Comparison of SOGI-FLL with SOGI-PLL for Grid Synchronization of Single-Phase Systems

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***Abstract*— This paper presents a comparison between SOGI-PLL and SOGI-FLL methods for grid synchronization in single-phase systems. Both methods are tested under three types of input disturbances: phase, frequency, and magnitude changes. Simulation results show that SOGI-PLL performs better in response to sudden phase shifts, while SOGI-FLL offers improved performance under frequency and amplitude variations. Additionally, the effect of different settling times on FLL behavior is examined. The results highlight the strengths and limitations of each method and provide insights for selecting the appropriate synchronization strategy based on application needs.**

Keywords— SOGI-PLL, SOGI-FLL, grid synchronization, single-phase systems, phase-locked loop, frequency-locked loop, settling time, disturbance response.

I. Introduction (*Heading 1*)

In modern power systems, the integration of renewable energy sources and power electronic converters is increasing rapidly. These systems must synchronize accurately with the grid to operate reliably and efficiently. In single-phase systems, grid synchronization might be ensured using some techniques, such as PLL, FLL, Zero-Crossing Detection, Adaptive Notch Filters [1].

In this project, the performance of SOGI-PLL and SOGI-FLL will be compared through simulations in MATLAB/Simulink. The comparison will focus on their behavior under three conditions: sudden phase disturbance, sudden frequency disturbance, and sudden amplitude disturbance in the input signal. The aim is to evaluate the dynamic response, stability, and accuracy of both synchronization methods.

The rest of this report includes a brief explanation of each synchronization method, the simulation setup and criteria for comparison, detailed results, and a final discussion on their advantages and limitations under various disturbances.

II. Background

The Second Order Generalized Integrator (SOGI) is a structure used to extract the fundamental component of an input signal and generate a quadrature (90° phase-shifted) version of it. This makes it suitable for signal synchronization in single-phase systems, where only one input signal is available.

The SOGI-PLL combines the SOGI block with a traditional Phase-Locked Loop. The SOGI generates the in-phase and quadrature components, which are then used in a Park transformation to estimate the phase angle and frequency through a feedback loop with a PI controller.

The SOGI-FLL is a simplified alternative to the SOGI-PLL. It eliminates the PI controller and instead uses a Frequency-Locked Loop, which adjusts the internal frequency of the SOGI directly using a frequency adaptation algorithm.

While PLL offers fast dynamic response and precise phase tracking, it may require tuning and can be sensitive to frequency variations. On the other hand, FLL has a simpler structure, better handles frequency deviations, and requires less tuning, but its response can be slightly slower during sudden changes

III. Simulation Overview

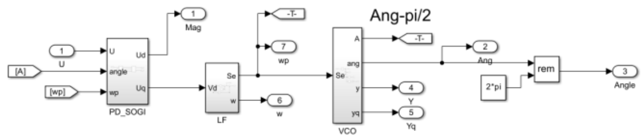

Figure 1 PLL System Overview

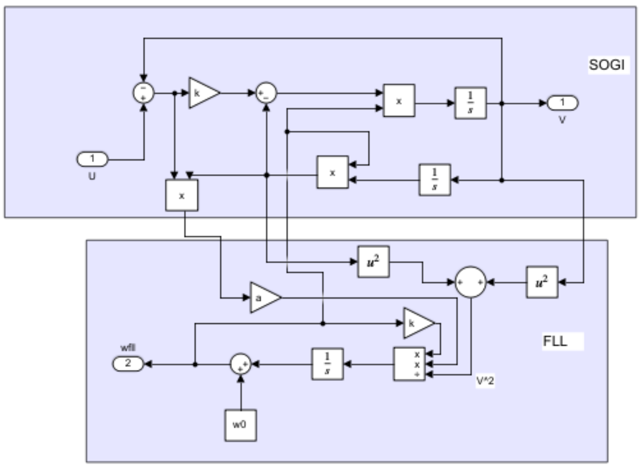

Figure 2 FLL System Overview

IV. Simulation scenarios and performance assessment criterias

To evaluate and compare the performance of the SOGI-PLL and SOGI-FLL methods, several simulation scenarios are designed in Simulink. These scenarios introduce sudden disturbances to the input signal to test the dynamic response, stability, and accuracy of each synchronization method. Scenarios are applied in order in simulation. At t= 0.25s, phase is disturbed, at t=0.5s frequency is disturbed, at t = 0.75 s magnitude is disturbed.

