

Performance Analysis of a Three-Phase SEIG Feeding Single-Phase Loads Using a STATCOM-Based Controller

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ABSTRACT

Electricity suppliers today are increasingly focused on delivering high-quality power to customers. With advancements in power electronics, various solutions have been developed to counteract fluctuations in distribution networks, aiming to provide the best possible power quality.

This thesis examines the use of a three-phase self-excited induction generator (SEIG) with a static compensator (STATCOM) for voltage regulation. The current-controlled voltage source inverter (CC-VSI) functions as the STATCOM, providing a rapid dynamic response to stabilize the SEIG terminal voltage during significant load changes, acting as both a source and sink of reactive power.

To model the SEIG-STATCOM system feeding unbalanced loads, performance equations are derived using stationary reference frame d-q variables. A transient analysis is conducted to evaluate the voltage build-up, STATCOM switching, and the impact of applying and removing balanced or unbalanced resistive/reactive loads. The STATCOM maintains SEIG terminal voltage through reactive power compensation and reduces harmonics introduced by consumer loads. A control algorithm based on single-phase synchronous D-Q frame theory is used to generate gating pulses for the three-phase STATCOM, implemented using MATLAB/SIMULINK software.

INTRODUCTION

The three-phase induction machines (IMs) are used as generators in electrical power systems. The induction generator offers advantages for wind and hydro applications in terms of simplicity and cost. It plays an important role in the renewable energy industries today.

However, the induction generator has some limitations, it generally needs an external power source

for provide an excitation. This means that is difficult to employ in remote areas where there is no electrical power supply network.

The potential outcomes of utilizing a Self-energized Induction Generator (SEIG) where a three-phase capacitor banks is associated over the stator terminals, provide the reactive power requirement of a load and generator. At the point when an induction machine is driven by an outside mechanical power source, the leftover magnetism in the rotor delivers an Electromotive Force (EMF) in the stator winding.

An induction machine connected and excited in this manner is acting as a standalone generator. It is supplying real and reactive power to the loads. In

this mode of operation, the capacitor bank supplies the reactive power requirement to the load and generator, the real power demand of the terminal load is supplied by the prime mover. However, the main drawbacks of the SEIG system are that frequency and voltage produced by the system is highly dynamic under variable load conditions.

FACTS Applications:

In interconnected and in addition in long transmission power system specialized issues happen which constrains the load capacity and quality of the system.

The best devices for the utilization in complex power system are the phase angle controller, the controlled series compensator, particularly when gate turn of thyristors with bound together power system controller. In long transmission, TCSC or SSSC offers contrasting ability against the rating, and costs.

STATCOM STRUCTURE

- The STATCOM (Static Compensator), shown schematically in Figure 3.1, consists of a two-

level Voltage Source Converter (VSC), a DC energy storage device, and a coupling transformer connected in parallel with the distribution network. The VSC converts DC voltage from the storage device into a three-phase AC voltage sequence, synchronized with the AC system and connected via the coupling transformer's reactance. By adjusting the phase and magnitude of the STATCOM's output voltages, it effectively controls active and reactive power exchange with the AC system, enabling it to either absorb or supply controlled amounts of active and reactive power. However, several critical factors must be considered in designing the STATCOM and its control circuits, particularly for the power circuit. The key design considerations include:

- DC link capacitor size
- Coupling transformer reactance and transformation ratio
- Output filters equipment

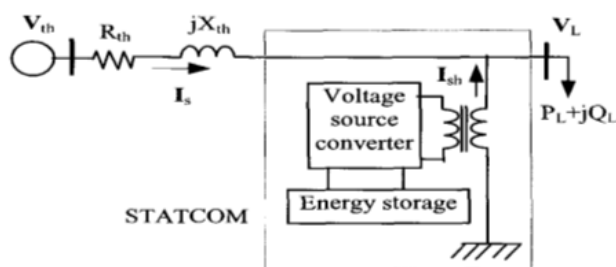


Fig: Schematic diagram of a STATCOM

The VSC (Voltage Source Converter) connected in shunt with the AC system provides a versatile configuration that can serve three distinct functions:

