Probabilistic Transmission Planning: Framework, Sample Analysis, & Tools

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Probabilistic Planning Motivation

Goal: Apply current tools to perform probabilistic transmission on Texas electricity system

- Evaluate modeling tools
- Compare sample projects
- Determine gaps and needs to be used

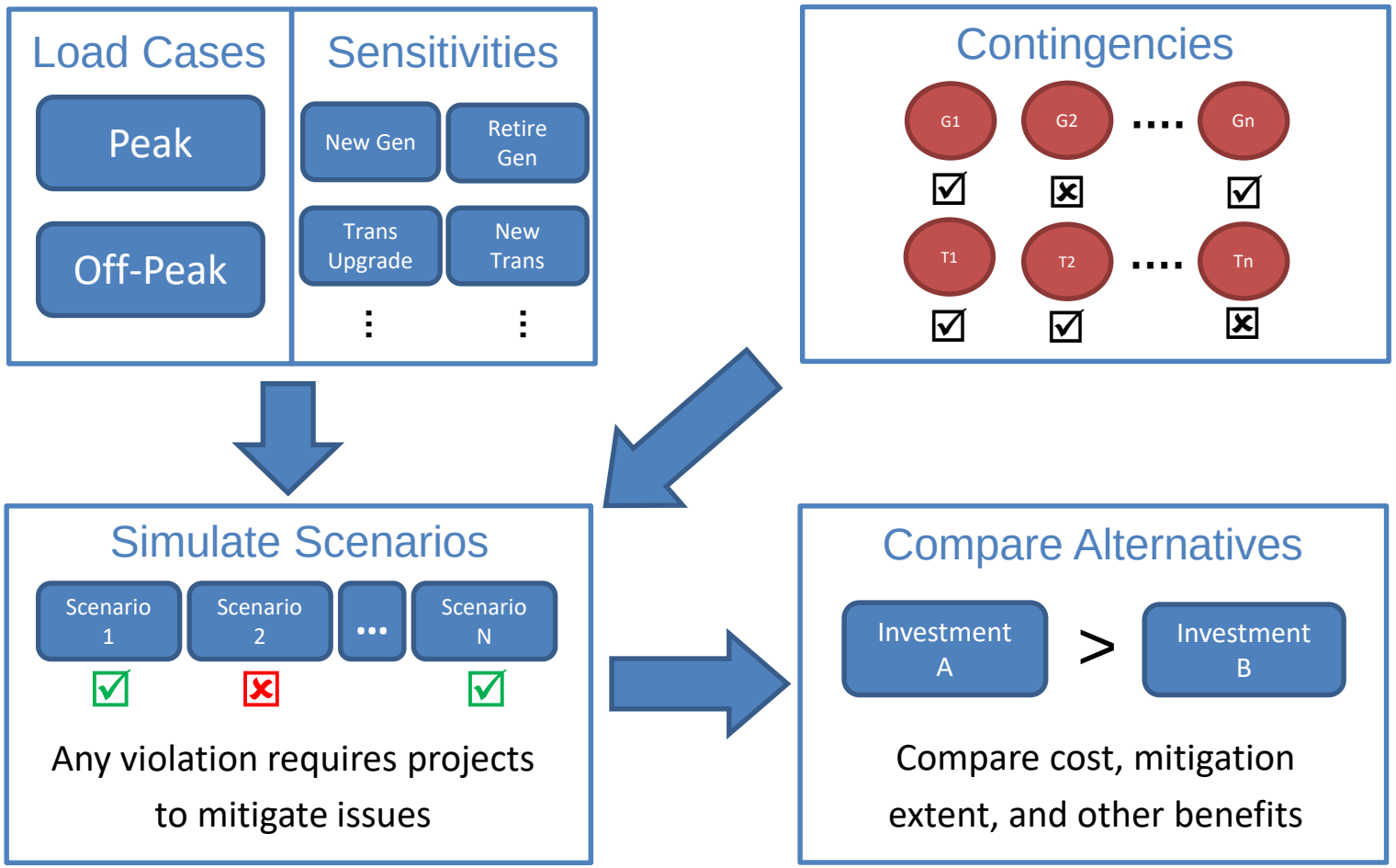
Focused on practical considerations of modeling and analysis

Outline

- Probabilistic Planning Introduction
- Sample Case on ERCOT system
  - Scenario Creation
  - Contingency Simulation
  - Risk-based indices
- Outstanding Modeling Issues

PROBABILISTIC PLANNING INTRODUCTION

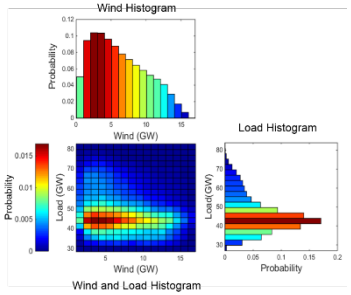
Deterministic Planning



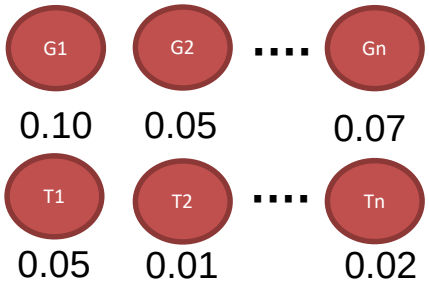
NERC TPL-001-4 outlines requirements for scenarios, contingencies, and allowable remedial actions

