

Performance Analysis of SOGI and FADSOGI Based PLLs for Grid Synchronization under Distorted Conditions

Sumant Kumar
M.Tech Student
School of Electrical & Electronics
Engineering
Scope Global Skills University
Bhopal, M.P., India
ssumantbhp@gmail.com

Anjana Tripathi
Assistant Professor
School of Electrical & Electronics
Engineering
Scope Global Skills University
Bhopal, M.P., India

Balram Yadav
HOD
School of Electrical & Electronics
Engineering
Scope Global Skills University
Bhopal, M.P., India

Abstract: For grid-connected systems to operate more effectively, synchronization is crucial. Because of their simplicity of construction and resilience to different grid fluctuations, phase-locked loops, or PLLs, are among the most widely used synchronization techniques. In single-phase systems, grid synchronization in grid-connected power converters is achieved primarily through the use of Second-order generalized integrator (SOGI) based phase-locked loops (PLLs) for improved performance. Because of its straightforward design, specific filtering ability, and frequency adaptability, PLL based on second-order generalized integrators (SOGI-PLL) is utilized. Numerous solutions have been put out in response to the literature's study of SOGI-PLL's sensitivity to lower-order harmonics, swell, and sag. PLLs based on FADSOGI are utilized for the three-phase system. The performance of FADSOGI-PLL is significantly reduced due to the more severe and evident non-linear loop coupling phenomena, particularly in the presence of weak grid and grid frequency changes.

Keywords: Grid synchronization, second-order generalized integrator-based PLL

I. INTRODUCTION

In the modern world, integrating various renewable energy sources like solar and wind power with the grid is essential for solving several energy requirement issues. Perhaps most urgently, the imperative to combat climate

change underscores the critical role of renewables. With their minimal number of different types of greenhouse gas emissions, technologies such as wind, solar, and hydroelectric power offer a pathway towards decarbonizing our energy systems. Moreover, as concerns over energy security and geopolitical stability persist, diversifying our energy mix with renewables reduces dependence on finite fossil fuels and mitigates the risks of supply disruptions. Economically, renewable energy presents a boon, fostering job creation, attracting investment, and promoting innovation in technology and infrastructure. The stability of renewable energy prices, which have seen significant declines in recent years, further enhances their appeal in an uncertain energy market characterized by volatile fossil fuel prices

II. DISTRIBUTED POWER GRID SYSTEM

A Distributed Power Grid System (DPGS) is of great importance in terms of electricity generation and distribution that decentralizes energy generation and includes various energy sources in the grid. Therefore, synchronization of the DGPS system becomes very essential. The distribution grid is integrated with various renewable resources, including as solar, wind, hydro, and variable frequency drives, through the use of grid-connected to the voltage source inverters (VSI). However, because of different types of disturbances like power fluctuations, harmonics, unbalances, sag, swell and other

events of power quality (PQ) problems, cause a voltage disturbance at the VSIs' point of common coupling (PCC).

