Efficient Uncertainty Analysis of Wind Farms in the Time Domain using the Unscented Transform

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Agenda

Introduction

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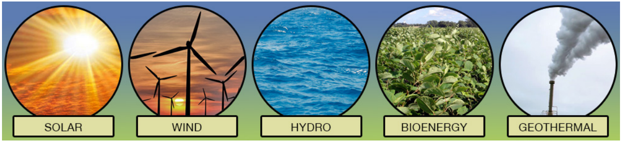

Figure 1: Renewable Energy Sources.(EDUCATION, 2017)

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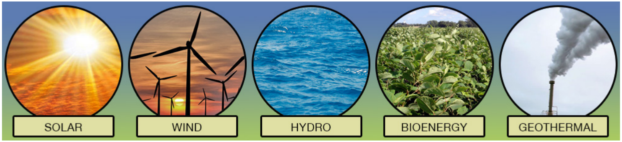

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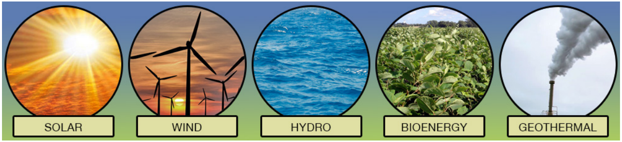
- Several sources of renewable energy: solar, hydro, biomass, geothermal, tides, etc;
- The wind energy has being used for more than 3000 years;
- Advantages:
  1. The very low level of CO2;
  2. Economical benefits.



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- The wind energy systems design is strongly dependent on numerical simulations;
- Examples: power flow, fault effects and transient stability;
- Software packages are capable of simulate large scale power systems and provide accurate results;
- Renewable systems are highly affected by uncertain inputs.

The Monte Carlo Method (MC)

A common method for treating uncertainties

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There has been a great effort to develop more efficient Uncertainty Quantification methods.

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- The UT approximates a nonlinear mapping by a set of points, called *sigma points*;
- Expected value and the variance are obtained from a weighted average using the simulation outputs. (MENEZES et al., 2008)

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The Main Goal

The problem considered in this paper consists of determining the average (μ) and standard deviation (σ) of any model's output, given the average and standard deviation of N uncertain parameters.

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$$\vec{U} = [U_1, U_2, ..., U_{N-1}, U_N]$$

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Y(t) is a time-dependent random variable.

Sigma points: $\vec{S} = [S_1, S_2, ..., S_{N_S}]$

Weights: $\vec{w} = [w_0, w_1, w_2, ..., w_{N_S}]$

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According to Menezes et al. (2008), the method to obtain μ_y is given as follows :

$$\mu_y = E\left\{G(\vec{\mu_u} + \vec{\hat{u}})\right\} = w_0 G(\vec{\mu_u}) + \sum_{i=1}^{N_S} w_i G(\vec{\mu_u} + S_i) \quad (1)$$

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And the variance:

$$\begin{aligned} \sigma_y^2 &= E\left\{(G(\vec{\mu_u} + \vec{\hat{u}}) - \vec{\mu_y})^2\right\} \\ &= w_0(G(\vec{\mu_u} + \vec{\hat{u}}) - \vec{\mu_y})^2 + \sum_{i=1}^{N} w_i(G(\vec{\mu_u} + S_i) - \mu_y)^2 \end{aligned} \quad (2)$$

System Model
Input random variable: Wind Speed

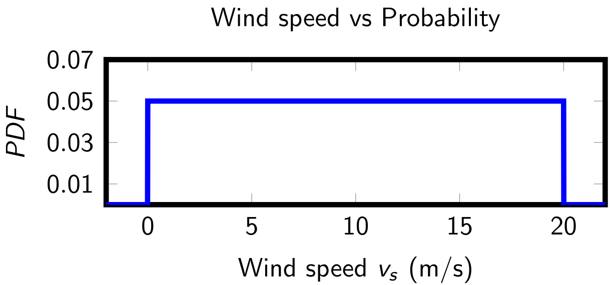

Figure 3: Probability density function of the wind speed, uniform, $\mu = 10$m/s and $\sigma_s = 5,7735 m/s$ (AUTHORS, 2017)

Random Variable:	$\vec{U} = [Wind\ Speed]$
Average Vector:	$\vec{\mu_u} = [Wind\ speed\ average]$
SD Vector:	$\vec{\sigma_u} = [Wind\ speed\ standard\ deviation]$

System Model

Matlab/Simscape Power System toolbox example

- Wind farm with six turbines of 1.5MW each;
- A fault of 0.5 p.u. happens at 0.03s;
- The DC bus capacitor voltage was analyzed.