Additionally, SOGI-FLL is simulated for different settling times and same scenario is applied.

The performance of SOGI-PLL and SOGI-FLL are assessed using certain criterias. First one is, the steady-state error between the estimated and actual frequency or phase after the disturbance has settled. Second one is, the presence and magnitude of overshoot or oscillatory behavior in the phase or frequency estimation during transients. Last one is the ability of the method to maintain correct phase and frequency estimation despite changes in signal amplitude.

V. Simulation Results

A first look at the simulation results reveals distinct responses of the two methods to different types of disturbances. At 0.25 seconds, when a phase disturbance is applied, the PLL (bottom plot) responds more quickly and smoothly, showing better phase tracking with minimal oscillations. In contrast, the FLL (top plot) exhibits noticeable transient oscillations and takes longer to settle. At 0.5 seconds, during a frequency disturbance, the FLL adapts faster and maintains synchronization with the input signal, while the PLL shows a brief mismatch in frequency tracking. At 0.75 seconds, when a magnitude disturbance occurs, the FLL output remains closely aligned with the input signal, indicating good robustness to amplitude changes, whereas the PLL shows a temporary deviation. In summary, the PLL performs better during phase disturbances, while the FLL shows superior performance under frequency and magnitude disturbances.

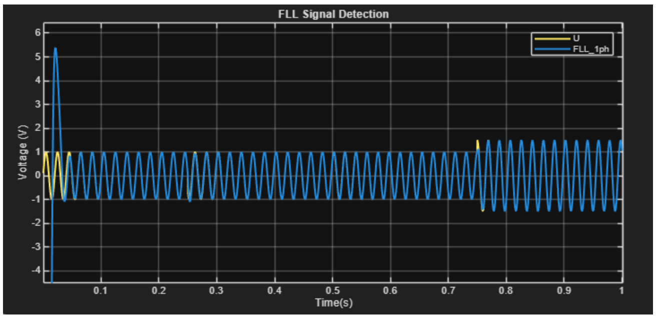

Figure 3 FLL Signal Detection plot

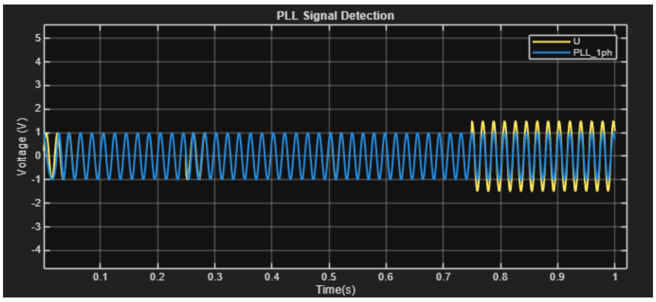

Figure 4 PLL Signal Detection plot

VI. Comparison

The performance of SOGI-PLL and SOGI-FLL has been compared under three different input signal disturbances: sudden phase disturbance, sudden frequency disturbance, and sudden magnitude disturbance. The goal is to evaluate how each synchronization method responds to changes in grid conditions in terms of accuracy, stability, and dynamic response.

A. Sudden Phase Disturbance

In the case of a sudden change in the phase angle of the input signal, the SOGI-PLL shows superior performance. Thanks to the presence of a PI controller and feedback loop, it reacts more quickly and accurately to phase shifts. The estimated phase settles faster and exhibits less overshoot and oscillation compared to the FLL. SOGI-FLL, on the other hand, responds more slowly to phase jumps, since its structure is designed primarily for frequency adaptation rather than fast phase correction.

