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# Small-signal dynamic modeling of Symmetrical SOGI-PLL (SSOGI-PLL) structure


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## INTRODUCTION & AIM

Modern power systems face growing synchronization challenges due to DC offsets, subharmonics, and voltage distortions. The symmetrical second-order generalized integrator phase-locked loop (SSOGI-PLL) effectively addresses these issues by incorporating a low-pass filter (LPF) tuned to the grid frequency, enabling band-pass filtering behavior and accurate total harmonic distortion (THD) estimation. However, in existing small-signal models, the third pole—introduced by internal filtering and control dynamics—is typically approximated, leading to reduced modeling accuracy. This work refines the small-signal model by systematically identifying the optimal location of the third pole. Multiple candidate models, with the pole placed at different multiples of the fundamental frequency (e.g., 2.5, 2.8, and 3 times), are analyzed and validated against the nonlinear SSOGI-PLL using MATLAB/Simulink under various grid disturbances. Results show that the proposed approach significantly improves model accuracy and alignment with nonlinear behavior, providing a more reliable basis for stability analysis and design of SSOGI-PLL systems.

## METHODOLOGY

Fig. 1 shows the architecture of the proposed scheme [1]. Here, there are three main pillars, i.e., SSOGI, PLL, and THD [2]. Fig. 2 shows the SSOGI internal architecture, and the Bode plots showing the symmetrical behavior of this technique are presented in Fig. 3. Equations (1) and (2) show the quadrature outputs of this system. The small signal model of SSOGI-PLL model is presented in Fig. 4, but to systematically identify the most accurate third pole location, the empirical factor α = 3 in the published open-loop transfer function is replaced by a generalized variable α as can be observed in (3), yielding three candidate models corresponding to α = 2.5, 2.8, and 3.0. These values represent the third pole locations at 549.8, 615.8, and 659.7 rad/s, respectively. Each candidate model is evaluated through frequency-domain analysis using Bode plots and root locus, and time-domain analysis using closed-loop step response. The design target phase margin of 53°, established analytically in the original SSOGI-PLL work, serves as the reference criterion for model accuracy. All analyses are performed in MATLAB, and results are validated against the nonlinear SSOGI-PLL Simulink model subjected to a 2 Hz frequency step.

