference parameter vector.
$\mathbf{X}_i$ State i of power system.
$\mathbf{X}_i^G$ $n_G \times 1$ vector of generator statuses, state i.
$\mathbf{X}_i^L$ $n_L \times 1$ vector of transmission line statuses, state i.
X_i^{LD} Load level, state i.
p_b Power generated at bus b.
d_b Demand served at bus b.
f_l Flow on transmission line l.
δ_b Voltage angle at bus b.

Functions

$S(\cdot)$ State performance function.
$H(\cdot)$ Load shedding indicator function.
$J(\cdot)$ Amount of load shedding.
$W(\cdot)$ Likelihood ratio.
$f^{LD}(\cdot)$ PDF of load.
$c^{LD}(\cdot)$ PDF of load importance sampling function.
$\text{org}(l)$ Originating bus for transmission line l.
$\text{term}(l)$ Terminating bus for transmission line l.

Parameters

n_G Number of generators.
n_B Number of buses.
n_L Number of transmission lines.
$\mathbf{u}$ Component forced outage rates.
$\overline{d}_b$ Demand at bus b.
$\underline{f}_l$, $\overline{f}_l$ Lower and upper transmission limits for line l.
γ_l Negative susceptance of transmission line l.
$\mathbf{C}_G$ Generation connection matrix.
$\overline{\mathbf{G}}_G$ Installed capacity of generators.
$\overline{p}_b$ Available generation at bus b.
$\overline{\mathbf{P}}_B$ $n_B \times 1$ vector of $\overline{p}_b$.
M A large number.
α Pre-simulation smoothing parameter.
β Coefficient of variation, CV.
ρ Pre-simulation share of highest performing states.
N_{CE} Number of samples for pre-simulation iteration.
N_β Number of samples for main simulation, CV β.

I. INTRODUCTION

METHODS for composite reliability analysis dealing with the overall evaluation of generation and transmission configurations were not widespread prior to the 1970s [1]. Later in the 1980s, methods for multi-area evaluation of the risk of capacity deficit were developed. Reference [2] proposed a two-phased method which applied both an analytic state space decomposition phase and a Monte-Carlo simulation phase where an optimization problem was solved to minimize

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Case study for Nordic System

Area	2020	2025	2030
SE1	10,9 s/winter	15,7 s/winter	14,1 s/winter
SE2	363 ms/winter	695 ms/winter	596 ms/winter
SE3	23 s/winter	24,9 s/winter	24,5 s/winter
SE4	1,33 s/winter	1,65 s/winter	1,31 s/winter
FI	8,69 min/winter	6,44 min/winter	13,3 min/winter
NO1	8,28 min/winter	17,3 min/winter	17,2 min/winter
NO2	862 ms/winter	1,06 s/winter	1,10 s/winter
NO3	5,74 s/winter	8,37 s/winter	7,30 s/winter
NO4	1,20 s/winter	2,16 s/winter	1,93 s/winter
NO5	437 ms/winter	1,15 s/winter	1,06 s/winter
DK1	20,8 s/winter	55,4 s/winter	49,5 s/winter
DK2	14,6 s/winter	31,9 s/winter	29,9 s/winter

Risk för effektbrist - mått

”Risk för effektbrist” = Risk att det inte finns tillräckligt med produktionskapacitet för att inte tillgodose den icke pris-känsliga elförbrukningen:

- **LOLP** = Loss Of Load Probability = genomsnittlig förväntat antal timmer per år (eller %) som man inte kan möta elförbrukningen. Tidigare mått (innan avregleringen) i Sverige var 0,1% (dvs **9 timmar per år !!!**)
- **EENS** = Den energimängd som kopplas bort pga effektbrist. I procent är mängden MYCKET lägre än procentsiffran för motsvarande LOLP, eftersom en mycket liten andel kopplas bort av möjlig förbrukning

På gång: Effektvärde – multi-area

Ett kraftverks ”effektvärde”: Om man installerar **X** MW av något kraftslag så kan man öka förbrukningen med **Y** MW med samma LOLP som innan ➔ **X** MW har **effektvärdet Y** MW

- Om man bygger ett kraftverk i ett specifikt område, så minskar även risken för effektbrist i grann-områdena, eftersom möjligheten att importera ökar.
- Med **”Multi-area-LOLP”** kan man definiera **”Multi-area-effektvärde”** = summan av möjlig ökning av elförbrukningen $= \sum Y_i$ i samtliga areor när kraftverket i ett specifikt område ökar med **X** MW

NEPP-KTH – Fortsatt LOLP-arbete:

- Beräkningarna hittills har gjorts för ett specifikt system
- Men det finns andra scenarier
- Vi ska uppskatta Multi-area-LOLP för andra scenarier.