Probabilistic Planning

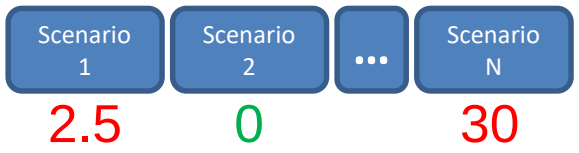
Operating Point Distribution



Outage Statistics



Simulate Scenarios



Determine reliability impact such as loss of load

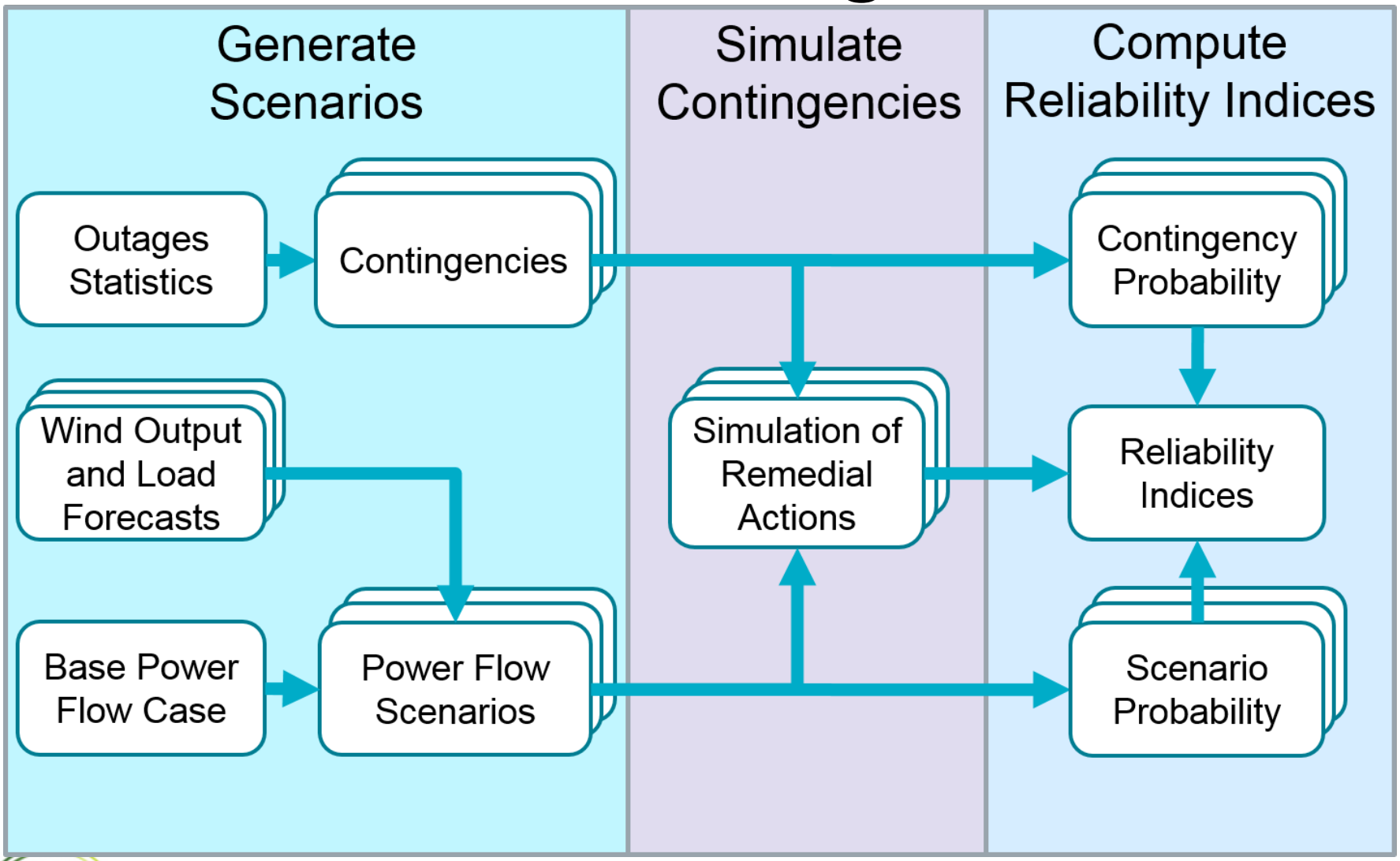
Compare Alternatives

Include risk-based reliability indices

Objectives:

- **Quantify risk** of low probability but high impact scenarios
- **Additional decision criteria** to compare transmission investments

Probabilistic Planning Framework



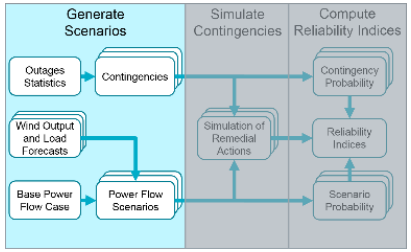
ERCOT CASE STUDY

ERCOT Case Study

- Electric Reliability Council of Texas (ERCOT) system model
  - Texas, USA
  - Independent System Operator

- Transmission > 100 kV
- Research performed at ERCOT in summer 2016

Statistical Input Data



Transmission and Generation Outage Statistics

- Include samples of deep contingency events

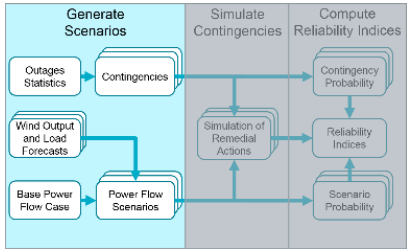
  (N-3, N-4, N-5, …)