1. Voltage regulation and reactive power compensation
2. Power factor correction
3. Current harmonics elimination

Proposed Concept

This chapter explains the system configuration, operating principles, Single-Phase Synchronous Rotating D-Q Frame Theory, and the estimation of reference source currents based on this theory. A remotely excited squirrel-cage induction machine with its stator terminals connected to a reactive power source (capacitor) is widely known as a Self-Excited Induction Generator (SEIG). Squirrel-cage induction machines have certain advantages over conventional synchronous machines, including simplicity, brushless operation, durability, and inherent short-circuit protection. SEIGs are

commonly used in remote and isolated power generation systems as mechanical energy conversion devices. However, when SEIGs are powered by prime movers like biomass, biogas, or biodiesel engines, poor voltage regulation has been a significant challenge. Various voltage regulation schemes have been developed for SEIG-based standalone power systems.

The proposed technique involves voltage compensation for a three-phase SEIG using both long-shunt and short-shunt compensation methods. Systems that rely solely on passive components are often inadequate for maintaining terminal voltage stability with varying loads. Subsequently, several approaches have been implemented to maintain a stable terminal voltage using dynamic switches, such as the capacitor and thyristor-controlled inductor combination, known as the Static Var Compensator (SVC). With the advancement of fast-switching, self-commutating devices, Pulse Width Modulation (PWM) Voltage Source Inverter (VSI)-based static reactive power compensators (STATCOMs) have been developed to address these challenges effectively.

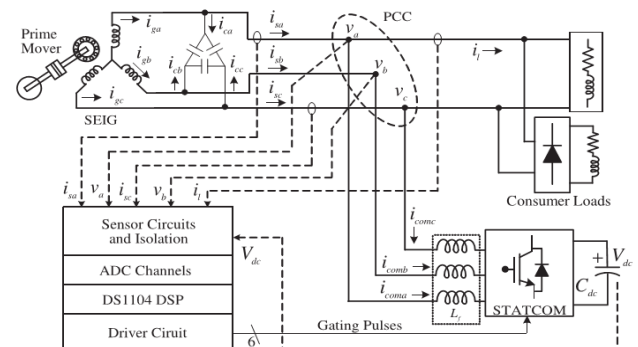


Fig: Schematic diagram of the SEIG-STATCOM system feeding single-phase loads

This section presents simulations of PI (Proportional Integral) controller-based control schemes for voltage profile improvement using STATCOMs. A key limitation of PI controller-based schemes arises during transient conditions, as they do not account for load current when estimating the active and reactive components of the reference source current.

To address this, the proposed approach uses a single-phase synchronous D-Q frame-based control algorithm for a three-phase STATCOM system. This method generates balanced source currents even under significant current and voltage imbalances caused by single-phase loads. Consequently, the proposed method eliminates the need to adjust PI controller gains during transients.

MATLAB/SIMULATION RESULTS

This chapter discusses the MATLAB mathematical function library, MATLAB language features, graphics, MATLAB tools, and MATLAB/SIMULINK Results.

MATLAB is a high-performance language for technical computing that offers an integrated environment for computation, visualization, and programming. It allows users to express problems and solutions in familiar mathematical notation, making it intuitive and accessible. Common applications of MATLAB include:

- Mathematics and computation
- Algorithm development
- Data acquisition
- Modeling, simulation, and prototyping
- Data analysis, exploration, and visualization
- Scientific and engineering graphics

MATLAB/SIMULINK RESULTS

A) Steady-State Performance of the SEIG-STATCOM System

i) Steady-state performance of the SEIG-STATCOM system supplying single-phase linear loads.

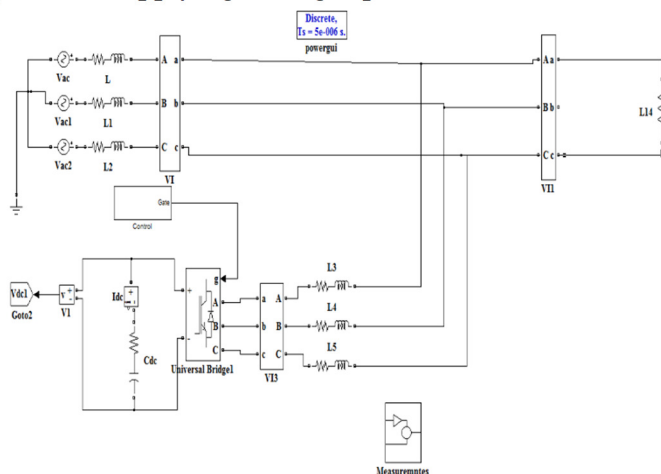


Figure 5.12: simulation diagram of the SEIG-STATCOM system feeding single phase linear loads

