An Investigation of Modeling and Parameterization of Intermittency Induced Renewable Outages

EPRI Risk-Based Planning Workshop for Transmission System Planning

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Objective

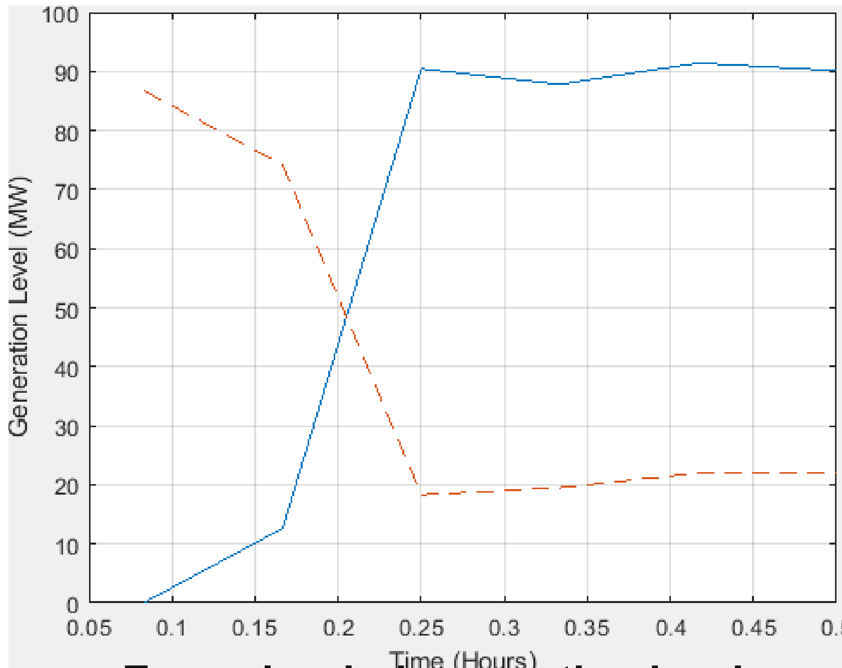
- The purposes of this study are
  - the investigation of intermittency induced fast wind transients or ramps that can be potentially considered as generator outages
  - the modeling and parameterization of such outage modes to fit into a probabilistic contingency analysis (PCA) framework

Current Practices of Including Renewables in Contingency Analysis

- Renewable sources are generally aggregated based on locations and modeled as generators in system models
- In contingency analysis, each renewable generator is treated like a conventional generator
  - Each is assigned with a generation level based on, e.g., seasonal average generation capacity
  - The contingency is modeled by the loss of the generation
  - The parameters for a PCA include frequencies and duration times of renewable generator outages derived from random failures of mechanical and/or control mechanisms

Intermittency-induced Fast Transients of Renewables

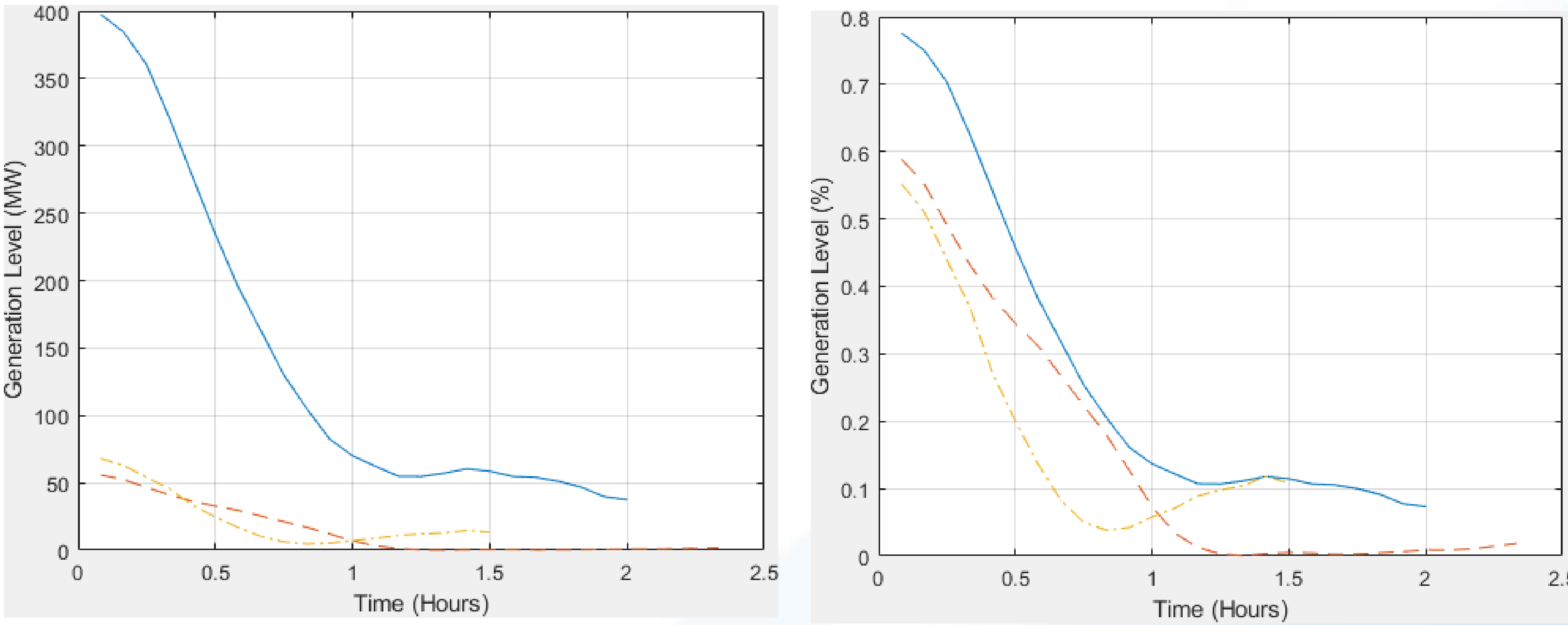
- In addition to random failures, intermittency may also cause changes of generation level
  - For a single wind generator, there can be a complete loss of generation, under- or over-generation of renewable generators due to change in wind speed and direction within a short time period



