Security of Optimal Transmission Switching

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Optimal Transmission Switching

- Objective: reduce congestion cost
- Constraint: maintain N-1 security

- How does OTS affect the operational reliability of the system?
- Are consumers really saving money?

Everybody loves N-1 security..

- Operators
  - Because it is unambiguous
- Reliability councils
  - Because it can be monitored easily
- But does it serve the consumers well?
  - We still get blackouts and large outages, don't we?

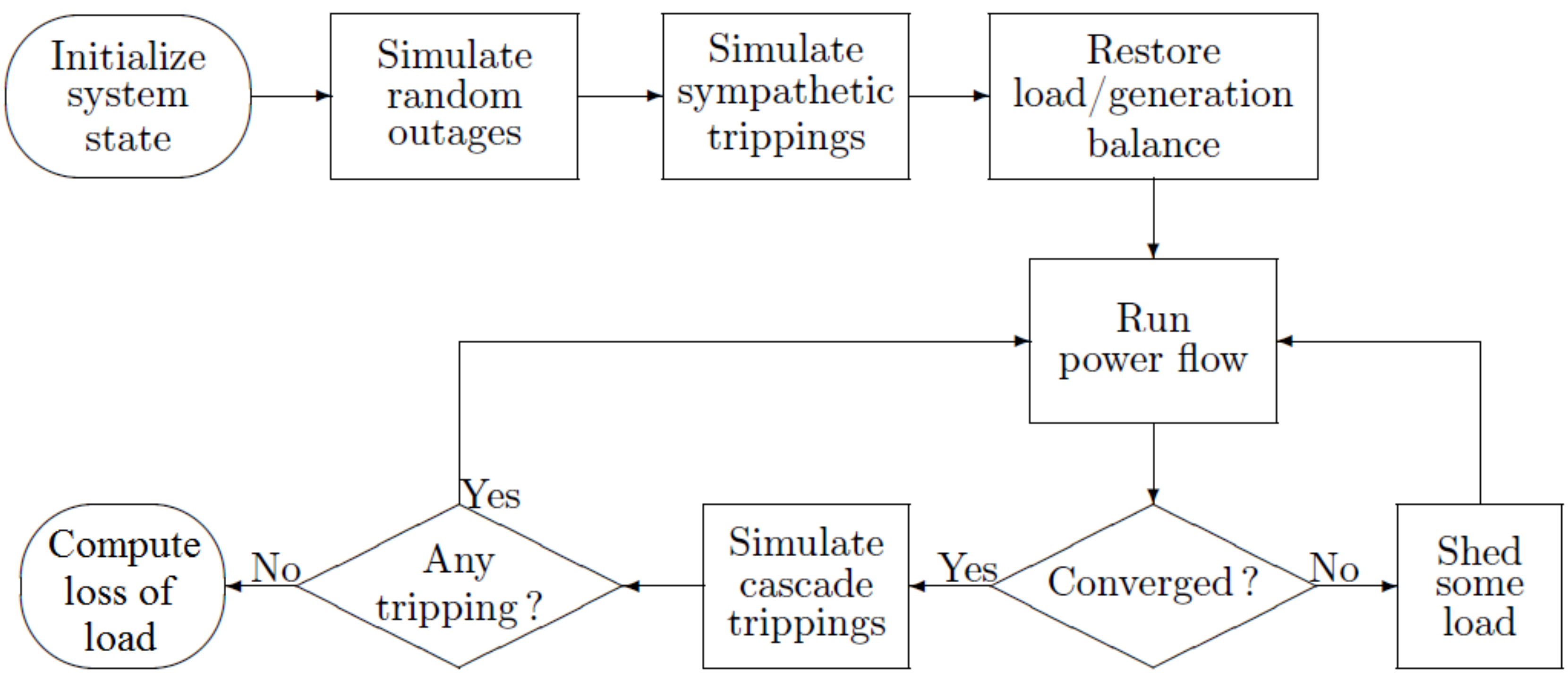
Limitations of N-1 security

- It does not consider the probability of failures:
  - All components are treated the same
- It does not consider the consequences of failures:
  - Minor overload vs. voltage collapse
- It assumes that all failures are independent events:
  - No protection failures, no operator errors, ..