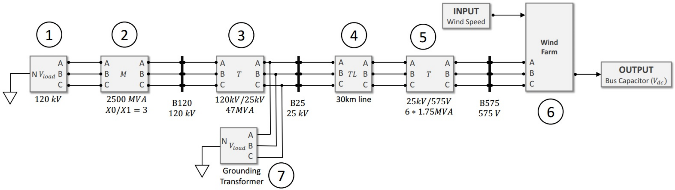

Figure 4: Model of the wind farm consisting of: (1) 120 kV faulting system, (2) three phase impedance with mutual coupling between phases, (3) 120/25 kV transformer, (4) 30 km transmission line, (5) 25 kV distribution system, (6) DFIG wind turbine , and (7) transformer providing a neutral to the three phase system. (MATHWORKS, 2016)

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Parameter	**Value**
Solver	Discrete, Fixed Step
Time step	5μs
Time for one simulation	38.8s
Computer used	Intel® Core^{TM} i7 CPU @ 2.40GHz

Table 1: Simulation details. (AUTHORS, 2017)

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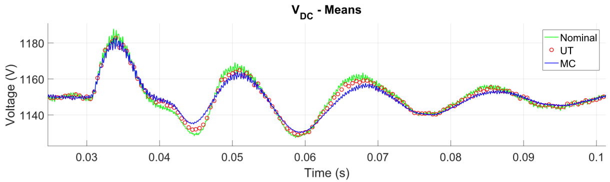

Figure 5: Nominal voltage: 1150V; Peak value: $\simeq$ 1185V; Lowest value: $\simeq$ 1130V. (AUTHORS, 2017)

V_{DC} Average behavior when the wind speed varies from 0 to 20 m/s.

1D Results

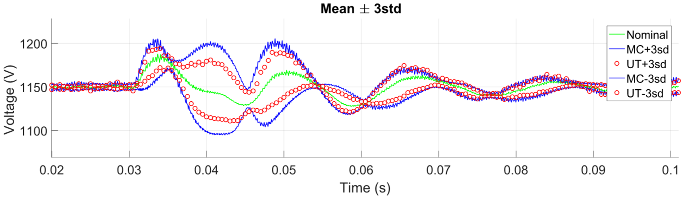

Figure 6: Upper and lower voltage bounds at 0.1% confidence levels. $1100V < V_{DC} < 1200V$. (AUTHORS, 2017)

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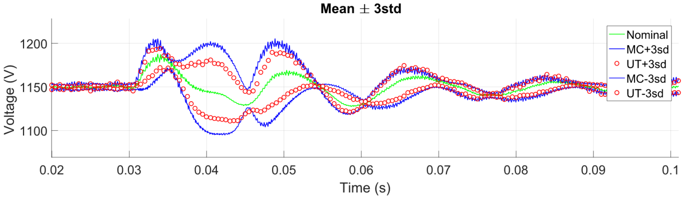

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Monte Carlo	6 hours and 36 minutes
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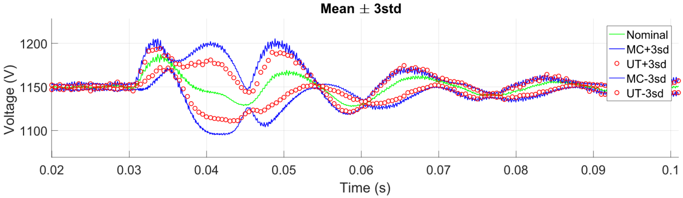

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The UT method $\simeq$ 161 times faster than the MC method.