Example wind generation level changes (MW) due to ramp-up and ramp-down transients

Intermittency-induced Fast Transients of Renewables (cont'd)

- Concurrent, fast transients may occur in multiple wind sites and can also cause loss of generation, under- or over-generation of renewable generators



Example of concurrent ramp-down transients in three different wind farms (left: MW and right: normalized capacity)

Intermittency-induced Outage Modes

- Regardless of causes, generation level variations can be significant and need to be captured for contingency analysis
  - The intermittency induced transients can become more impactful for higher penetration of renewables such as wind
- The magnitudes and speed of generation level variations in wind farms are caused by changes in gust wind speed and/or direction and are difficult to forecast
  - It is natural to consider these intermittency induced fast transients as random outages and include these intermittency induced outages (IIO) in the PCA

Inclusion of Renewable IIOs in PCA

- Renewable sources will be modeled as generators with a focus on intermittency induced transients or outages
  - Different outage modes for renewables need to be considered and modeled, e.g.,
    - a complete loss of generation, under- or over-generation (due to ramp-down or –up transients) of renewable generators
    - Common mode outages of wind generation due to temporal and spatial correlation of wind speeds
  - Parameters for probabilistic outage models include frequencies, duration, as well as generation level variation during a transient

Parameterization of Models for Renewable IIOs

- Renewable outage modeling based on historical time series data:
  - Frequencies and durations of loss of generation, over-generation and under-generation can be obtained by evaluating sudden increase/decrease in wind power
    - Change in generation level during a transient also needs to be captured
  - The same parameters are derived for common mode outages (CMOs) by considering the tendency of covariations of two or more wind farms
    - Pearson's correlation

Extraction of Fast Ramp–up and –down Transients from Time Series Wind Generation

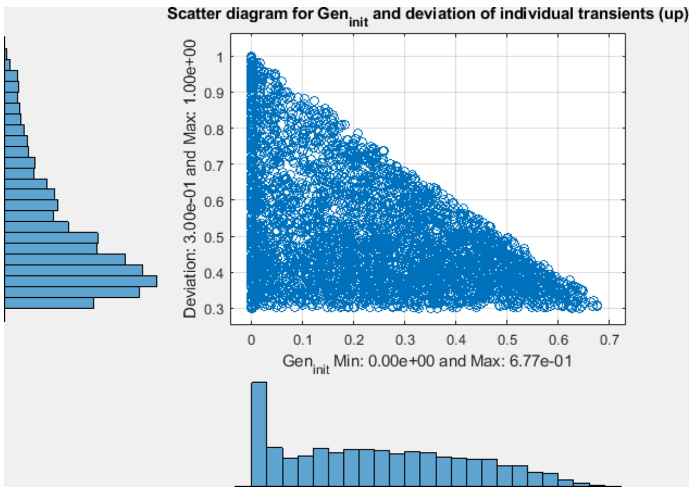
- Given time series generation $\boldsymbol{X}=\{(t_1, p_1),(t_2, p_2),\ldots,(t_N, p_N)\}$, a transient $T(i, j)=\{(t_i, p_i),\ldots,(t_j, p_j)\}$ is a subsequence that generation continuously increases (for an up ramp) or decreases (for a down ramp)
- An IIO $O(i, j, k)$ consists of a transient $T(i, j)$ and another segment $D(j+1, k)=\{(t_{j+1}, p_{j+1}),\ldots,(t_k, p_k)\}$ with relatively flat generation
  - Three parameters are used to characterize a transient,
    - the initial generation level prior to the transient Gen_{init} ,
    - the deviation *dev* at the end of transient , and
    - the duration time $t_{duration}$ within which the post-transient generation remains flat.
  - For an extracted outage $O(i, j, k)$, we have $Gen_{init}=p_i$, $dev=|p_j - p_i|$, and $t_{duration}=k-j$

