

MS Thesis Progress Report for Sem 2, 2020-21

Data Analysis for Predicting Instabilities in Power Systems

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Introduction

Transient vs Steady State Stability

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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.



Theory

Autocorrelation Definition

$$\int_{-\infty}^{\infty} x(t) * x(t + \tau) dt = c(\tau) \quad (1)$$



$$c(\tau) \propto \exp(-\alpha\tau) \quad (2)$$

$$c(\tau) \sim \exp(-\tau/T) \quad (3)$$



Procedure

- On similar lines of [1], 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

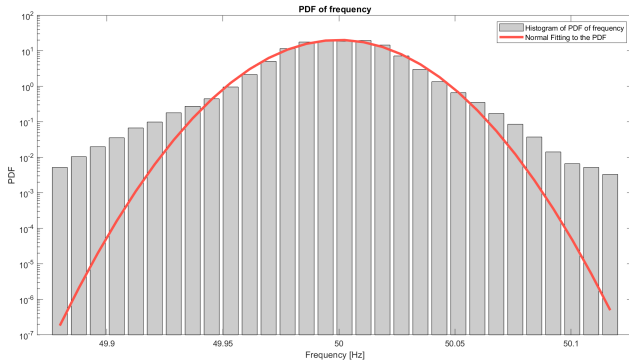


Figure 1: Continental European Grid frequency PDF: Heavier tails than a Gaussian Distribution.



Results

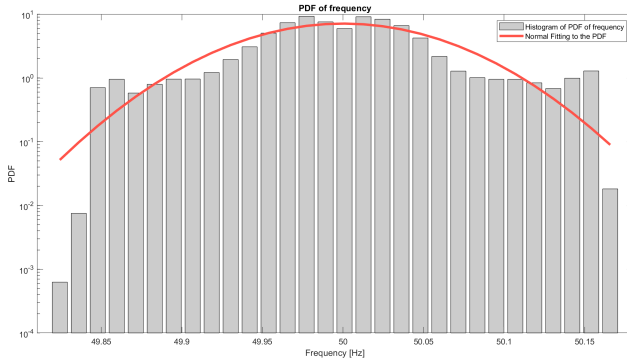


Figure 2: Mallorcan (an islanded Spanish grid) frequency pdf



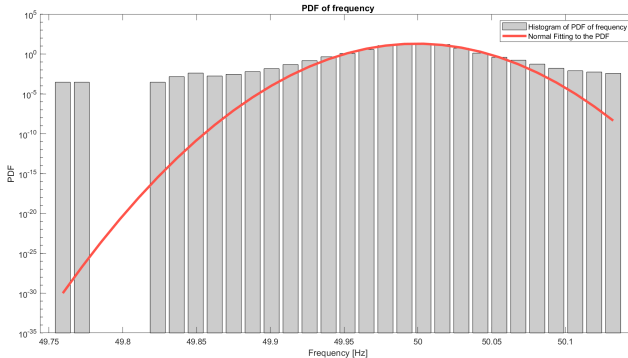


Figure 3: French grid frequency pdf including a blackout



Results

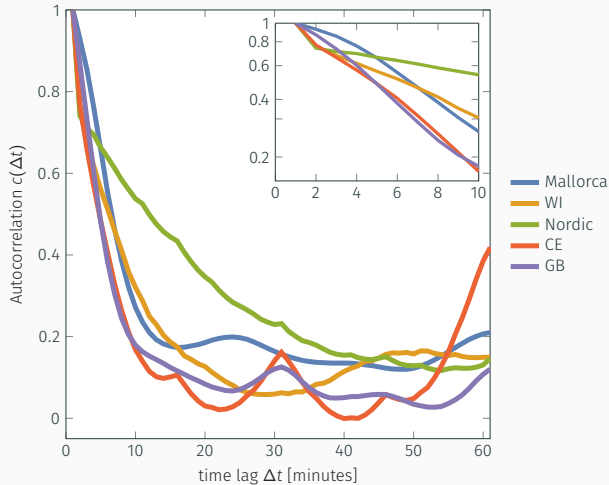


Figure 4: Autocorrelation decay of different synchronous regions.



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.



Future Work

- Examine different mathematical processes for modelling and examining the steady state stability of the grid.
- Research on optimum sampling rates as done in [2]
- Attempt to simulate different control strategies for increasing grid stability
- Collect Indian grid frequency data from the laboratory and perform the above tasks



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References

- [1] Benjamin Schäfer et al. “Non-Gaussian power grid frequency fluctuations characterized by Lévy-stable laws and superstatistics”. In: *Nature Energy* 3.2 (2018), pp. 119–126. ISSN: 2058-7546. DOI: [10.1038/s41560-017-0058-z](https://doi.org/10.1038/s41560-017-0058-z). URL: <http://dx.doi.org/10.1038/s41560-017-0058-z>.
- [2] Leonardo Rydin Gorjão et al. “Open database analysis of scaling and spatio-temporal properties of power grid frequencies”. In: *Nature Communications* 11.1 (2020), p. 6362. ISSN: 2041-1723. DOI: [10.1038/s41467-020-19732-7](https://doi.org/10.1038/s41467-020-19732-7). URL: <https://doi.org/10.1038/s41467-020-19732-7>.

