SYNOPSIS OF

Data Analysis for Predicting Instabilities in Power Systems

A THESIS

to be submitted by

Aryan Ritwajeet Jha

2020EEY7525

under the guidance of

Prof. Nilanjan Senroy

for the award of the degree

of

Master Of Science

(by Research)

Department Of Electrical Engineering

INDIAN INSTITUTE OF TECHNOLOGY DELHI

July 2022

Proposed Contents of the Thesis

1 Introduction

Unlike transient faults in a power grid which can generally be attributed to a sudden but tangible anomaly (corrective outcomes of protection mechanisms, sudden failure of a generator or transformer, line faults), steady state instabilities can be hard to detect until they accumulate over time to manifest as a major upset to the grid `CITE HERE FOR FRENCH GRID COLLAPSE IN Augu` or make the grid less robust/more susceptible to collapses [CITE schafer01] [1].

2 Literature Review

For real-time/online analysis, authors in [2] have utilized PSAT to simulate a steadily stressed power grid and have demonstrated that the computation of autocorrelation of detrended bus voltages and the computation of variance of detrended line currents can function as reliable Early Warning Signs of increasing instability. The detrending is required in order to filter any measurement noise from the data, which may skew the computed statistical parameters towards bogus values. Authors in [3] test various power grids which are/were driven towards bifurcation and demonstrate that an increase of autocorrelation and variance values of bus voltages (tested in simulation) and grid frequency (tested on the time-series data measured at the Bonneville Power Administration minutes before the blackout of 10 August 1996) can reliably predict the impending bifurcation early enough for mitigating actions to be taken by the grid operator.

3 Motivation and Objectives

Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consectetuer id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo. Cras viverra metus rhoncus sem. Nulla et lectus vestibulum urna fringilla ultrices. Phasellus eu tellus sit amet tortor gravida placerat. Integer sapien est, iaculis in, pretium quis, viverra ac, nunc. Praesent eget sem vel leo ultrices bibendum. Aenean faucibus. Morbi dolor nulla, malesuada eu, pulvinar at, mollis ac, nulla. Curabitur auctor semper nulla. Donec varius orci eget risus. Duis nibh mi, congue eu, accumsan eleifend, sagittis quis, diam. Duis eget orci sit amet orci dignissim rutrum.

4 Theory

Nulla malesuada porttitor diam. Donec felis erat, congue non, volutpat at, tincidunt tristique, libero. Vivamus viverra fermentum felis. Donec nonummy pellentesque ante. Phasellus adipiscing semper elit. Proin fermentum massa ac quam. Sed diam turpis, molestie vitae, placerat a, molestie nec, leo. Maecenas lacinia. Nam ipsum ligula, eleifend at, accumsan nec, suscipit a, ipsum. Morbi blandit ligula feugiat magna. Nunc eleifend consequat lorem. Sed lacinia nulla vitae enim. Pellentesque tincidunt purus vel magna. Integer non enim. Praesent euismod nunc eu purus. Donec bibendum quam in tellus. Nullam cursus pulvinar lectus. Donec et mi. Nam vulputate metus eu enim. Vestibulum pellentesque felis eu massa.

5 Offline Analysis

Quisque ullamcorper placerat ipsum. Cras nibh. Morbi vel justo vitae lacus tincidunt ultrices. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. In hac habitasse platea dictumst. Integer tempus convallis augue. Etiam facilisis. Nunc elementum fermentum wisi. Aenean placerat. Ut imperdiet, enim sed gravida sollicitudin, felis odio placerat quam, ac pulvinar elit purus eget enim. Nunc vitae tortor. Proin tempus nibh sit amet nisl. Vivamus quis tortor vitae risus porta vehicula.

6 Online Analysis

On similar lines as [2, 3], we're interested in testing if symptoms of Critical Slowing Down can be detected by a real-time/online analysis of the state variables of a power grid. In other words, we're interested in checking if computing the autocorrelation and variance of real-time PMU data processed over a running window can provide us with Early Warning Signs of an impending instability.