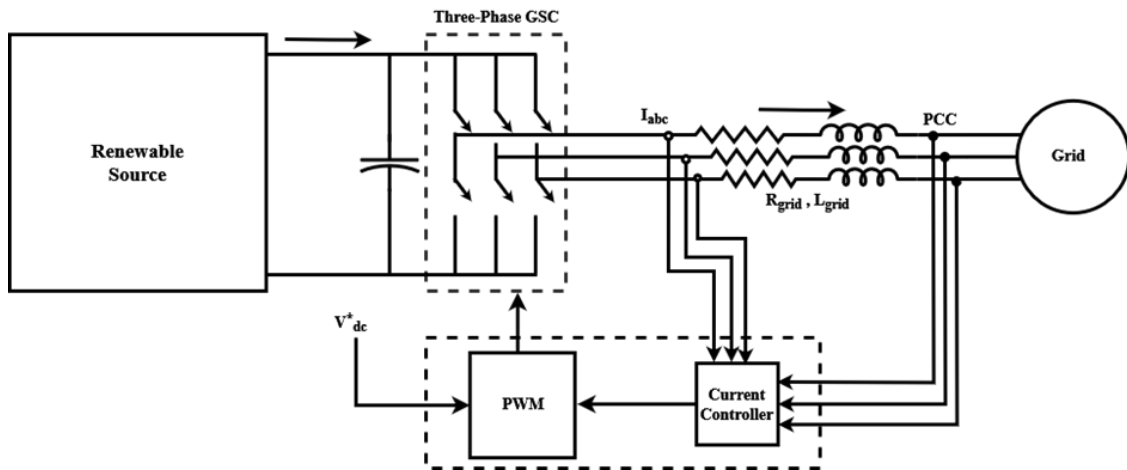


Figure 1 The DGPS in an on-grid power generation system

III. SECOND-ORDER GENERALIZED INTEGRATOR

A SOGI component's primary job is to act as a frequency-adaptive PLL prefilter for the SRF PLL. If the tuning or centre frequency $\hat{\omega}$ is equal to the grid frequency ω , the orthogonal output signals of the SRF PLL indicate the fundamental voltage at the point of connection. Figure 2. Shows the SOGI scheme's structure, which is where the transfer functions come from.

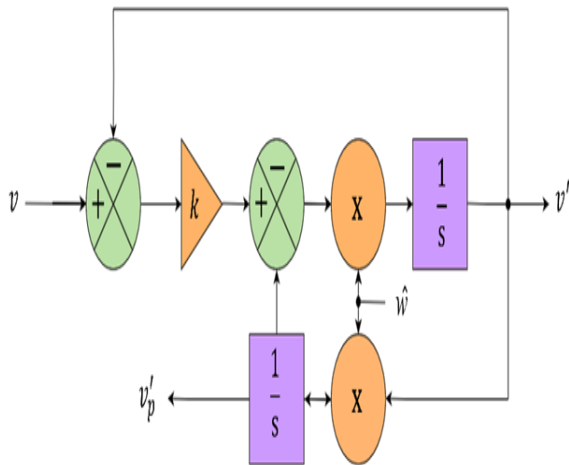


Figure 2. Basic structure of SOGI

The features of the SOGI filter are stated in the introduction part. It is used for the quadrature signal generation as PD that has Band Pass and Low Pass Filter capability that filters out unwanted signal components present in QSG. Figure 2. Depicts the SOGI, a generalized structure, while Figure 3. displays its bode plot.

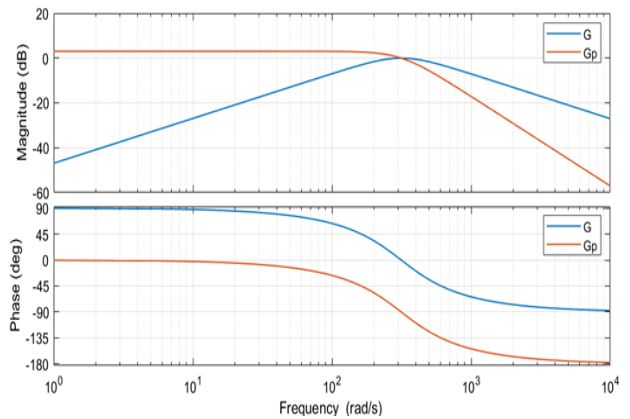


Figure 3. Bode plot for SOGI

Figure 3. shows that at nominal frequency, the phase angle of $G_p(s)$ is 90° behind the direct axis and quadrature-phase axis, with a gain of unity. The SOGI produces the direct axis and quadrature-phase axis components of the filtered signal simultaneously while enabling the signal to be filtered out at a rate of 20 dB/dec attenuation.

IV. FREQUENCY ADAPTIVE DSOGI(FADSOGI) PLL

A typical FADSOGI-PLL structure is shown in Figure 4. Usually, it is employed to synchronize the three-phase grid parameters that are distorted and out of balance. There are three primary sections to it.