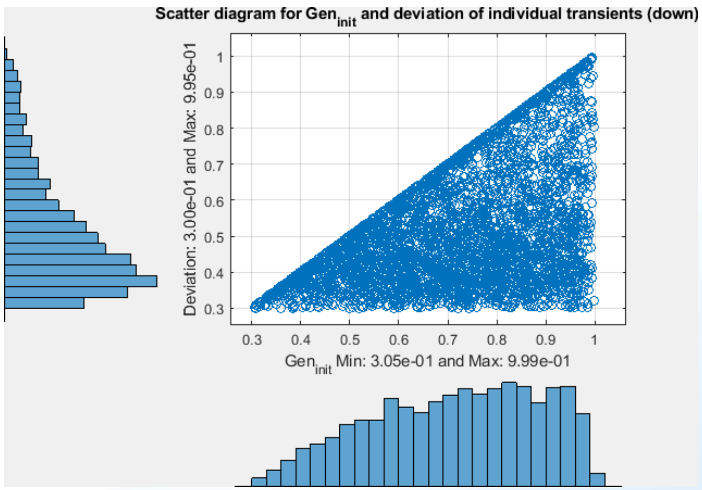
Extracting All Individual Transients

- Criteria were developed based on definition of IIOs and pre-selected thresholds including
  - Monotonic increase or decrease in generation
  - A minimum generation variation of 30%, i.e., *dev=0.3*
- A total number of 15,184 transients were identified from one and a half year's data of 53 wind plants
  - The numbers of ramp-up and down transients are very close to each other, i.e., 7,606 vs. 7,578.

Statistical Analyses for Single Transients: Parameter Correlations

- To extract statistics of transients for parameters Gen_{init} , *dev*, and $t_{duration}$, care has to be taken to understand correlations among these parameters





Scatter diagrams for *Gen_{init}* and *dev* of ramp –up (left) and –down transients (right)

$$Gen_{init} + dev \leq 1.0$$

$$Gen_{init} - dev \geq 0.0$$

Statistical Analyses for Single Transients: Parameter Correlations (cont'd)

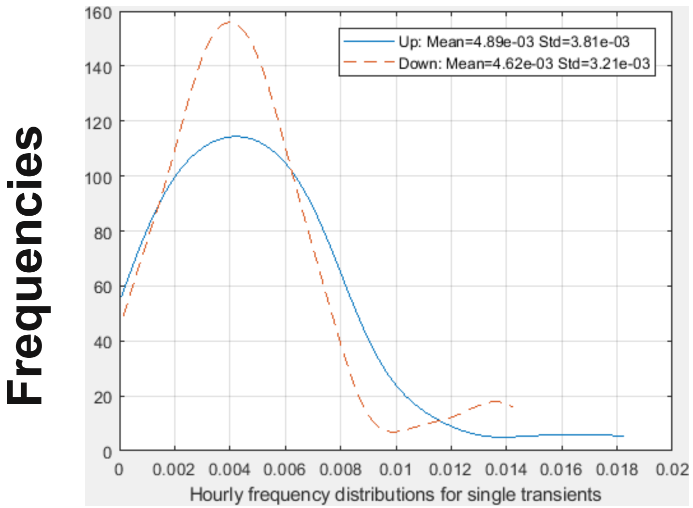
- Cross-correlation can be used to capture relationship between these parameters
- For realizations of two random variables X and Y

