Preprints of the 21st IFAC World Congress (Virtual)
Berlin, Germany, July 12-17, 2020

A Cascade Structure of Damped-SOGI to Identify Multimode Low-Frequency Oscillations

Mohammad Mansouri * **David Westwick** ** **Andrew M Knight** ***

* *Electrical and Computer Engineering Department, University of Calgary, Calgary, Canada, (e-mail: mohammad.mansourihab@ucalgary.ca).*
** *Electrical and Computer Engineering Department, University of Calgary, Calgary, Canada, (e-mail: dwestwic@ucalgary.ca)*
*** *Electrical and Computer Engineering Department, University of Calgary, Calgary, Canada, (e-mail: andyknight@ieee.org)*

Abstract: The on-line estimation of low-frequency oscillations in an interconnected power system has attracted much attention as this provides vital information about the stability condition of the power system. In this paper, a measurement-based structure for estimation of the frequency, magnitude, and damping of multimode oscillations is proposed. The method can be applied to the Phasor Measurement Unit (PMU) to extract further information about the power system. The proposed method is derived by applying modifications to the parallel structure of an existing method called Damped Second Order Generalized Integrator (Damped-SOGI). The paper details the proposed cascade structure and presents simulation results to confirm the analytical derivations and the desired performance of the proposed method.

Keywords: Model, Identification, Signal Processing, Oscillations, Stability, SOGI, Estimation, PMU, Real time simulation.

A damped oscillation or an exponentially damped sinusoid (EDS) occurs as a result of interaction among different components of a system. These oscillations are often a combination of multiple single EDS signals with unknown parameters such as dampings, magnitudes, and frequencies. A relatively general expression for a damped oscillation is

$$u(t) = a_0 + \sum_{n=1}^{N} a_n e^{-\sigma_n t} \sin(\omega_n t + \delta_n) \qquad (1)$$

where a_0 is the dc component, σ_n, $\omega_n \geq 0$ and δ_n are damping, frequency and initial angle of the nth component, respectively, while $a_n e^{-\sigma_n t}$ for $a_n \geq 0$ signifies the instantaneous magnitude of this component. All these parameters are in general unknown. The frequencies are assumed to be distinct and ordered as $0 \leq \omega_1 \leq \omega_2 \leq ... \leq \omega_n$.

The electromechanical oscillations, which violate the stability of power systems, can be described by the model of (1), (Zhu et al., 2019). Such oscillations are reflected on the synchrophasor data provided by the phasor measurement units (PMUs) across the power system (Barchi et al., 2013). Accurate extraction of these oscillations is used to take appropriate control actions to maintain the balance of the system; consequently, it can prevent instabilities and blackouts (Du et al., 2018).

The estimation of electromechanical oscillations is categorized into two categories: model-based methods and measurement-based methods. In model-based methods, the governing equations of a power system are linearized about its operating point, and the oscillations' parameters (frequencies and dampings) are obtained by computing eigenvalues of the linearized system. In measurement-based methods, a linear model of the power system, such as an autoregressive moving average exogenous (ARMAX) model, is fitted to the wide-area system measurements (Du et al., 2018). Measurement-based methods benefit from the fact that they use data directly measured data from the system by PMUs; therefore, they do not need the model of the power systems. Consequently, more recent developments have focused on measurement-based methods. Various measurement-based methods have been proposed to estimate the parameters of electromechanical oscillations. Some of the existing techniques have been reported and compared in (Agrawal et al., 2019; Jiang et al., 2018). Although they have acceptable performance for one-single mode or two-single mode of electromechanical oscillation, they fail to estimate electromechanical oscillations that have more than two modes.

The second-order generalized integrator (SOGI) has been introduced as a building block for the orthogonal signal generator (OSG). The orthogonal signal is used in a direct integration for adapting the center frequency of SOGI, and this has resulted in the SOGI-FLL (for frequency-locked loop) and the adaptive notch filter (ANF). The SOGI-FLL and ANF have been developed for several applications such as power system frequency estimation (Mojiri and

Bakhshai, 2004), harmonics extraction, and grid synchronization (Rodriguez et al., 2007). (Mansouri et al., 2015) modifies SOGI and propose an algorithm, called Damped-SOGI, to extract the parameters of EDS signals. A parallel structure of Damped-SOGI also proposes to extract the multimode electromechanical oscillations; however, its performance fails when there are more than two electromechanical modes.

In this paper, motivated by damped-SOGI, a cascade structure to estimate multimode electromechanical oscillations is proposed. The performance of this structure for multimode electromechanical oscillations is robust in comparison with the parallel structure of damped-SOGI. It goes without saying that in addition to intrinsic benefits, the proposed method has the advantages of measurement-based methods, as discussed before.

The paper is organized as follows. Section I provides a brief review of the Damped-SOGI; afterward, it explains the structure of the proposed cascade structure. Section II evaluates the performance of the proposed algorithm and concluding remarks are drawn in Section III.