- Two SOGI make up a FADSOGI, which eliminates low-order harmonics from the observed grid voltages.
- The positive sequence component of voltages is extracted using a Positive Sequence Calculator

(PSC).

- the frequency and phase angle of the grid voltages are determined by a synchronous frame PLL at the PCC. The term FADSOGI PLL comes

from the fact that this system's estimated frequency is then sent back into the DSOGI to make SRF frequency-adaptive.

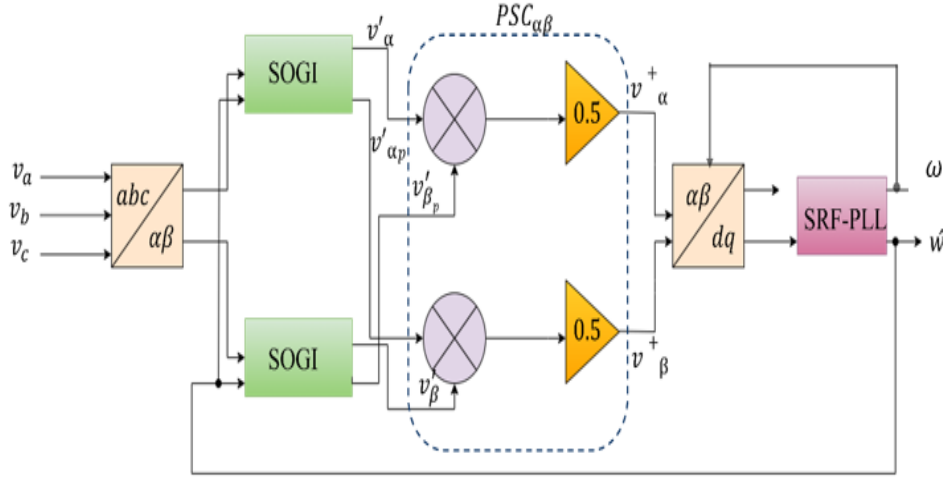


Figure 4. Structure of FADSOGI PLL

V. POSITIVE SEQUENCE CALCULATION WITH FADSOGI

An imbalanced three-phase system's fundamental frequency component can be extracted using the SOGI. In order to accomplish this, we take into consideration the symmetrical components approach to extract the imbalanced three-phase system's positive and negative sequences.

With the help of the positive sequence calculator (PSC) and two separate SOGIs for each component of the Clarke transform, the FADSOGI can extract the positive sequence of the three-phase voltage, where v_α and v_β are achieved.

$$\begin{bmatrix} v_a^+ \\ v_b^+ \\ v_c^+ \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & a & a^2 \\ a^2 & 1 & a \\ a & a^2 & 1 \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad a = e^{-j\frac{2\pi}{3}} \quad (\text{eqn 1})$$

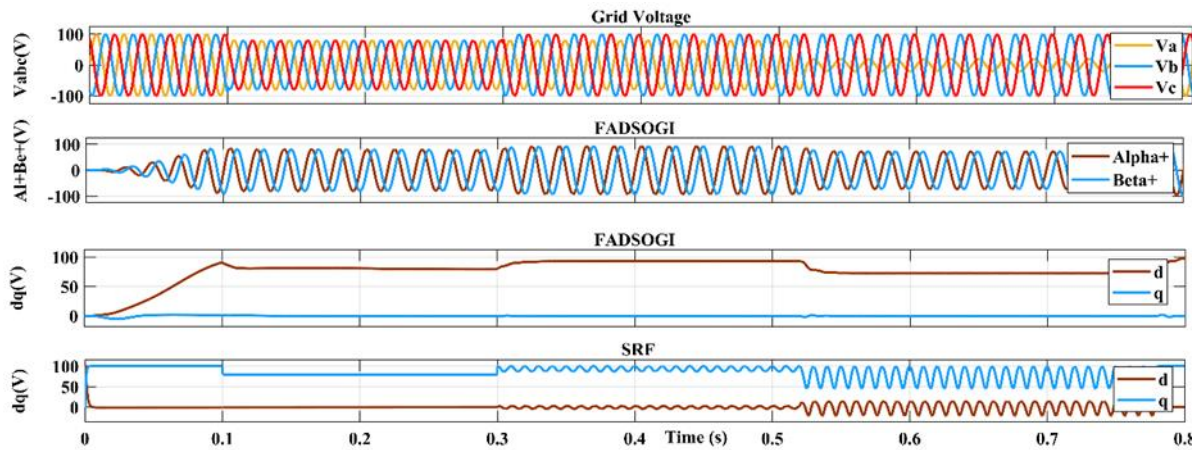
$$v_{\alpha\beta}^+ = [T_{\alpha\beta}] v_{abc}^+ \quad (\text{eqn 2})$$

