

Comparative Analysis of SOGI-Based Structures for Fault Diagnosis in EV Charging Rectifiers

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INTRODUCTION & AIM

The rapid expansion of EV fast-charging infrastructure demands reliable real-time fault diagnosis in power electronic converters such as Vienna rectifiers and DC–DC stages, which are prone to faults in switching devices and DC-link components. Undetected faults can degrade power quality, reduce system efficiency, and can lead to severe reliability issues in charging stations. Operational safety and grid stability are seriously threatened by malfunctions in switching components like DC link charging capacitors, Diodes, MOSFETs and IGBTs. Signal-based methods using Second-Order Generalized Integrator (SOGI) structures have gained attention for their low computational complexity and effectiveness in harmonic estimation [1,2]. This work presents a comparative analysis of different SOGI-based structures for THD-based fault diagnosis, evaluating their detection performance, robustness, and real-time feasibility under various fault conditions using MATLAB and Typhoon HIL.

METHODOLOGY

1. System Description- A detailed model of a DC fast-charging station is developed, consisting of a three-phase grid interface, an RL input filter, a three phase-three level rectifier, a split DC-link, and an isolated DC–DC converter feeding an EV battery load. The three phase-three level rectifier regulates the DC-link voltage while ensuring near-unity power factor, and the DC–DC converter controls the charging current.

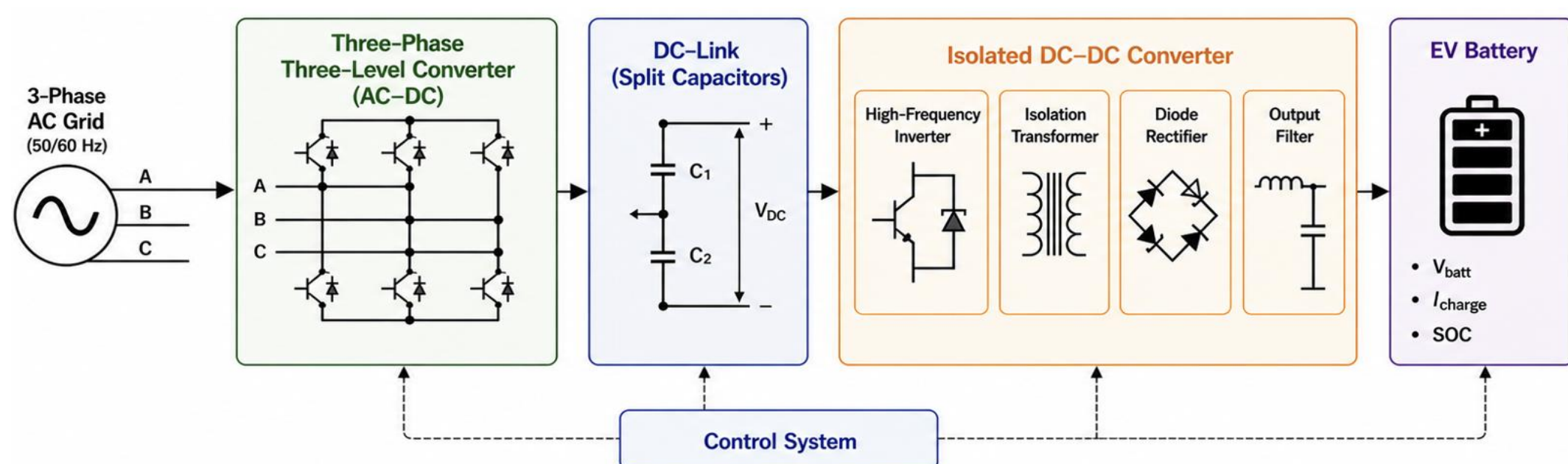


Fig1. DC fast charging station connected to the battery system of an electric vehicle (EV)