1. CASCADE STRUCTURE

In this section, we firstly review the parallel structure of Damped-SOGI; afterward, the proposed cascade structure is explained.

1.1 Review of Damped-SOGI

Second-Order Generalized Integrator is a well-known structure for estimating the frequency of sinusoid signals. (Mansouri et al., 2015) modifies this structure and introduce a new structure called Damped-SOGI. Damped-SOGI can estimate the frequency and damping of damped sinusoid signals and EDS signals. The extraction of electromechanical oscillations is a potential application for Damped-SOGI. Each Damped-SOGI can extract the frequency and damping of a single electromechanical mode; however, the electromechanical oscillations typically have more than one mode. To solve this issue, (Mansouri et al., 2015) proposed a parallel structure of Damped-SOGI, as shown in figure (1), to extract the multimode electromechanical modes. However, this structure is not robust and has an error when there are three electromechanical modes and more at the same time.

1.2 Proposed Cascade Structure

To solve the robustness of the parallel structure of Damped-SOGI, we proposed a cascade structure, as shown in figure (2). If we consider the input signal as follows:

$$u = x_1 + x_2 + \cdots + x_n \tag{2}$$

where x_n is the nth mode of the input signal. The first Damped-SOGI block extract the first component of the input signal called x_{12}; therefore,

$$e_1 = u - x_{12} \tag{3}$$

Now, e_1 is applied to the second Damped-SOGI block, and x_{22} is extracted. Thus, e_2 can be calculated as

$$e_2 = e_1 - x_{22} = u - x_{12} - x_{22} \tag{4}$$

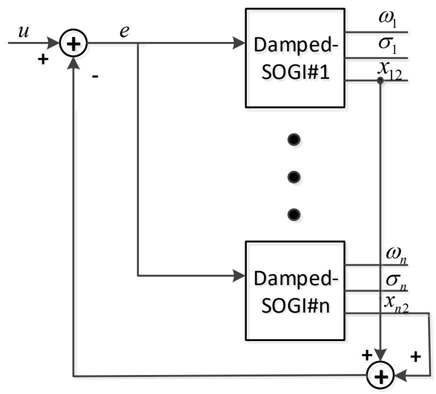

Fig. 1. Parallel structure of Damped-SOGI. u, ω, σ, and x are the input, the estimated frequency, the estimated damping, and the extracted input signal by Damped-SOGI, respectively.

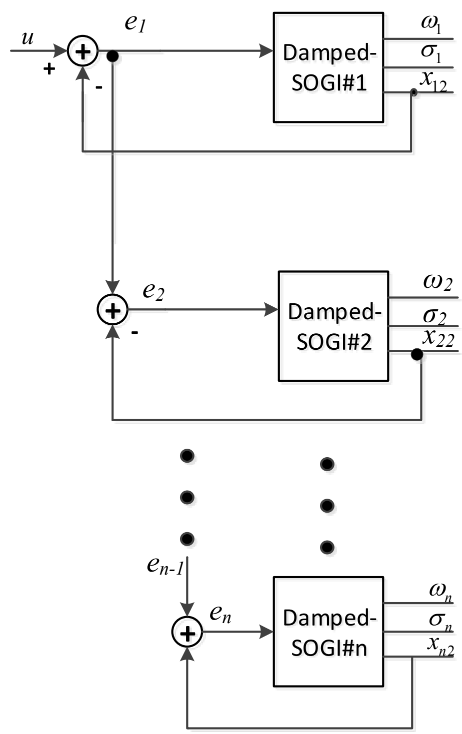

Fig. 2. Proposed cascade structure of Damped-SOGI

Then, e_2 is applied to the third Damped-SOGI block, and it continues until all components of the input signal extracted. Moreover, the algorithm will stop to search the new component when the error becomes less than the value defined by a user.

The simulation shows that this method is more robust in comparison with the parallel structure of Damped-SOGI. The robustness and less calculation load are the advantages of the proposed structure.

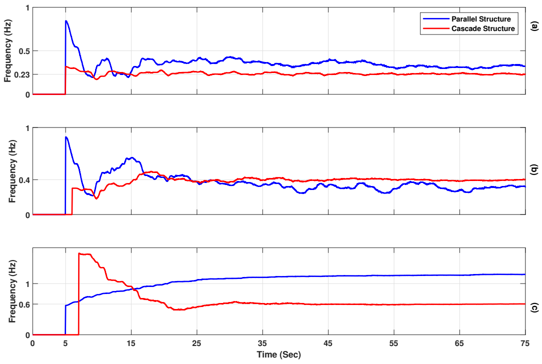

Fig. 3. Estimation of the frequency by both structure: a)The estimated frequency of first component b)The estimated frequency of second component c)The estimated frequency of third component

