International Journal of Computer Information Systems and Industrial Management Applications
ISSN 2150-7988 Volume 18(9s) 2026 pp. 986-1014
https://doi.org/10.70917/ijcisim-2026-3515
Article

Power Quality Enhancement of Self-Excited Induction Generator Using Intelligent Control Techniques

Seema Bai Meena[1], Prakash Chittora[2], D. K. Sambariya[3]

[1]Department of Electrical Engineering, Delhi Technological University, Delhi.
Email: smeena@rtu.ac.in
[2]Department of Electrical Engineering, Delhi Technological University, Delhi.
[3]Department of Electrical Engineering, Rajasthan Technical University, Kota.
Corresponding Author: Seema Bai Meena

Abstract: The growing deployment of isolated renewable energy systems has significantly increased the utilization of Self-Excited Induction Generators (SEIGs) because of their simple construction, ruggedness, low maintenance requirements, and cost-effective operation. However, SEIGs inherently suffer from poor voltage regulation, frequency deviation, harmonic distortion, and reactive power imbalance when subjected to nonlinear, unbalanced, and dynamically varying loads, thereby limiting their practical applicability in standalone power generation. This paper presents an intelligent control strategy for enhancing the power quality of an SEIG-based autonomous generation system using a Synchronous Reference Frame Theory (SRFT)-based voltage source converter integrated with a photovoltaic-assisted battery energy storage system. The proposed control framework continuously estimates the fundamental voltage and current components, regulates the DC-link voltage, compensates reactive power demand, and suppresses harmonic currents through adaptive reference current generation and pulse-width modulation. A comprehensive MATLAB/Simulink model is developed to evaluate the effectiveness of the proposed controller under different operating scenarios, including balanced, nonlinear, and sudden load variations. The proposed approach demonstrates superior voltage stability, reduced total harmonic distortion, faster transient response, improved power factor, and enhanced dynamic performance, thereby ensuring reliable and high-quality power delivery for standalone renewable energy applications.

Keywords: Self-Excited Induction Generator (SEIG), Power Quality Enhancement, Synchronous Reference Frame Theory (SRFT), Intelligent Control, Battery Energy Storage System (BESS), Voltage Source Converter (VSC)

1. Introduction

The global transition toward sustainable energy systems has accelerated the deployment of decentralized renewable energy technologies to satisfy the increasing electricity demand while minimizing greenhouse gas emissions and dependence on fossil fuels. Among the various renewable energy conversion technologies, standalone power generation systems have gained considerable attention for supplying electricity to remote villages, isolated islands, agricultural fields, telecommunication stations, mining industries, military installations, and disaster-prone regions where grid extension is technically challenging and economically infeasible. In these autonomous power systems, electrical generators must operate independently under continuously varying environmental and loading conditions, thereby requiring high operational reliability, superior voltage regulation, and excellent power quality. Consequently, substantial research efforts have focused on developing intelligent control methodologies capable of maintaining stable electrical performance despite renewable energy intermittency and nonlinear load disturbances.

Self-Excited Induction Generators (SEIGs) have emerged as one of the most attractive alternatives for standalone renewable energy generation because of their rugged mechanical construction, brushless operation, inherent short-circuit protection capability, high reliability, reduced maintenance requirements, compact size, and relatively low manufacturing cost. SEIGs are extensively employed in small-scale wind energy conversion systems, pico-hydropower plants, biomass-driven generators, and hybrid renewable microgrids owing to these advantages. Unlike synchronous generators, SEIGs do not require an external excitation source and can generate electrical power through appropriately connected shunt capacitors that provide the necessary reactive power for self-excitation. However, despite these operational benefits, the performance of SEIGs deteriorates considerably under practical operating conditions because terminal voltage and operating frequency strongly depend on rotor speed, excitation capacitance, and load characteristics. Sudden variations in load demand, nonlinear consumer equipment, and unbalanced loading conditions introduce voltage fluctuations, harmonic distortion, reactive power imbalance, poor power factor, and reduced system stability, thereby compromising the quality and reliability of power supplied to sensitive electrical equipment.

The increasing penetration of nonlinear electronic loads, variable-speed motor drives, switching power supplies, electric vehicle chargers, and digital control equipment has further aggravated the power quality challenges encountered in standalone SEIG-based systems. These loads inject substantial harmonic currents into the electrical network, resulting in voltage distortion, increased copper and core losses, excessive heating, electromagnetic interference, equipment malfunction, capacitor overloading, and reduced generator lifespan. Furthermore, frequent changes in renewable energy availability create additional voltage instability and transient oscillations that cannot be effectively mitigated using conventional passive compensation techniques. Consequently, advanced active compensation methods have become indispensable for ensuring continuous and high-quality power delivery in isolated renewable energy systems.