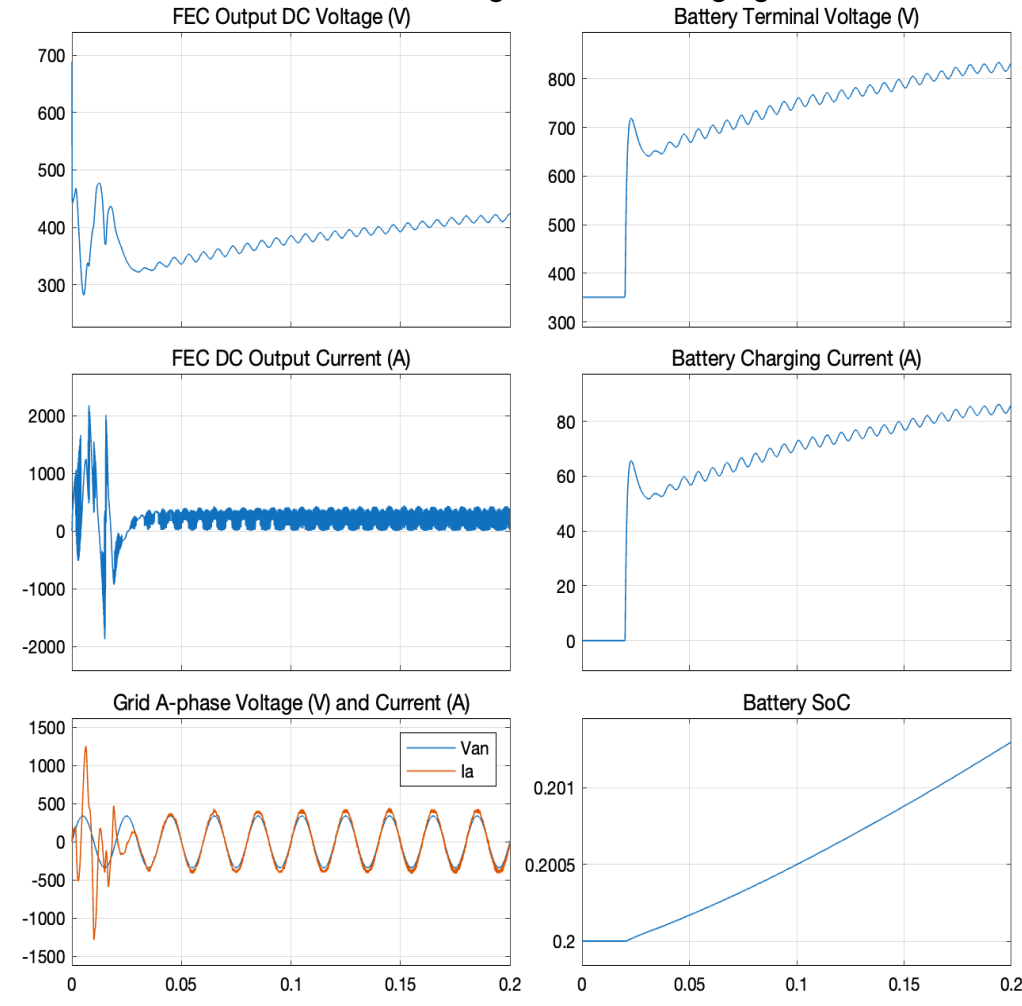


Fig2. DC bus voltage and current, Input Voltage and current, the voltage at the battery terminals, the charging current and SOC.

DC charging module	Location and Type of the fault	
Front stage	Open circuit at swithing module S1 at phase A	F1
	Open circuit at swithing module S2 at phase A	F2
	Open circuit at swithing module S3 at phase A	F3
	Open circuit at swithing module S4 at phase A	F4
	Open-circuit at C1	F5
	Open-circuit at C2	F6
	Open-circuit at C1 and C2	F7
Back stage	Open circuit at swithing module S1 in inverter	F8
	Open circuit at swithing module S2 in inverter	F9
	Open circuit at swithing module S3 in inverter	F10
	Open circuit at swithing module S4 in inverter	F11

Table1. Location and type of faults

2. Faults injection- Open-circuit faults are introduced in both front-end converter switches, DC-link capacitors and back-end inverter switches, under identical operating conditions to evaluate diagnostic performance.