3D Results

Simulation Details

1. Wind Speed $(0, 20) m/s$
2. Line Capacitance
   - Positive Sequence Capacitance $(2.505, 7.515) nF$
   - Zero Sequence Capacitance $(5.665, 16.995) nF$
3. Fault Level $(0, 1) p.u.$

3D Results
DC Bus Voltage

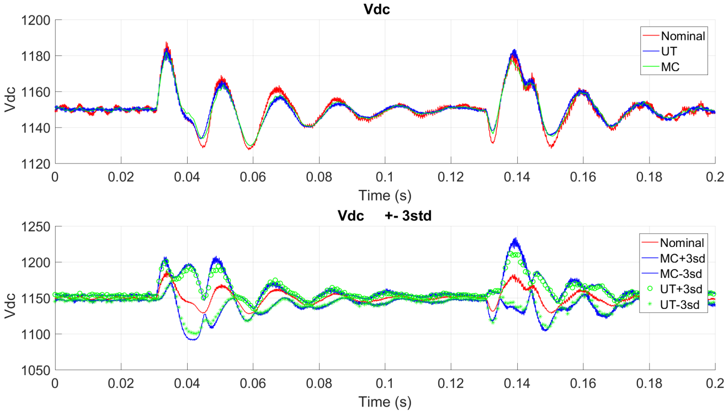

Figure 7: Averages and voltages bounds at 0.1% confidence levels.

3D Results

Rotor speed p.u.

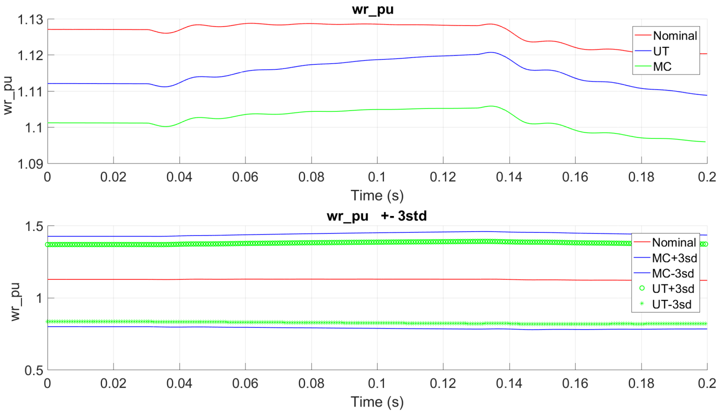

Figure 8: Averages and voltages bounds at 0.1% confidence levels.

3D Results

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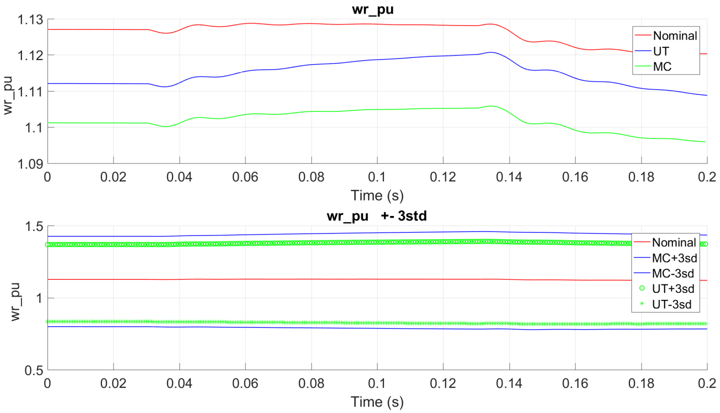

Figure 9: Averages and voltages bounds at 0.1% confidence levels.

3D Results

25 KV bus, phase A's voltage.

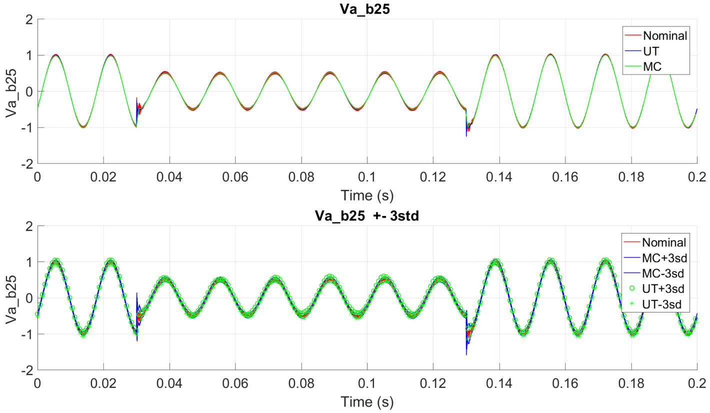

Figure 10: Averages and voltages bounds at 0.1% confidence levels.

Conclusion

Presentation Summary

- UT method applied to a relevant model based on a real world wind farm;
- The method presented a similar accuracy to the MC method;
- The time reduction factor over 160;
- This work the importance of considering the wind speed variability for components specification was shown.

Future tasks

- Implement multiple inputs;
- Evaluate multiple outputs;
- Application in different models.

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