Dichotomous Markov Noise Technique to Model Wind Power Uncertainty in Microgrid Operation

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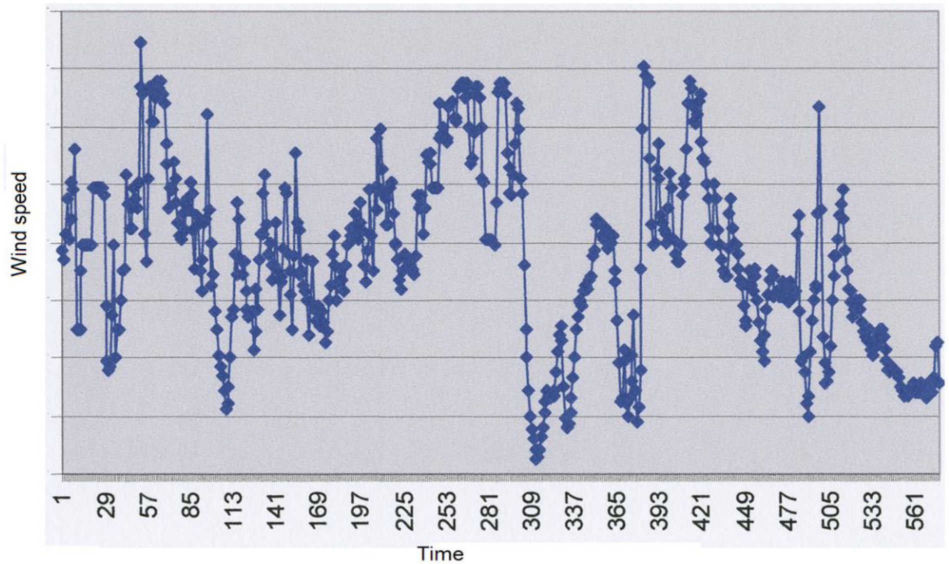
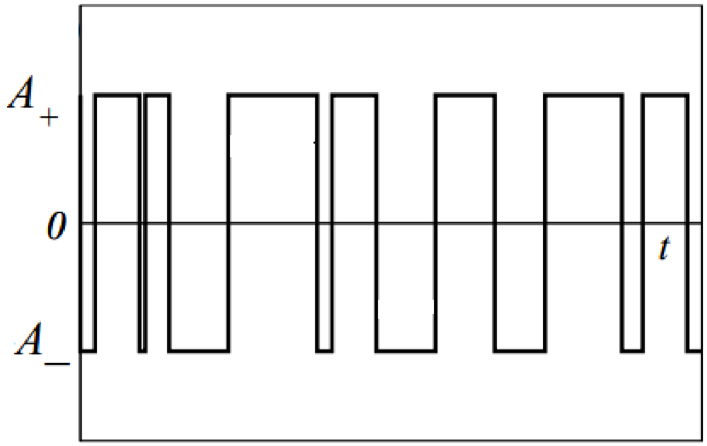
Introduction

- Probabilistic behavior of the wind power generation brings many challenges in power systems operation and control.
- How to model wind power uncertainty?
- How if there is no PDF and we have only actual hourly wind speed forecast?
- How about in hour-ahead system scheduling?