Area	2020	2025	2030
SE1	10,9 s/winter	15,7 s/winter	14,1 s/winter
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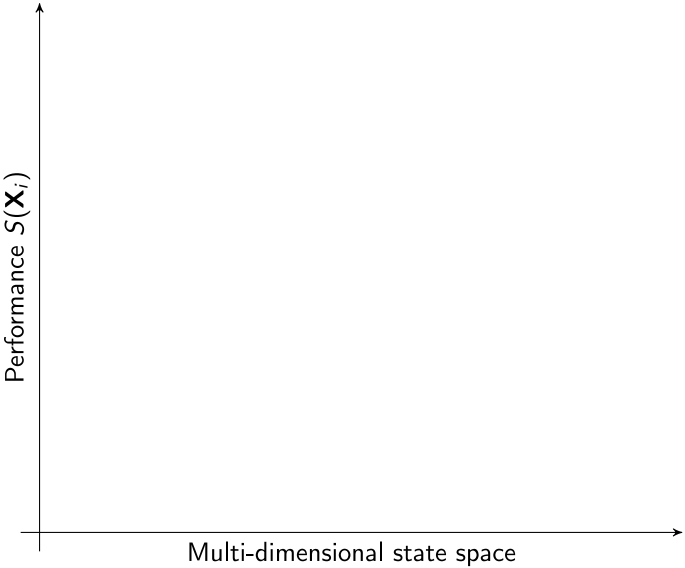
The Cross-Entropy Method - Pre-simulation iteration



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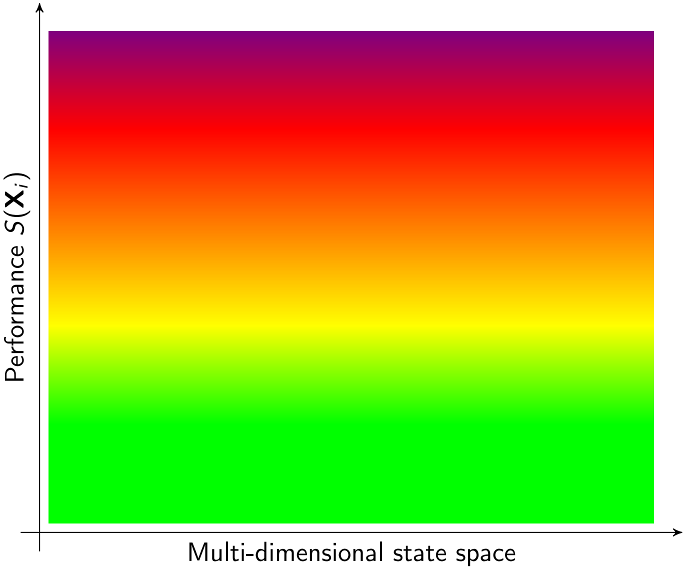

