Method and Tool Development for Assessing Renewable Impacts on Probabilistic Contingency Analysis

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Project Purpose

- Problem statement:
  - Contingency analyses (CAs) are currently deterministic and only address uncertainties by using a limited number of scenarios.
  - Transforming grid possesses more stochasticity due to, e.g., higher penetrations of distributed energy resources (DERs), which is more difficult for existing deterministic contingency analysis (DCA) to handle.
  - Probabilistic methods are available; however, utilities are reluctant to abandon existing proven techniques due to various barriers such as data, tools, and culture.
- The proposed study intends to overcome these barriers and make it practical to perform probabilistic contingency analysis (PCA).

Achievements

- This study facilitates a PCA study by developing
  - Methods for data poolability analysis and probabilistic modeling and parameterization of renewable generation outages, especially for common mode outages (CMOs)
  - An outage data repository that better models population variability
  - An implementation of well-being approach that can facilitate decision-making process based on the PCA results
  - A Python-driven PSS/E based tool with enhanced PCA features that can be readily used by utilities

Technical Approach: Data Poolability

- Formal Statistical Testing for Data Poolability Issue
  - Raw data sources include NERC TADS, GADS (i.e., pc-GAR software), some Canadian data, and some other publicly available data
  - Data from different sources (e.g., different NERC regions) are usually lumped and averaged (i.e., arithmetic means) for PCA input
  - This study uses a formal statistical test process to determine whether there is a need to model the population variability of data
    - ✓ E.g., environmental impact or maintenance schedule.
  - Not all data sources are poolable

Outage Data Repository for Non-poolable Transmission Components (Lognormal Distributions)

Components	Parameters	χ^2(N-1)	μ	σ	Arithmetic Mean	Mean Value	Variance	5th Percentile	95th Percentile	Error Factors
AC Circuit: 200–299kV	*fmt*	682.8	-4.63	0.37	0.01	0.01	1.62E-5	0.005	0.018	1.84
	dmt	114,420.4	3.27	0.86	41.51	37.88	1,548.35	6.43	107.32	4.09
	ft	810.8	-1.85	0.60	0.20	0.19	0.015	0.059	0.42	2.66
	dt	96,440	3.03	1.17	22.82	41.10	4,995.77	3	142.24	6.89
AC Circuit: 300–399kV	*fmt*	922.6	-4.74	0.64	0.009	0.01	5.78E-5	0.003	0.025	2.85
	dmt	39,390	3.04	1.12	45.90	39.06	3,804.74	3.32	131.56	6.30
	ft	839.3	-1.45	0.55	0.34	0.27	0.03	0.095	0.58	2.46
	dt	312,978	3.46	1.49	46.97	96.25	76,004.2	2.74	367.93	11.60
AC Circuit: 400–599kV	*fmt*	77.1	-5.96	0.59	0.005	0.003	3.89E-6	0.00098	0.0068	2.64
	dmt	27,341.6	1.53	1.91	28.09	28.7	30,818.8	0.2	107.21	23.15
	ft	207.4	-0.90	0.82	0.31	0.57	0.31	0.11	1.57	3.87
	dt	6,336.2	2.65	1.12	22.59	26.54	1,752.6	2.26	89.36	6.29
Transformer: 300–399kV	*d*	174,195	4.23	2.18	271.87	734.3	6.16E+7	1.9	2,464.02	36.01
Transformer: 400–599kV	*f*	81.5	-1.60	0.70	0.09	0.26	0.04	0.065	0.64	3.14
	d	10,569.3	3.49	1.45	142.80	94.56	64,916.8	3.01	359.2	10.92
Fossil Fuel Generator: 0–399MW	*f*	8,655.9	1.74	0.21	6.25	5.83	1.46	4.08	8.00	1.40
	d	159,300	4.04	0.14	54.82	57.40	62.87	45.35	71.29	1.25
Fossil Fuel Generator: 400–799MW	*f*	4,326.8	2.35	0.18	10.18	10.63	3.77	7.76	14.08	1.35
	d	66,860	3.64	0.096	40.69	38.14	13.56	32.40	44.48	1.17
Gas/Jet Turbine: 0–99MW	*f*	11,892.9	1.27	0.35	4.14	3.77	1.80	2.01	6.27	1.77
	d	1,778,084.2	4.53	0.50	78.94	104.48	3053.19	40.81	209.1	2.26
Gas/Jet Turbine: 100–199MW	*f*	961.3	1.33	0.37	4.42	4.04	2.35	2.07	6.91	1.83
	d	43,616.0	4.03	0.41	46.56	61.23	698.09	28.49	110.95	1.97

