Modeling the delay in signal transmission for synchro-phasor based power system controllers

A. I. Konara, U. D. Annakkage, University of Manitoba

I. T. Fernando, B. A. Archer, Manitoba Hydro

Introduction

Availability of PMUs (Phasor Measurements Units) enables wide area controllers through the use of remote signals. However, issues such as latency and missing signals should be properly addressed before a step into wide area concepts. This study is focused on modeling delays to assess the stability in closed loop feedback control systems.

Modeling of the Delay

Discrete time approximation

Time delayed systems are inherently infinite dimensional. Therefore, modeling involves approximations. The method we employed approximates the continuous time system to a discrete time system by zero order hold sampling [1].

- This computation method allows us to calculate closed loop system matrix and the sensitivity of the critical modes to the delay
- Delay can be modeled as additional state variables representing the past sampled values [1]

Consider a state space system

$$\dot{x}(t) = Ax(t) + Bu(t)$$
$$y(t) = Cx(t)$$

For the delay τ, where $0 < \tau \leq lh$, l is an integer, h is the sampling period

$$x_{k+1} = \phi x_k + \Gamma_0 u_k + \Gamma_1 u_{k-1}$$
$$y_k = Cx_k$$

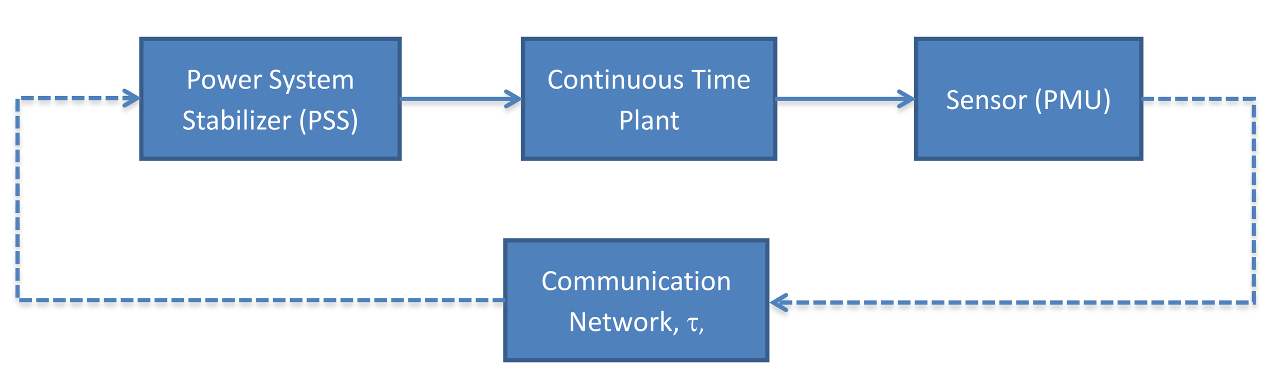
$$\phi = e^{Ah}$$
$$\Gamma_0(\tau') = \int_0^{h-\tau'} e^{Ah} ds\, B$$
$$\Gamma_1(\tau') = \int_{h-\tau'}^{h} e^{Ah} ds\, B$$
$$\tau' = \tau - (l-1)h$$

Closed loop system combining states representing delay

$$z_{k+1} = \tilde{\phi} z_k$$

$$\tilde{\phi} = \begin{bmatrix} \phi & \Gamma_1(\tau') & \Gamma_0(\tau') & \cdots & 0 \\ 0 & 0 & I & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \cdots & I \\ C & 0 & 0 & \cdots & 0 \end{bmatrix}$$

