MS Thesis Progress Report for Sem 1, 2021-22

Data Analysis for Predicting Instabilities in Power Systems

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Introduction

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

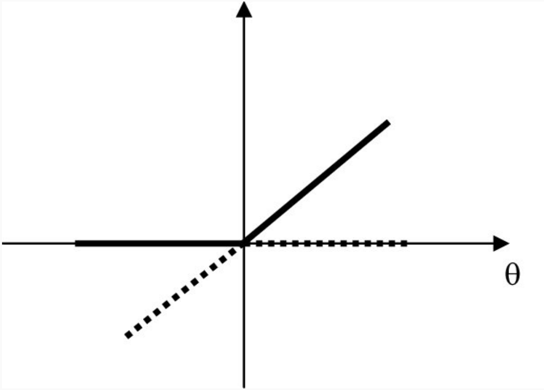

Figure 1: Bifurcation Diagram showing the Normal form of Transcritical Bifurcation

$$\frac{dx}{dt} = \theta x - x^2 \tag{1}$$

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.

Last Semester's Work

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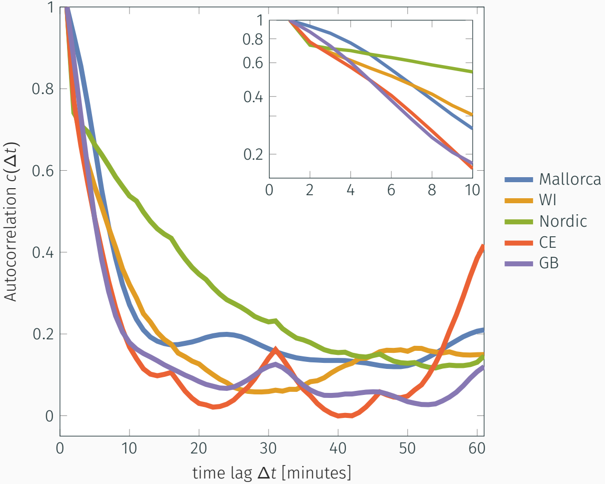


Figure 2: Autocorrelation decay of different synchronous regions.

Last Semester's Work

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 3: Inverse correlation time is proportional to the damping constant of the grid.

Procedure

Procedure: Simulation

- Created and simulated the IEEE 9 Bus System in PSSE 34.
- Added stochastic disturbance to the loads (at Bus 5, 6 and 8) via white noise modeled as

$$(P_L)_i[k] = (P_L)_i[k-1] + N(0, \sigma^2) \tag{2}$$

for load bus i at discrete sample k. $\sigma = 0.01$ pu.

- In order to drive the power grid towards bifurcation, steadily increased the three loads at different rates, between 20% to 30% per minute.
- Ran a time analysis simulation until critical bifurcation attained.
- Extracted the bus voltages.

Procedure: Detrending Bus Voltages

Passed the voltage signals through a Low Pass Filter in order to capture the slow changing trends not an effect of CSD. Eg. Change in bus voltages due to the gradual increasing of loads. Gaussian Kernel Smoothing Filter was used for the same.

$$h(n, \sigma_f) = \frac{1}{\sqrt{2\pi}\sigma_f} \exp^{\frac{-n^2}{2\sigma_f^2}} \tag{3}$$

where σ_f can be varied between 5 to 10 .
The detrended signal is obtained by subtracting the filtered signal from the original signal.

$$d[x] = x[k] - GKS(x[k]) \tag{4}$$

Procedure: Applying AR1 and Variance

Windows varying between $W = 1$ second to $W = 40$ seconds were used for computing autocorrelations and variances.