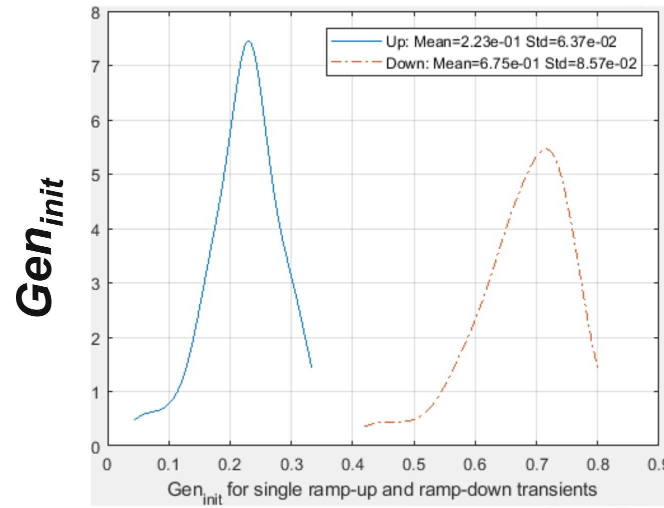
$$R_{XY} = \frac{S_{XY}}{\sqrt{S_{XX}S_{YY}}}$$

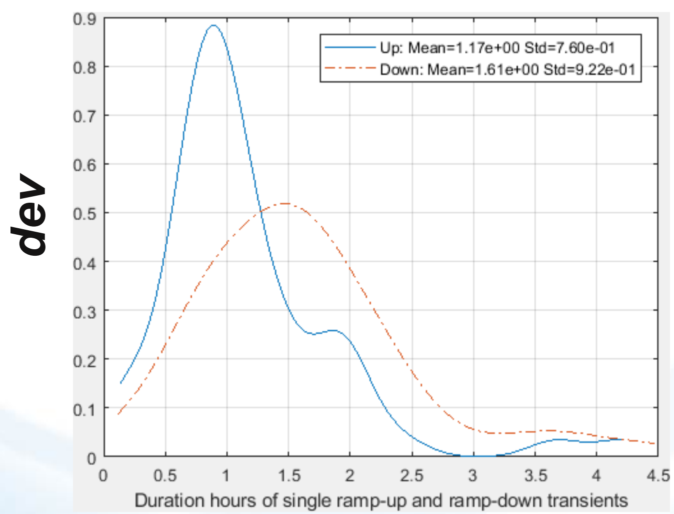
	Initial Generation Level *Gen_{init}*	**Variation of Generation** *dev*	**Transient Times** $t_{duration}$
Initial Generation Level Gen_{init}	1.00e+00	-2.28e-02	-9.84e-03
Variation of Generation *dev*	-2.28e-02	1.00e+00	1.32e-01
Duration $t_{duration}$	-9.84e-03	1.32e-01	1.00e+00

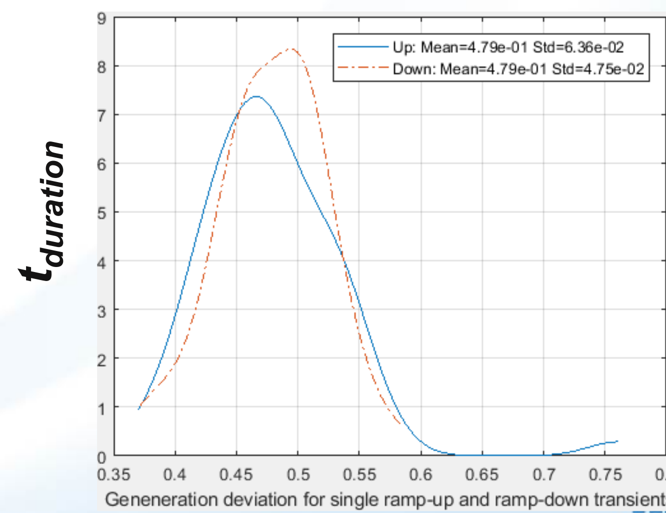
- The correlations are very weak.