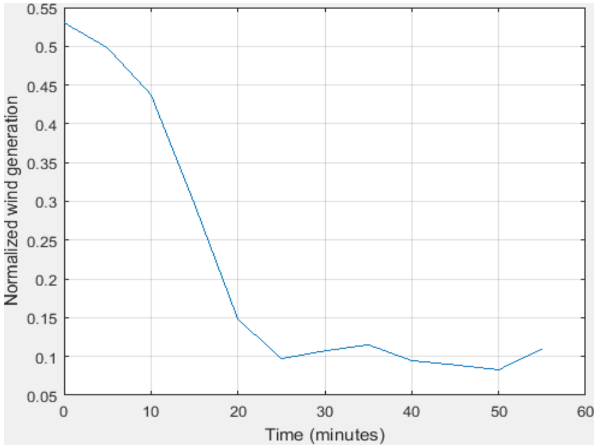
- *fmt*: The frequency for single circuit outages per mile
- *dmt*: The duration of single circuit outages
- *ft*: The frequency for terminal-caused single circuit outages.
- *dt*: The duration for terminal caused single circuit outage.
- *f*: the outage frequency
- *d* : the duration per outage.

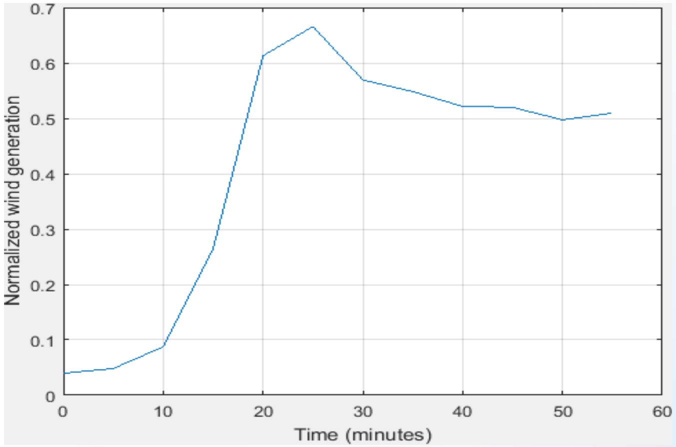
Technical Approach: Renewable Outage Modes

- Modeling and Parameterization of Intermittency Induced Outages (IIOs)
  - Major differences between conventional generator and renewable outages.
    - Generation increase or decrease caused by fast ramping events should also be modeled as an outage mode
      - ✓ E.g., wind speed is lower than cut-in or higher than cut-out speed
    - For each outage modes, there can be associated CMOs for different generation sites.