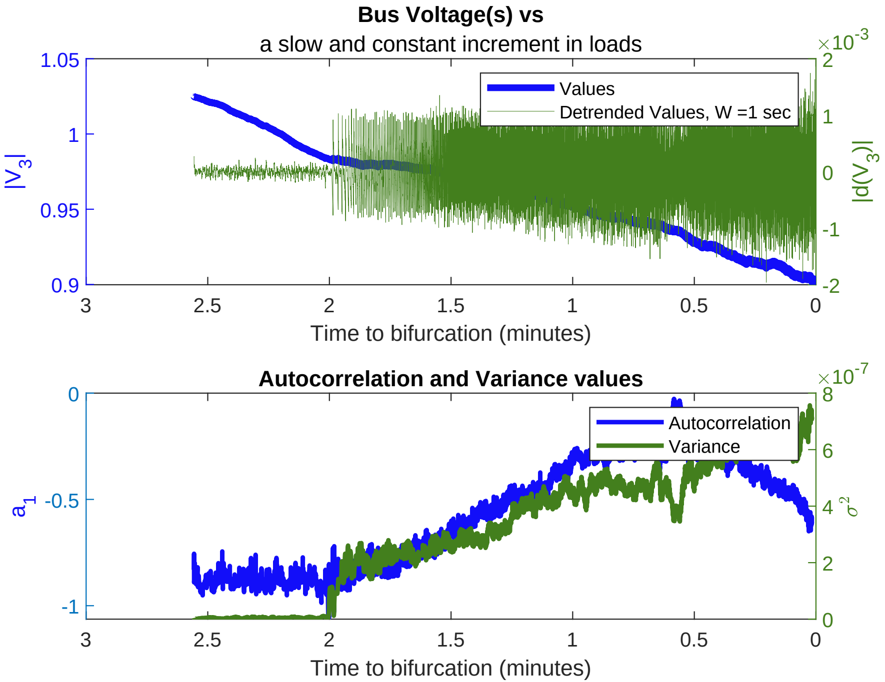
For every window, Autoregressive Model of Order 1 was fitted onto the detrended voltages using least squares of error approach.

$$d[k] = a_1 d[k-1] + e[k] \tag{5}$$

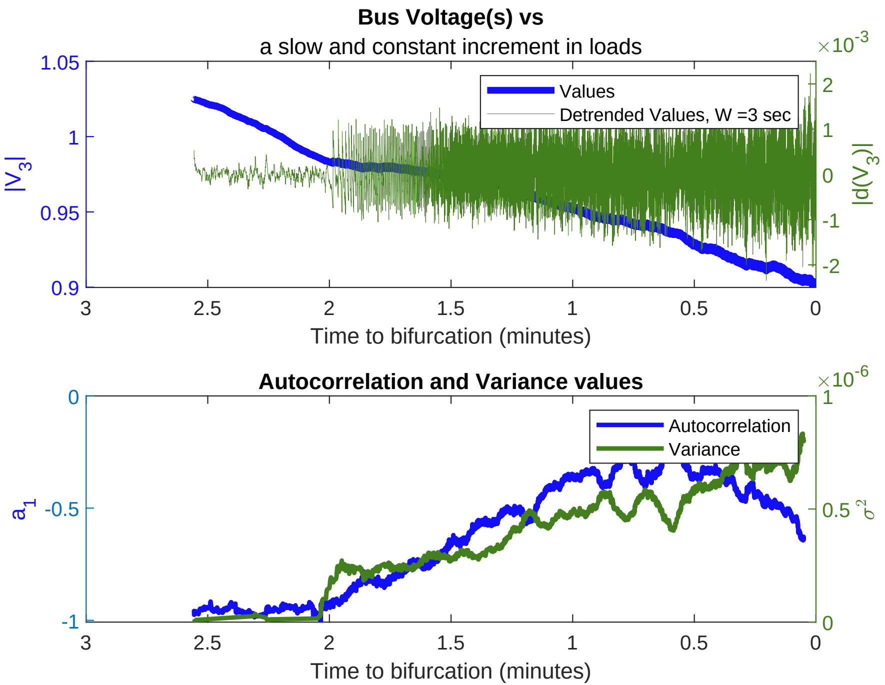
Variances were also computed for every window.

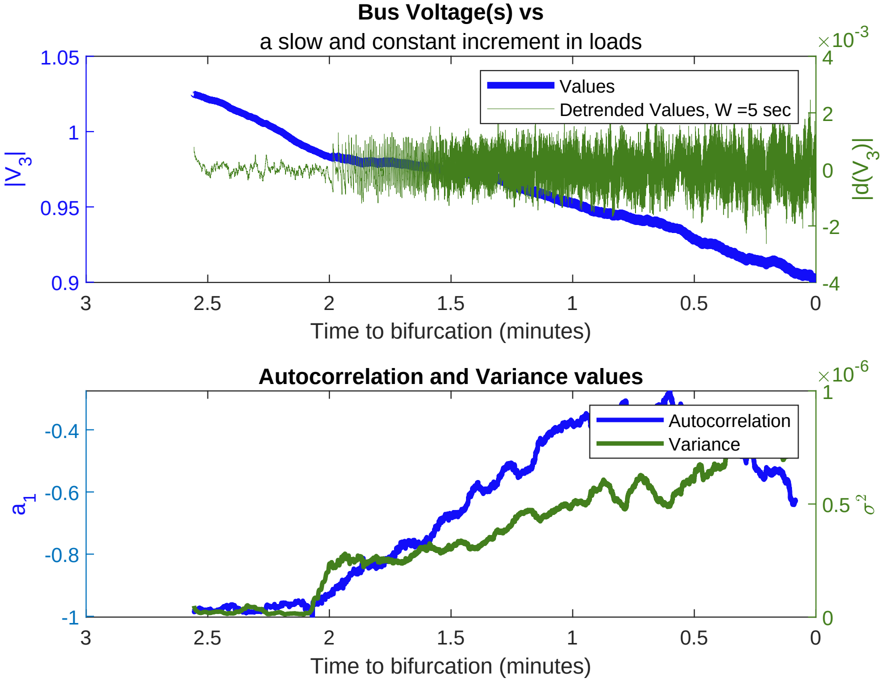
$$\sigma^2 = \frac{1}{n_k} \sum_{k=1}^{n_k} d[k]^2 \tag{6}$$