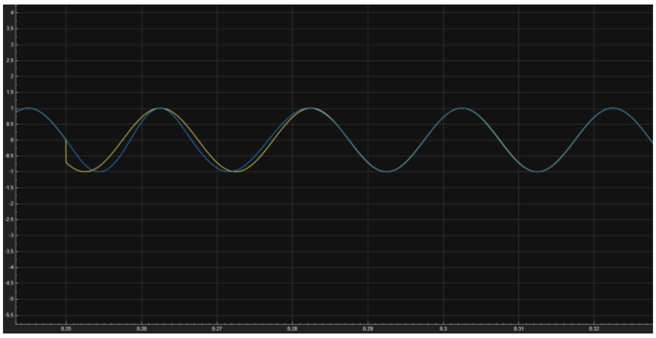

Figure 5 PLL Signal Detection 0.25-0.35s

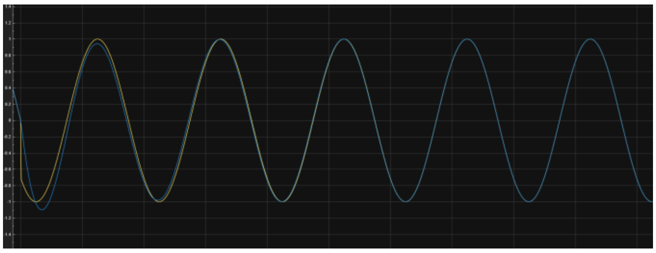

Figure 6 FLL Signal Detection 0.25-0.35s

B. Sudden Frequency Disturbance

Under a step change in frequency, SOGI-FLL performs better than SOGI-PLL. The FLL structure allows the system to adapt its internal frequency directly, without relying on indirect estimation through a phase error. This leads to faster and more accurate tracking of the new frequency. In contrast, SOGI-PLL exhibits slower adaptation and transient errors, especially when the frequency deviation is large or persistent.

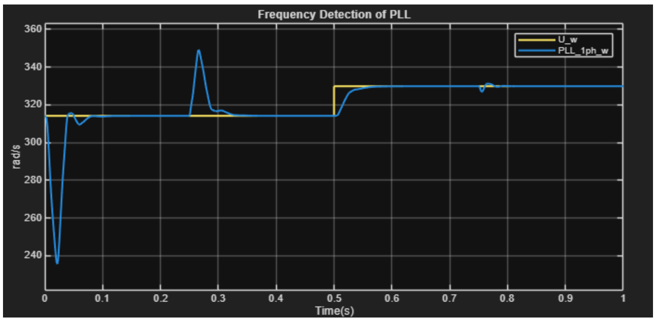

Figure 7 Frequency of the input and output signals with PLL

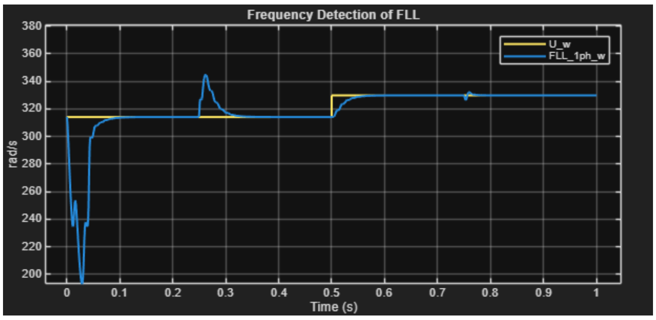

Figure 8 Frequency of the input and output signals with FLL

Under a step change in frequency, SOGI-FLL performs better than SOGI-PLL. The FLL structure allows the system to adapt its internal frequency directly, without relying on indirect estimation through a phase error. This leads to faster and more accurate tracking of the new frequency. In contrast, SOGI-PLL exhibits slower adaptation and transient errors, especially when the frequency deviation is large or persistent.

