Modelling energy storage systems in power grids

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Abstract

- There is a need for more sustainable energy production: this leads to the incorporation of renewable energy resources in power grids.
- Renewable energy resources provide a fluctuating output (depending on weather, season, etc.) which needs to be compensated with a control mechanism.
- A possible control mechanism is the introduction of a battery, which can store and provide energy when needed.
- The objective of this work is to introduce a battery in a model of a conventional power plant for frequency control and grid stability.

Model

Power plant - Swing Equation

Deviation from reference frequency

Generator power

Demand

$$\frac{d\underline{\omega}}{dt} = \frac{\omega_R^2}{2\underline{H}(\omega+\underline{\omega_R})}(\underline{P_m^0}+\underline{P_B}-\underline{P_e})$$

generator inertia

Reference frequency

Battery power

Demand - Ornstein-Uhlenbeck noise

$P_e = P^0_m + \xi_{ou}$

ξ_{ou} is coloured Ornstein-Uhlenbeck noise with correlation function:

$$\langle \xi_{ou}(t), \xi_{ou}(t')\rangle \propto e^{-\frac{|t-t'|}{\tau_{ou}}}$$

Battery dynamics

Battery power and charge: P_B, P_s, Q

Auxiliary variables: $\bar{P_B}, \bar{Q}$

$$\frac{d\bar{P_B}}{dt} = \frac{1}{\tau}(P_s - P_B - \underline{\alpha}\omega) \qquad \frac{d\bar{Q}}{dt} = \bar{P_B}$$

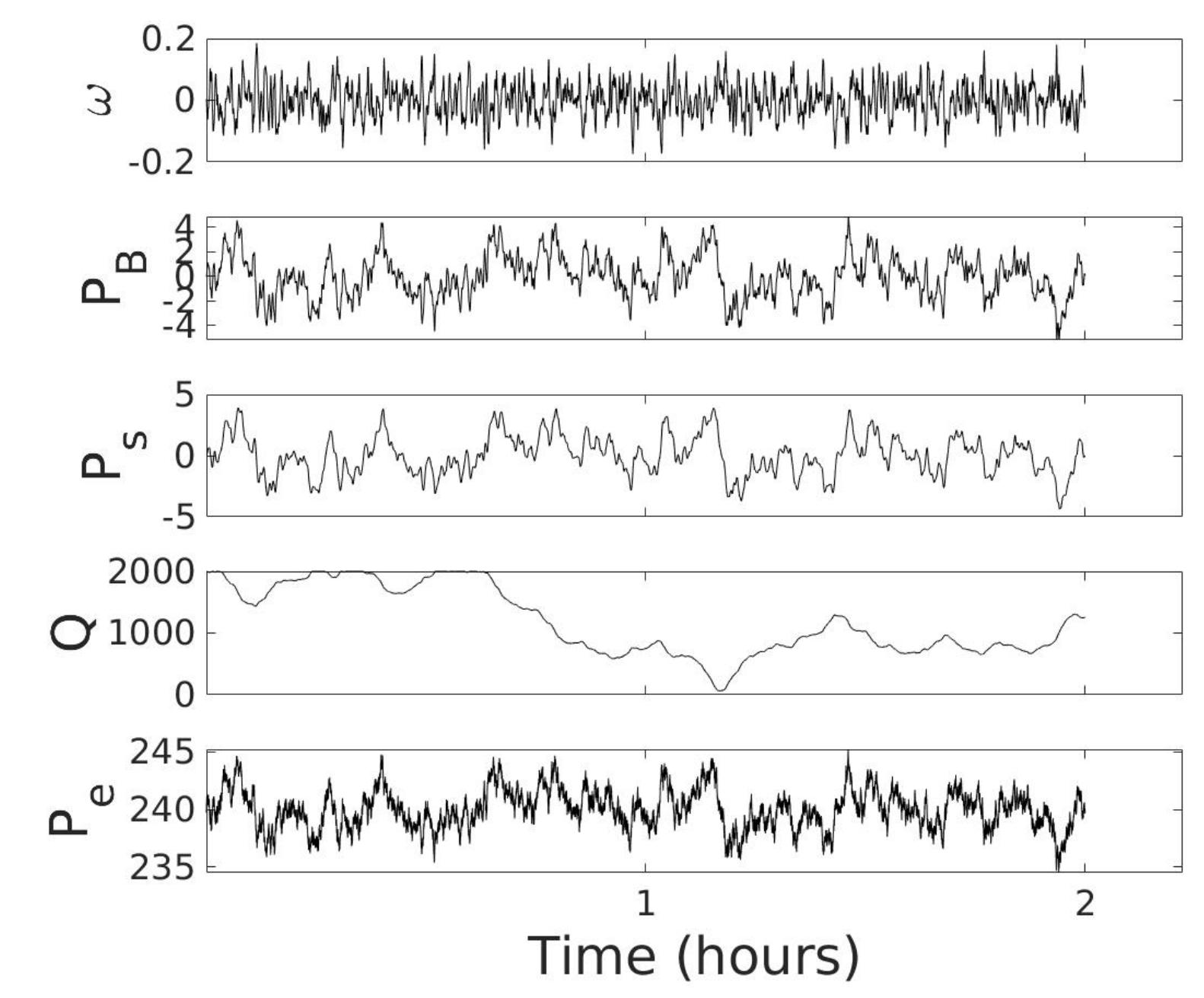
$$\frac{dP_s}{dt} = -\underline{\beta}\omega$$