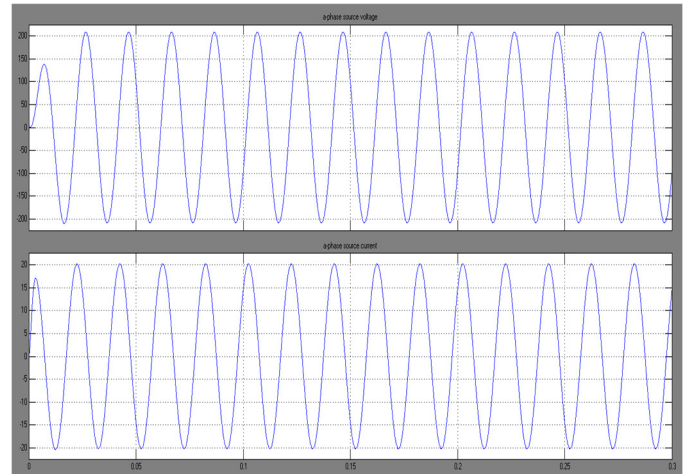


Figure 5.13: a-phase source voltage and source current

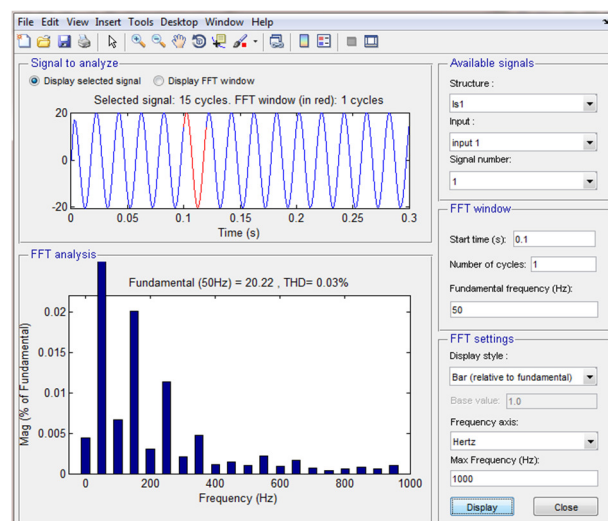


Figure 5.14: THD values of source current

Figure 5.12 illustrates the steady-state performance of the SEIG-STATCOM system when supplying a single-phase resistive load of 3.35 kW. In Figure 5.13, the SEIG current (i_a) is displayed alongside the PCC line voltage (v_a). Figure 5.14 presents the harmonic spectrum for the SEIG current in phase "a." The Total Harmonic Distortion (THD) of the generator currents is measured to be below 5%, which complies with standard limits for current harmonics.

