# A Complex LASSO-Approach for Localizing Forced Oscillations in Power Systems

## A brief reiteration

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# Introduction

# Forced Oscillations in Power Systems

| Natural Oscillations | Forced Oscillations |
|---|---|
| natural | forced |
| naturla | forced |
| natural | forced |

# Theory

# State Space Representation

Express Power System Dynamics in State Space:

$$\begin{aligned}
\underset{n\times 1}{\dot{\mathrm{x}}(t)} &= \underset{n\times n}{\mathrm{A}}\,\underset{n\times 1}{\mathrm{x}(t)} + \underset{n\times m}{\mathrm{B}}\,\underset{m\times 1}{\mathrm{u}(t)} \\
\underset{b\times 1}{\mathrm{y}(t)} &= \underset{b\times n}{\mathrm{C}}\,\underset{n\times 1}{\mathrm{x}(t)} \\
&\forall t \geq 0
\end{aligned} \tag{1}$$

$\underset{n\times 1}{\mathrm{x}(t)}$ : internal state variables + controller variables vector

$\underset{m\times 1}{\mathrm{u}(t)}$ : forced oscillation vector

# Forced Oscillation Vector

Express Forced Oscillations based on locations of origin and signal composition:

$$\underset{m\times 1}{\mathbf{u}(t)} = \underset{m\times 1}{\begin{bmatrix} u_1(t) \\ u_2(t) \\ \vdots \\ u_m(t) \end{bmatrix}} = \underset{m\times 1}{\begin{bmatrix} \sum_{l=1}^{M_1} a_{1,l} \sin(\omega_{1,l}t + \phi_{1,l}) \\ \sum_{l=2}^{M_2} a_{2,l} \sin(\omega_{2,l}t + \phi_{2,l}) \\ \vdots \\ \sum_{l=m}^{M_m} a_{m,l} \sin(\omega_{m,l}t + \phi_{m,l}) \end{bmatrix}} \tag{2}$$

$a_{r,l} \geq 0$

$\omega_{r,l} = 2\pi f \geq 0$

$(r, l)$ refer to the $l^{th}$ sinusoid at the $r^{th}$ location

# Introduction to My Work

# Transient vs Steady State Stability

| Transient Stability | Steady State Stability |
| --- | --- |
| A sudden, out-of-trend, high magnitude change in a state variable(s) causes blackouts. | Accumulation of several seemingly minor trends in state variables over time, ultimately leading to a critical point where a small change could cause blackouts. |
| Chief parameters of concern are ROCOF, frequency nadir, steady-state frequency deviation. | Autocorrelation and covariance are some of the commonly used parameters for prognosis. |
| Inertia is a fundamental parameter here. | Inertia plays a minor role here. |

# Bifurcations and Critical Slowing Down

**Bifurcation**: A qualitative change in the 'motion' of a dynamical System due to a quantitative change in one of its parameters. Serious bifurcations, called Critical Bifurcations, cause the system to become unstable from stable.

# Bifurcations and Critical Slowing Down

Critical Slowing Down: Dynamical Systems exhibit early statistical warning signs before collapsing:

- Increased recovery times from perturbations.
- Increased signal variance from the mean trajectory.
- Increased flicker and asymmetry in the signal

The above three properties can be identified by increasing variance and autocorrelation in time-series measurements taken from the system.

# Procedure

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- Accessed a bunch of real-world frequency time-series data and plotted their:
    - bulk distribution (pdf)
    - auto-correlation curves
- Obtained explanation for the *signature dynamics* of each grid.

# Results

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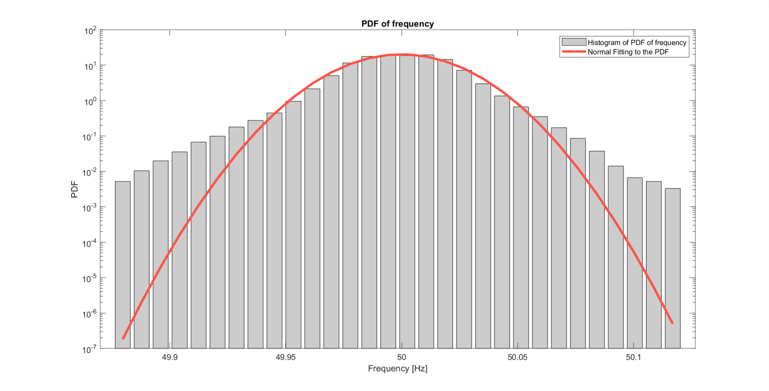