Results

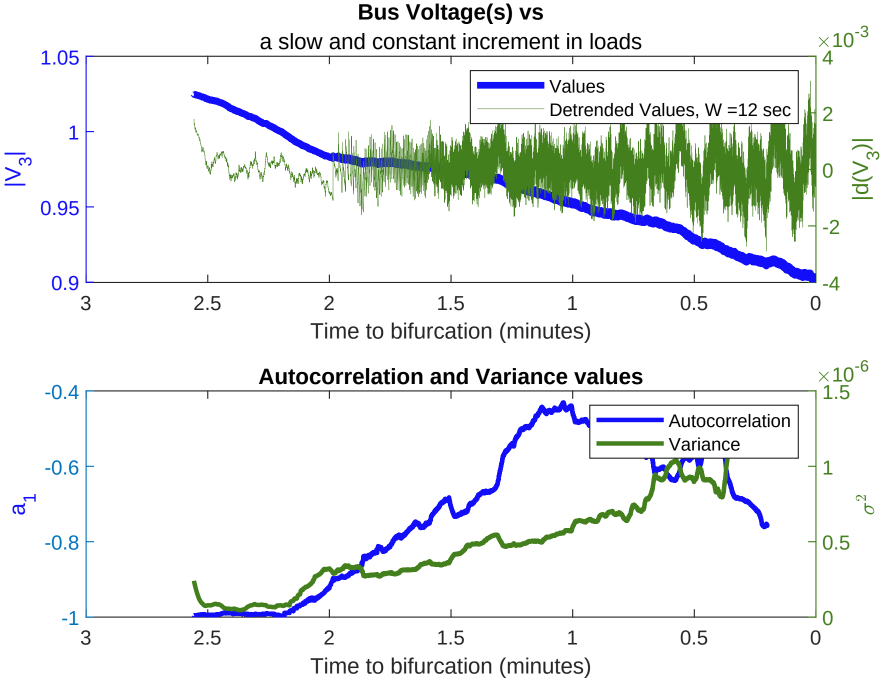


Bus Voltage(s) vs
a slow and constant increment in loads
Values
Detrended Values, W =1 sec
$|V_3|$
$|d(V_3)|$
$\times 10^{-3}$
1.05
1
0.95
0.9
2
1
0
-1
-2
3
2.5
2
1.5
1
0.5
0
Time to bifurcation (minutes)
Autocorrelation and Variance values
Autocorrelation
Variance
a_1
σ^2
$\times 10^{-7}$
0
-0.5
-1
8
6
4
2
0
3
2.5
2
1.5
1
0.5
0
Time to bifurcation (minutes)