Using the concepts of Bifurcation Theory, a small change in system parameters, such the governor reference power for a generator (P_{Gen}) at certain points, can lead to major upsets in the stability of the power grid. We intend to run a simulation in which a system is purposefully stressed (via a near constant linear load increment) as time progresses but many restrictions/safety mechanisms being lifted with the aim of singling-out the cause of bifurcation to a change in P_{Gen}(s), in order to best demonstrate that the proposed statistical mechanisms (computing autocorrelations and variances) function well as Early Warning Signs even for slow and steady variations of loads, and not just for sudden changes in state variables caused due to sudden corrective protection mechanisms or the machines not being given 'free-range' for chasing load increments due to specified safety limits on maximum allowed generated powers. Below is the set of special conditions for the simulation of the IEEE 9 Bus system:

1. The three load points of the system (Buses 5, 6 and 8) are linearly increased in time, at a rate of $\Delta P\%$ per minute plus a small white noise component $\mathcal{N}(0, \sigma_v)$, with every increment happening at Δt time intervals.

$$P_{L_i}(t + \Delta t) = P_{L_i}(t) * \left(1 + \frac{\Delta P_{L_i}}{100}\right) + \mathcal{N}(0, \sigma_v) \tag{1}$$

   Here, we've assigned ΔP_L values randomly between $8 - 12\%$ for every load bus, $\sigma_v = 0.01$ and $\Delta t = 0.1$ seconds.

2. Simulation ODE solver solves for the new state variables and parameters for the system every 0.01 seconds. This means that the simulation output can be likened to a stream of PMU data whose sampling rate is 100 Hz.

3. Protection mechanisms are disabled. There will be no remedial/corrective action taken for any drop in bus voltages/grid frequency or any increase in line currents/line MVAs.

4. 'Dummy' governors have been placed on the three generators (at buses 1, 2 and 3) which can respond instantly to load changes by changing the set reference generation powers P_{Gen}(s) with zero time lag.

5. The generator limits for $P_{Gen_{MAX}}$, $Q_{Gen_{MAX}}$, etc. have been removed. Thus the generators have the complete freedom to 'chase' the load increments at the load buses, including factoring in the extra line-losses.

It should be noted that while autocorrelation was used in both online/real-time and offline/postmortem analyses, the two usages are different in:

- their mode of procuring and processing input data (a running window of an incoming stream of data vs previously stored months/years worth of time series),
- the degrees of freedom allowed for its two parameter variables (which out of t and τ is allowed to be constant),
- their theoretically expected output data (autocorrelation is expected to decrease exponentially with respect to time lag τ but increase with respect to time t if that the system is being progressively stressed with time)

7 Conclusions

Offline/Postmortem Analysis

- Visual inspection of the probability distribution function obtained from a grid's frequency time-series over a longer period gives many insights into the presence of longstanding steady-state instabilities in the grid as well as the grid's resilience against any additional instability causing agents.

8 Future Work

Despite the successful application of statistical analysis to detect symptoms of Critical Slowing Down in various phenomena [4], autocorrelation and variance are not certain indicators for the same, at least by themselves [5].

References

[1] Benjamin Schäfer et al. "Non-Gaussian power grid frequency fluctuations characterized by Lévy-stable laws and superstatistics". In: *Nature Energy* 3.2 (Jan. 2018), pp. 119–126. ISSN: 2058-7546. DOI: `10.1038/s41560-017-0058-z`. URL: `http://dx.doi.org/10.1038/s41560-017-0058-z`.

[2] Goodarz Ghanavati, Paul D. H. Hines, and Taras I. Lakoba. "Identifying Useful Statistical Indicators of Proximity to Instability in Stochastic Power Systems". In: *IEEE Transactions on Power Systems* 31.2 (2016), pp. 1360–1368. DOI: `10.1109/TPWRS.2015.2412115`.

[3] Eduardo Cotilla-Sanchez, Paul D. H. Hines, and Christopher M. Danforth. “Predicting Critical Transitions From Time Series Synchrophasor Data”. In: *IEEE Transactions on Smart Grid* 3.4 (2012), pp. 1832–1840. DOI: 10.1109/TSG.2012.2213848.

[4] Marten Scheffer et al. “Early-warning signals for critical transitions”. In: *Nature* 461 (Sept. 2009), pp. 53–59. ISSN: 1476-4687. DOI: 10.1038/nature08227.

[5] Maarten C. Boerlijst, Thomas Oudman, and André M. de Roos. “Catastrophic Collapse Can Occur without Early Warning: Examples of Silent Catastrophes in Structured Ecological Models”. In: *PLOS ONE* 8.4 (Apr. 2013), pp. 1–6. DOI: 10.1371/journal.pone.0062033. URL: https://doi.org/10.1371/journal.pone.0062033.