3. Signal Acquisition- Key electrical signals - Grid voltage (v_{abc}), Grid current (i_{abc}), DC-link voltage (V_{DC}), DC-link current (I_{DC}), Transformer current (i_{tr}), Output (charging) voltage (v_o), Output (charging) current (i_o) are measured and used for real-time fault analysis. Fault characteristics in the front-end stage are identified using input current and voltage signals, while back-end faults are analysed using transformer current [3]; these signals are then processed through SOGI-based variants for THD estimation and further analysis.

4. Signal processing- A total of six SOGI-based variants are considered for the comparative study: SOGI, Symmetrical SOGI (SSOGI), Cascaded SOGI (CSOGI), Cascaded Symmetrical SOGI (CSSOGI), Modified SOGI (MSOGI), and Modified Symmetrical SOGI (MSSOGI).

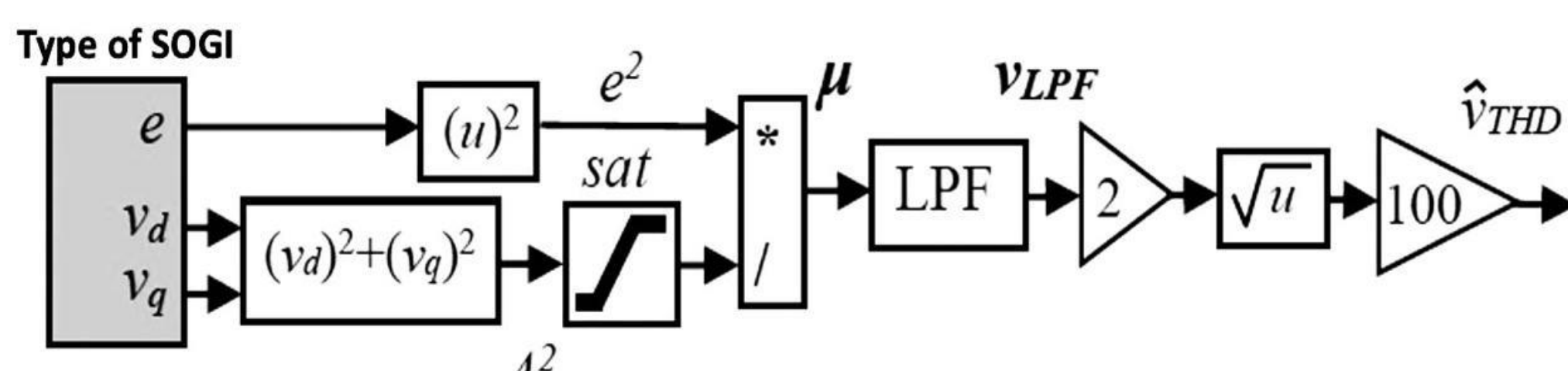


Fig3. Block diagram for THD measurement using different variants of SOGI

RESULTS & DISCUSSION

The performance of different SOGI-based structures is evaluated using THD tracking of incoming grid and transformer currents under both healthy and faulty operating conditions. Under normal condition and under faults (Fig. 4-9), all SOGI variants accurately track the THD, frequency. Minor differences are observed in dynamic response, where Cascaded SOGI exhibits a higher transient peak, while symmetrical and modified variants show improved damping and reduced overshoot.