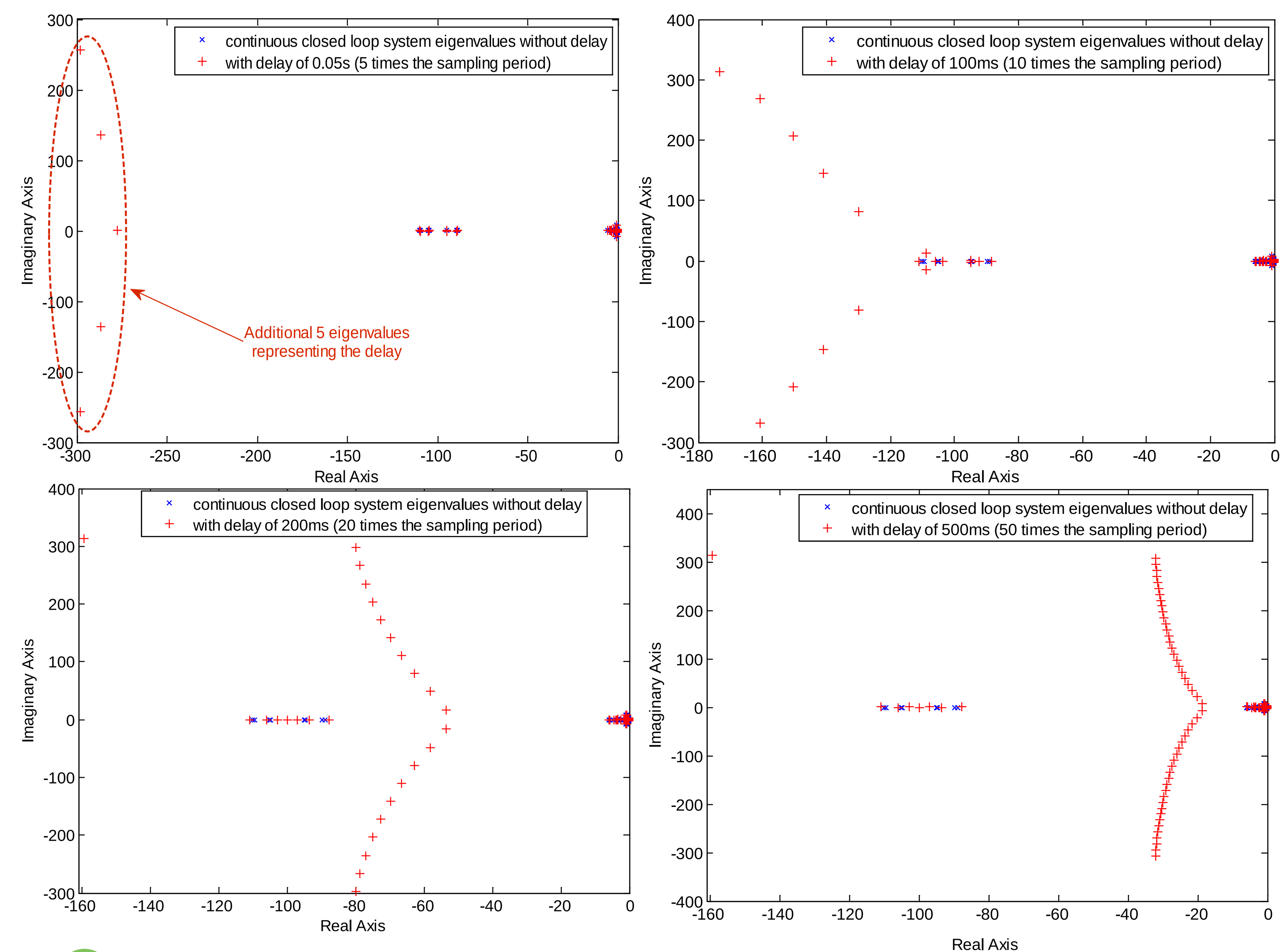
Test system



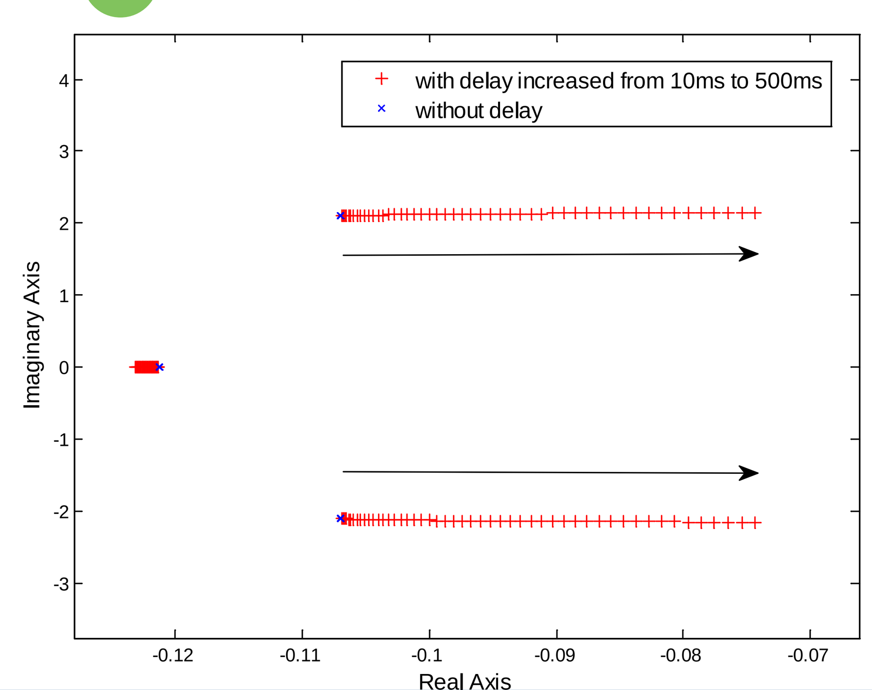
- Two Area Four Generator system was selected as the test system [2].
- Eigen analysis of the system revealed a poorly damped inter-area mode.
- Using residue analysis, a PSS was designed employing a remote signal.
- Using the PSS, the critical eigenvalue pair was moved to improve the damping to 5%.

Delay Analysis steps – discrete case

1. Selection of a sampling rate that best represents the continuous system (100Hz)
2. Observe the effect on increasing delay on the Eigenvalues representing the delay. This gives an indication of the maximum delay that can be represented with this method.