- Future work should include probability common mode outages

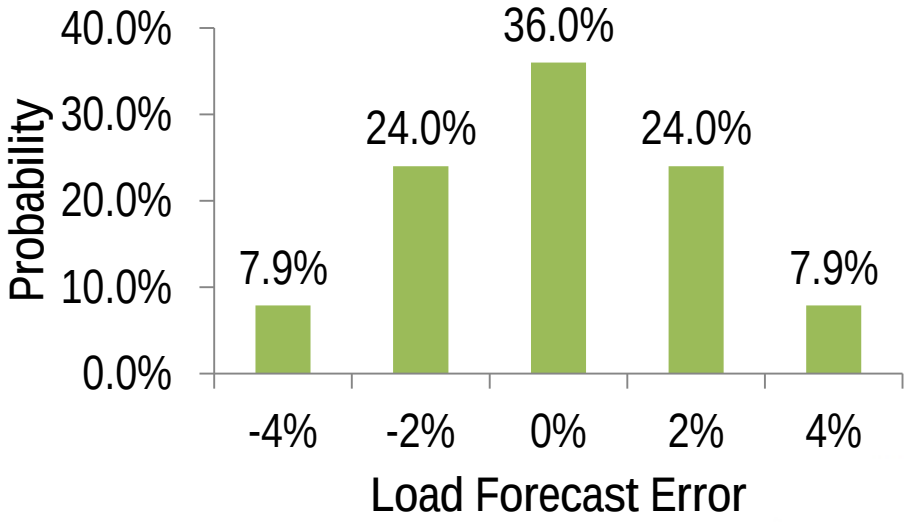
Forecasted System Operating States

- Include wind outputs, distributed energy resources, electric vehicles, and other uncertain futures
- Not limited to bivariate distributions

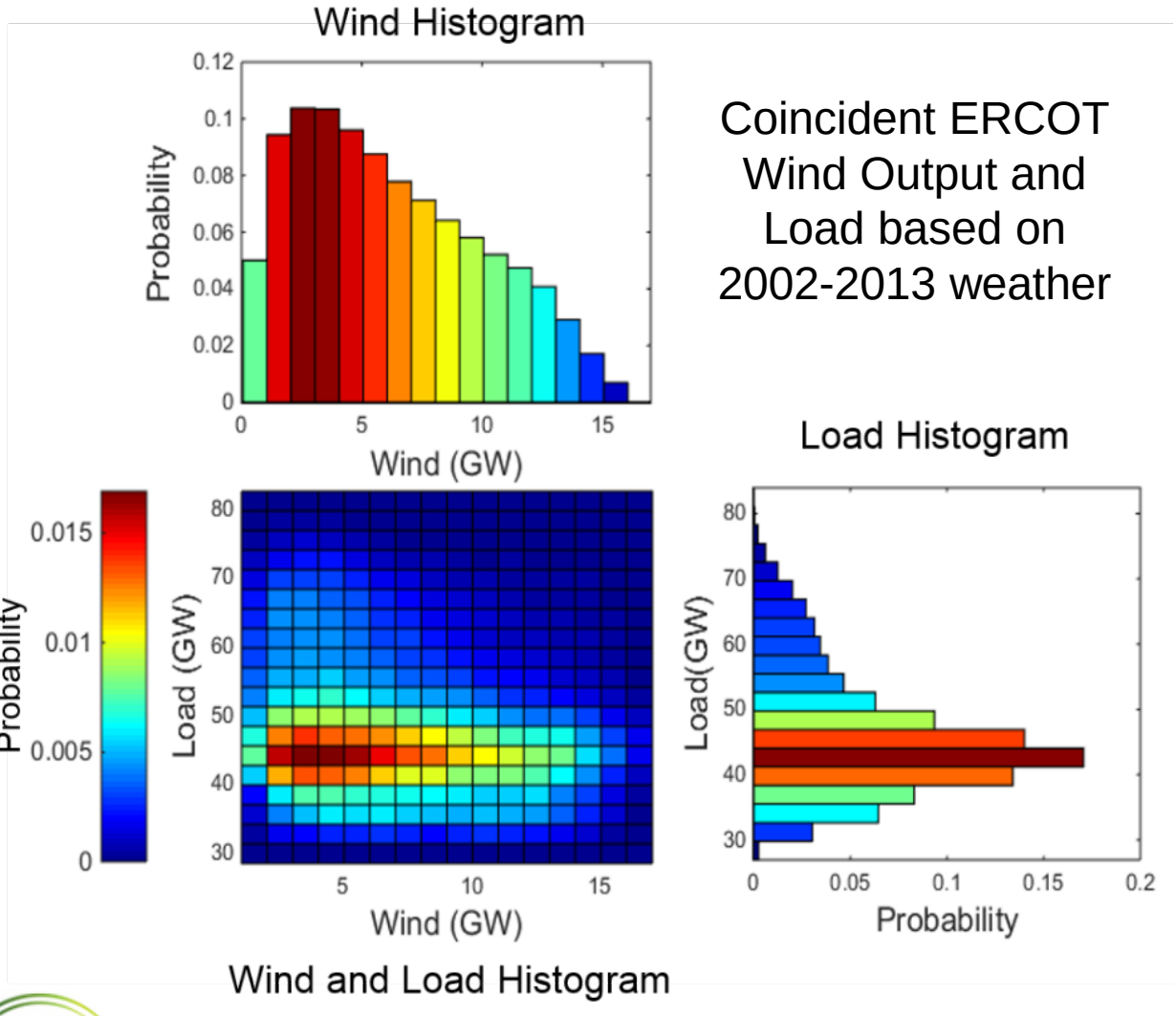
Load Scenarios



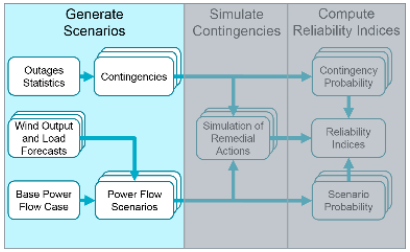
- 2002-2013 historical data
  - Forecast for 2017
- Include load growth uncertainty
- 481,800 hourly scenarios