C. *Sudden Magnitude Disturbance*

When a sudden change in the amplitude of the input signal is introduced, SOGI-FLL again demonstrates better robustness. Its frequency estimation is not significantly affected by variations in magnitude, allowing stable synchronization even under voltage sags or swells. While SOGI-PLL can also maintain synchronization, its PI controller may briefly react to amplitude changes, resulting in slower settling or small disturbances in phase estimation.

VII. Different Settling Times

To investigate the impact of the frequency adaptation gain on the performance of the SOGI-FLL, simulations were performed using three different settling time values: **0.01 s**, **0.1 s**, and **1 s**. Each value affects how quickly the FLL adapts to frequency changes, and how stable the output remains during disturbances. The results show noticeable differences in the oscillatory behavior and overall response quality.

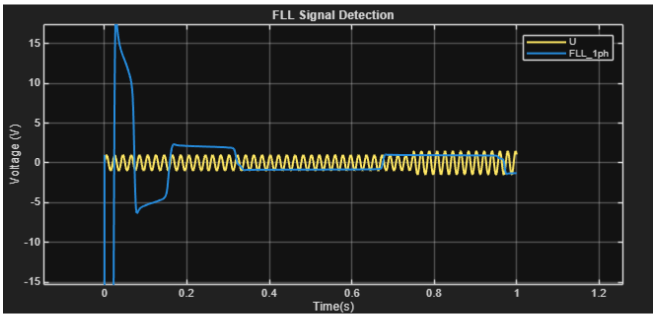

Figure 9 FLL Signal Detection with ts= 0.01s

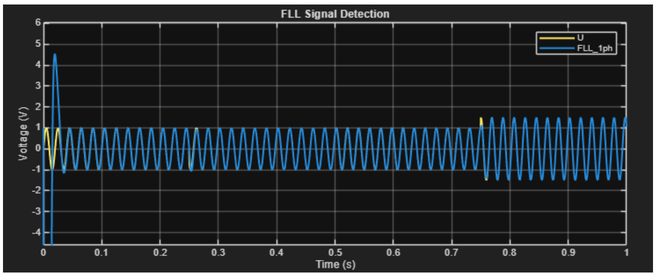

Figure 10 FLL Signal Detection with ts = 1s

A. *Settling Time = 0.01 s*

With the shortest settling time, the FLL reacts very quickly to frequency disturbances. However, this fast adaptation results in significant oscillations in the output signal. The high gain causes the system to respond aggressively, which leads to overshoot and reduced stability. It can be seen in figure 9 , first oscilation reaches to 15 and signal did not follows the input signal. While the system tracks changes rapidly, the output becomes sensitive to small variations and less smooth during transients.

B. *Settling Time = 0.1 s*

This intermediate value provides a balanced performance between response speed and stability. The oscillations are reduced compared to the 0.01 s case, while the frequency tracking remains sufficiently fast. It can be seen in figure 3 , first oscilation reaches to 5 and output signal follows the input signal. The FLL output is more stable, and this setting appears to offer a good compromise in most practical scenarios.

C. *Settling Time = 1 s*

At the highest settling time, the FLL exhibits the least amount of oscillation. The system adapts slowly, but the output remains very smooth and stable throughout the simulation. This indicates that a lower adaptation gain improves damping and reduces overshoot. However, the slow response may be a disadvantage in applications where rapid tracking of frequency deviations is required. It can be seen in figure 9 , first oscilation does not reaches to 5 and signal follows the input signal later than 0.1s condition.

VIII. Conclusion

This paper presents a comparison between SOGI-PLL and SOGI-FLL methods for grid synchronization in single-phase systems. Both methods are tested under three types of input disturbances: phase, frequency, and magnitude changes. Simulation results show that SOGI-PLL performs better in response to sudden phase shifts, while SOGI-FLL offers improved performance under frequency and amplitude variations. Additionally, the effect of different settling times on FLL behavior is examined. The results highlight the strengths and limitations of each method and provide insights for selecting the appropriate synchronization strategy based on application needs.

References

[1] https://imperix.com/doc/implementation/grid-synchronization-methods?currentThread=active-front-end-afe