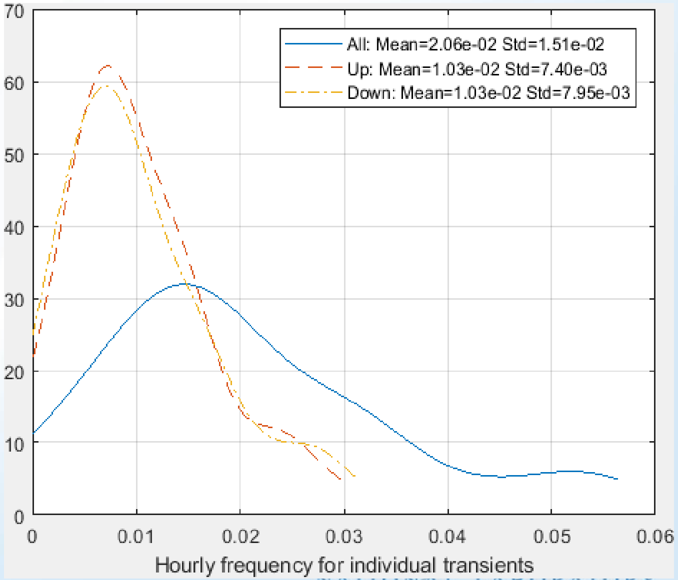
Modeling and Parameterization of IIOs

- Fast ramping events were extracted from utility wind generation data and modeled as IIOs



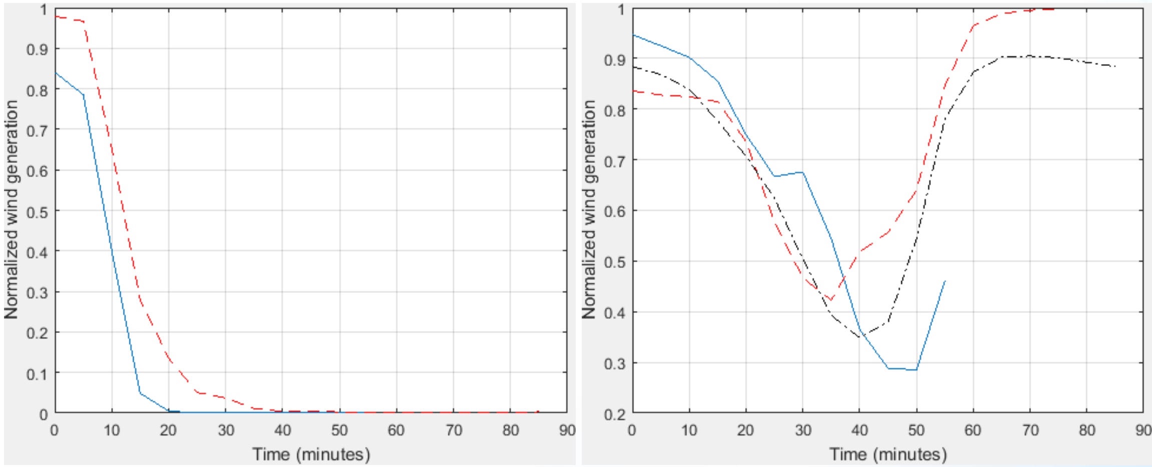


- Empirical distribution of frequencies and durations of IIOs was fitted
  - Also, initial generation level prior to the ramping, the deviation of generation
- Distributions for both up and down transients can be considered the same and modeled using the same distribution



Modeling and Parameterization of CMOs

- Output of two wind sites may be highly correlated because they are very close to each other or located along the same wind path
- Need to extract concurrent ramping events of wind generation sites, especially those highly correlated