Probabilistic security assessment

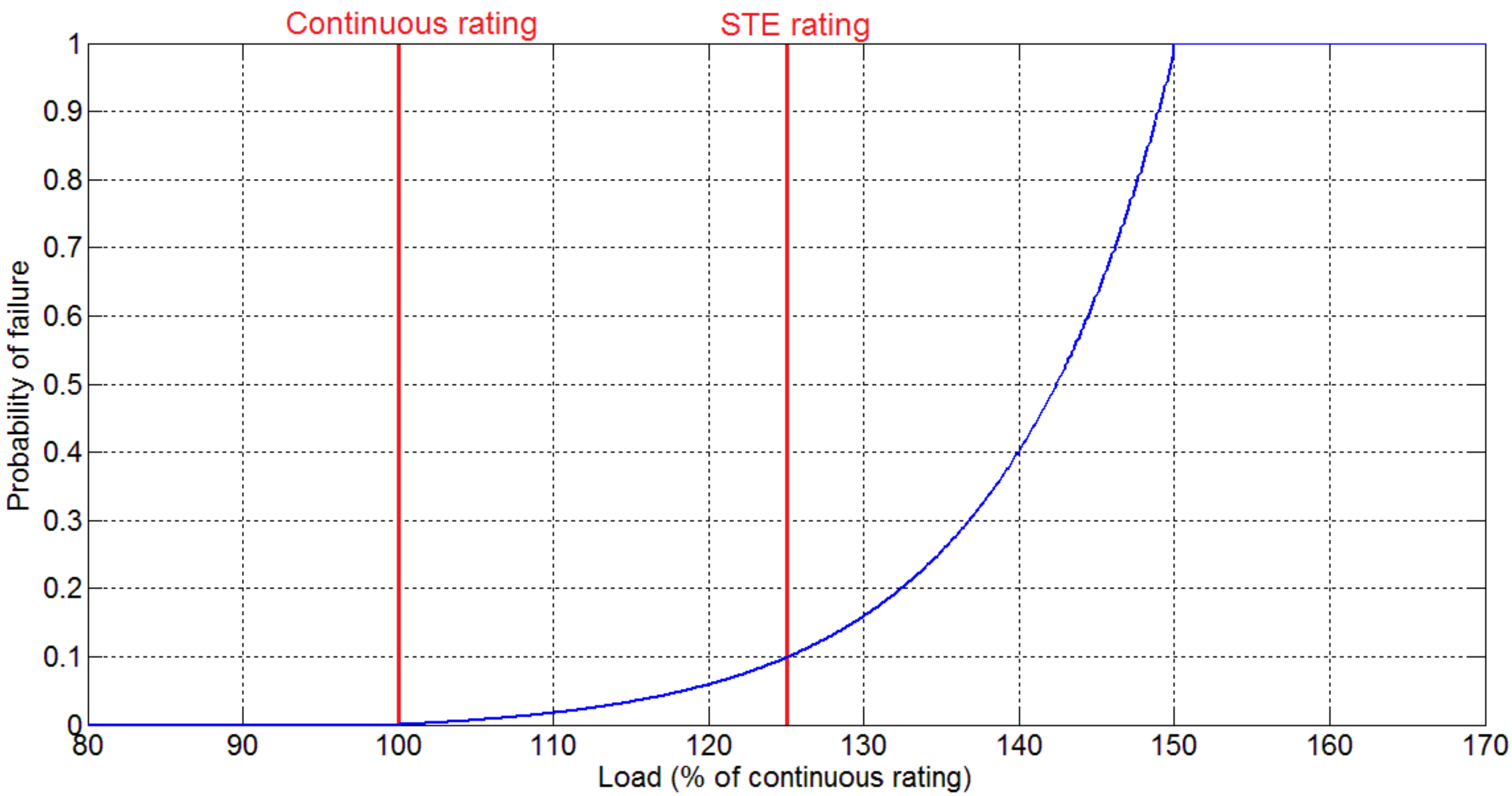
- A true measure of security must be risk-based
- Risk = probability x consequences
- Assessed using a Monte Carlo simulation
  - Multiple simultaneous failures
  - Probability of protection malfunctions
  - Cascading outages
- Consequences measured in terms of Expected Energy Not Served