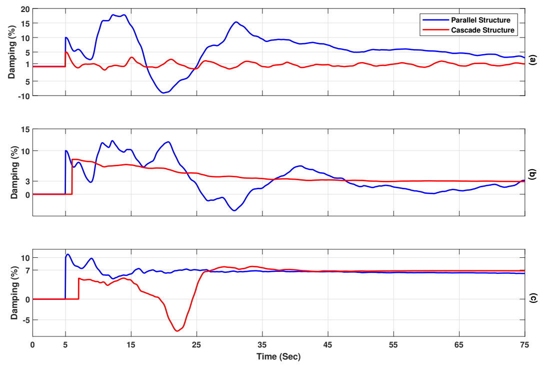

Fig. 4. Estimation of the damping by both structure: a)The estimated damping of first component b)The estimated damping of second component c)The estimated daming of third component

2. SIMULATION

To show the effectiveness of the proposed structure, a three-mode EDS signal is applied to both parallel structure and proposed cascade structure. The applied signal is as

$$\begin{aligned} u(t) &= 1 + 0.2e^{-0.01t}\sin(2\pi(0.23)t + 0.2) \\ &+ 0.2e^{-0.03t}\sin(2\pi(0.4)t + 0.2) \\ &+ 0.2e^{-0.07t}\sin(2\pi(1.2)t + 0.2) \\ &+ n(t) \end{aligned} \tag{5}$$

where $n(t)$ is a zero mean white Gaussian noise with a variance of 0.1. This noise add to input signal because PMU data is usually violated by noise. Figures (3) and (4) indicate the extracted frequency and damping, respectively. Comparing the performance of the parallel structure proposed by (Mansouri et al., 2015) and the proposed cascade structure shown in figure (3), it is obvious that the proposed cascade structure can extract the frequency of all modes while the parallel structure fails to extract the frequencies. As it is indicated in figure (4), the cascade structure can estimate the damping faster and more accurate in comparison with the parallel structure.

3. CONCLUSION

A measurement-based method for direct estimation of the magnitude, frequency and damping of multimode electromechanical oscillations in a power system from the phasor measurement data is proposed in this paper. The proposed method is based on introducing a new structure for using Damped-SOGI. Simulation results show the desirable performance of the proposed method. In comparison with some existing methods such as Damped-SOGI. Direct estimation of parameters, structure simplicity, fast convergence, and capability of estimation of multiple modes of electromechanical oscillations are the advantage of the proposed method. These features of the proposed method render it a promising analysis tool to be incorporated in PMU algorithms or in the analysis algorithms at the concentrated data centers to increase the situational awareness of the power system and/or to be used to improve the stability of the system against the system contingencies.

REFERENCES

Agrawal, U., Follum, J., Pierre, J.W., and Duan, D. (2019). Electromechanical mode estimation in the presence of periodic forced oscillations. *IEEE Transactions on Power Systems*, 34(2), 1579–1588. doi: 10.1109/TPWRS.2018.2876128.

Barchi, G., Macii, D., and Petri, D. (2013). Synchrophasor estimators accuracy: A comparative analysis. *IEEE Transactions on Instrumentation and Measurement*, 62(5), 963–973. doi:10.1109/TIM.2012.2236776.

Du, W., Bi, J., and Wang, H. (2018). Damping degradation of power system low-frequency electromechanical oscillations caused by open-loop modal resonance. *IEEE Transactions on Power Systems*, 33(5), 5072–5081. doi: 10.1109/TPWRS.2018.2805187.

Jiang, T., Li, X., Yuan, H., Jia, H., and Li, F. (2018). Estimating electromechanical oscillation modes from synchrophasor measurements in bulk power grids using fssi. *IET Generation, Transmission Distribution*, 12(10), 2347–2358. doi:10.1049/iet-gtd.2017.1492.

Mansouri, M., Mojiri, M., Ghadiri-Modarres, M.A., and Karimi-Ghartemani, M. (2015). Estimation of electromechanical oscillations from phasor measurements using second-order generalized integrator. *IEEE Transactions on Instrumentation and Measurement*, 64(4), 943–950. doi:10.1109/TIM.2014.2365401.

Mojiri, M. and Bakhshai, A.R. (2004). An adaptive notch filter for frequency estimation of a periodic signal. *IEEE Transactions on Automatic Control*, 49(2), 314–318. doi: 10.1109/TAC.2003.821414.

Rodriguez, P., Pou, J., Bergas, J., Candela, J.I., Burgos, R.P., and Boroyevich, D. (2007). Decoupled double synchronous reference frame pll for power converters control. *IEEE Transactions on Power Electronics*, 22(2), 584–592. doi:10.1109/TPEL.2006.890000.

Zhu, Y., Liu, C., and Yao, L. (2019). A faster estimation method for electromechanical oscillation frequencies. *IEEE Transactions on Power Systems*, 34(4), 3280–3282. doi:10.1109/TPWRS.2019.2914855.