2017 Wind and Load Forecasts

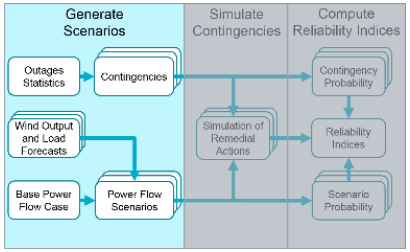


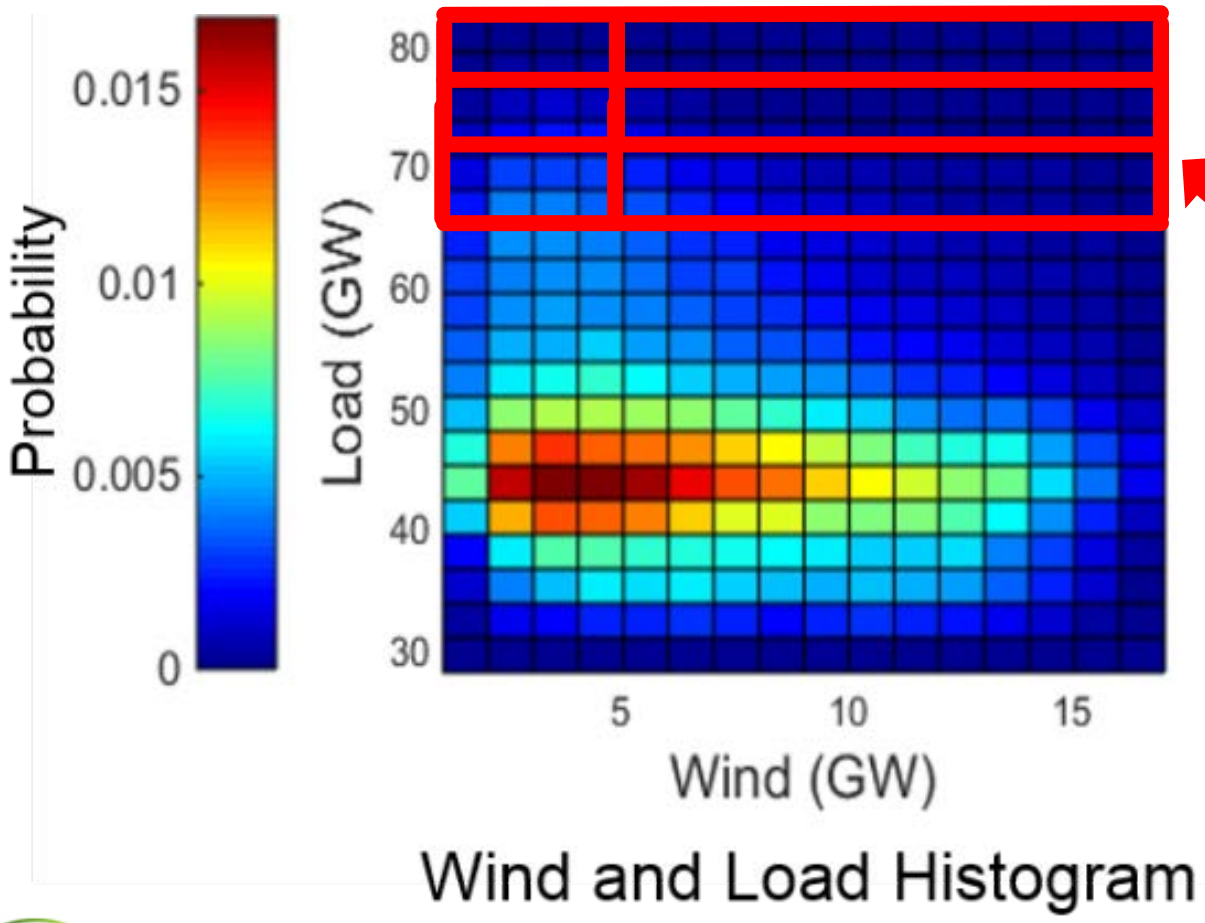
Coincident ERCOT Wind Output and Load based on 2002-2013 weather



Load probability includes uncertainty of forecasts

Stratified Sampling



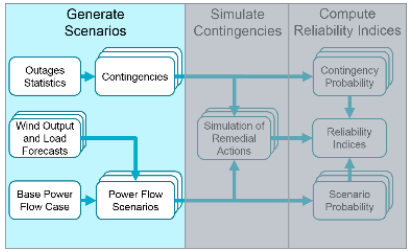


Wind and Load Histogram

Stratified Sample Space

Ensures analysis of high impact but low probability events

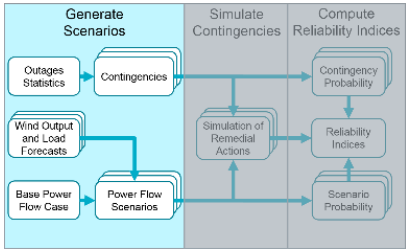
Strata Definitions



- From historical wind and load data including load growth forecast

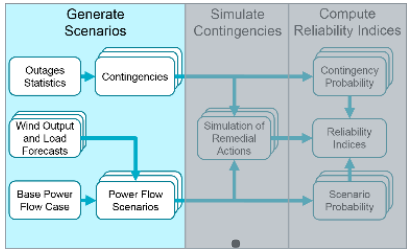
			Load Bounds (MW)		Wind Bounds (MW)	
Scenario Name	**Probability**	**Number of Hours**	**Upper**	**Lower**	**Upper**	**Lower**
Load1\W1	2.97E-05	24	81,511	78,668	16,114	4,025
Load2\W1	2.69E-04	168	78,668	75,825	16,114	4,025
Load3\W1	1.25E-03	589	75,825	72,982	16,114	4,025
Load1\W2	3.13E-05	28	81,511	78,668	4,025	0
Load2\W2	3.67E-04	252	78,668	75,825	4,025	0
Load3\W2	1.84E-03	944	75,825	72,982	4,025	0
Total	3.78E-03	2,005	81,511	72,982	16,114	0

