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Comparision of Robustness of SOGI Synchronization Techniques in Weak Grid Conditions for Railway Converter Applications in DQ Coordinates

Andrej Blaško[1], Matej Pácha[1], Pavol Makyš[1], Matúš Horník[1]

1 Department of Power System and Electric Drives, University of Zilina,

INTRODUCTION

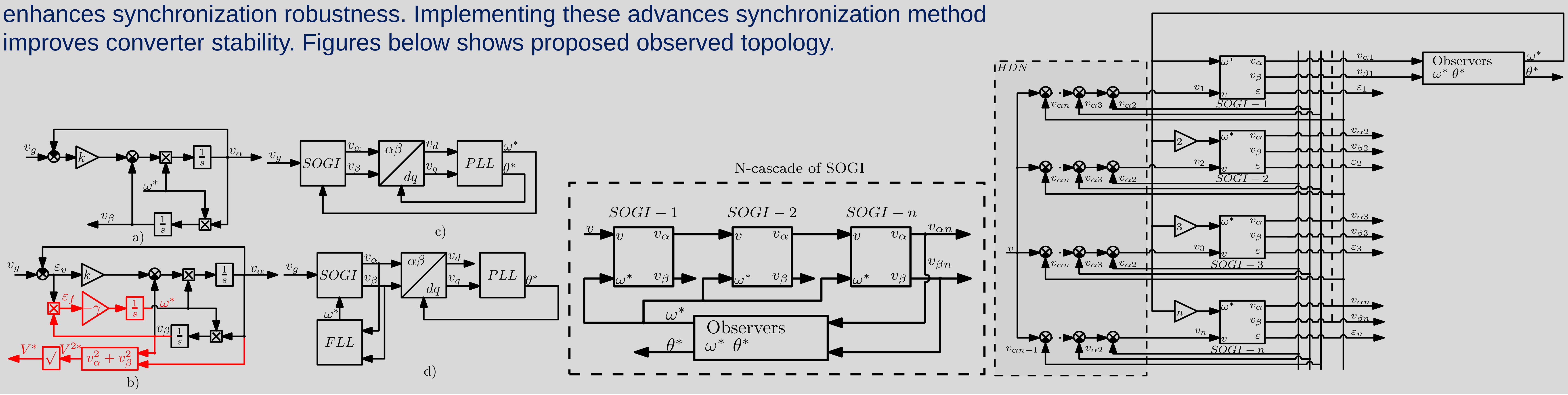
In recent years, there has been a strong industry interest in upgrading locomotives for multi-system locomotives. Moder railways systems are switching from energy inefficient uncontrolled rectifiers to regenerative active rectifiers, which bring higher quaility parameters, energy efficiency and reduce harmonic disturbances in the electrical grid. Multi-system locomotives operate on both AC and DC network where synchronization problems are solved by advanced control techniques.

Electric railway converters require precise synchronization with the single-phase grid to ensure stable operation and minimize deformal power. Since single-phase networks lack Pack and Clark transformation, virtual signal generation methods like the Second Order Generalized Integrator (SOGI) are essential. Weak grids with frequency variations, votlage assymetries, harmonic distortions and DC offsets necessitate robust synchronization algorithms such as SOGI-WPF and MSOGI.

By refining SOGI-base method and integrating observers combinations strategies, the study aims to improve dynamic response, stability, and power quality, ensuring reliable converter operation under real-world grid conditions.