ii) Steady-State Performance of the SEIG Feeding Single-Phase Nonlinear Loads

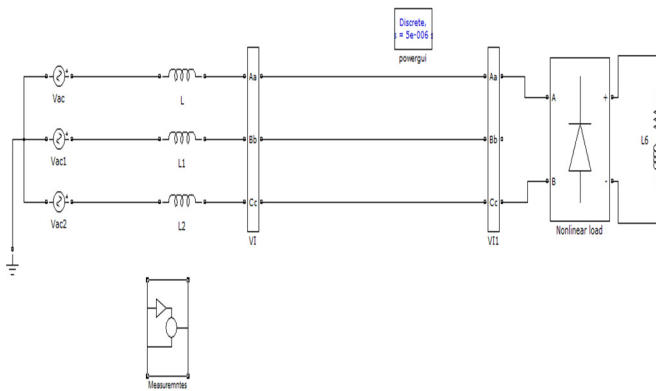


Figure 5.15: simulation diagram of single-phase nonlinear load without STATCOM

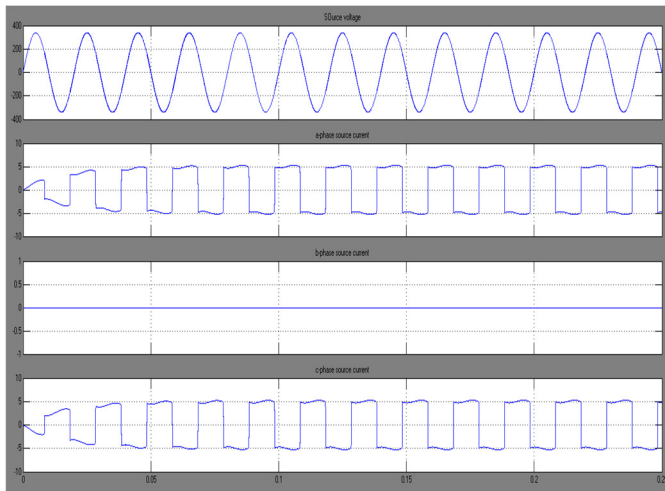


Figure 5.16: source voltage and source current

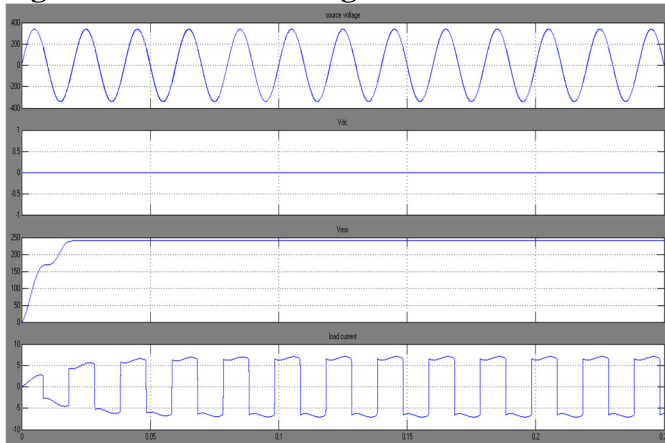


Figure 5.17: Source voltage, V_{DC} , V_{rms} and load current

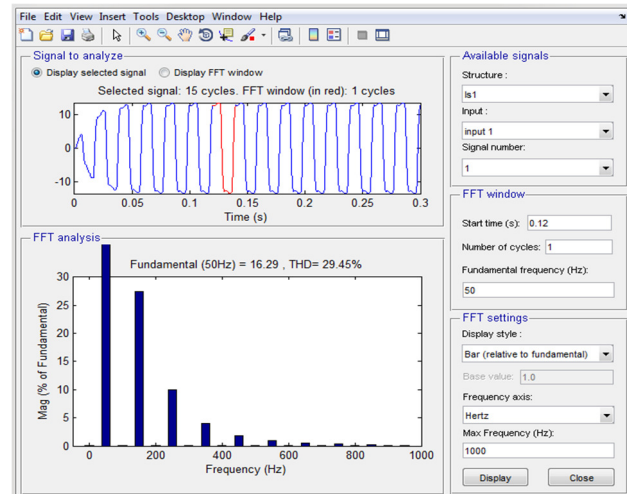


Figure 5.18: THD value of source current

The steady-state performance of the SEIG system feeding nonlinear loads is shown in Figure 5.15. The generator currents (i_a , i_b , and i_c) and the PCC line voltage v_a are shown in Figure 5.16. Figure. The steady-state waveforms of the PCC voltage v_a , the load current i_l , the DC-bus voltage V_{DC} , and the RMS value of the PCC line voltage V_t RMS are given in Figure 5.17. From Figure 5.18, it is observed that the SEIG currents are unbalanced which demonstrates the Total Harmonic Distortion (THD).

iii) Steady-State Performance of the SEIG-STATCOM System Feeding Single-Phase Nonlinear Loads