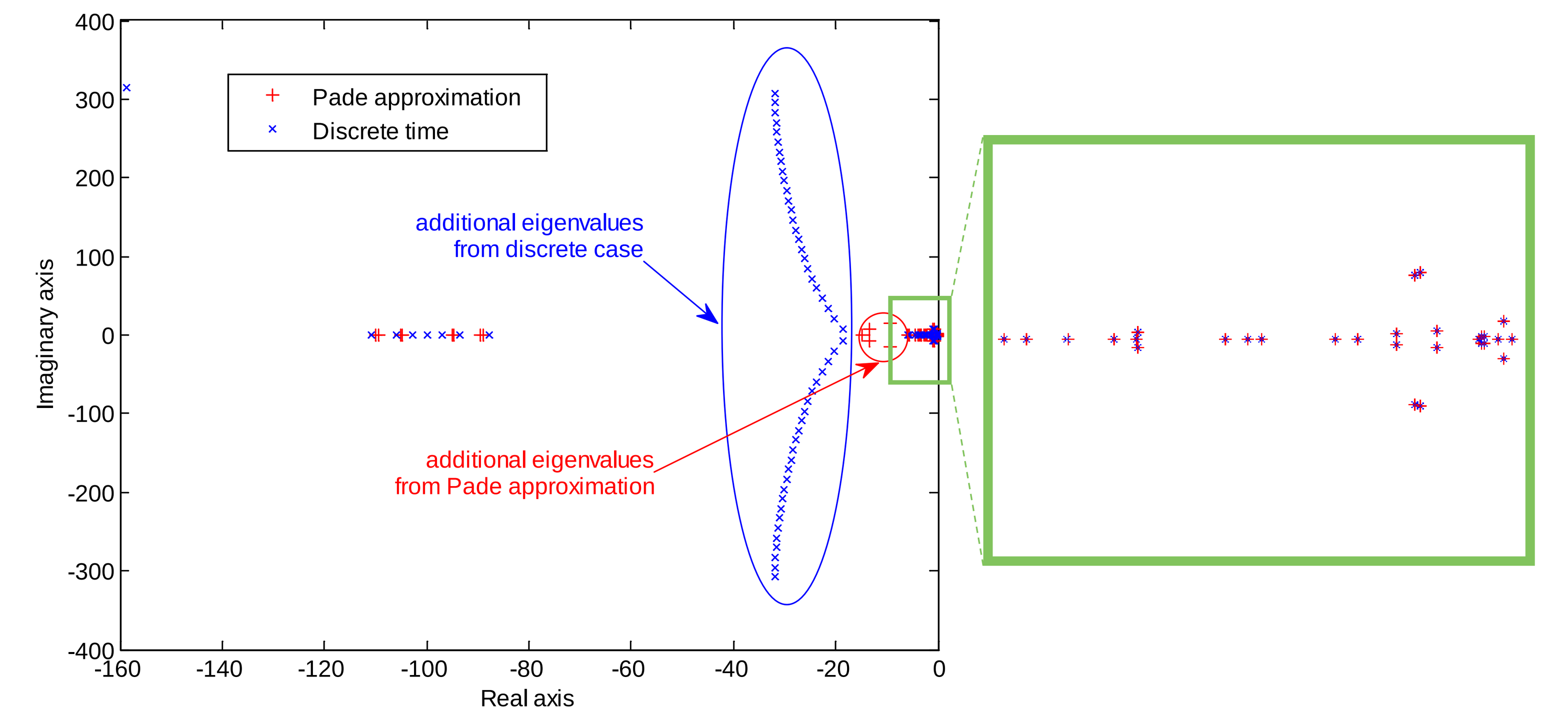


3. Sensitivity of the critical eigenvalue to the delay



- This figure shows the variation of the critical eigenvalue pair as the delay is increased
- The delay is increased from 10ms to 500ms
- The mode moves towards the right half plane
- With increasing delay, it moves further towards instability region even beyond the original critical eigenvalue before adding the PSS
- Hence it is vital to consider the delay in signal transmission

Eigenvalues compared with Padé approximation



- The eigenvalues are compared with the eigenvalues obtained by representing the delay as a Padé approximation [3] with the order of five.
- System eigenvalues closely match with the corresponding eigenvalues from that of Padé approximation when the Padé order is high (around 20).

Time domain simulation in Simulink with real delay representation can also be used to validate the results obtained from approximated methods.

Conclusions

- This method is acceptable for studying the effect of constant delays on the performance of the damping controller.
- Effects due to discretization limit the applicability of this method for large systems
- The dimension of the model increases with the sampling frequency
- This method can be easily extended for systems that have multiple delayed inputs to the controller with different delay magnitudes.

References

1. K. J. Astrom and B. Wittenmark. *Computer Controlled Systems: Theory and Design. Englewood* Clis N. J. , Prentice Hall, 1984
2. N. Kshatriya, U. D. Annakkage, A. M. Gole, and I. T. Fernando. A comparision of the use of participation factors and residues for design and location of power system stabilizers. *X SEPOPE,* 2006.
3. Joe H. Chow, Juan J. Sanchez-Gasca, Haoxing Ren, and Shaopeng Wang. Power system damping controller design using multiple input signals. IEEE Control Systems Magazine, 2000.