Contingency Statistics



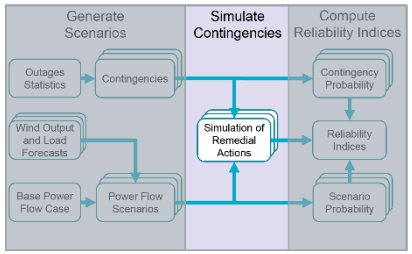
- Generator outage data from Generator Availability Database System (GADS)
- Transmission outage data based on NERC Transmission Availability Database System (TADS) based on voltage class

Contingency Scenarios



- Enumerated ~8,000 N-2 (generator and transmission) contingencies in coastal region of ERCOT
- Analysis would ideally include higher level contingencies
- Statistics include frequency and mean time to repair to measure severity

Simulating Contingency Events



Contingency List

Power Flow Scenario

Power Flow w/ Remedial Actions

1. Re-dispatch generators
2. Adjust switched components
3. Adjust taps

⋮

N. Load Shedding

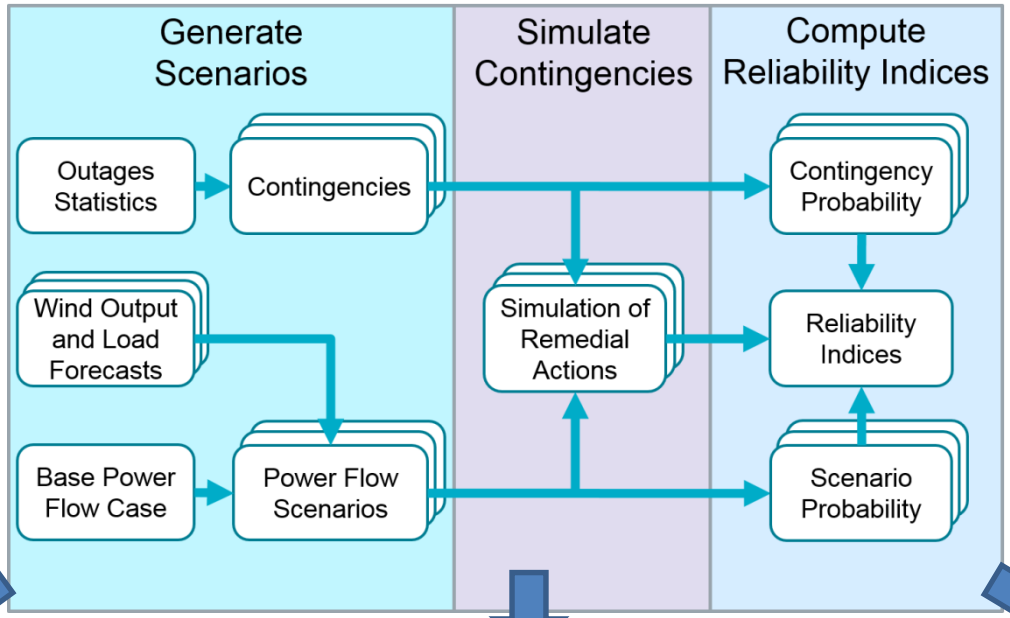
Contingency Impacts

Frequency
Duration
Severity

Remedial actions solve system violations resulting from contingency through control actions

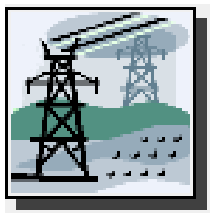
Load shedding give severity of events instead of binary failures

Probabilistic Planning Tools



Risk-Based Planning Scenario Builder

RBPSB
(EPRI Research Level Tool)



TransCARE
(EPRI Research Level Tool)

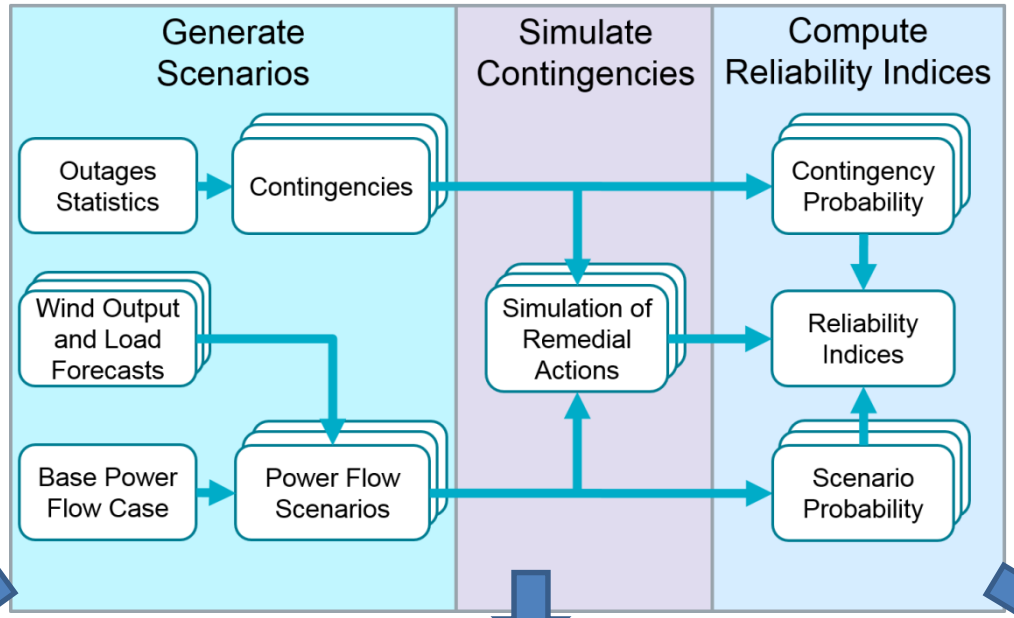
PSS®E

PSS/E
(Siemens Commercial Tool)