Battery parameters

Algorithm for battery charge:

- if $0 \le \bar{Q} \le Q_{max}$ then $Q(t+dt) = \bar{Q}$ and $P_B(t+dt) = \bar{P_B}$
- if $\bar{Q} \le 0$ then $Q(t+dt) = 0$ and $P_B(t+dt) = \frac{Q(t)}{dt}$
- if $\bar{Q} > Q_{max}$ then $Q(t+dt) = Q_{max}$ and $P_B(t+dt) = \bar{P_B}$ (energy curtailment)

Example of solution



Results: Linear stability and Frequency control

(1) Linearized model without noise around its steady state

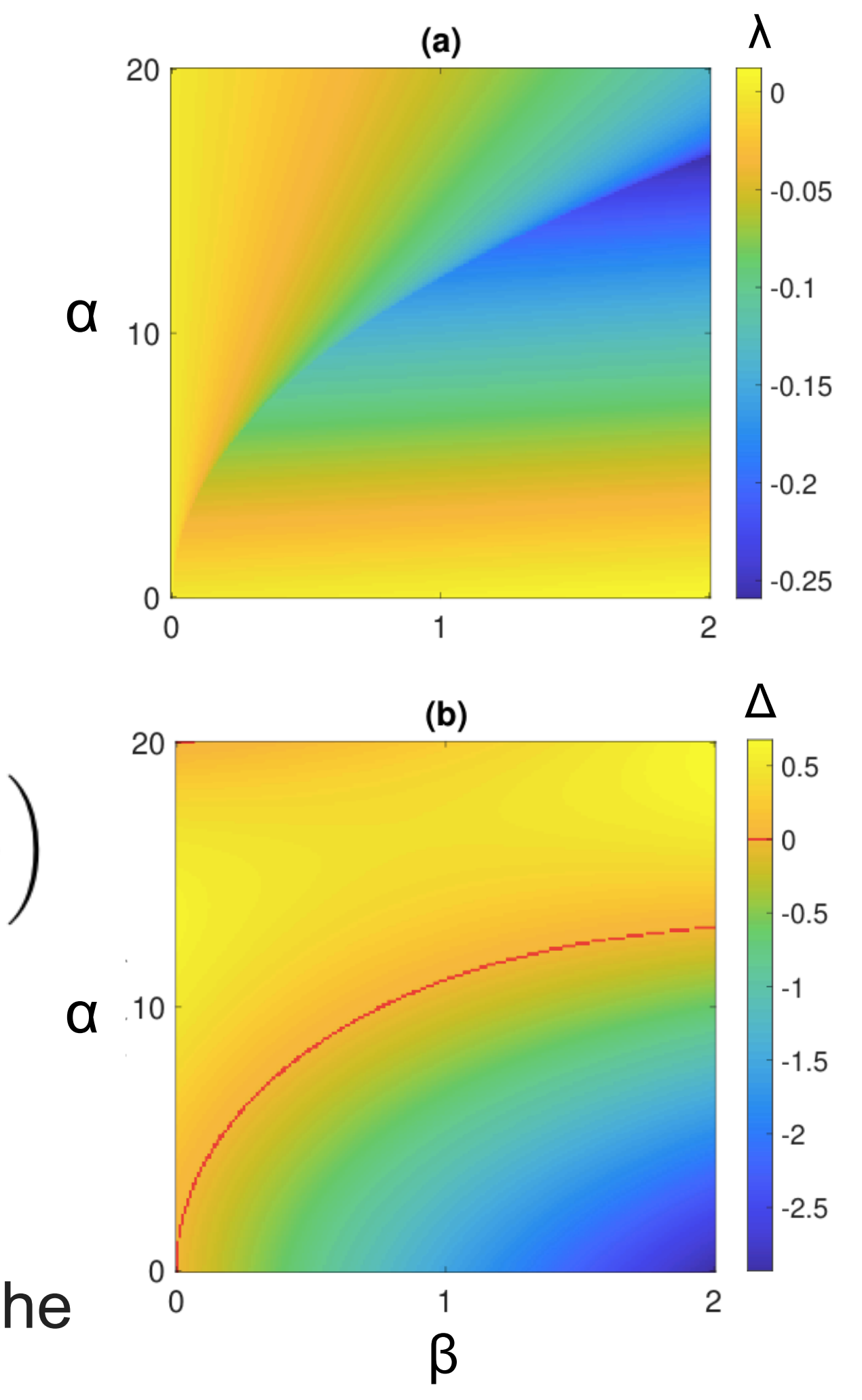
$$\omega = 0,\ P_0^m = P_e,\ P_B = P_s = 0$$