Monte Carlo Simulation



Probability of line fault

Important for cascading failures



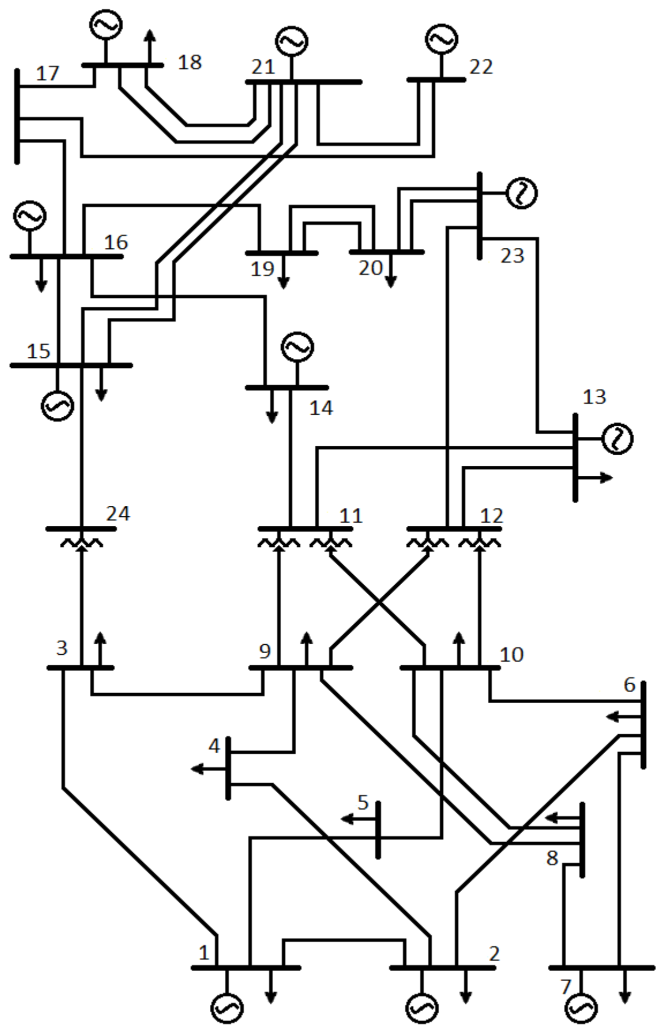
Methodology

1. DC OTS with N-1 security
   – Optimize the topology
2. AC OPF with N-1 security
   – Optimize the generation and voltage profiles
3. Monte Carlo based security assessment
   1. Simulate outages
      - Loss of Load
   2. Model restoration
      - Expected Energy Not Served (EENS)
   3. Calculate the cost of outages
      - = EENS X Value of Lost Load (VoLL)