Self Developed code

(Post Processing)

Probabilistic Planning Tools



Risk-Based Planning Scenario Builder

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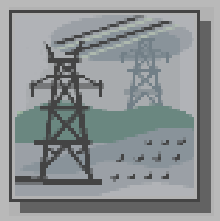

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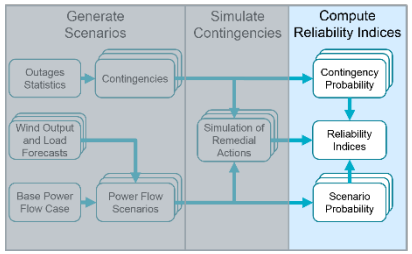
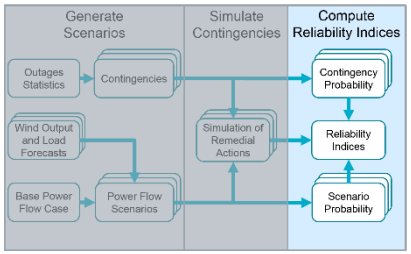
Calculation of Probabilistic Indices



Quantifying risk indices

- Includes likelihood and severity of events
- Currently, no established criteria for acceptable risk or indices
  - System wide (e.g. expected unserved energy (EUE), frequency of loss of load, etc.)
  - Component or contingency level (e.g. probability and frequency of violations)
- Better for ranking alternatives than as absolute metric

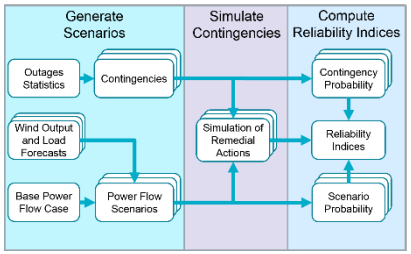
Calculation of Probabilistic Indices



Potential uses of probabilistic criteria and indices

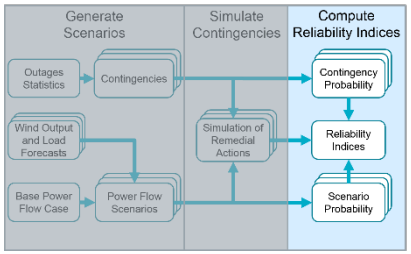
- Evaluate cost/benefit of investment alternatives
- Used to identify weak areas of system
- Benchmark reliability over time and define acceptable risk

Contingency Probability



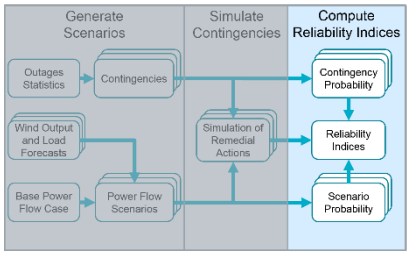
- Individual element probabilities used calculate probability of scenario
- Assumes that deeper contingencies has at least the impact of similar higher contingency
- Deeper contingencies are dependent on shallower contingencies
  - i.e. Probability Gen A and Gen B out together is subset of both probabilities of Gen A and Gen B

Expected Unserved Energy (EUE)



- Expected value of load shedding unmitigated by remedial actions
- PSSE was used to calculated EUE for each operational scenario (strata samples)
- Common list of contingencies for all scenarios

Indices Calculations



- EUE – Expected Unserved Energy

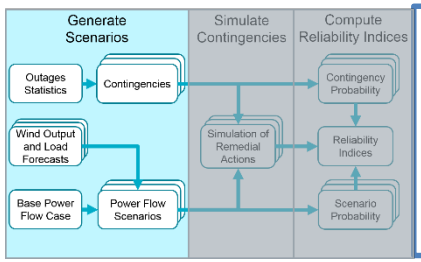
$$EUE = \sum_{s \in S} P(s) \times avg_i(EUE_{i,s})$$

$EUE_{i,s}$ is unserved energy for operational scenario, i, in stratum, s

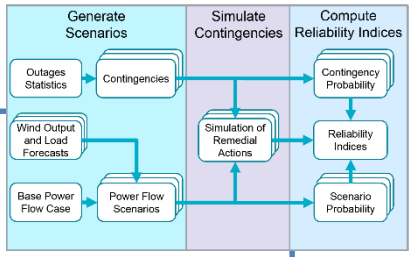
- IRI – Incremental Reliability Index

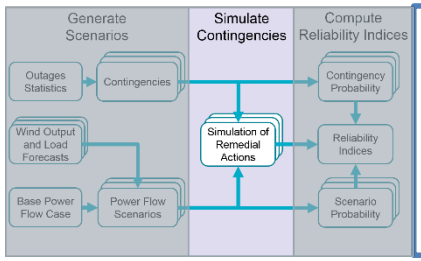
$$IRI = \frac{EUE}{Project\ Cost}$$

Modeling Assumptions

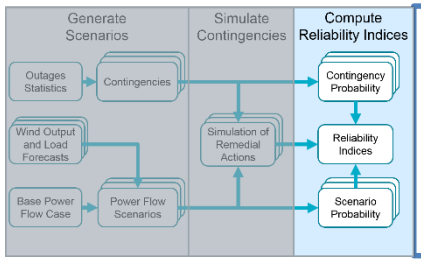


- Sampling from 4/6 high load strata
- 5 wind\load samples per strata
- ~8,000 enumerated N-2 contingencies for coast region