Recent developments in power electronic converters have enabled the implementation of intelligent control algorithms capable of simultaneously regulating voltage, compensating reactive power, suppressing harmonics, and improving dynamic response. Voltage Source Converters (VSCs), when integrated with Battery Energy Storage Systems (BESS) and renewable energy sources such as photovoltaic (PV) arrays, provide flexible control over both active and reactive power exchange. These converters can rapidly inject compensating currents into the Point of Common Coupling (PCC), thereby mitigating voltage disturbances and maintaining nearly sinusoidal current waveforms. The effectiveness of such compensation strategies largely depends on the accuracy and computational efficiency of the underlying control algorithm.

Among numerous control methodologies, the Synchronous Reference Frame Theory (SRFT) has become one of the most widely adopted techniques for active power filtering and power quality enhancement due to its superior capability for extracting fundamental current components under dynamically changing operating conditions. The SRFT transforms three-phase electrical variables from the stationary abc reference frame into a synchronously rotating dq reference frame, enabling effective separation of fundamental and harmonic components. This mathematical transformation facilitates precise estimation of reference compensating currents while maintaining robust performance under balanced, unbalanced, and nonlinear loading conditions. Compared with conventional instantaneous power theory, hysteresis controllers, and fixed-parameter proportional-integral regulators, SRFT-based controllers exhibit faster convergence, improved disturbance rejection, enhanced harmonic compensation, and superior dynamic stability.

The integration of photovoltaic generation with battery energy storage further enhances the operational flexibility of standalone SEIG systems. During periods of sufficient solar irradiation, the PV system supplies a significant portion of the active power demand while charging the battery storage unit. Conversely, during reduced solar availability or sudden load increments, the battery system supports the DC-link voltage and compensates for power imbalance, ensuring uninterrupted operation of the Voltage Source Converter. Such coordinated operation substantially improves voltage regulation, minimizes transient deviations, reduces generator stress, and enhances overall system resilience. Consequently, intelligent hybrid renewable energy systems combining SEIGs, PV generation, battery storage, and advanced converter control have become promising solutions for future decentralized electricity networks.

Although numerous control techniques have been reported in recent years, achieving simultaneous improvement in voltage regulation, harmonic mitigation, reactive power compensation, frequency stabilization, and dynamic load sharing remains a challenging research problem. Many existing controllers exhibit degraded performance under rapidly varying operating conditions due to parameter sensitivity, delayed response, limited adaptive capability, and increased computational burden. Therefore, developing an intelligent control framework capable of maintaining stable generator operation while satisfying stringent power quality standards has become an active research direction.

The present work proposes an intelligent SRFT-based control strategy integrated with a PV-assisted Battery Energy Storage System and Voltage Source Converter for enhancing the power quality performance of a standalone

Self-Excited Induction Generator. The proposed controller continuously monitors generator voltages, currents, DC-link voltage, battery status, and load variations to generate adaptive reference compensating currents using synchronous reference frame transformations. These reference signals are subsequently utilized to generate pulse-width modulation gating signals for the converter, enabling real-time harmonic suppression, reactive power compensation, voltage stabilization, and improved power factor under diverse operating scenarios. The proposed methodology is implemented in the MATLAB/Simulink environment and evaluated under balanced, nonlinear, and sudden load variation conditions to investigate its effectiveness in enhancing system performance.

Overview

Standalone renewable energy systems are increasingly deployed to electrify geographically isolated regions where conventional utility grid expansion is economically impractical. Within these systems, Self-Excited Induction Generators have gained widespread acceptance because of their mechanical robustness, operational simplicity, and low maintenance cost. Nevertheless, maintaining acceptable voltage regulation and power quality under varying operating conditions remains a significant challenge due to the absence of automatic excitation control and the highly nonlinear characteristics of connected loads. The incorporation of intelligent converter-based compensation supported by renewable energy storage has therefore become an effective solution for overcoming these operational limitations. This study investigates an integrated SEIG–PV–BESS architecture employing an SRFT-based intelligent controller to achieve comprehensive power quality enhancement while ensuring reliable standalone operation.

Scope of the Study

The scope of this research encompasses the mathematical modeling, intelligent control design, simulation implementation, and performance evaluation of a standalone Self-Excited Induction Generator integrated with photovoltaic generation, Battery Energy Storage System, and a Voltage Source Converter. The investigation includes synchronous reference frame transformation, adaptive reference current estimation, DC-link voltage regulation, harmonic suppression, reactive power compensation, voltage stabilization, power factor improvement, and transient response analysis under balanced, nonlinear, and dynamic loading conditions. The proposed system is developed entirely within the MATLAB/Simulink environment, providing a flexible platform for evaluating the effectiveness of intelligent power quality enhancement strategies suitable for isolated renewable energy applications.