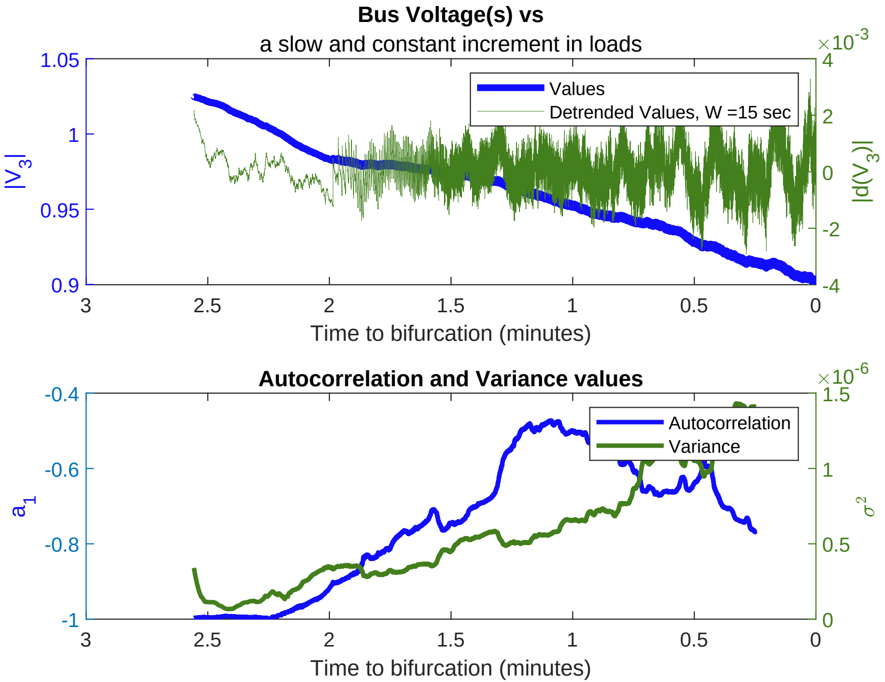

Bus Voltage(s) vs
a slow and constant increment in loads
Values
Detrended Values, W =3 sec
$|V_3|$
$|d(V_3)|$
$\times 10^{-3}$
1.05
1
0.95
0.9
2
1
0
-1
-2
3
2.5
2
1.5
1
0.5
0
Time to bifurcation (minutes)
Autocorrelation and Variance values
Autocorrelation
Variance
a_1
σ^2
$\times 10^{-6}$
0
-0.5
-1
1
0.5
0
3
2.5
2
1.5
1
0.5
0
Time to bifurcation (minutes)

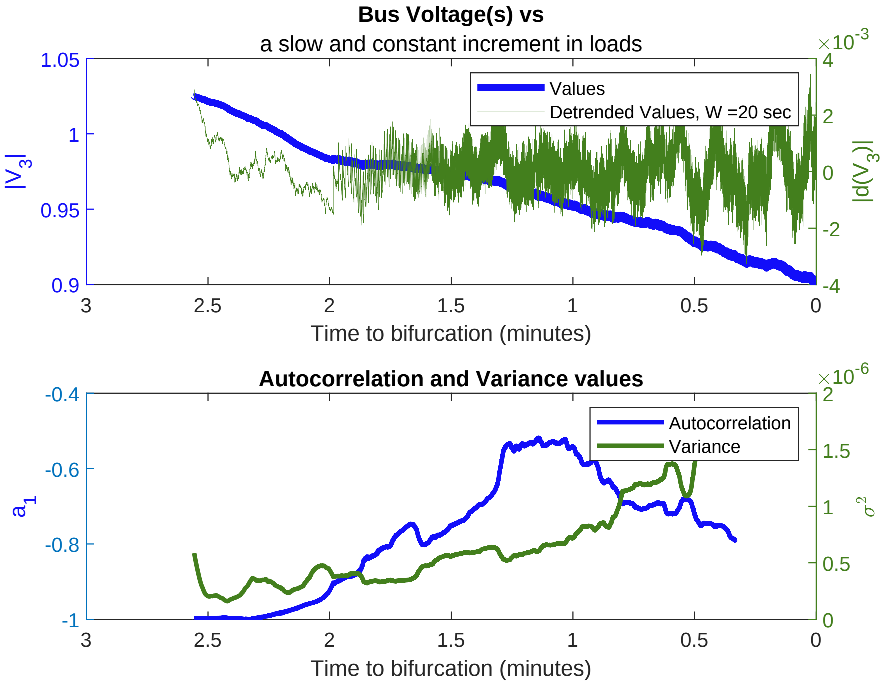


Bus Voltage(s) vs
a slow and constant increment in loads
Values
Detrended Values, W =5 sec
|V3|
|d(V3)|
×10-3
1.05
1
0.95
0.9
4
2
0
-2
-4
3
2.5
2
1.5
1
0.5
0
Time to bifurcation (minutes)
Autocorrelation and Variance values
Autocorrelation
Variance
a1
σ2
×10-6
-0.4
-0.6
-0.8
-1
1
0.5
0
3
2.5
2
1.5
1
0.5
0
Time to bifurcation (minutes)