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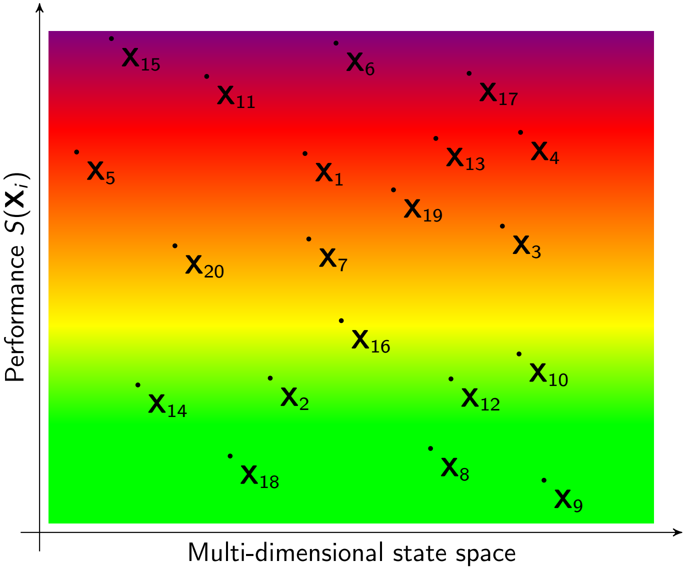
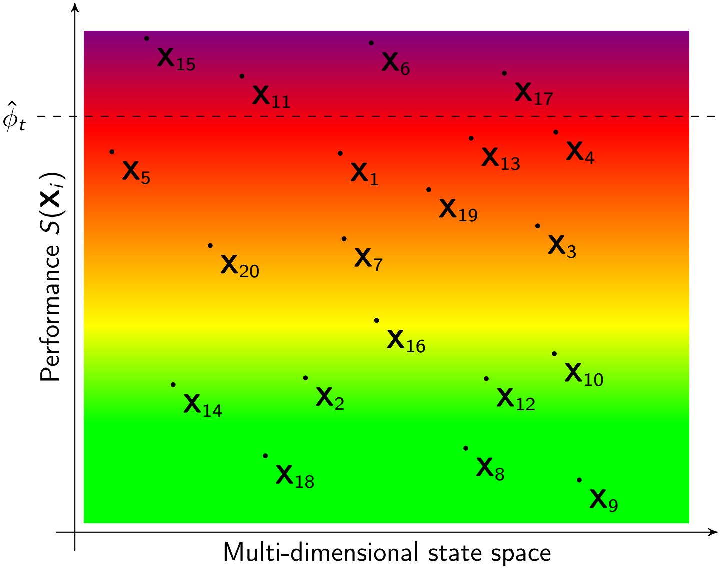
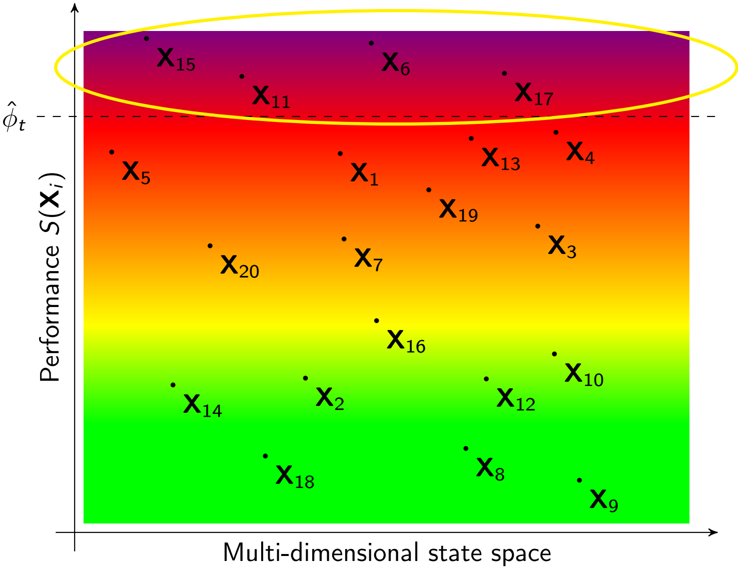


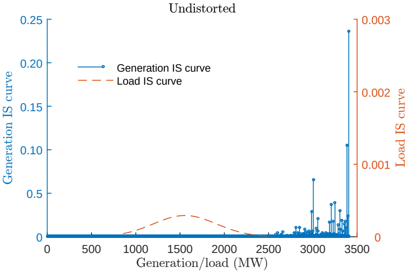


$\hat{\phi}_t$
Performance $S(\mathbf{X}_i)$
Multi-dimensional state space
$\mathbf{X}_{15}$
$\mathbf{X}_{6}$
$\mathbf{X}_{11}$
$\mathbf{X}_{17}$
$\mathbf{X}_{5}$
$\mathbf{X}_{1}$
$\mathbf{X}_{13}$
$\mathbf{X}_{4}$
$\mathbf{X}_{19}$
$\mathbf{X}_{20}$
$\mathbf{X}_{7}$
$\mathbf{X}_{3}$
$\mathbf{X}_{16}$
$\mathbf{X}_{10}$
$\mathbf{X}_{14}$
$\mathbf{X}_{2}$
$\mathbf{X}_{12}$
$\mathbf{X}_{18}$
$\mathbf{X}_{8}$
$\mathbf{X}_{9}$