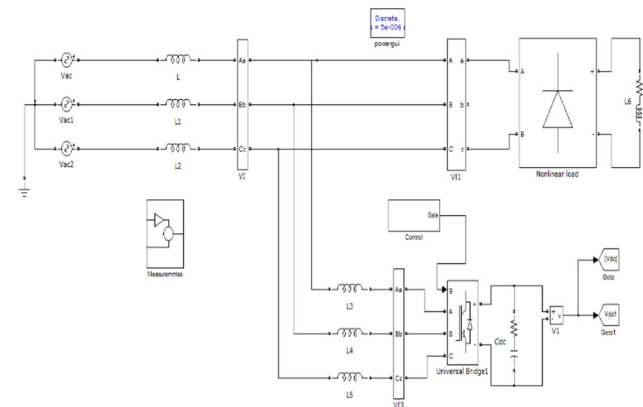


Figure 5.19: simulation diagram of single-phase nonlinear load

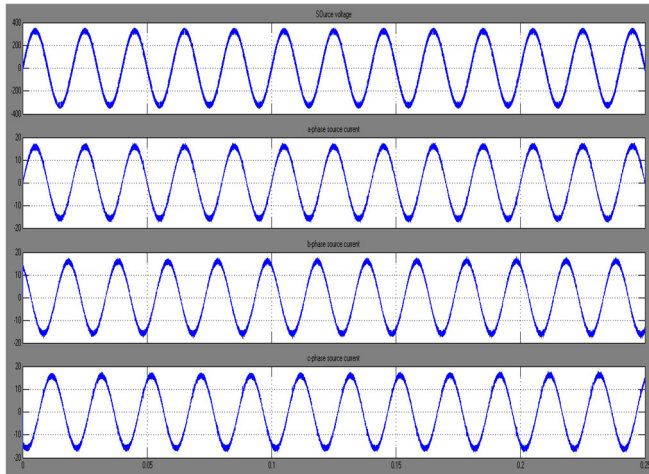


Figure 5.20: source voltage and source current

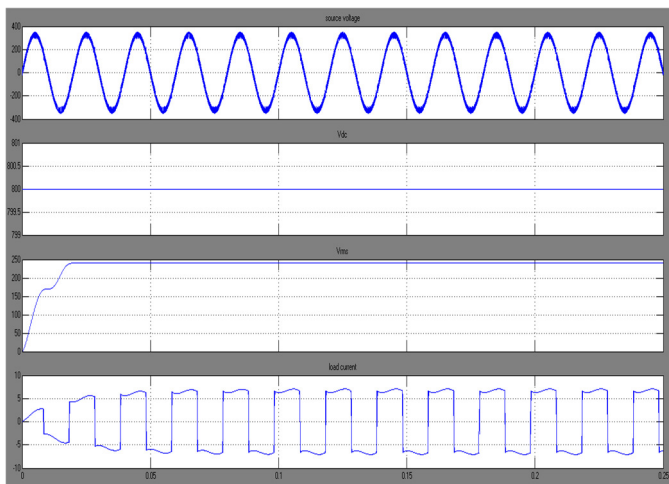


Figure 5.21: source voltage, V_{DC} , V_{rms} and load current

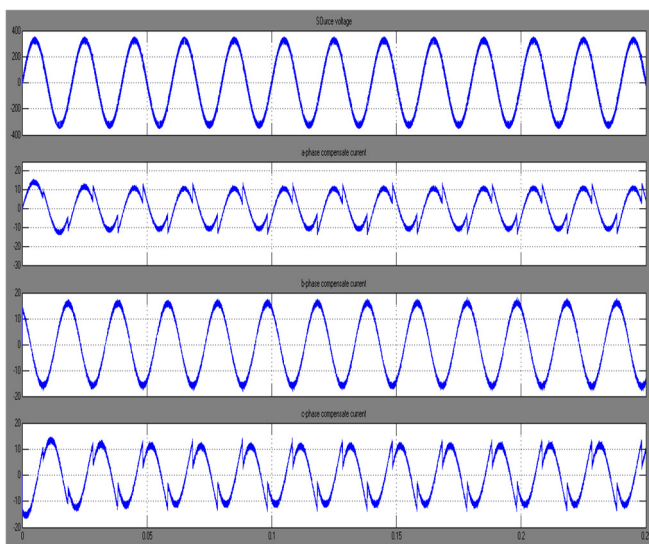


Figure 5.22: source voltage, compensate currents

Figure 5.19 displays the steady-state performance of the SEIG-STATCOM system when supplying nonlinear loads. The generator currents (i_a , i_b , and i_c) and the PCC line voltage (v_a) are shown in Figure 5.20. Figure 5.21 presents the steady-state waveforms of the PCC voltage (v_a), load current

(i_l), DC-bus voltage (V_{DC}), and the RMS value of the PCC line voltage (V_t RMS). Figure 5.22 shows the compensation currents injected by the STATCOM to balance the source currents. It can be observed in Figure 5.22 that the SEIG currents are balanced and sinusoidal, demonstrating the STATCOM's effectiveness in harmonic suppression and load balancing.