$$\begin{bmatrix} v_\alpha^+ \\ v_\beta^+ \end{bmatrix} = \frac{1}{2} \begin{bmatrix} 1 & -q \\ q & q \end{bmatrix} \begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} \quad q = e^{-j\frac{\pi}{2}} \quad (\text{eqn 3})$$

VI. SIMULATION PARAMETERS

A. BALANCED SAG AND UNBALANCED SAG

SAG: The balanced system three-phase voltage is set at time $t = 0.0s$ to time $t = 0.1s$, fundamental balanced system three-phase voltage Sag of 20% is set in all three phases A, B, C for time $t=0.1s$ to $0.3s$, fundamental unbalanced voltage Sag 20% is set in phase A for time $t=0.3s$ to $0.5s$ and fundamental unbalanced voltage Sag of 80% is set in phase A for time $t=0.5s$ to $0.7s$. The grid voltage, positive of Alpha-Beta for SOGI, dq component of SOGI and dq component of SRF- PLL is shown in Figure 5. using MATLAB SIMULINK. The frequency and angle of phase are tracked using FADSOGI and SRF- PLL is depicted in Figure 5.



Figure

5. (a) Sag case of 3-Ø voltage (b) $\alpha+\beta+$ component (c) dq component by FADSOGI (d) dq component by SRF

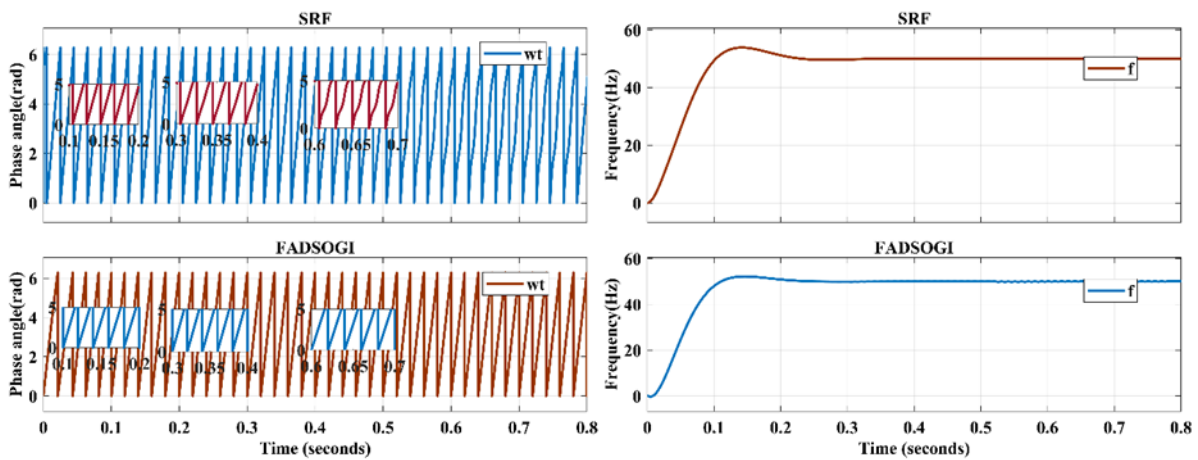


Figure 6. Phase angle detected by (a)SRF PLL (b) FADSOGI Frequency detected by (c)SRF PLL (d) FADSOGI