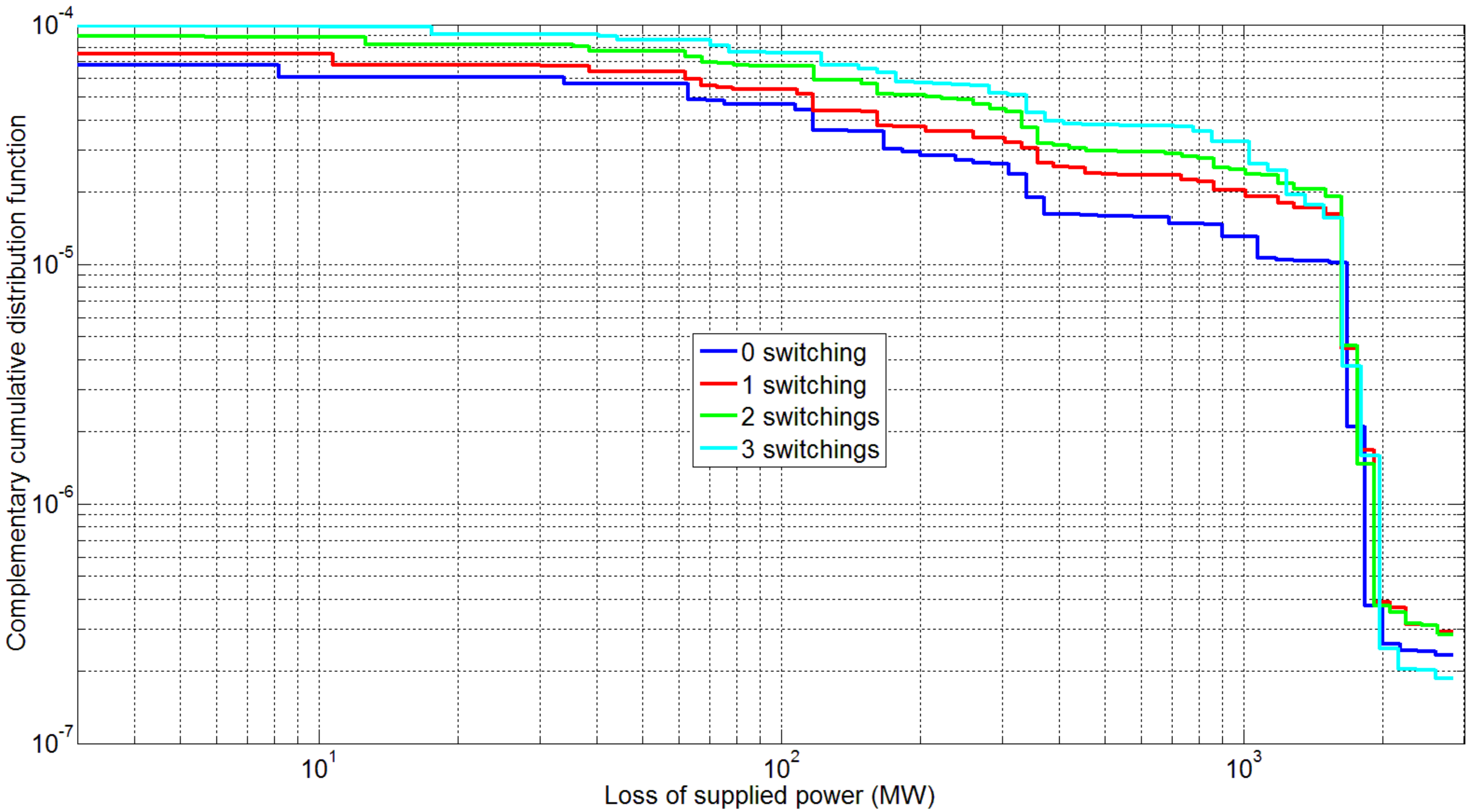
Test results – IEEE RTS

Lines disconnected	DC cost ($/h)	Savings (%)
	76,118	-
9-11	72,807	4.3
9-11, 10-23	72,084	5.3
6-10, 9-11, 10-23	71,754	5.7
1-2, 3-9, 8-9, 10-11	71,377	6.2

Lines disconnected	AC cost ($/h)	Savings (%)
	75,547	-
9-11	73,152	3.2
9-11, 10-23	72,414	4.1
6-10, 9-11, 10-23	73,375	2.9
1-2, 3-9, 8-9, 10-11	Infeasible	Infeasible