$$\begin{bmatrix} \dot{\omega} \\ \dot{P_B} \\ \dot{P_s} \end{bmatrix} = \begin{bmatrix} 0 & \frac{\omega_R}{2H} & 0 \\ -\frac{\alpha}{\tau} & -\frac{1}{\tau} & \frac{1}{\tau} \\ -\beta & 0 & 0 \end{bmatrix} \begin{bmatrix} \omega \\ \mathrm{P}_B \\ \mathrm{P}_s \end{bmatrix}$$

Characteristic polynomial and its discriminant:

$$p(x) = -x^3 - \frac{1}{\tau}x^2 - \frac{\omega_R\alpha}{2H\tau}x - \frac{\omega_R\beta}{2H\tau}$$

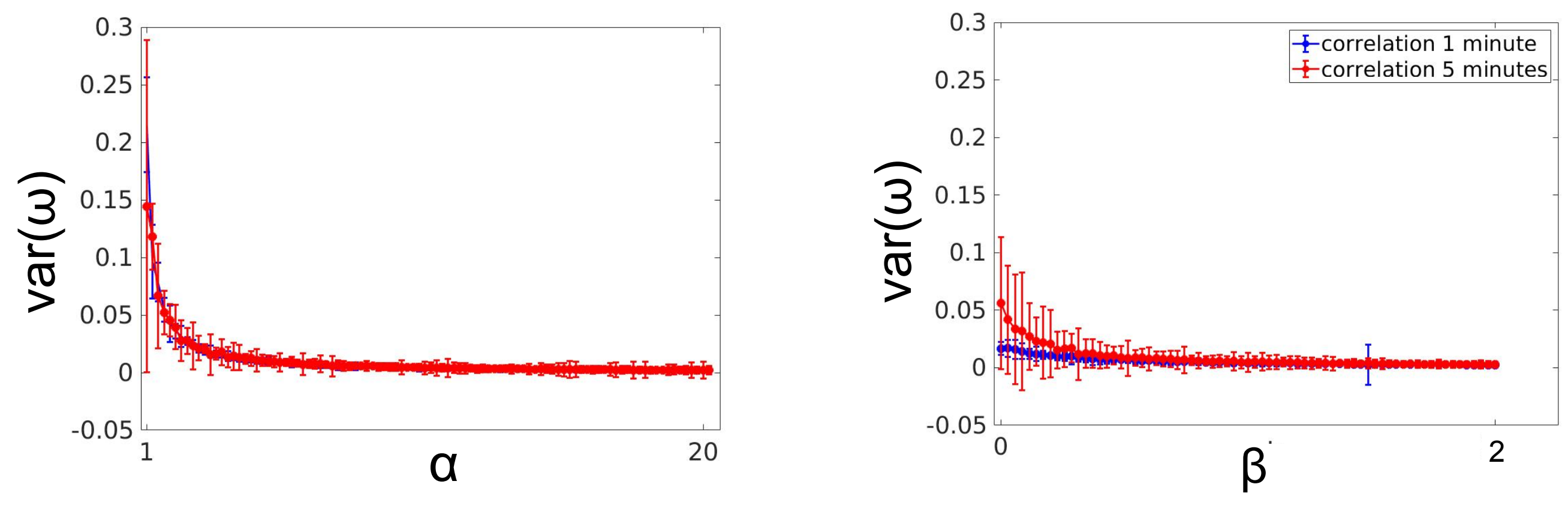
$$\Delta = \frac{\omega_R}{2H\tau^2}\left(\frac{18\omega_R\alpha\beta}{2H\tau} - \frac{4\beta}{\tau^2} + \frac{\omega_R\alpha^2}{\tau} - \frac{\omega_R^2\beta^3}{H^2\tau} - \frac{27\omega_R\beta^2}{2}\right)$$



(a) Real part of the largest eigenvalue obtained linearizing around the steady state. The optimal choice of parameters is where λ has its minimum.