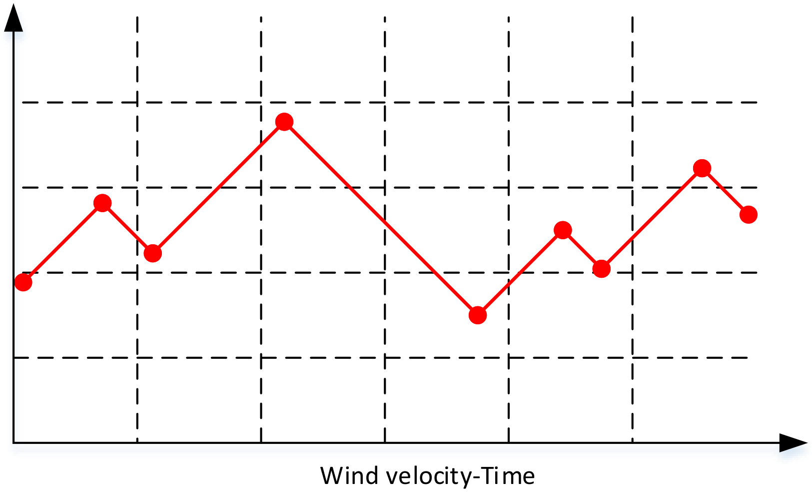
Dichotomous Markov Noise

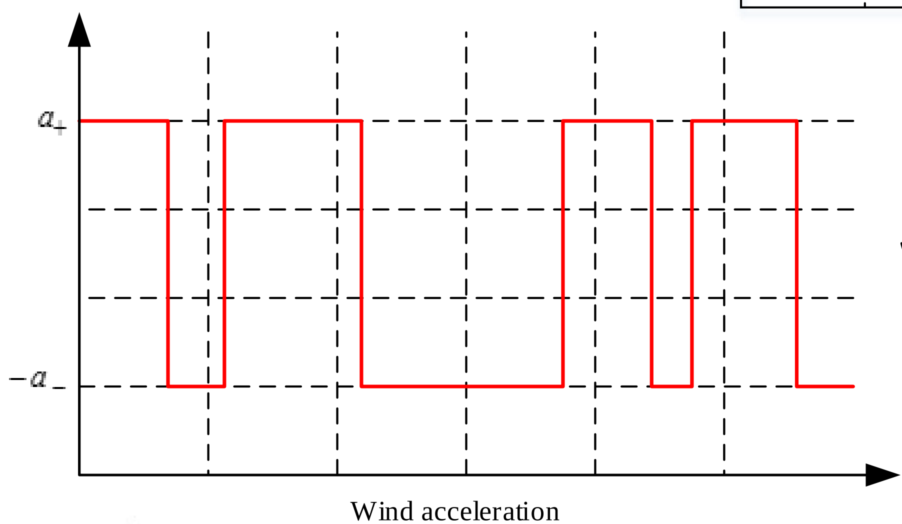
- Dichotomous Markov Noise (DMN) is defined as a two-valued stochastic process with the state space values $A_{\pm}$ with constant transition frequencies of $f_{\pm}$, for the increase $(+)$ and decrease rate $(-)$ with the appropriate probabilities $\mathrm{p}_{\pm}(t)$.
- The switches of $a(t)$ are Poisson process.



Dichotomous Markov Noise

Wind velocity





Wind acceleration

Dichotomous Markov Noise

- Differential equations

$$\frac{d}{dt}\begin{pmatrix} p_+ \\ p_- \end{pmatrix} = \begin{pmatrix} -f_+ & f_- \\ f_+ & -f_- \end{pmatrix}\begin{pmatrix} p_+ \\ p_- \end{pmatrix}$$

- By using the initial values $p_+(0)=1$ and $p_-(0)=0$, the solutions are calculated as follows:

$$p_+(t) = \frac{f_-}{f_- + f_+} + \frac{f_+}{f_- + f_+} e^{-(f_- + f_+)t}$$

$$p_-(t) = \frac{f_+}{f_- + f_+} - \frac{f_+}{f_- + f_+} e^{-(f_- + f_+)t}$$

Dichotomous Markov Noise

- Defining the average acceleration as:

$$\bar{a}(t) = a_+ p_+(t) - a_- p_-(t)$$

- The average acceleration and the equilibrium point can be calculated as:

$$\bar{a}(t) = \frac{a_+ f_- - a_- f_+}{f_- + f_+}\left(1 - e^{-(f_- + f_+)t}\right) + v_+ e^{-(f_- + f_+)t}$$

- Thus the equilibrium point of the system is characterized by

$$\lim_{t \to \infty} \bar{a}(t) = \mathrm{A} = \frac{a_+ f_- - a_- f_+}{f_- + f_+}$$

Microgrid Operation

- Minimizing operating cost

$$Min \quad OC = \sum_{\forall i} F(P_i) + \lambda P_{u,m}$$

S.t.