Probability of lost load

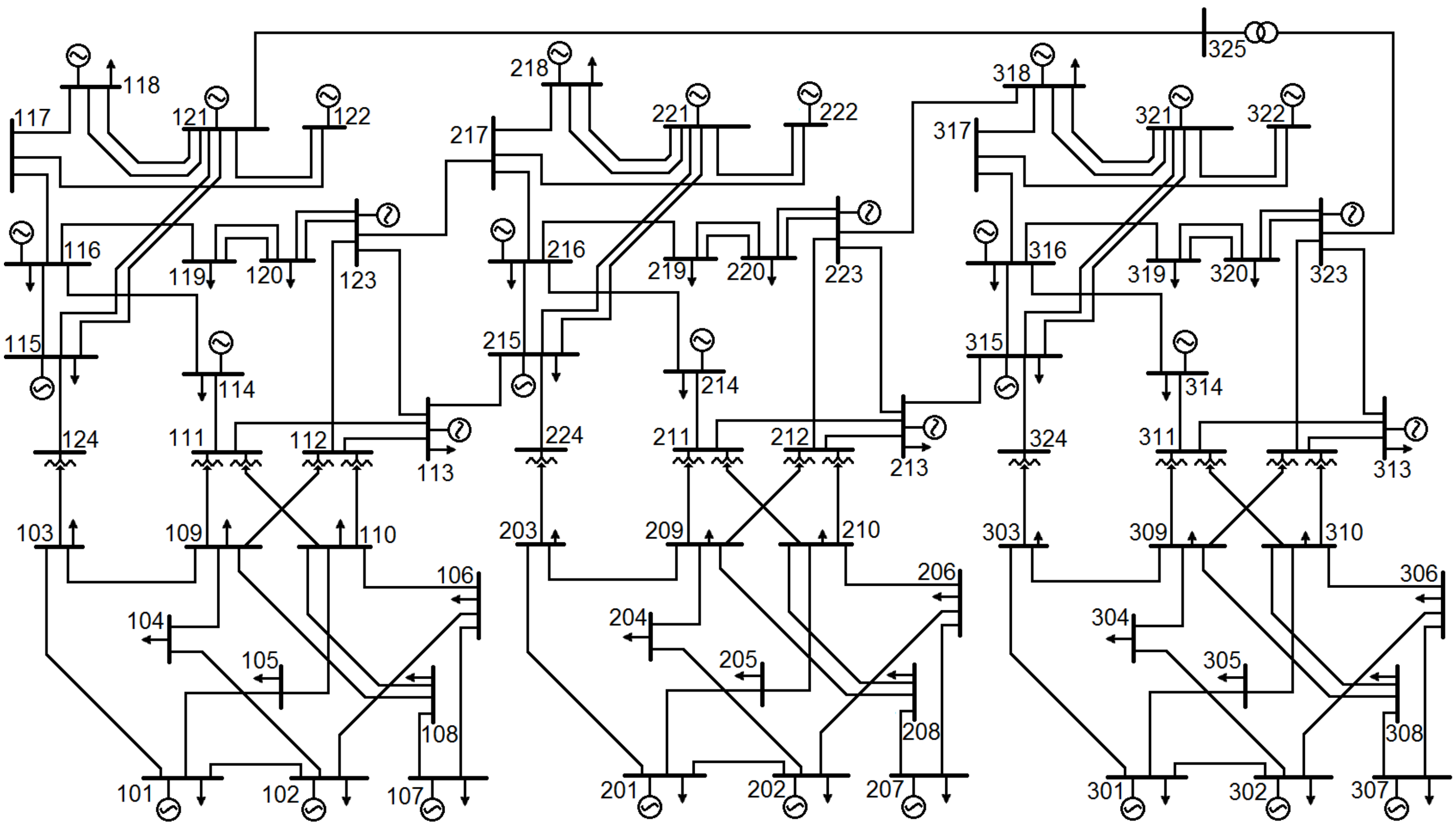


Costs

Lines disconnected	Gen. cost ($/h)	EENS (kWh/h)	Outage cost ($/h)	Total cost ($/h)
	75,547	60	507	76,054
9-11	73,152	94	795	73,947
9-11, 10-23	72,414	113	955	73,369
6-10, 9-11, 10-23	73,375	122	1031	74,406

Outage costs based on VOLL: 8,453 $/MWh (which is a low estimate)