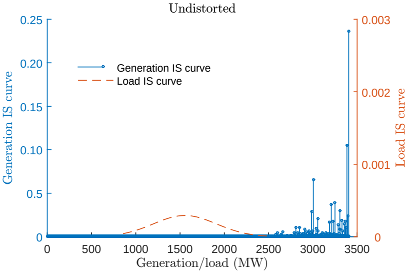
The Cross-Entropy Method - Pre-simulation iteration

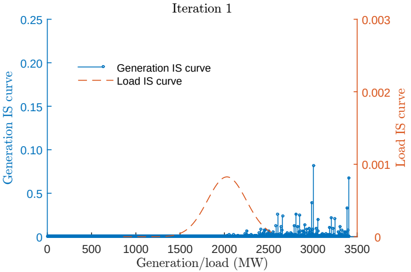


Evolution of IS distributions



Evolution of IS distributions





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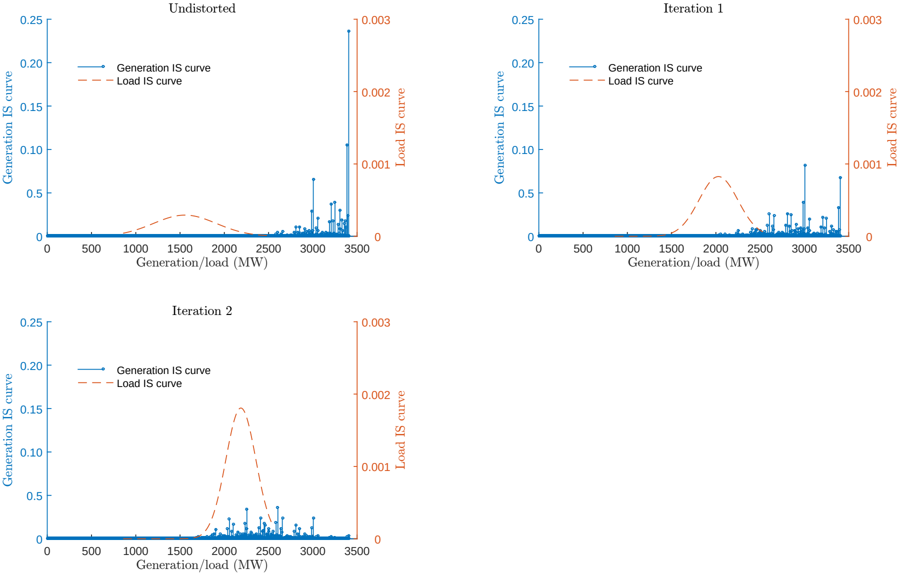

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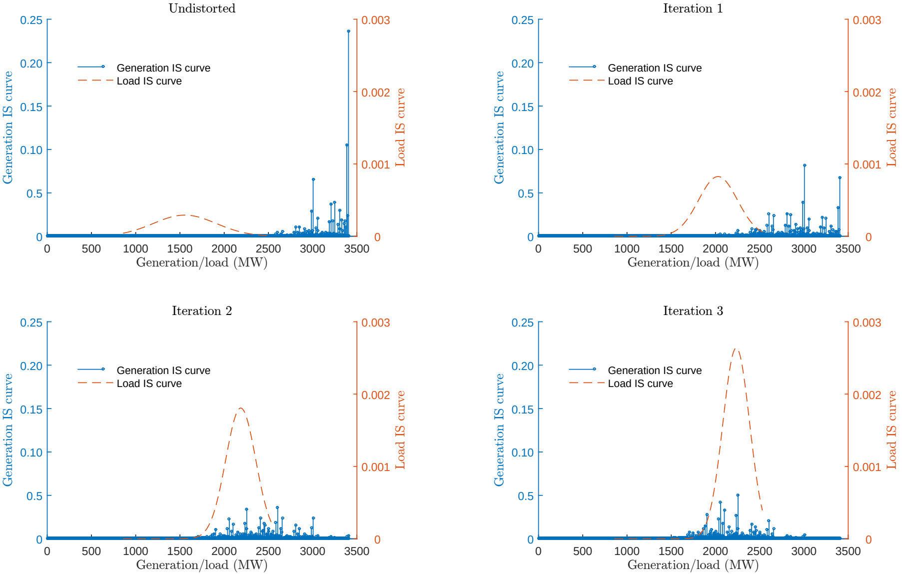