B. BALANCED SAG AND UNBALANCED SWELL

SWELL: The balanced system three-phase voltage is set at time $t = 0.0s$ to $t = 0.1s$, fundamental balanced system three-phase voltage Swell of 20% is set in all three phases A, B, C for time $t=0.1s$ to $0.3s$, a fundamental unbalanced voltage Swell 20% is set in phase A for time $t=0.3s$ to $0.5s$ and a fundamental unbalanced voltage Swell of 80% is set

in phase A for time $t=0.5s$ to $0.7s$. The grid voltage, positive of Alpha-Beta for SOGI, dq component of SOGI and dq component of SRF- PLL is shown in Figure 7. using MATLAB SIMULINK. The frequency and angle of phase are tracked using FADSOGI and SRF - PLL is depicted in Figure 8.

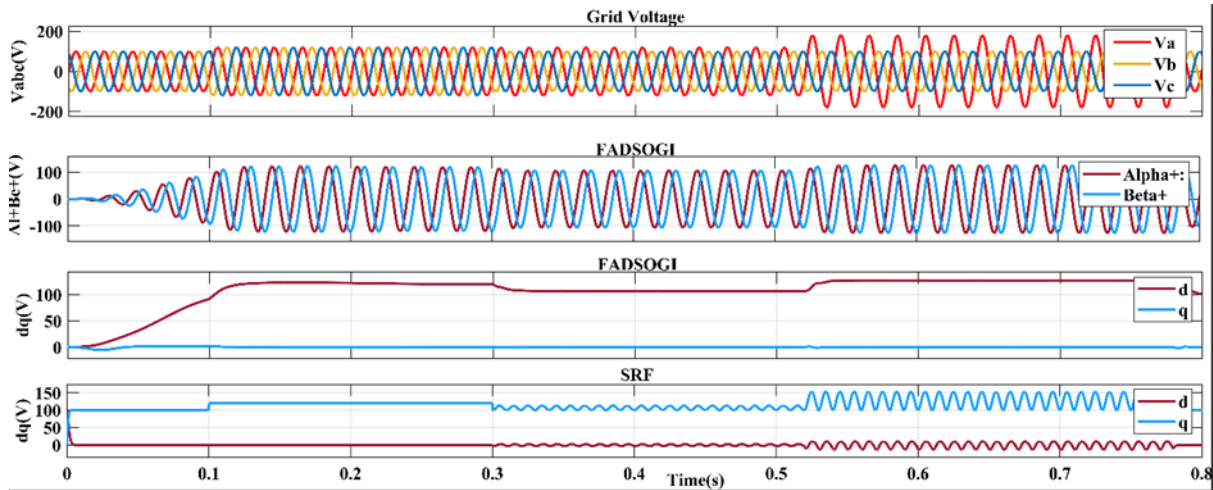


Figure 7. (a) Swell case of 3- \emptyset voltage (b) $\alpha+\beta+$ component (c) dq component by DSOGI (d) dq comp. by SRF