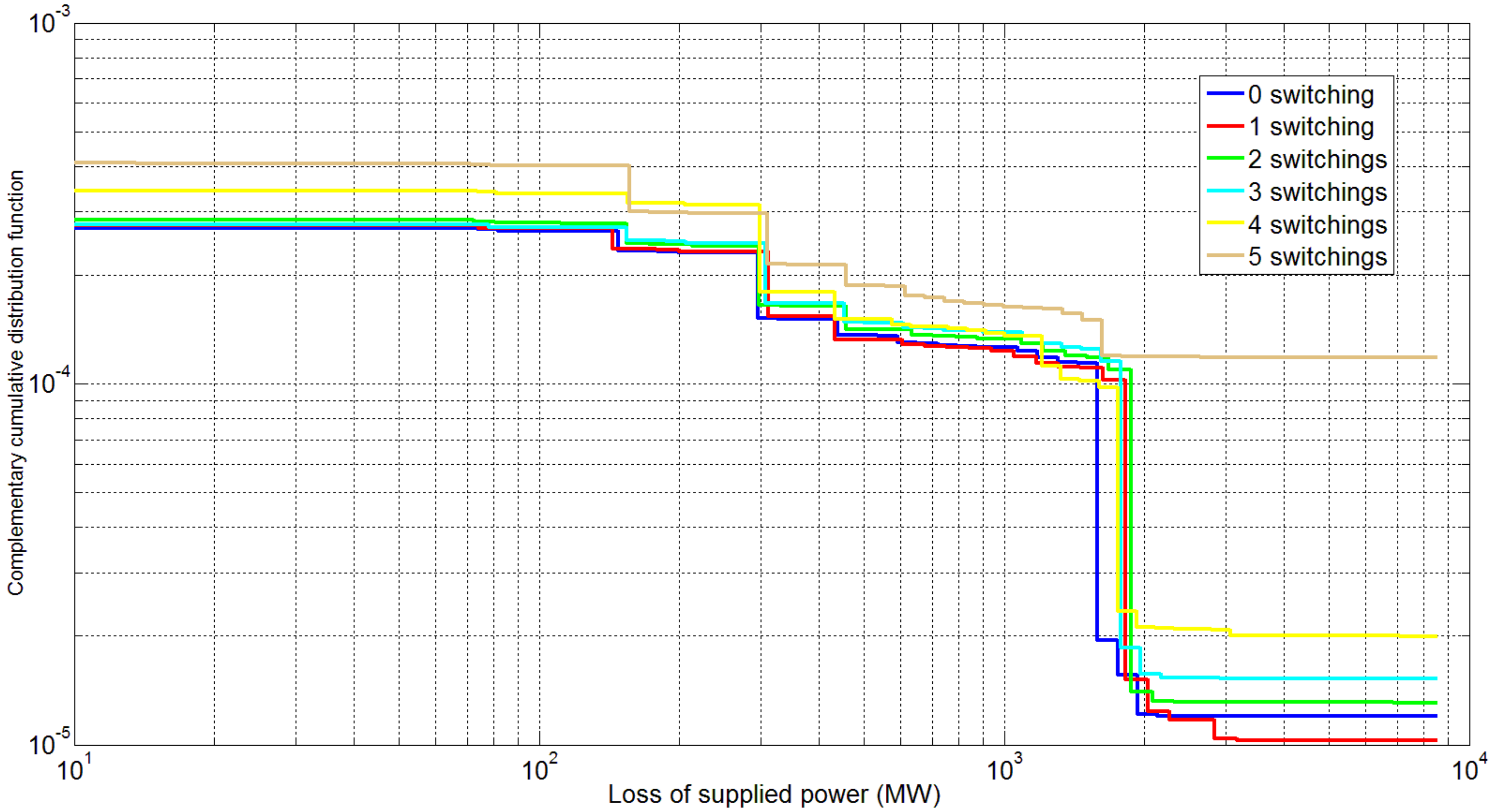
Test Results – Three-area RTS



Optimal transmission switching

Lines disconnected	DC cost ($/h)	Savings (%)	AC cost ($/h)	Savings (%)
	217,319	-	216,006	-
109-111	212,936	2.0	212,268	1.7
109-111, 210-211	211,715	2.6	212,290	1.7
109-111, 210-211, 118-121	210,959	2.9	211,867	1.9
109-111, 210-211, 118-121, 310-311	210,355	3.2	211,594	2.0
109-111, 210-211, 118-121, 310-311, 106-110	209,836	3.4	212,551	1.6
109-111, 210-211, 118-121, 310-311, 106-110, 101-103	209,457	3.6	Infeasible	Infeasible
109-111, 210-211, 118-121, 310-311, 106-110, 101-103, 303-309	209,451	3.6	Infeasible	Infeasible

Probability of lost load



Costs

Lines disconnected	Gen. cost ($/h)	EENS (kWh/h)	Outage cost ($/h)	Total cost ($/h)
	216,006	677	5,723	221,729
109-111	212,268	634	5,359	217,627
109-111, 210-211	212,290	754	6,374	218,664
109-111, 210-211, 118-121	211,867	846	7,151	219,018
109-111, 210-211, 118-121, 310-311	211,594	1,020	8,622	220,216
109-111, 210-211, 118-121, 310-311, 106-110	212,551	4,832	40,845	253,396

Outage costs based on VOLL: 8,453 $/MWh (which is a low estimate)

Conclusions

- Calculation of the value of optimal transmission switching must take into account the socio-economic costs of outages
- Depending on the chosen VoLL, this value could be negative

A metaphor for N-1 security..