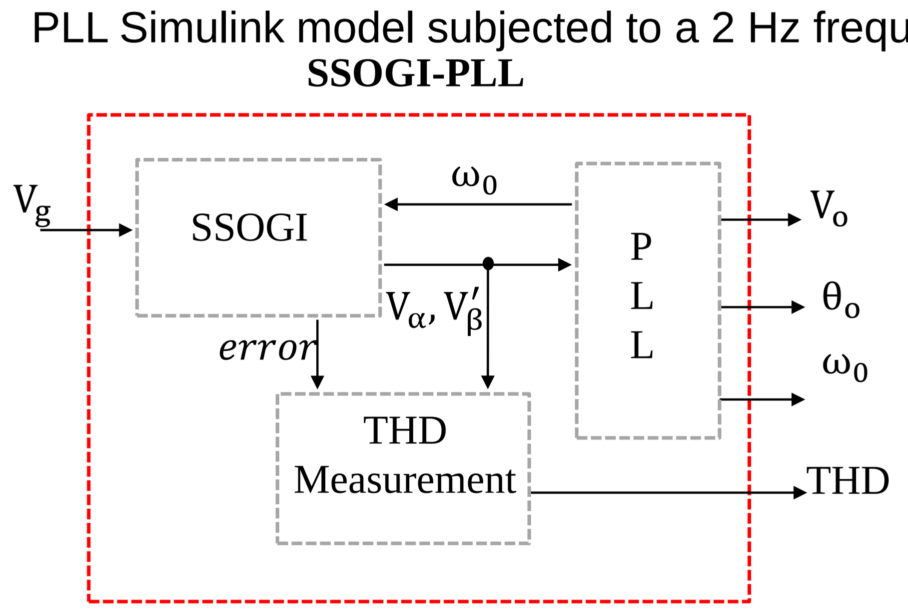


**Fig. 1.** Block diagram of the proposed SSOGI-PLL

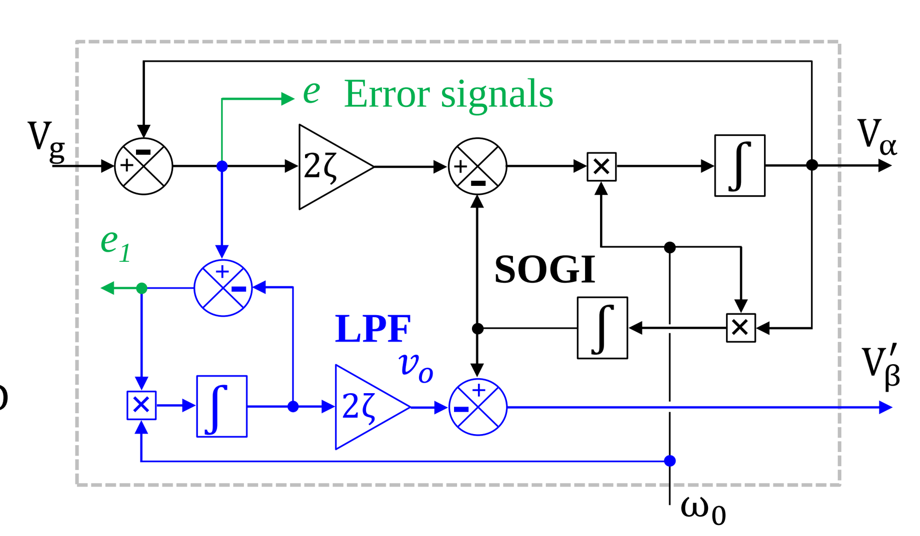


**Fig. 2.** Block diagram of the SSOGI structure.

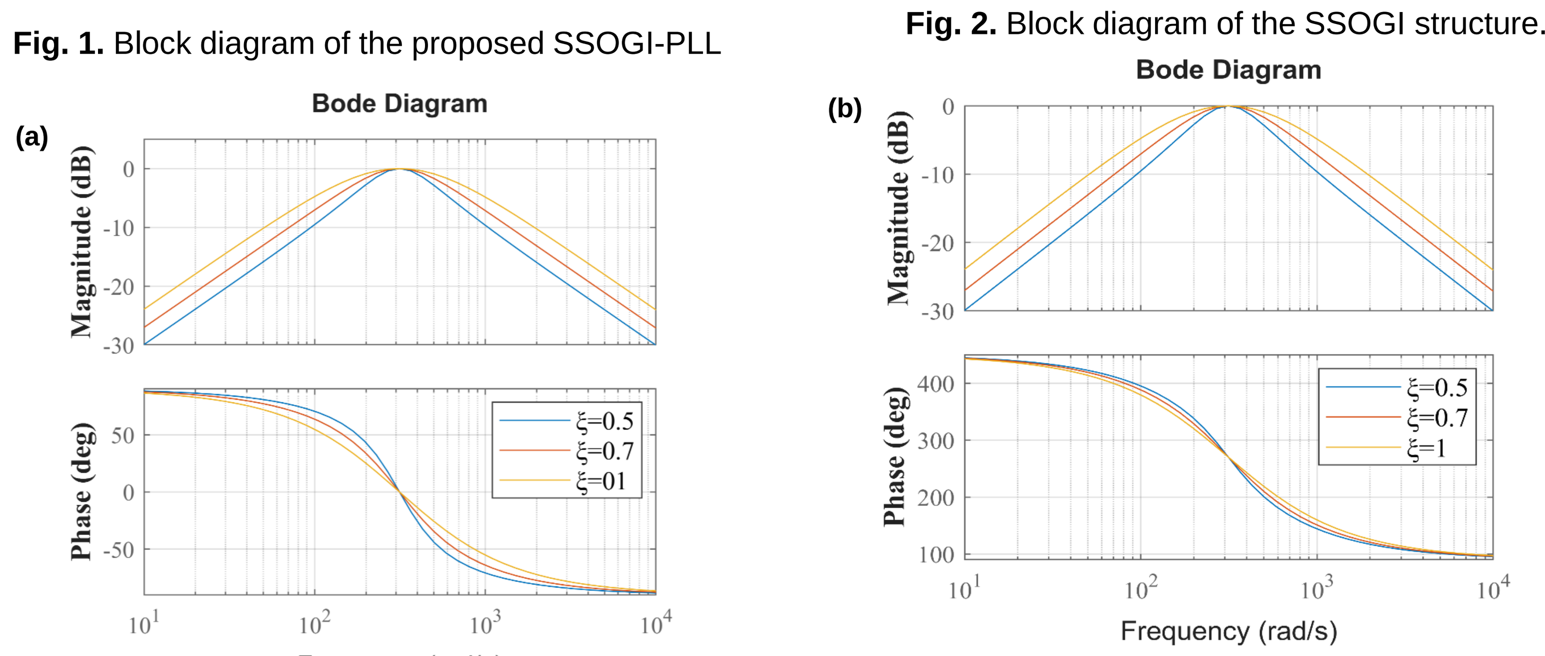


**Fig. 3.** Bode plots of the quadrature outputs of SSOGI with identical BPF characteristics at different values of ξ as (a) SSOGI_$G_\alpha$. (b) SSOGI_$G'_\beta$.

$$G_\alpha(s) = \frac{V_\alpha(s)}{V_g(s)} = \frac{2\xi\omega_o s}{s^2 + 2\xi\omega_o s + {\omega_o}^2} \quad (1)$$

$$G'_\beta(s) = \frac{V'_\beta(s)}{V_g(s)} = \frac{2\xi\omega_o(-s+\omega_o)s}{s^3 + \omega_o(1+2\xi)s^2 + \omega_o^2(1+2\xi)s + \omega_o^3} \quad (2)$$

## RESULTS & DISCUSSION

The frequency-domain analysis reveals that all three candidate models achieve phase margins close to the design target, with values of 52.60°, 