B) Dynamic Performance of the SEIG-STATCOM System Feeding Single-Phase Nonlinear Loads

i) Dynamic performance of the SEIG-STATCOM during load removal.

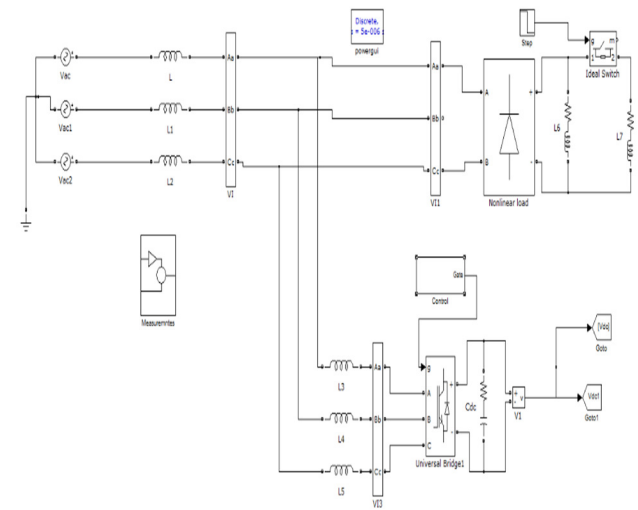


Figure 5.23: simulation diagram of single-phase nonlinear load remove

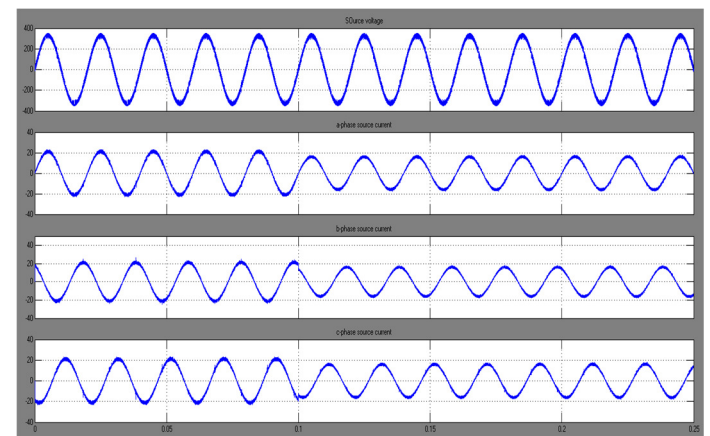


Figure 5.24: source voltage and source currents

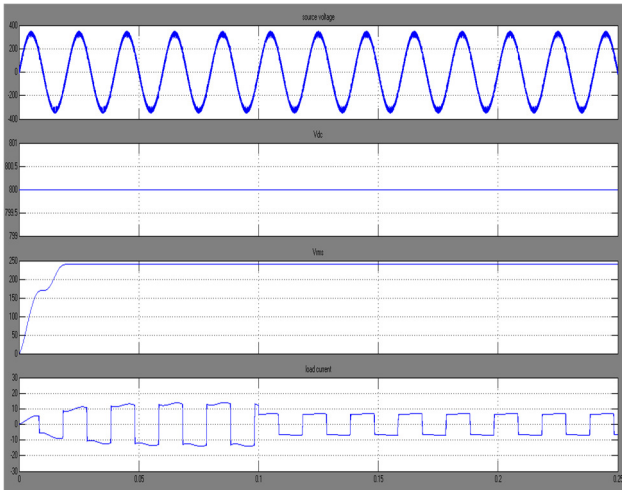


Figure 5.25: source voltage, V_{DC} , V_{rms} and load current

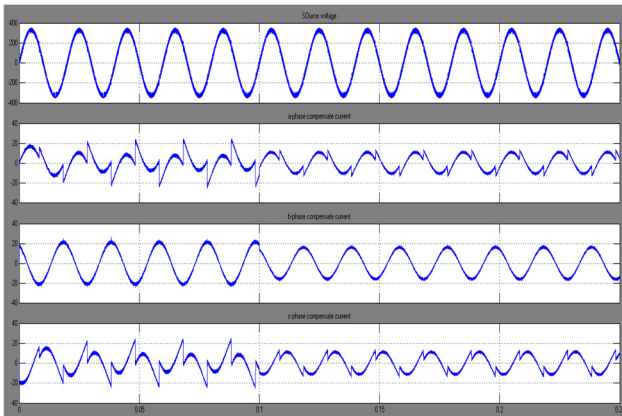


Figure 5.26: source voltage, compensate currents

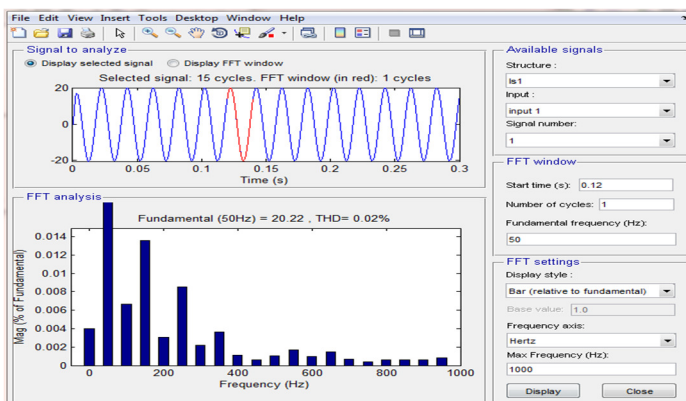


Figure 5.27: THD value of source current

Figure 5.23 shows the dynamic performance of the SEIG- STATCOM system feeding single-phase nonlinear loads under load reduction. Figure 5.24 shows the line voltage v_a , the SEIG current i_a , i_b , and i_c . The STATCOM current i_{com} and load currents i_l before and after the load reduction. Reduction in the magnitude of the SEIG current and STATCOM currents can be observed during the load change. Figure 5.26 shows the three-phase STATCOM currents i_{coma} , i_{comb} and i_{comc} along with the PCC line voltage v_a and it can be noticed that the STATCOM currents are decreasing as the load is

reduced. Figure 5.25 Shows the DC-bus voltage of the STATCOM, the load current and the V_{DC} .

ii) Dynamic performance of the SEIG-STATCOM during load application.