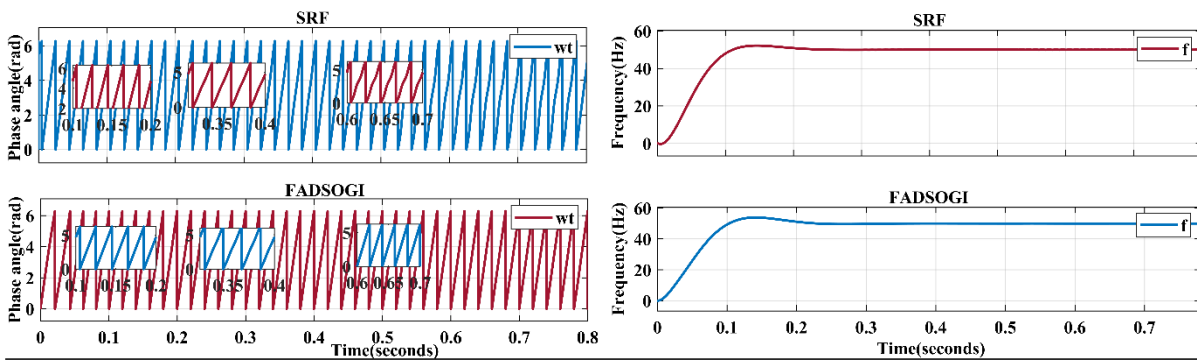


Figure 8. Phase angle detected by (a)SRF PLL (b) FADSOGI Frequency detected by (c)SRF PLL (d) FADSOGI

VII. CONCLUSION

The Frequency Adaptive DSOGI PLL performance is studied in comparison to SRF PLL using MATLAB SIMULINK. In ideal grid settings, the SRF PLL responds better; however, in non-ideal grid conditions, such as imbalanced swell and sag, FADSOGI responds better when determining the angle of phase and frequency of the grid voltage. Here, in the case of Sag, three cases are tested such as balanced Sag of 20%, unbalanced sag of 20% in phase A and unbalanced Sag of 80% in phase A. Similarly, in the case of Swell, three cases are tested such as a balanced Swell of 20%, an unbalanced Swell of 20% in phase A and an unbalanced Swell of 80% in phase A. For the balanced Sag and Swell SRF and FADSOGI, both performed well but for unbalanced Swell the performance of FADSOGI is better compared to SRF PLL in the case of frequency and phase detection.

Conflict of Interest: The corresponding author, on behalf of second author, confirms that there are no conflicts of interest to disclose.

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REFERENCE

[1] R. Teodorescu, M. Liserre, and P. Rodriguez, "Grid Converters for Photo-voltaic and Wind Power Systems," 2011.

- [2] Li et al., "A Novel Zero-Crossing Detector Based Phase Locked Loop for Power System Application," *IEEE Trans. on Power Delivery*, 2017.
- [3] Guerrero et al., "An Improved Synchronous Reference Frame PLL for Power Quality Applications," *Trans. on Power Electronics*, 2010.
- [4] Zhang et al., "Adaptive Synchronous Reference Frame PLL for Enhanced Grid Synchronization of Renewable Energy Systems," *IEEE Trans. on Sustainable Energy*, 2010.
- [5] Hua e. al., "Enhanced Second-Order Generalized Integrator PLL with Harmonic Compensation for Single-Phase Grid-Tied Converters," *IEEE Trans. on Industrial Electronics*, 2020.
- [6] Li et al., "Robust Frequency-Adaptive Second-Order Generalized Integrator PLL for Single-Phase Grid-Tied Applications," *IEEE Trans. on Industrial Electronics*, 2022.
- [7] Morales et al., "A Double Second-Order Generalized Integrator-Based Phase-Locked Loop for Grid-Connected Power Converters Under Distorted Grid Conditions," *IEEE Trans. on Industrial Electronics*, 2017.
- [8] Han et al., "Robust Double Second-Order Generalized Integrator PLL for Three-Phase Grid-Connected Converters Under Grid Voltage Disturbances," *IEEE Trans. on Power Electronics*, 2019.
- [9] Wang et al., "Adaptive Double-Second-Order Generalized Integrator PLL for Three-Phase Grid-Tied Converters Under Dynamic Grid Conditions," *IEEE Trans. on Power Electronics*.
- [10] Liu et al, "Enhanced Double-Second-Order Generalized Integrator PLL with Harmonic Compensation for Three-Phase Grid-Connected Converters," *IEEE Trans. on Industrial Electronics*, 2022.