(b) Discriminant of the characteristic polynomial of the matrix associated to the linearized model without noise. The red line corresponds to Δ=0.
Δ<0: one real eigenvalue and two complex conjugates (damped oscillations).
Δ>0: three real eigenvalues.

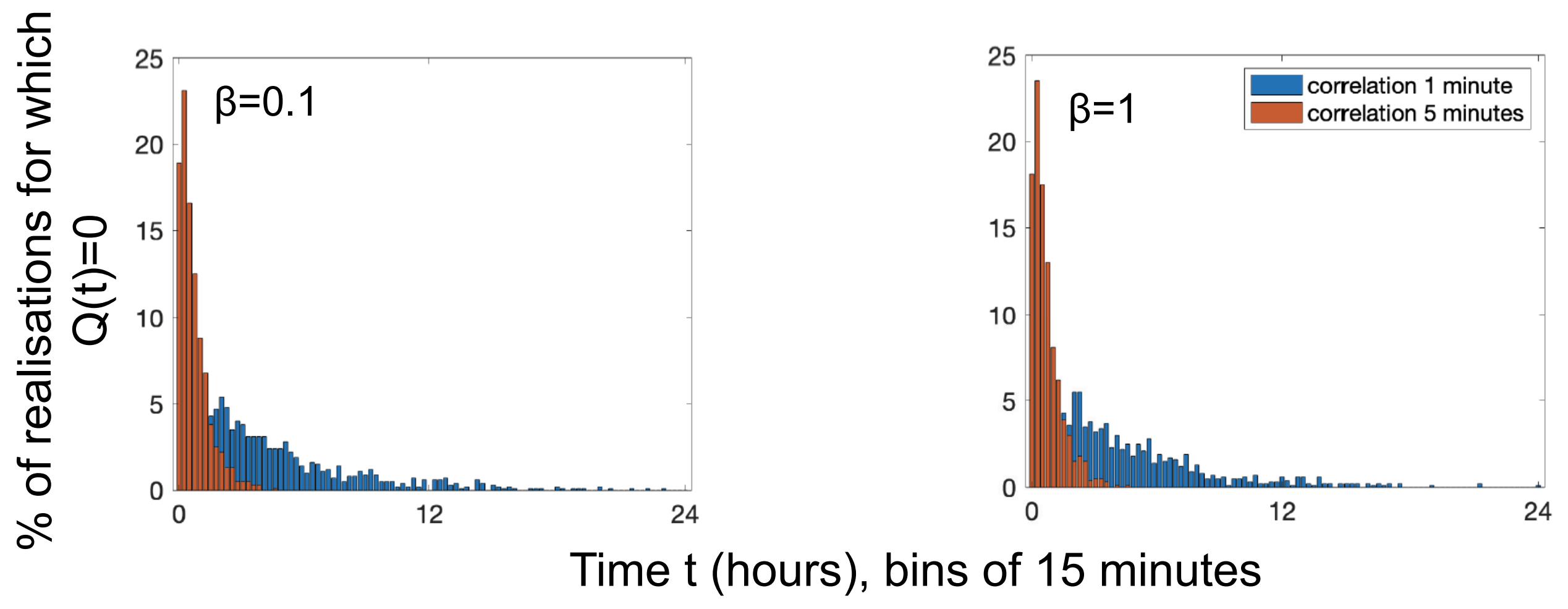
(2)



Increasing the intensity of primary/secondary control reduces the variance of frequency fluctuations. The variance of ω is small even before reaching optimal parameters.