$$P_{Gb} - P_{Db} = P_b(\theta, V) \quad \forall b$$

$$Q_{Gb} - Q_{Db} = Q_b(\theta, V) \quad \forall b$$

$$P_i^{min} \le P_i \le P_i^{max} \quad \forall i$$

$$Q_i^{min} \le Q_i \le Q_i^{max} \quad \forall i$$

$$Q_C^{min} \le Q_C \le Q_C^{max} \quad \forall C$$

$$V_b^{min} \le V_b \le V_b^{max} \quad \forall b$$

$$| S_l(\theta, V) | \le S_l^{max} \quad \forall l$$

Microgrid Operation

- Minimizing Energy Loss

$$Min \quad EL = \sum_{\forall i} P_{Gi} - \sum_{\forall b} P_{Db}$$

- Minimizing Voltage Profile Deviation

$$Min \quad VPD = \sqrt{\sum_{\forall b} (V_b - V_{b,desire})^2}$$

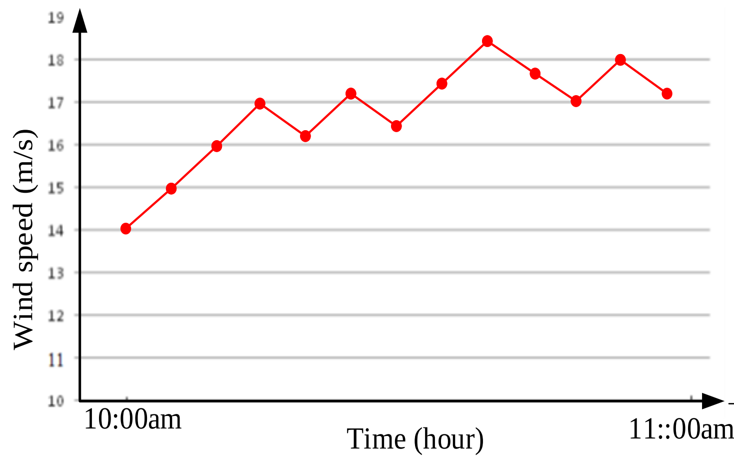
Microgrid Operation

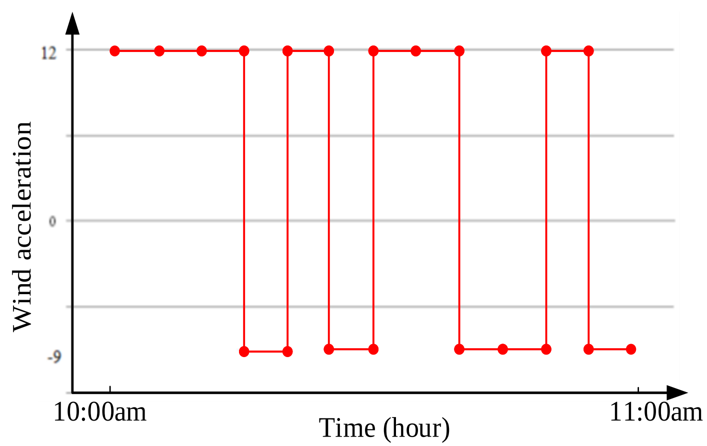
- Multiobjective Cost Function

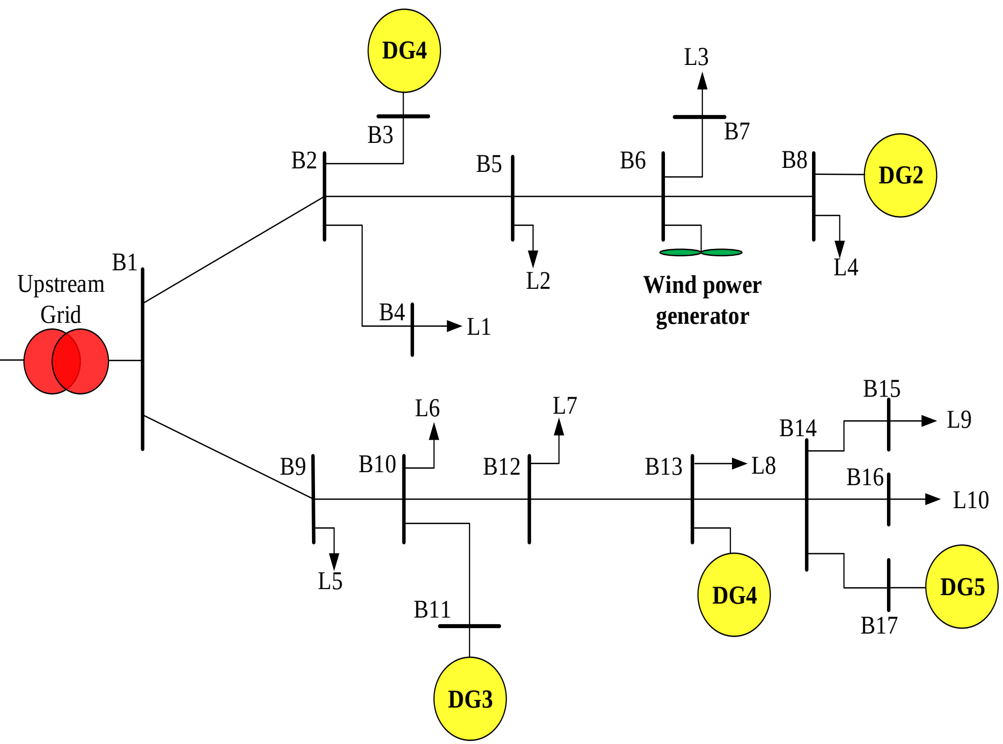
$$Min \quad SMCF = \sqrt{\beta(\frac{OC - OC^*}{OC^*})^2 + \gamma(\frac{EL - EL^*}{EL^*})^2 + \mu(\frac{VPD - VPD^*}{VPD^*})^2}$$

- where *OC**, *EL**, and *VPD** are the minimum accessible values for OC, EL, and VPD.
- Parameters β, γ, and μ are weighting factors adjusting the impact of different terms in the objective.

Case Study


Wind speed (m/s)
19
18
17
16
15
14
13
12
11
10
10:00am
Time (hour)
11::00am


Wind acceleration
12
0
-9
10:00am
Time (hour)
11:00am


Upstream Grid
B1
B2
B3
DG4
B4
L1
B5
L2
B6
B7
L3
Wind power generator
B8
L4
DG2
B9
L5
B10
L6
B11
DG3
B12
L7
B13
L8
DG4
B14
B15
L9
B16
L10
B17
DG5

Case Study

$$f_+ = 4 \qquad f_- = 4$$