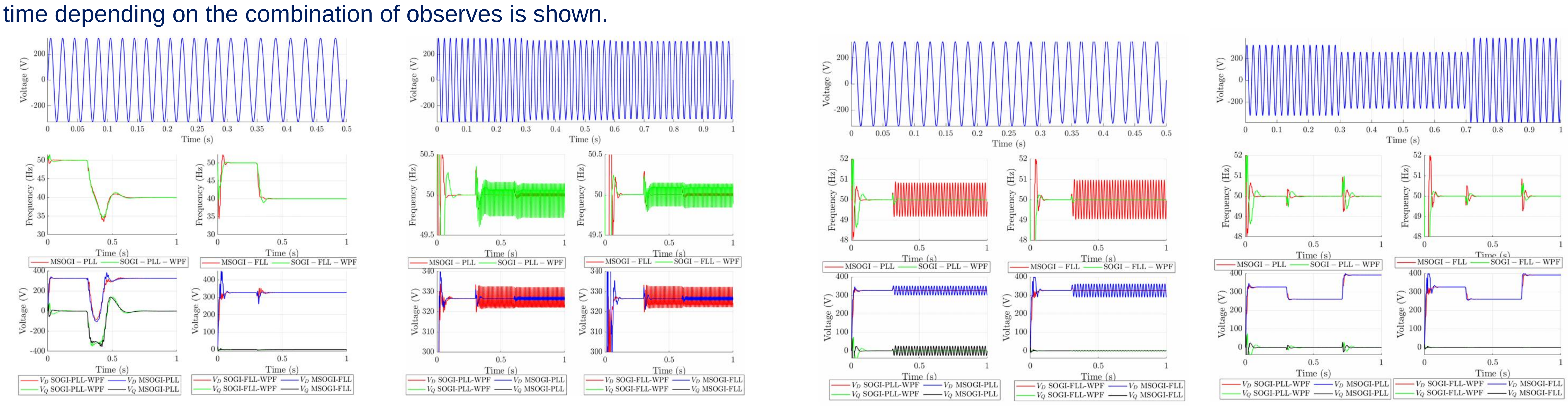
SYNCHRONIZATION ALGORITHMS

Fundamental structure of SOGI filter employs a band-pass filter to estimate the phase voltage and a low-pass filter with 90° phase shift to obtain orthogonal component. A conventional SOGI-PLL incorporates feedback loops for frequency and phase estimation, whose nonlinear interaction can adversely affect system dynamics. To stabilize frequency estimation, the FLL is integrated, adaptively correcting the frequency based on the frequency error. The MSOGI extends the basic SOGI structure by incorporating multiple selective filters tuned to specify harmonic components even under extreme nonlinearities. A key component of MSOGI is the harmonic Decoupling Network (HDN), which employs cross - feedback within a network of SOGI filters to ensure effective separation of harmonic components and improve synchronization accuracy under distorted grid conditions. The SOGI-WPF addresses challenges by cascade configuration of the SOGI structures, where the first SOGI functions as a band-pass prefilter and the second as a SOGI with an observer. Dynamic tuning of the first filter based on the estimated frequency significantly reduces harmonic distortion effects and enhances synchronization robustness. Implementing these advances synchronization method improves converter stability. Figures below shows proposed observed topology.



RESULTS

Figures below shows simulation results. All synchronization techniques were tested with a 4Q converter to capture the dynamic behaviour of the entire regulation structure. Algorithms was tested for DC distortion, voltage sags, harmonic distortion nad frequency changes. In the simulation the settling time depending on the combination of observes is shown.



a) b) c) d)

CONCLUSION

This study addresses the critical challenges of single-phase synchronization for 4Q converter under weak grid conditions. Through simulations techniques, including SOGI-WPF and MSOGI, was evaluated under dynamic conditions. The findings highlight the strengths and limitation of each approach, providing valuable insights into their application in railway converter systems. SOGI-WPF demonstrates superior resilience to higher harmonic disturbance, maintaining minimal oscillations in observed values. However, its configuration requires prior knowledge of the number and order of harmonic components in the grid, limiting its adaptability in highly dynamic environments. In contrast, MSOGI offers the advantage of not requiring predefined harmonic orders, making it a flexible solution for environments with unpredictable harmonic content. Nevertheless, MSOGI showed reduced performance in filtering higher-order harmonics due to the limitation of its fifth-order design. Expanding these methods to multi-phase systems and exploring their scalability for broader grid synchronization applications represent promising way for future research.