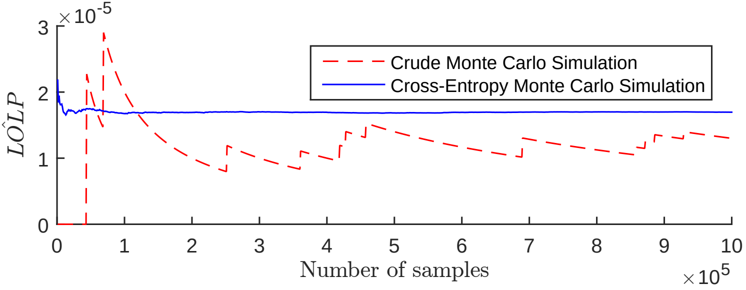

Figure: Convergence of the LOLP estimator for crude Monte Carlo simulation as well as CE Monte Carlo simulation for the IEEE-RTS 96 where transmission lines are considered to be perfectly reliable.

Resultat från en tillämpad studie (2017):

http://kth.diva-portal.org/smash/get/diva2:1077673/FULLTEXT01.pdf

KTH VETENSKAP OCH KONST

DEGREE PROJECT IN ELECTRICAL ENGINEERING,
SECOND CYCLE, 30 CREDITS
STOCKHOLM, SWEDEN 2017

North European Power Systems Reliability

VIKTOR TERRIER

KTH ROYAL INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL ENGINEERING

Beaktar t ex:

- Officiella data
- Överföringsbegränsningar – NTC
- Omvärlden (utanför Norden)
- Korrelationer för vindkraft och elförbrukning i olika områden

Results - current system (2015)

Coldest months 2015: January, February, March, November, December.

Area	LOLP	LOLP (time)	CV	EPNS
SE1	less than 8.10^{-8}	less than 10 ms/winter	–	–
SE2	less than 4.10^{-8}	less than 5 ms/winter	–	–
SE3	$7,80.10^{-7}$	102 ms/winter	3,17%	293,7 W
SE4	$2,34.10^{-7}$	30,5 ms/winter	5,78%	44,2 W
FI	$5,78.10^{-4}$	1,26 min/winter	0,12%	266,4 kW
NO1	$4,14.10^{-4}$	54 s/winter	0,14%	137,9 kW
NO2	less than 4.10^{-8}	less than 5 ms/winter	–	–
NO3	$7,81.10^{-7}$	92,8 ms/winter	3,31%	67,0 W
NO4	less than 8.10^{-8}	less than 10 ms/winter	–	–
NO5	less than 4.10^{-8}	less than 5 ms/winter	–	–
DK1	$3,85.10^{-5}$	5,03 s/winter	0,45%	7,38 kW
DK2	$1,45.10^{-5}$	1,89 s/winter	0,74%	2,38 kW

Results - future scenarios

Changes in the system:

- **2020:**
  - Oskarshamn 1, Ringhals 1, Ringhals 2 decommissioned (2158 MW - SE3)
  - SE2-SE3 (+500 MW), SE3-SE4 (+25%), DK1-NO2 (+700 MW) and NO2-Germany (+ 1400 MW)
- **2025:**
  - NO2-United Kingdom: +1400 MW
- **2030:**
  - Loviisa 1 and 2 decommissioned (1004 MW - FI)
  - SE4-Germany: + 700 MW

Demand and wind power capacity increase proportionally to the increase of the forecasted peak values.

Results compared (LOLP)

Area	2020	2025	2030
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