**Figure 1:** Continental European Grid frequency PDF: Heavier tails than a Gaussian Distribution.

# Results

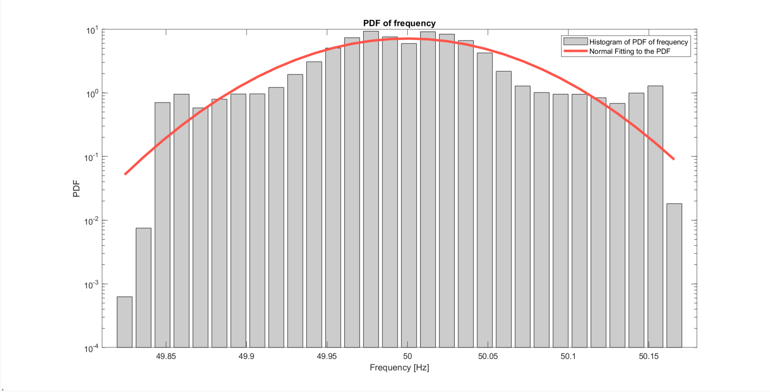


**Figure 2:** Mallorcan (an islanded Spanish grid) frequency pdf

# Results

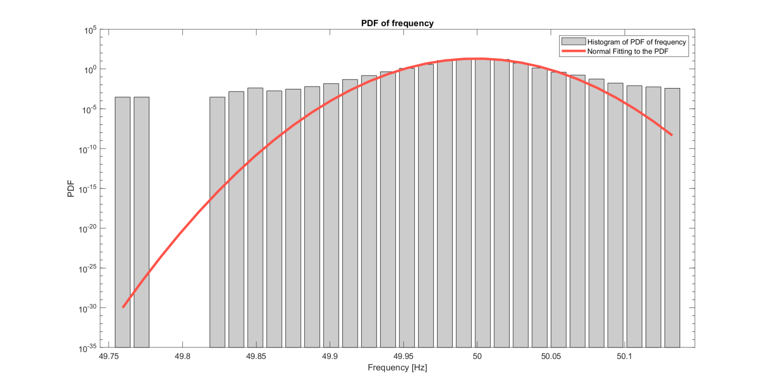


**Figure 3:** French grid frequency pdf including a blackout

# Results

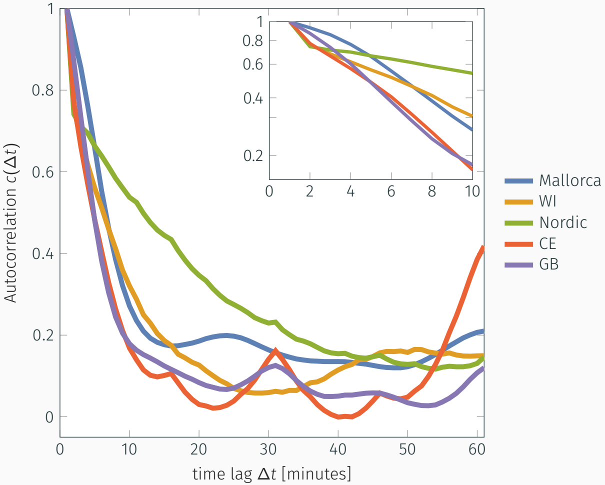


**Figure 4:** Autocorrelation decay of different synchronous regions.

# Results

**Table 1:** Inverse-correlation values for different grids

| Grid name | Inverse-correlation value $T^{-1}$ $[min^{-1}]$ |
|---|---|
| Mallorca | 0.0654 |
| Western Interconnection | 0.0498 |
| Nordic | 0.0235 |
| Continental Europe | 0.0829 |
| Great Britain | 0.0879 |

**Figure 5:** Inverse correlation time is proportional to the damping constant of the grid.