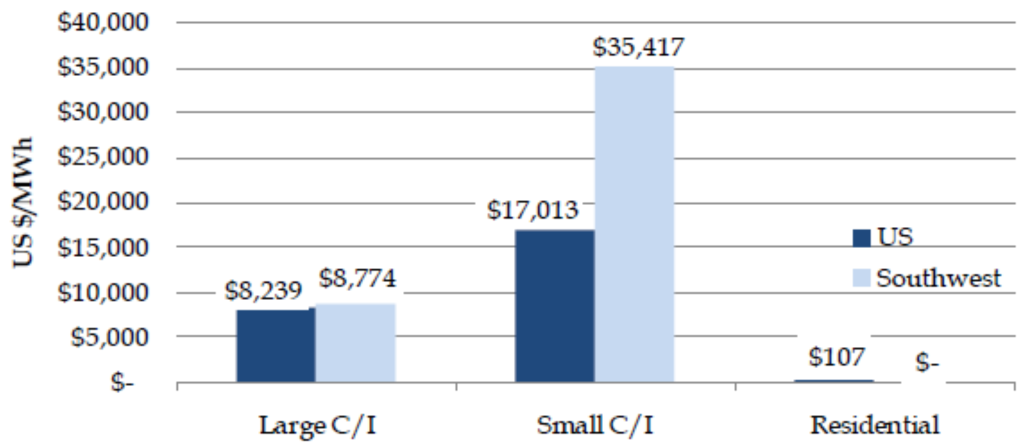
SUPPLEMENTARY SLIDES

Estimating the cost of outages

- Value of Lost Load (VoLL): $ value that an average consumer places on one kWh of energy not delivered without advance notice
- Depends on:
  - Types of load (industrial, residential…)
  - Region
  - Duration of outage
- Estimated using surveys:
  - Frayer, Keane & Ng, "Estimated Value of Service Reliability for Electric Utility Customers in the United States," Tech. Report, 2013, London Economics International LLC (summary of other studies)
  - Customer mix:
    - 1/3 of large & medium industrial & commercial
    - 1/3 of small industrial & commercial
    - 1/3 of residential
- → VOLL: 8,453 $/MWh (low value)

Variability according to the sector

Figure 7. Estimated VOLLs by Customer Class in US National Study (median value, $/MWh)

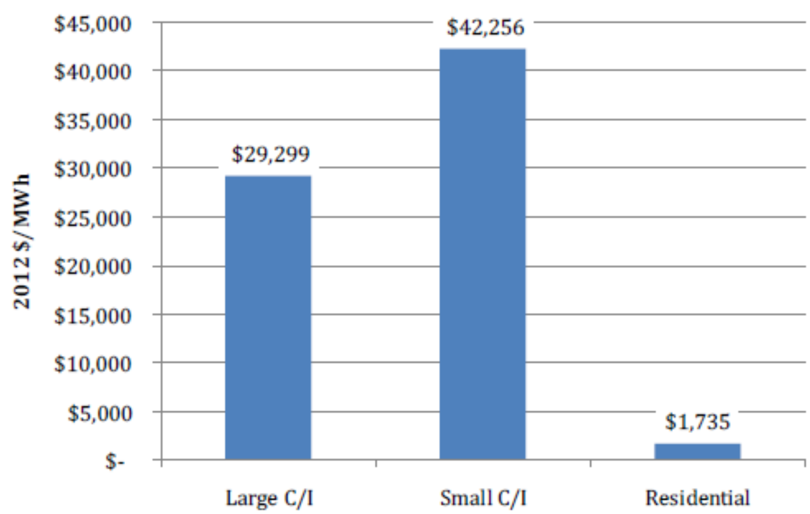


**Large C/I are customers with consumption greater than 50 MWh per annum*

•Frayer, Keane & Ng, "Estimated Value of Service Reliability for Electric Utility Customers in the United States," Tech. Report, 2013, London Economics International LLC (summary of other studies)

Variability according to the region

Figure 14. Estimated VOLL in the MISO Study (median value, $/MWh)



**Large C/I are customers with consumption greater than 1,000 MWh per annum*

- Frayer, Keane & Ng, "Estimated Value of Service Reliability for Electric Utility Customers in the United States," Tech. Report, 2013, London Economics International LLC (summary of other studies)

Variability according to the duration

Interruption duration:	1 min	20 mins	1 hr	4 hrs	8 hrs	24 hrs
$VOLL_x$ (£/kWh)	341.4	36.5	23.4	18.2	16.4	7.5

- Rios, Bell, Kirschen and Allan, "Computation of the Value of Security. Part I.," Tech. Report, UMIST, 1999.

OTS-OPF combination

- Active power generation after a contingency
  - Based on primary regulation
- Continuous ratings for lines power flows and voltages in N-0 state
- Short-Term Emergency (STE) ratings for lines power flows and voltages in N-1 states