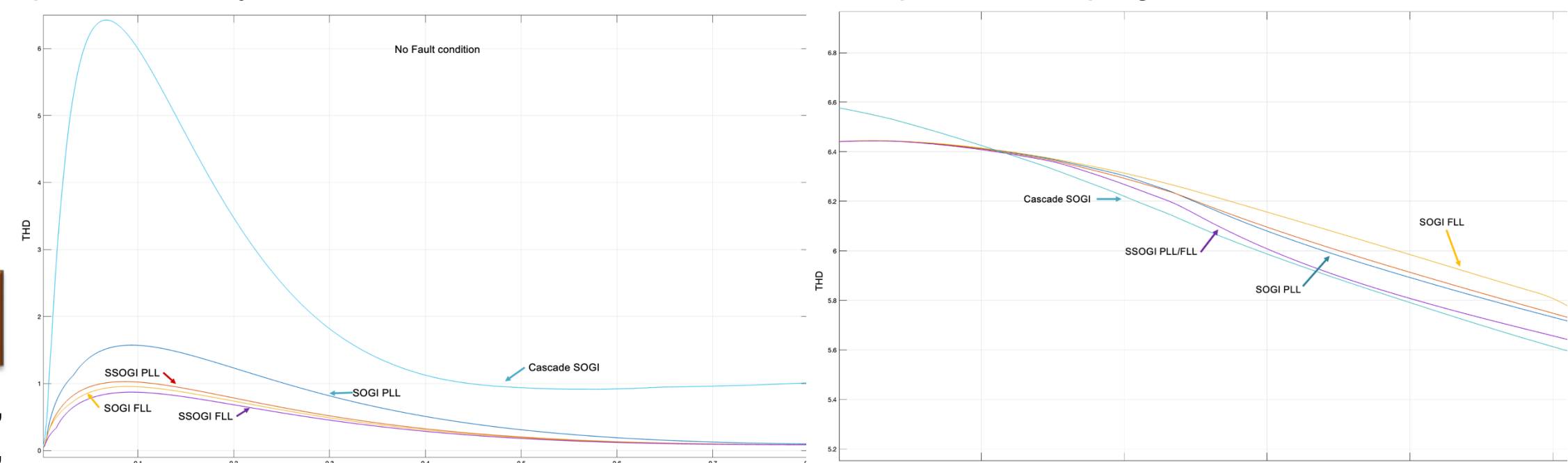


Fig4. THD tracking of Input current using different variants of SOGI.

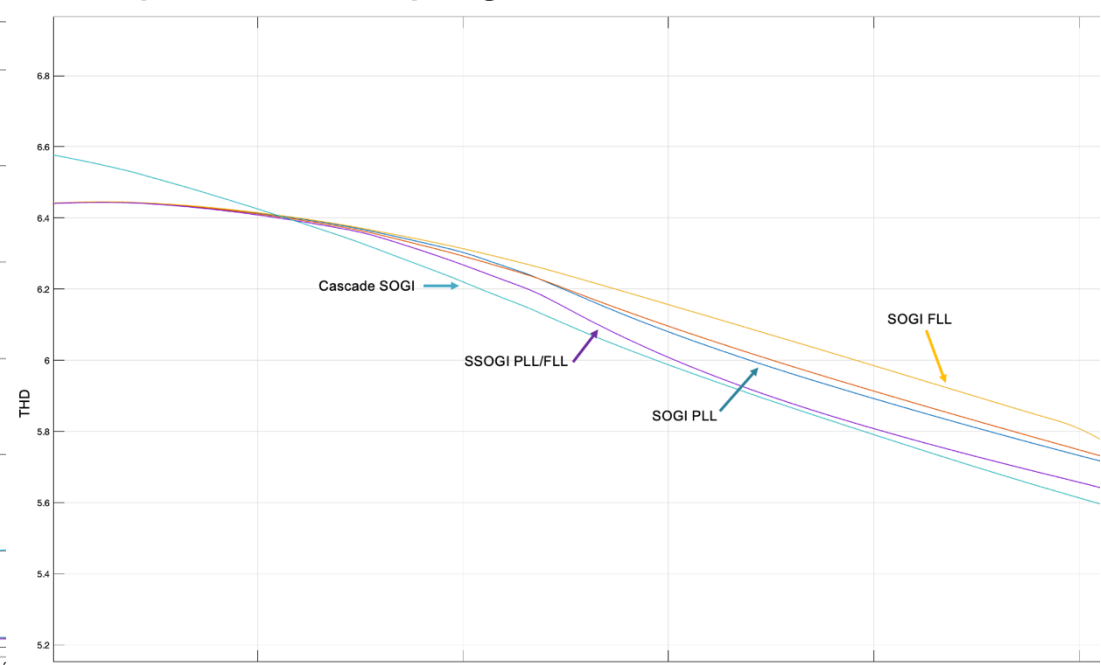


Fig5. THD tracking of transformer current using different variants of SOGI.