53.13°, and 53.42° for α = 2.5, 2.8, and 3.0, respectively as shown in Fig. 5. Among these, α = 2.8 achieves the smallest phase margin error of 0.13°, compared to 0.40° and 0.42° for α = 2.5 and α = 3.0, respectively, confirming it as the most accurate representation of the third pole location.

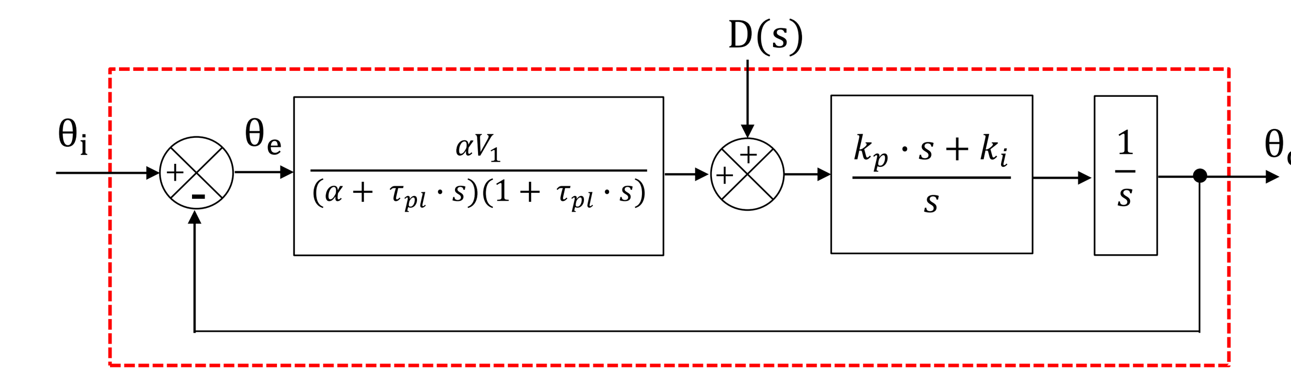


Fig. 4. Small signal model of SSOGI-PLL.

$$G_{OL,SSOGI-PLL}(s) = \frac{\alpha V_1}{(1+\tau_{pl}\cdot s)(\alpha+\tau_{pl}\cdot s)} \cdot \frac{k_p\cdot s + k_i}{s} \cdot \frac{1}{s} \quad (3)$$

The root locus analysis is shown in Fig. 6. It further confirms that all three models exhibit stable closed-loop behavior with comparable dominant pole positions, and the third real pole shifts further into the left-half plane as α increases. The expressions of parameters are given in (5) and (6).