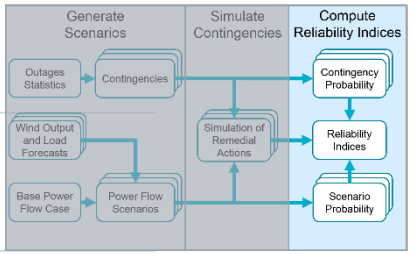


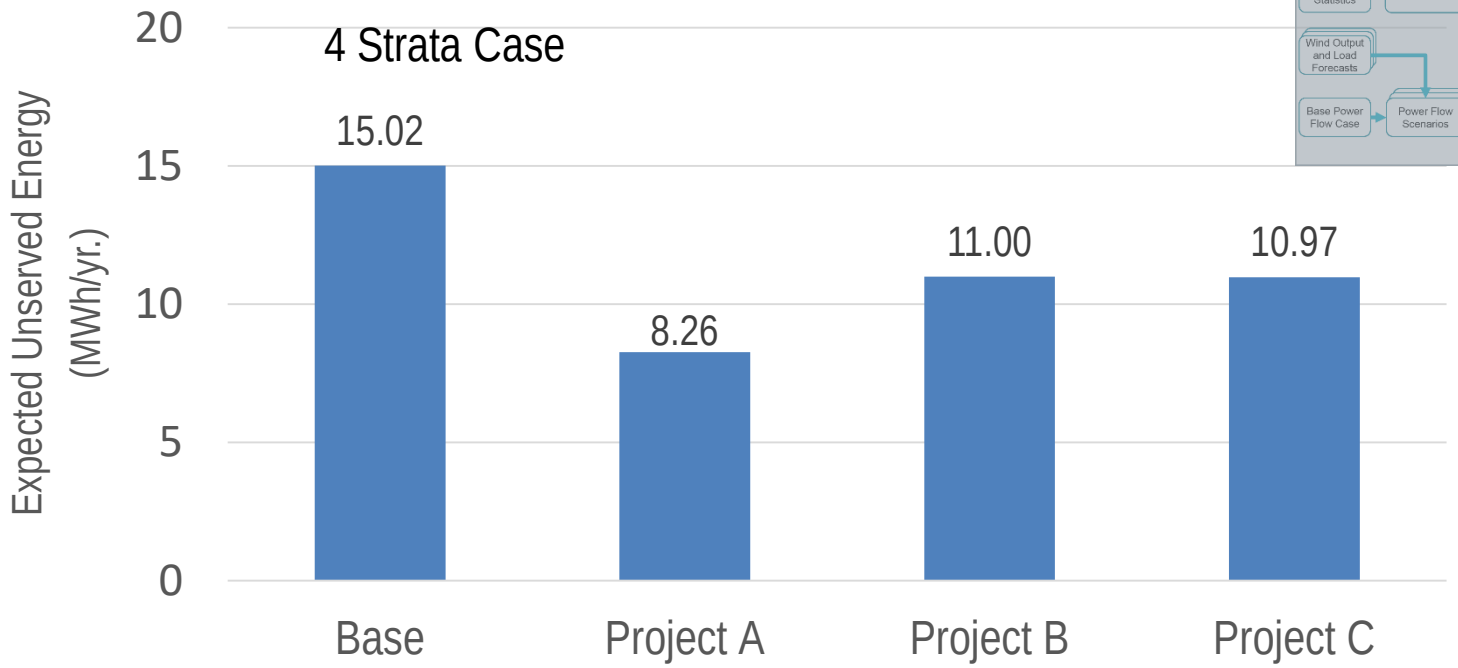
- Use ERCOT system in PSSE
- Base case without improvement is not N-1 secure
- Simulating 3 N-1 secure transmission options



- EUE assumes independence of failures and probability of wind\load strata conditions
- Determining project rank based on comparison of EUE

