

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
natural	forced
natural	forced



Theory

State Space Representation

Express Power System Dynamics in State Space:

$$\dot{\mathbf{x}}(t) = \mathbf{A}\mathbf{x}(t) + \mathbf{B}\mathbf{u}(t)$$

$$\mathbf{y}(t) = \mathbf{C}\mathbf{x}(t)$$

$$\forall t \geq 0$$

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

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



Forced Oscillation Vector

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

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

$$a_{r,l} \geq 0$$

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

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



Introduction to My Work

Transient vs Steady State Stability

Transient Stability

A sudden, out-of-trend, high magnitude change in a state variable(s) causes blackouts.

Chief parameters of concern are ROCOF, frequency nadir, steady-state frequency deviation.

Inertia is a fundamental parameter here.

Steady State Stability

Accumulation of several seemingly minor trends in state variables over time, ultimately leading to a **critical point** where a small change could cause blackouts.

Autocorrelation and covariance are some of the commonly used parameters for prognosis.

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

- 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

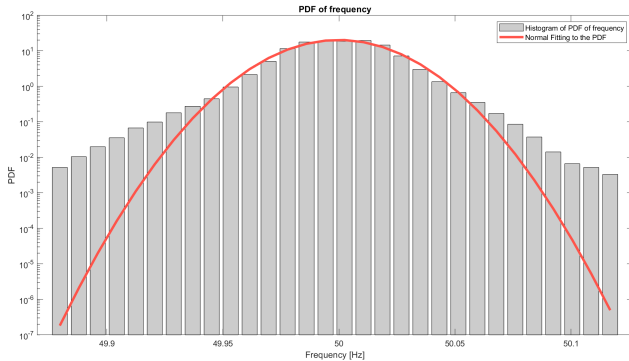


Figure 1: Continental European Grid frequency PDF: Heavier tails than a Gaussian Distribution.



Results

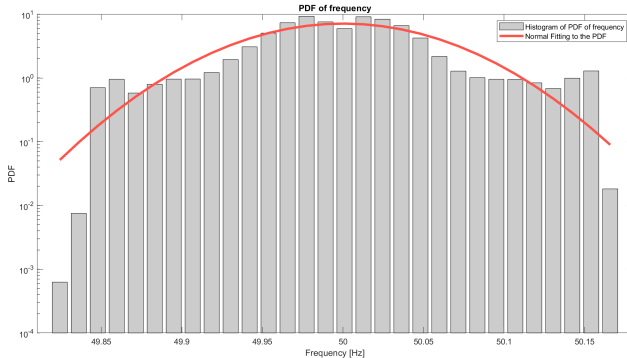


Figure 2: Mallorca (an islanded Spanish grid) frequency pdf



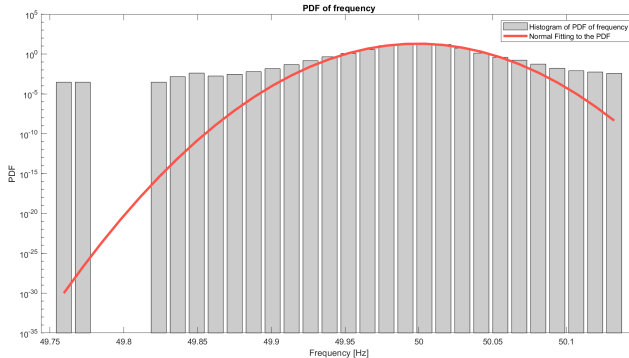


Figure 3: French grid frequency pdf including a blackout



Results

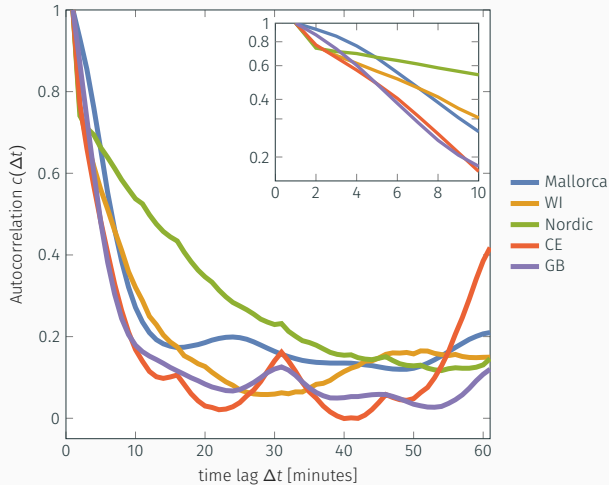


Figure 4: Autocorrelation decay of different synchronous regions.



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.