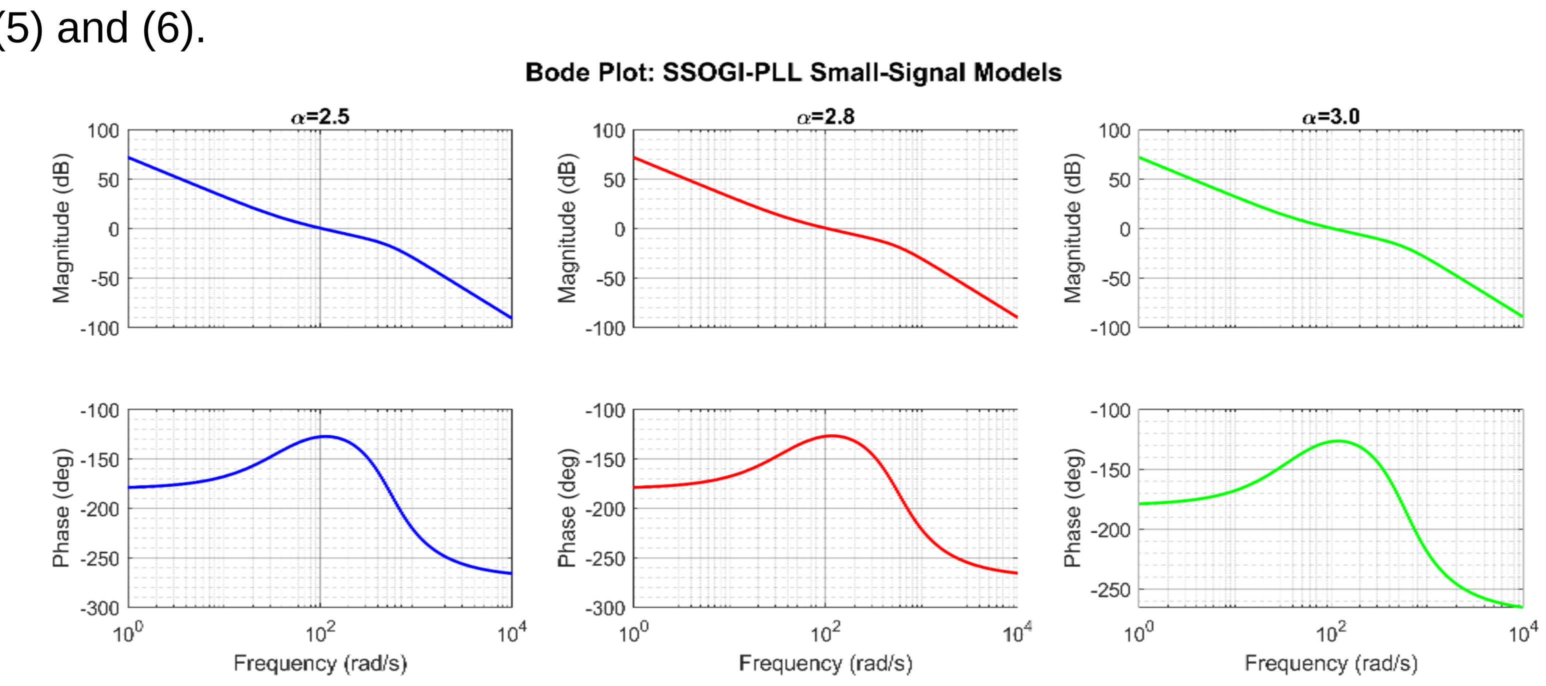


**Fig. 5.** Bode Plots for SSOGI-PLL at different values of $\alpha$-factor

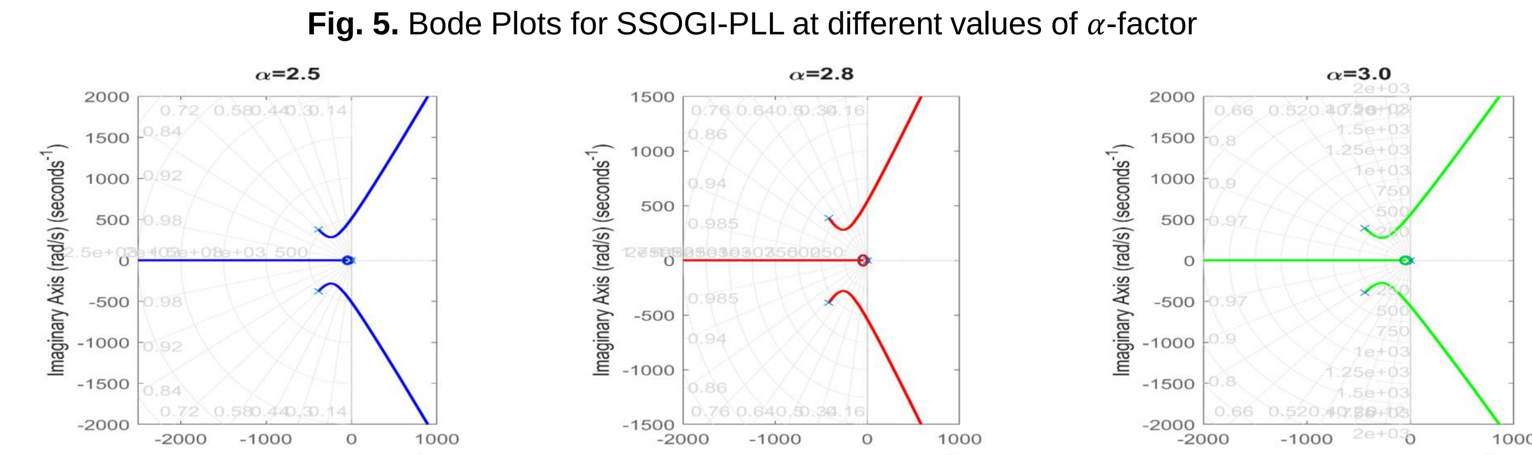


**Fig. 6.** Root Locus Plots for SSOGI-PLL at different values of $\alpha$-factor

$$\tau_{pl} = \frac{1}{\xi\cdot\omega_o} \quad (4) \qquad k_i = \frac{{k_p}^2}{b} \quad (5)$$

In the time domain, the closed-loop step responses of all three models show comparable settling times (~0.071 s) and overshoots (~25%), with α = 2.8 achieving the lowest overall distance metric of 0.1657 compared with the nonlinear system response.

Table 1. Design parameters and comparison

| Parameters | $\xi$=0.7, kp=98, ki=4002, b=2.4, $\omega_o$=2π50 rad/s | | |
|---|---|---|---|
| | α = 2.5 | α = 2.8 | α = 3.0 |
| Third real pole (rad/s) | 549.8 | 615.8 | 659.7 |
| Phase margin (°) | 52.60 | 53.13 | 53.42 |
| Stable | yes | yes | yes |

These findings demonstrate that α = 3.0 slightly overestimates the third pole location, and that α = 2.8 — corresponding to a third pole at 615.8 rad/s — provides a more accurate and reliable small-signal representation of the SSOGI-PLL for stability assessment and controller design. Table 1 presents the design parameters and results.

## CONCLUSION/ FUTURE WORK

This work presents a systematic refinement of the SSOGI-PLL small-signal model by identifying the optimal location of the empirically approximated third pole. Among the three candidate values evaluated (α = 2.5, 2.8, and 3.0), the model with α = 2.8 provides the most accurate representation. The refined model with these parameters provides a more reliable analytical foundation for stability assessment and PI controller design of SSOGI-PLL based grid synchronization systems.

## REFERENCES


1. M. Armughan Shakeel, J. Matas, H. Martínez-García, J.M. Guerrero, Improved SOGI-PLL model for grid distortions and THD measurement capability, International Journal of Electrical Power & Energy Systems, Volume 177, 2026, 111795, ISSN 0142-0615, https://doi.org/10.1016/j.ijepes.2026.111795.
2. Matas, José, et al. "A new THD measurement method with small computational burden using a SOGI-FLL grid monitoring system." *IEEE Transactions on Power Electronics* 35.6 (2019): 5797-5811.