Example Double (Left) and Triple CMOs

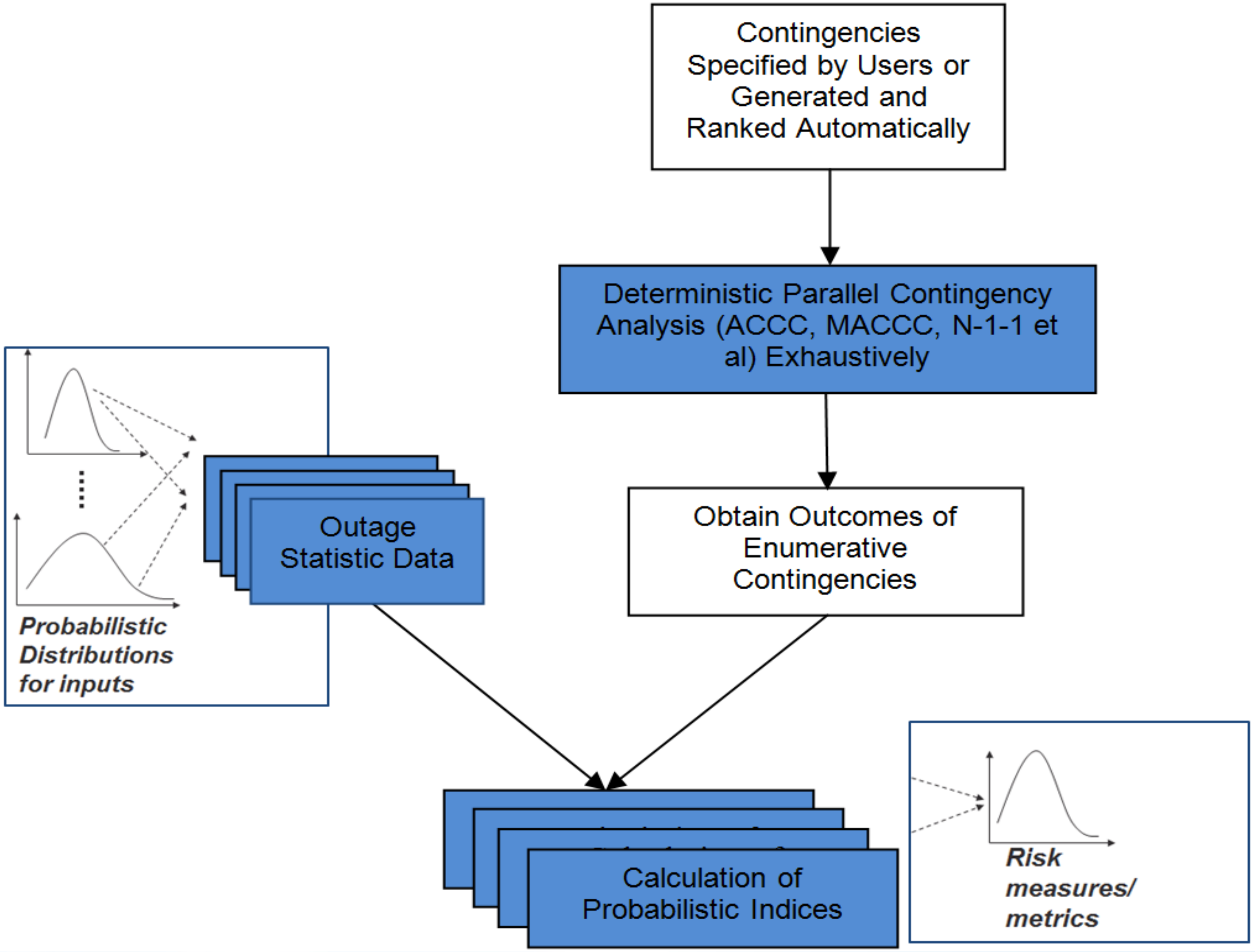
Triple Rampings	Correlation	Frequency	Deviation	Duration (Hours)
Up	0.8 – 0.1	0.0001	0.64	3.04
Down		N/A	0.67	0.57
Up	0.6 – 0.8	0.0002	0.75	1.78
Down		0.0001	0.75	0.26

Mean Values of Frequencies, Deviation, and Durations of Triple CMOs

Technical Approach: Simulation and Planning Criteria

- A Scheme for Enhancing PCA Capability of Existing Tools
  - Developed a generic scheme based on Monte Carlo simulation for distributions of different uncertainty parameters.
- Facilitation of Decision-making Process in Transmission Planning Using Probabilistic Reliability Metrics
  - Reviewed probabilistic planning criteria and discussed how to use the probabilistic and deterministic criteria together to facilitate making planning decision.
  - Investigated and implemented a well-being approach in the enhanced PCA tool.