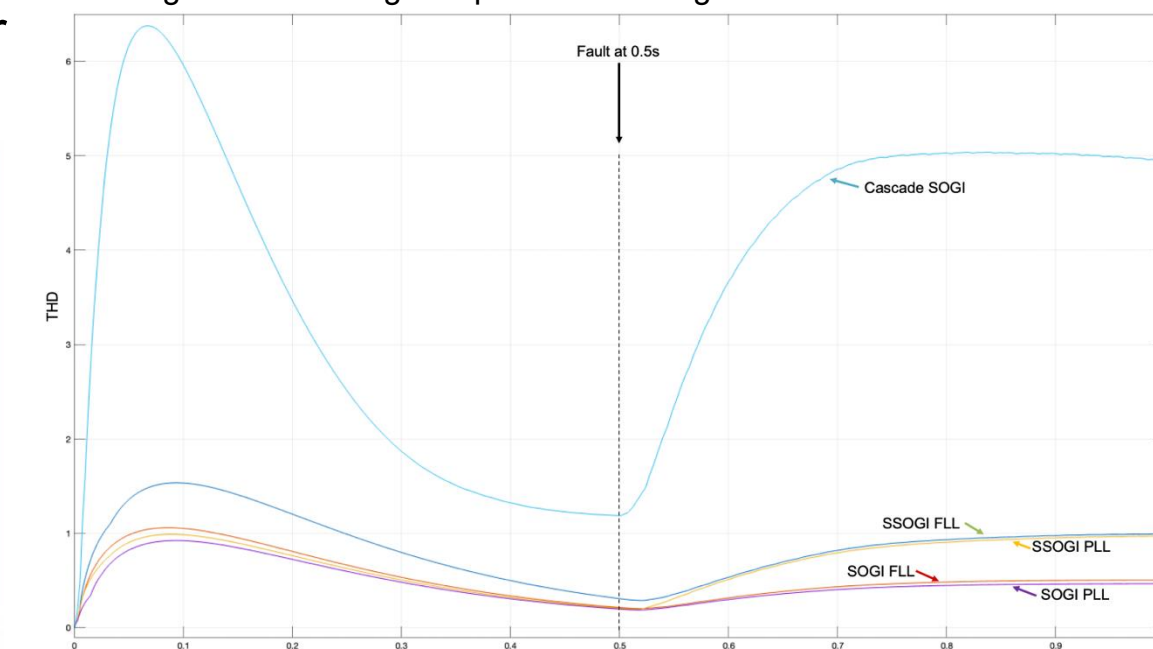


Fig6. THD tracking of input current under F1 fault at 0.5s.