Expected Unserved Energy

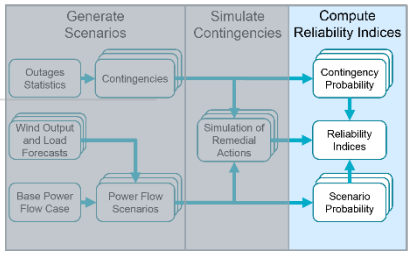


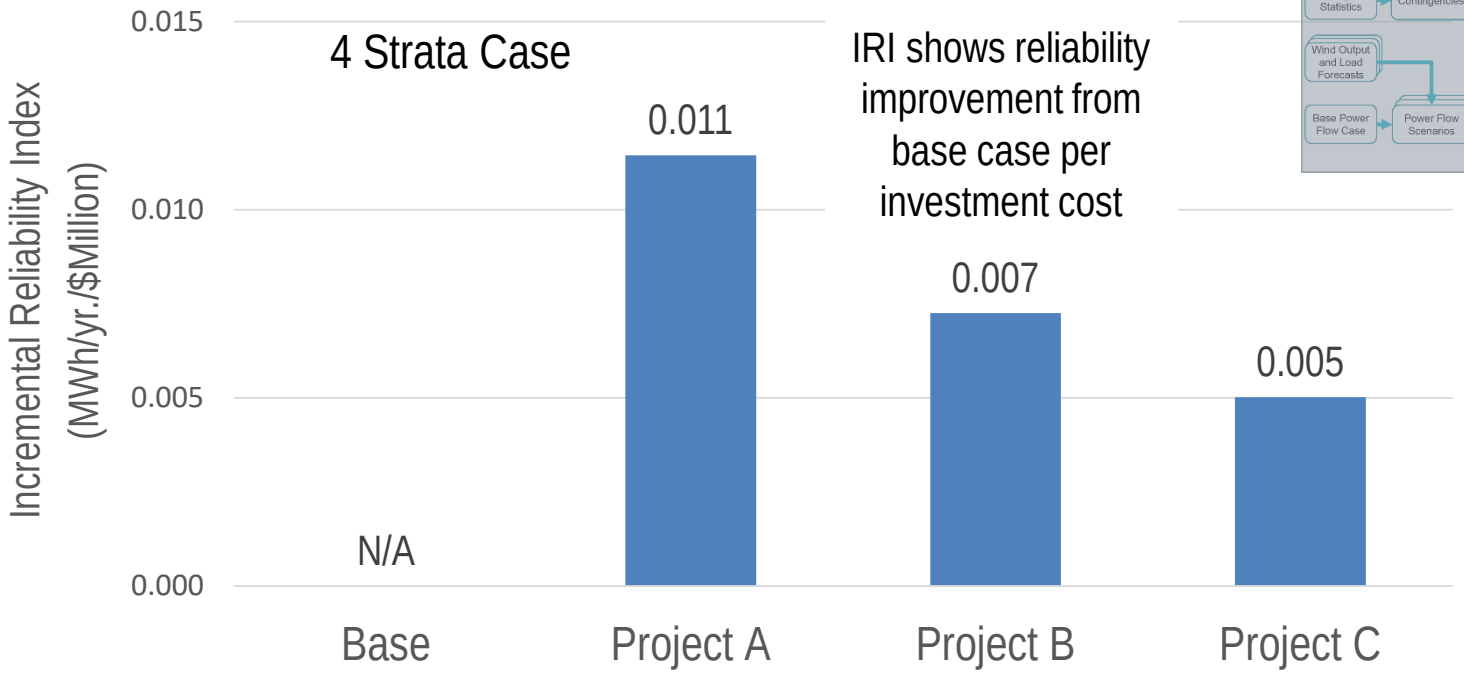


EUE allows ranking by risk of losing load in terms of severity and frequency

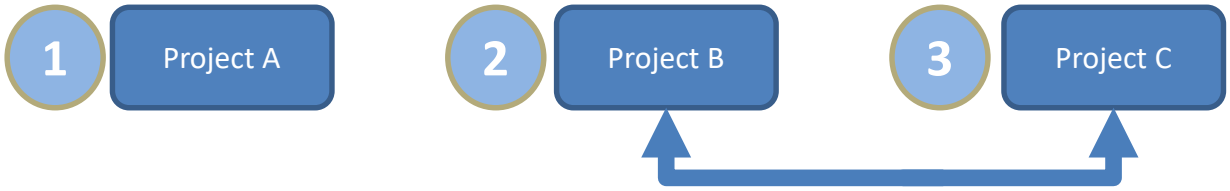
1. Project A
2. Project C
3. Project B

Incremental Reliability Index (IRI)

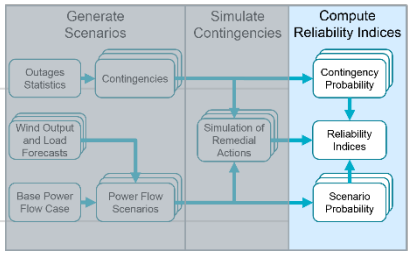




Capital Cost ($ Millions)	-	$ 590	$ 554	$ 806



EUE by Strata with 6 Strata



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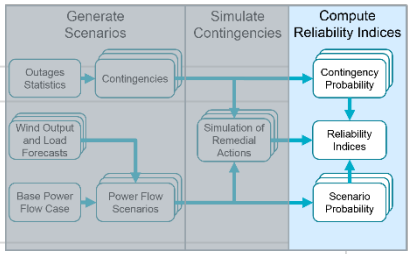
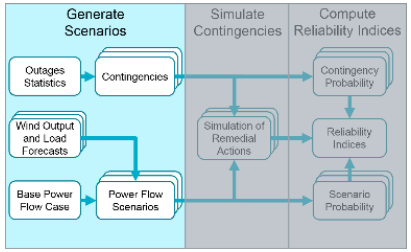
Contributions to Project EUE



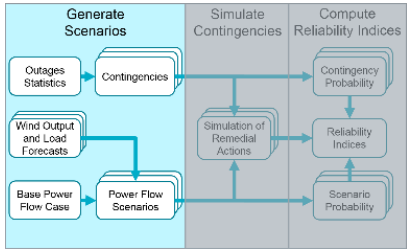
OUTSTANDING MODELING ISSUES

Input Data Needs



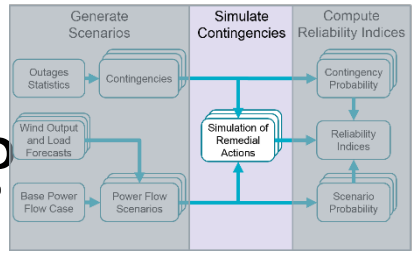
- Improved element outage statistics
- Incorporate statistics of common mode outages
  - Common tower or substations
  - Cascading failures
  - Low probability but high impact

Sampling Needs



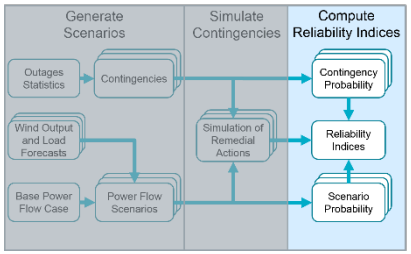
- Strata definitions?
  - Probability cutoffs
  - Operational conditions of interest
- Number of samples from strata?
  - What are the sufficient number of samples to characterized the region?
- Sampling techniques and contingency depth?

Remedial Actions Needs



- Handling failed power flow solutions?
  - Can you ignore failures?
  - Are they indications of high impact events or problem with numerical method?
  - Automate rerunning the cases?
- What are the appropriate remedial actions?
- Transparency of remedial action results?

Risk-Based Indices Needs



- Incorporating probability dependent deeper and shallower contingencies
- Comparison of different indices for decision support
- Determine how to be used for ranking alternatives or absolute metrics

Conclusions

- Barriers to application are primarily practical based on large, real systems
- Need improvements to modeling tools for remedial actions
- Useful as criteria to incorporate risk into current planning practices

Thank you!

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