$$a_+ = 12 \qquad a_- = 9$$

- Applying the DMN model, the expected wind acceleration is +1.5.
- The wind speed is in overall speed increasing class.
- The expected wind speed is calculated to be 14.75 (m/s).
- Using the power curve of the wind turbine, the power provided by this renewable generation source is 1.5 MW.

Case Study

Bus Voltage and Active of the MG

Bus No.	Voltage (p.u.)	Angle (rad/sec)
B1	1.06	0.000
B2	1.00	-0.059
B3	1.04	-0.047
B4	0.96	-0.105
B5	0.96	-0.059
B6	1.01	0.025
B7	1.01	-0.030
B8	1.04	-0.056
B9	0.99	-0.081
B10	0.99	-0.073
B11	1.02	-0.030
B12	1.00	-0.072
B13	1.06	-0.028
B14	1.00	-0.041
B15	0.96	-0.080
B16	0.96	-0.089
B17	1.05	0.029

Active and Reactive Power produced by Generation Sources

Gen. Sources	P (MW)	Q (MVar)
Upstream Grid	1.53	0.30
DG1	0.31	0.88
DG2	1.12	0.01
DG3	0.49	1.08
DG4	2.48	0.18
DG5	0.75	1.07
Wind turbine	1.50	-1.10

Objective functions value

Operating cost	Energy loss	Voltage profile deviation index
$6312	372 KW	0.028

Conclusion

- DMN technique can be applied to model wind power fluctuation in hour-ahead system scheduling.
- Actual forecasted wind speed is modeled in the OPF.
- DMN can model the uncertainty when there is no access to PDF of the uncertain variable.
- This method provide only one scenario for wind speed.
- As the future works, DMN technique can be applied to forecast wind speed, and the state of the system during the future operation hours.

Thank you!