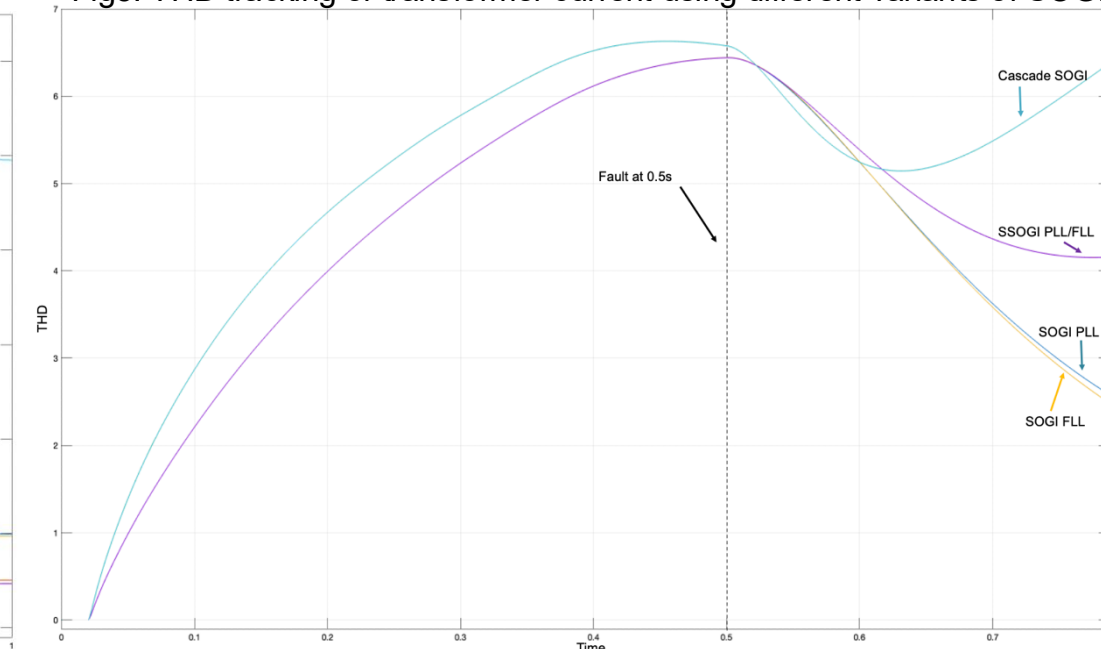


Fig6. THD tracking of input current under F1 fault at 0.5s.