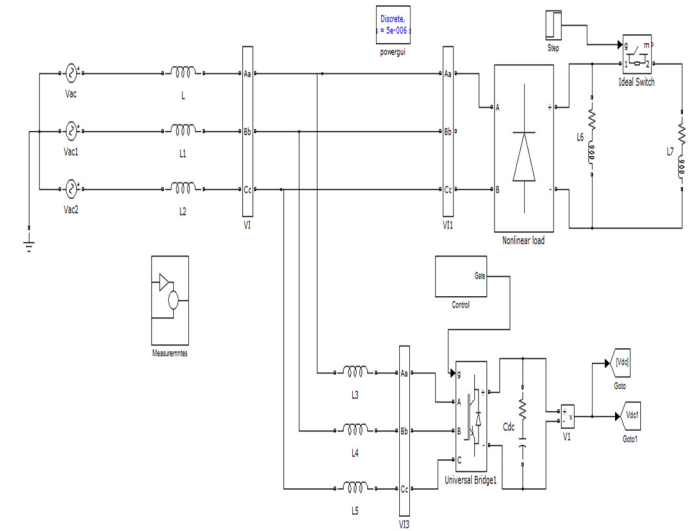


Figure 5.28: simulation diagram of during single-phase nonlinear load

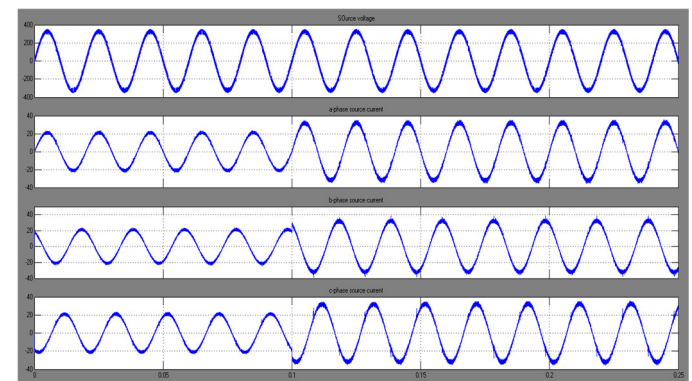


Figure 5.29: source voltage and source currents

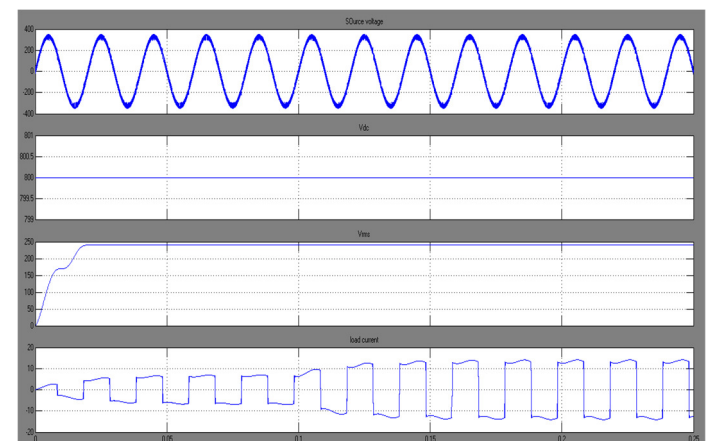


Figure 5.30: source voltage, V_{DC} , V_{rms} and load current

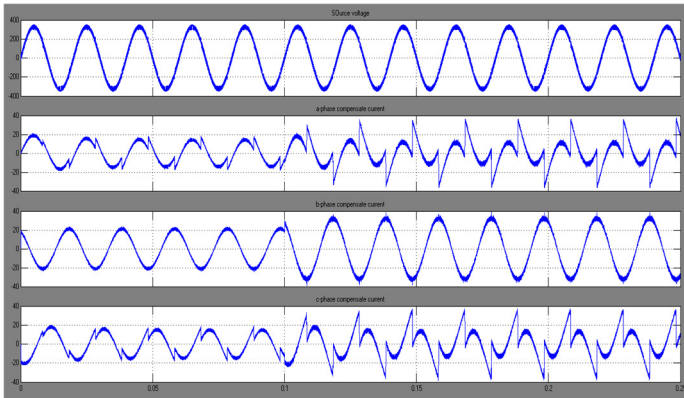


Figure 5.31: source voltage, compensate currents

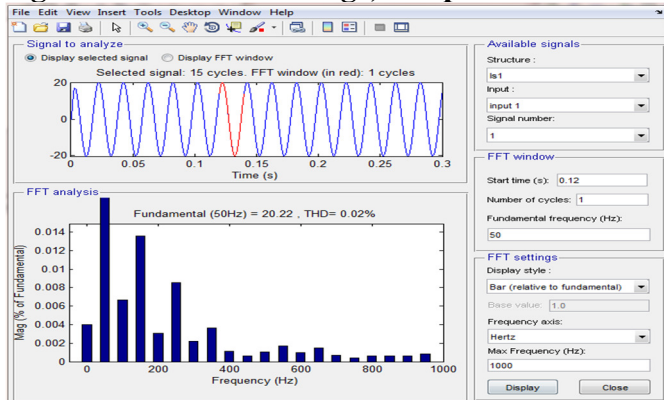


Figure 5.32: THD value of source current

The SEIG-STATCOM system's dynamic response during load application is shown in Figure 5.28. Figure 5.29 illustrates SEIG currents (i_a) , (i_b) , and (i_c) , along with the line voltage (v_a) at the PCC. In Figure 5.30, the load current (i_l) , DC link voltage (V_{DC}) , and line voltage (v_a) at the PCC are displayed, revealing an increase in SEIG and STATCOM current amplitudes during load adjustment. Figure 5.31 provides additional insight into the STATCOM currents and PCC line voltage (v_a) , where the compensation current increases with the load, resulting in a rise in STATCOM currents to accommodate the load change.

Conclusion

The proposed system for powering single-phase loads using a combination of a three-phase SEIG and STATCOM has been tested, enabling the SEIG to support single-phase loads up to its rated capacity. A single-phase synchronous D-Q frame-based control strategy was developed, analyzed, and implemented for current balancing in the SEIG system. Experimental evaluations of SEIG performance across various voltage levels helped identify the terminal voltage associated with maximum power output. The SEIG-STATCOM system demonstrated reliable performance, underscoring its suitability for standalone power generation using renewable energy

in remote locations where maintaining high power quality is critical.

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