Tool Implementation



Case Study

- For a 23-bus example system:
  - Differences between system reliability indices calculated using the mean input (Case 1) and the Monte Carlo simulation (Case 2) can be significant
  - The Monte Carlo simulation is able to calculate the true mean values as well as distributions of reliability indices

	Case 1: Built-in PCA	Case 2: Enhanced PCA
System Problem Frequency (per Year)	9.27	17.64
System Problem Duration (Hours)	47.1	34.15

- For the WECC system:

Case 3: PSS/E built-in PCA and arithmetic mean + base case
Case 4: enhanced PCA + base case
Case 5: enhanced PCA + 10% wind generation + IIOs and CMOs
Case 6: enhanced PCA + 10% wind generation

Cases	EENS (MW)	
	Mean	Standard deviation
3	81.66	N/A
4	22.69	29.44
5	8.8e-4	3.9e-3
6	2.14e-3	8.68e-3

Case Study (cont'd)

- Cases 5 vs. 6 (no IIOs): inclusion of renewable IIOs/CMOs will significantly increase the system problem frequencies but reduce the system problem durations

Problems	Cases	Frequency		Duration		Probability (hours)
		Mean	Standard deviation	Mean	Standard deviation	
Overvoltage	4	655.3	227.8	4.4	2.6	2,712.9
	5	993.1	389.7	2.8	1.8	2,572
	6	680.6	273.5	4.7	4.4	2,889.8
Undervoltage	4	72.3	27.0	4.2	4.8	277.4
	5	71.0	30.1	2.6	3.4	170.9
	6	75.8	33.2	3.5	6.1	227.9
System	4	663.0	230.9	4.4	2.7	2,741.5
	5	994.7	392.0	2.8	1.8	2,582.1
	6	681.1	274.2	4.7	4.4	2,901.2

Case Study (cont'd)

- Cases 5, 7, and 8 represents three different wind penetration levels: 10%, 30%, and 50%, respectively.
- As the wind penetration increases, system/voltage problem frequency increases while duration decreases.

Problems	Case	Penetration	Frequency		Duration		Probability
			Mean	Standard deviation	Mean	Standard deviation	
Overvoltage	5	10%	993.1	371.2	2.8	1.8	2,572.0
	7	30%	1911.1	629.8	1.3	0.8	2,558.9
	8	50%	5,993.6	3,520.4	0.6	0.5	3,368.4
Undervoltage	5	10%	71.7	28.2	2.6	3.3	170.9
	7	30%	283.0	93.1	0.8	1.2	230.4
	8	50%	1,410.1	1,039.7	0.5	0.8	738.9
System	5	10%	994.7	372.9	2.8	1.8	2,582.1
	7	30%	1,937.7	627.2	1.6	1.2	3,195.3
	8	50%	6,479.9	3,518.2	0.5	0.4	3,291.8

Summary and Conclusions

- A reliability data repository including both raw outage data and statistics was developed.
- The potential poolability issue was identified and a solution was provided.
- The fast ramping events of renewable generation caused by intermittencies were identified and extracted as IIOs and CMOs and the probabilistic models were built and incorporated in the PCA framework.
- The developed models were integrated into add-on Python modules to drive and enhance the PCA capability of PSS/E.
- The well-being method was implemented in the enhanced PCA capabilities to facilitate the decision-making process.
- Case studies were performed to confirm the impacts of data poolability and IIOs and CMOs associated with renewable generation.

Future Effort

- Solar PV generation is another important source of renewable generation and will need to be included.
- A generic algorithm will be developed to extract fast ramping events from data of different temporal resolutions to support the PCA study.
- A new quantification scheme is needed and will be developed to more precisely calculate the probabilistic indices in the PCA.
  - The existing PCA software included in PSS/E calculates probabilistic indices of system problems approximately based on the rare event approximation.
- Reach out to more utilities for exercising and refining the enhanced PCA tool and demonstrating the capabilities of the tool.

Acknowledgements and Contacts

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