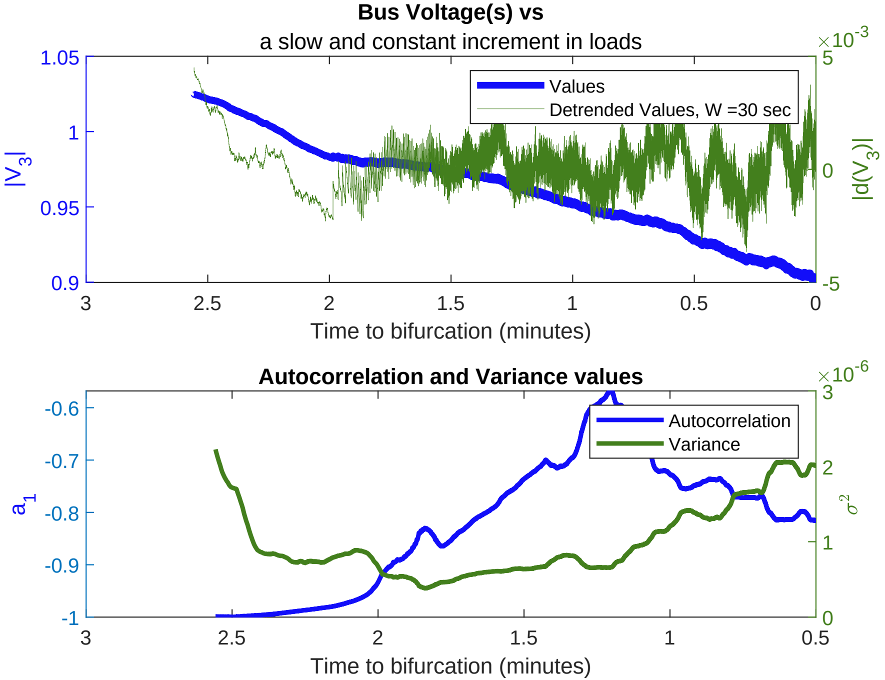


Bus Voltage(s) vs
a slow and constant increment in loads
Values
Detrended Values, W =12 sec
|V3|
|d(V3)|
×10-3
1.05
1
0.95
0.9
4
2
0
-2
-4
3
2.5
2
1.5
1
0.5
0
Time to bifurcation (minutes)
Autocorrelation and Variance values
Autocorrelation
Variance
a1
σ2
×10-6
-0.4
-0.6
-0.8
-1
1.5
1
0.5
0
3
2.5
2
1.5
1
0.5
0
Time to bifurcation (minutes)


Bus Voltage(s) vs
a slow and constant increment in loads
Values
Detrended Values, W =15 sec
$|V_3|$
$|d(V_3)|$
$\times 10^{-3}$
1.05
1
0.95
0.9
4
2
0
-2
-4
3
2.5
2
1.5
1
0.5
0
Time to bifurcation (minutes)
Autocorrelation and Variance values
Autocorrelation
Variance
a_1
σ^2
$\times 10^{-6}$
-0.4
-0.6
-0.8
-1
1.5
1
0.5
0
3
2.5
2
1.5
1
0.5
0
Time to bifurcation (minutes)



Bus Voltage(s) vs
a slow and constant increment in loads
Values
Detrended Values, W =20 sec
$|V_3|$
$|d(V_3)|$
$\times 10^{-3}$
1.05
1
0.95
0.9
4
2
0
-2
-4
3
2.5
2
1.5
1
0.5
0
Time to bifurcation (minutes)
Autocorrelation and Variance values
Autocorrelation
Variance
a_1
σ^2
$\times 10^{-6}$
-0.4
-0.6
-0.8
-1
2
1.5
1
0.5
0
3
2.5
2
1.5
1
0.5
0
Time to bifurcation (minutes)


Bus Voltage(s) vs
a slow and constant increment in loads
Values
Detrended Values, W =30 sec
$|V_3|$
$|d(V_3)|$
$\times 10^{-3}$
1.05
1
0.95
0.9
5
0
-5
3
2.5
2
1.5
1
0.5
0
Time to bifurcation (minutes)
Autocorrelation and Variance values
Autocorrelation
Variance
a_1
σ^2
$\times 10^{-6}$
-0.6
-0.7
-0.8
-0.9
-1
3
2
1
0
3
2.5
2
1.5
1
0.5
Time to bifurcation (minutes)

Conclusion and Future Work

Conclusion

Autocorrelation and Variance of the detrended bus voltage time series signal performed satisfactorily as early warning signs of Critical Slowing Down.

These statistical parameters may lose their effectiveness as EWS when the sampling window is outside the ‘suitable’ range. In this case this range may be said to be between 1 second to 15 seconds.

Future Work

- Examine CSD symptoms on line currents.
- Perform the analysis on bigger power grid models
- Attempt to construct an algorithm which can determine the 'Time to Bifurcation' for any particular power grid (supplied as a model) if given a stream of PMU data containing grid state variables.

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References

References i

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