Statistical Distributions Across 53 Sites for Parameters of Single Transients





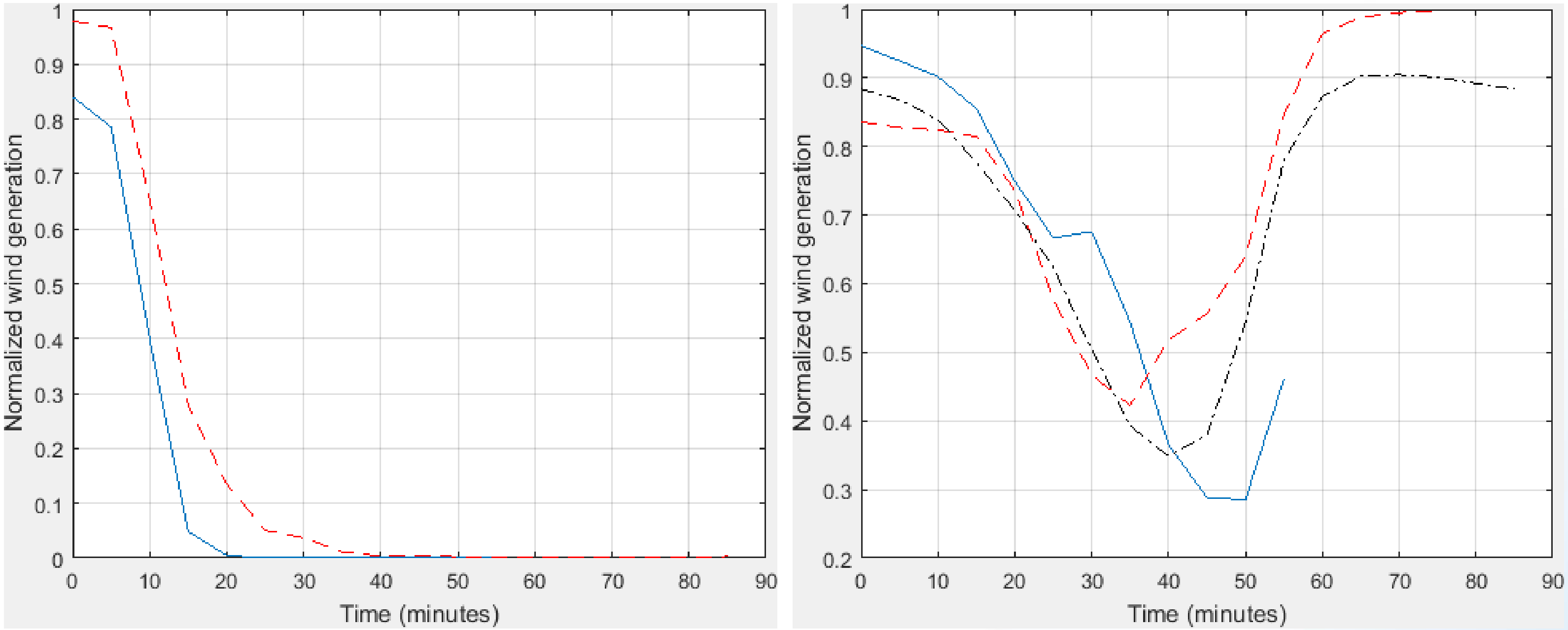




Concurrent Transients and Correlation between Multiple Wind Sites

- The output of two or more wind farms tend to vary in the same direction if they are colocated and/or located in the same wind corridor.
- This tendency of simultaneous generation changes can be mathematically measured in terms of correlation of two random variables representing the generation.
  - The stronger the correlation is, the stronger the tendency of generation covariation is.
  - It is therefore postulated that (1) the number of concurrent transients and (2) the resemblance of wind profiles (and therefore, the normalized generation) experienced at two wind farms are proportional to the strength of the correlation.

Concurrent Transients and Correlation between Multiple Wind Sites (cont'd)



Concurrent transients for two (left) and three (right) wind farms of strong correlation (>0.8)

- It is proposed to extract and categorize statistics based on strength of correlations between wind farms.

Extracting Concurrent Transients from Multi-sites

- Unless the correlation coefficient is 1.0, the generation variations from two generation sites cannot be exactly the same.
- The new criteria is that the starting and ending times of the same type transients (up or down) should not differ much from each other.
- Concurrent transients will be categorized according with different levels of correlation from historical data.
- Concurrent transients of different orders and single transients should exclude with each other.

Double Transients for different Correlations

Pearson's Correlation between wind farms (i, j)	Numbers of simultaneous under- or over-generation between i and j	Average point-wise distance between two transients
0.8 – 1.0	487	0.25
0.6 – 0.8	516	0.31
0.4 – 0.6	459	0.31
0.2 – 0.4	236	0.37
0.0 – 0.2	53	0.27

Correlation vs. concurrent modes between two wind generation sites

Triple Transients for different Correlations

Pearson's Correlation between wind farms (i, j)	Pearson's Correlation between wind farms (i,k) and (j,k)	Numbers of concurrent under- or over-generation of wind farms i, j, and k	Average point-wise distance between three transients
0.8 – 1.0	0.8 – 1.0	217	0.08
	0.6 – 0.8	68	0.11
	0.4 – 0.6	40	0.13
	0.2 – 0.4	21	0.11
	0.0 – 0.2	7	0.12

Correlation vs. concurrent modes between three wind generation sites

Summary and Next Steps

- Historical data have been collected and method has been developed to statistically analyze the data for input to PCA.
- Models and parameters for intermittency induced outages for renewables are being included to complete the reliability data repository and PCA tool.
- A case study using a utility scale system is being performed.