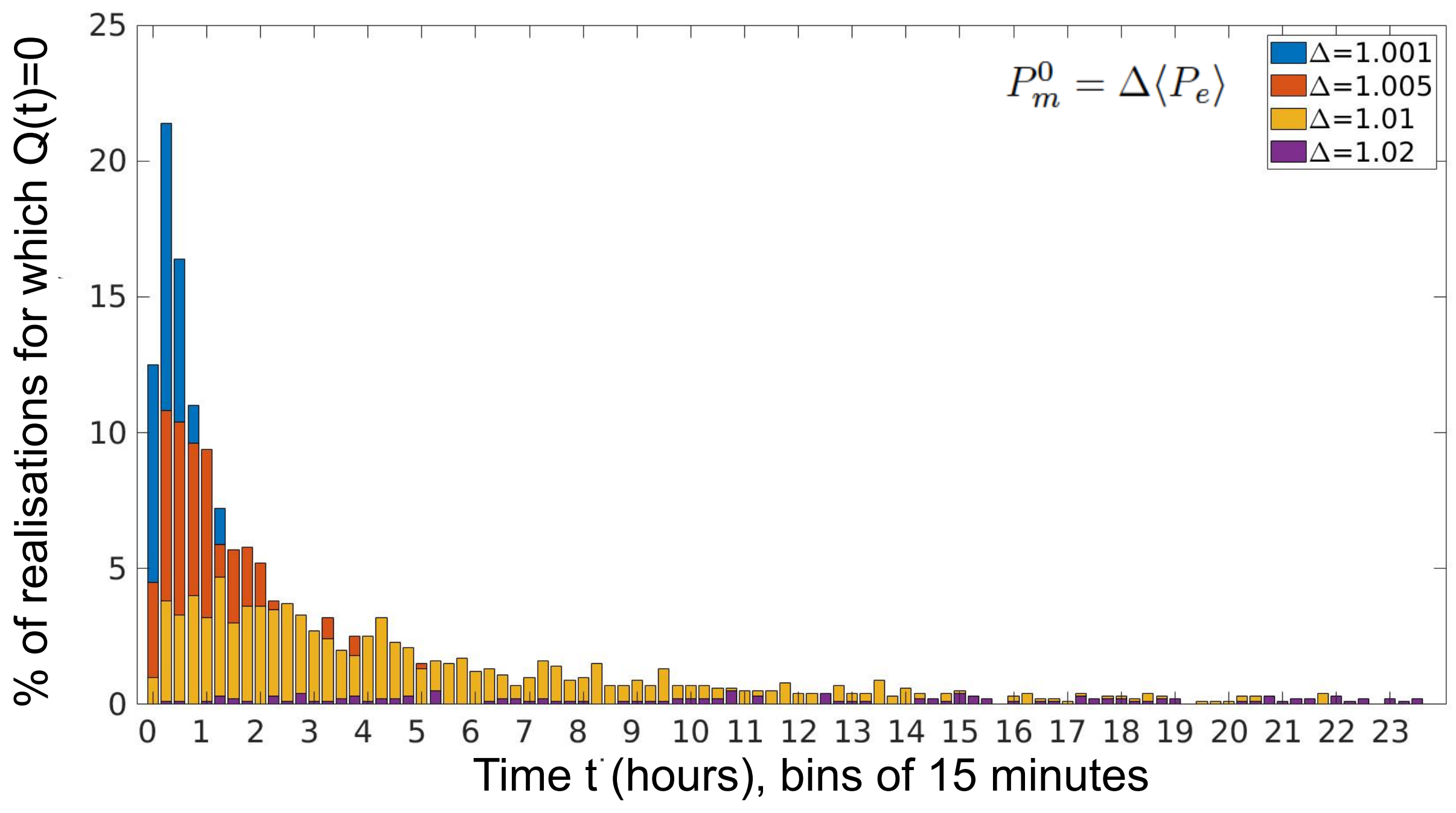
Results: Battery discharge time

(3)



Battery parameters α and β have little effect on the time for the battery to discharge (reaching Q=0). On the contrary the correlation time of the demand fluctuations does have a significant effect: increasing correlation leads to a faster discharge.

(4)



The distribution of the battery discharge times becomes flatter when the generator power P^0_m is slightly higher than the average of the demand P_e. Thus, if the mechanical power exceeds the average demand, the battery has a higher probability of lasting longer.

Future Work

- Extend this model to the grid. Which are the optimal nodes in which a battery can be installed?
- Compare model simulations with real data from various power grids.
- Adapt the model for VPP4Islands.

References

[1] H. Saadat, Power Systems Analysis, McGraw - Hill (1999)

[2] E. B. Tchawou Tchuisseu et al., Effects of dynamic-demand-control appliances on the power grid frequency, Physical Review E, 96, 2, 022302 (2017)

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