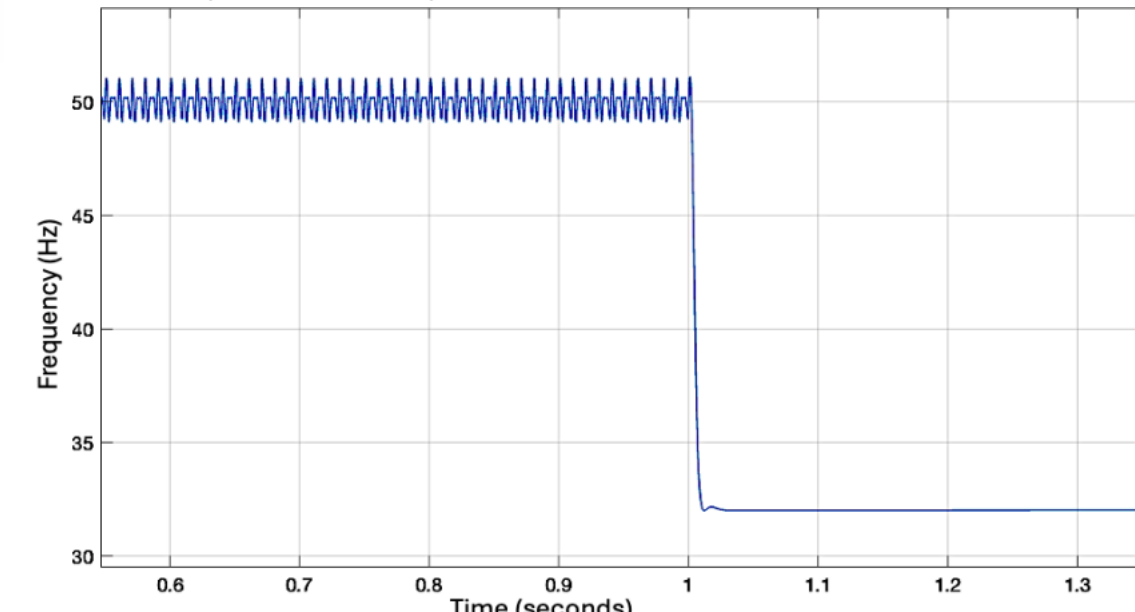


Fig.8 Frequency tracking for current with SOGI-FLL under F1 fault at 0.5s

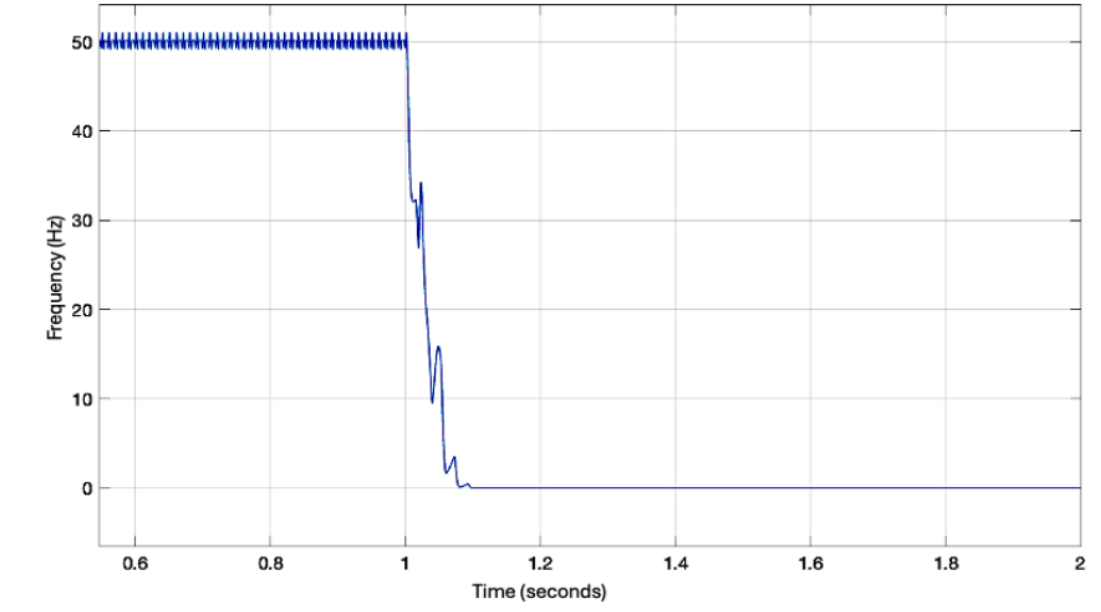


Fig.9 Frequency tracking for current with SOGI-FLL under F3 fault at 0.5s

Actual	Predicted		
	Healthy State	Front-Stage Fault	Back-Stage Fault
Healthy State	11	2	1
Front-Stage Fault	1	13	2
Back-Stage Fault	2	1	13

Table2. Confusion Matrix

The confusion matrix shows high classification accuracy with clear diagonal dominance, indicating reliable fault detection for both front-stage and back-stage faults achieving an overall classification accuracy of approximately 80%. A Monte Carlo-based validation approach is employed by performing multiple simulations with randomly varied input conditions to evaluate robustness, and the results demonstrate consistent fault detection performance with high classification accuracy, as confirmed by the confusion matrix analysis.

CONCLUSION/ FUTURE WORK

This work presents a comparative analysis of SOGI-based structures for THD-based fault diagnosis in EV charging rectifiers, demonstrating that all variants effectively detect faults, with input signals suited for front-end faults and transformer current for back-end faults. Cascaded SOGI shows higher sensitivity, while symmetrical and modified variants offer improved stability and robustness. In order to further improve diagnostic capability, future study will concentrate on examining DC-link capacitor degradation, simulating capacitor fault circumstances, and using 1D CNN-based techniques for improved fault diagnosis and classification.

REFERENCES

- 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.
- Desai, Keval Prakash, José Matas, and Josep M. Guerrero. "Development of a Diagnostic Method for Open/Short Circuit Faults in a Vienna Rectifier Based on the THD Method Using SOGI FLL." *Applied Sciences* 15.23 (2025): 12836.
- Chen, Yin, et al. "A diagnostic method for open-circuit faults in DC charging stations based on improved S-transform and LightGBM." *Energies* 17.2 (2024): 404.