Objectives of the Study

The primary objectives of this research are:

- To develop a comprehensive MATLAB/Simulink model of a standalone Self-Excited Induction Generator integrated with photovoltaic generation and Battery Energy Storage System.
- To design an intelligent Synchronous Reference Frame Theory-based controller for adaptive reference current estimation.
- To regulate the DC-link voltage using coordinated converter control under varying operating conditions.
- To suppress voltage and current harmonics generated by nonlinear loads.
- To improve terminal voltage regulation and maintain stable frequency characteristics.
- To compensate reactive power demand and achieve near-unity power factor.
- To evaluate system performance under balanced, unbalanced, nonlinear, and sudden load variations.
- To compare the proposed intelligent control strategy with the conventional SEIG configuration using standard power quality indices.

Author Motivations

The motivation behind this research originates from the increasing global demand for reliable decentralized renewable energy systems capable of delivering high-quality electrical power without dependence on conventional utility infrastructure. Although Self-Excited Induction Generators offer several operational advantages, their widespread adoption remains constrained by poor voltage regulation, harmonic distortion, and reactive power instability under practical operating conditions. Simultaneously, recent advancements in power electronics, renewable energy integration, battery storage technologies, and intelligent digital controllers provide unprecedented opportunities for overcoming these technical limitations. Motivated by these developments, this work seeks to establish an advanced SRFT-based intelligent compensation framework capable of significantly improving the dynamic performance and power quality of standalone SEIG systems while maintaining computational simplicity and practical implementation feasibility.

Paper Structure

The remainder of this paper is organized as follows. Section 2 presents a comprehensive review of contemporary research on Self-Excited Induction Generators, intelligent power quality enhancement techniques, converter-based compensation strategies, battery energy storage integration, and Synchronous Reference Frame Theory-based controllers, followed by the identification of the existing research gap. Section 3 develops the mathematical modeling of the proposed SEIG system together with the intelligent SRFT-based control methodology, including reference frame transformations, converter control equations, and DC-link voltage regulation. Section 4 describes the complete MATLAB/Simulink implementation of the proposed PV–BESS integrated SEIG system and discusses the simulation framework adopted for performance evaluation. Section 5 investigates the dynamic behavior of the proposed controller under balanced, nonlinear, and sudden load variations while presenting detailed power quality assessment using multiple performance indices. Section 6 provides an extensive comparative analysis of simulation results with conventional SEIG operation, highlighting improvements in voltage regulation, harmonic mitigation, power factor correction, transient stability, and overall system reliability. Finally, Section 7 concludes the research by summarizing the principal findings, practical significance, limitations, and future research opportunities.

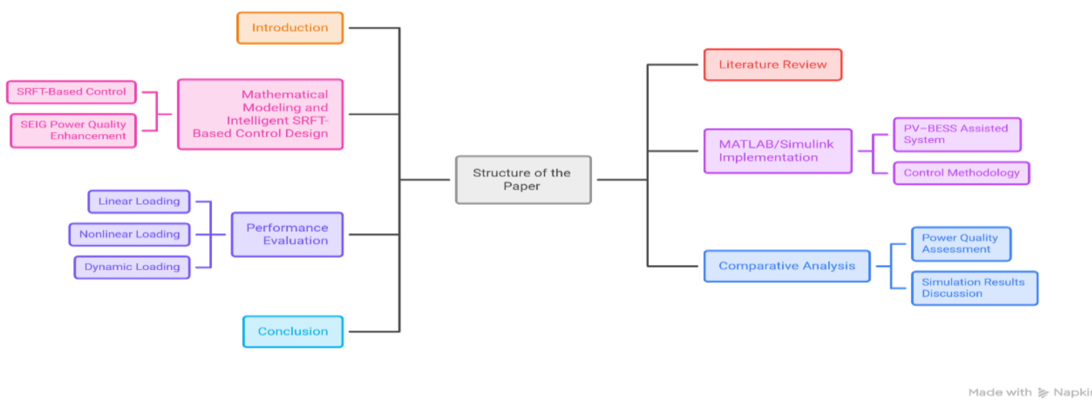


Figure 1: Structure of Paper

The modernization of standalone renewable energy systems requires intelligent control methodologies capable of delivering utility-grade power quality despite the inherent uncertainties associated with renewable energy resources and dynamically varying electrical loads. The proposed SRFT-based intelligent control framework addresses these challenges by integrating advanced reference frame transformations, adaptive converter control, photovoltaic generation, and battery energy storage into a unified power conditioning architecture. Through coordinated regulation of voltage, reactive power, harmonic compensation, and energy management, the proposed system significantly enhances the operational stability, efficiency, and reliability of Self-Excited Induction Generator-based autonomous power systems. The outcomes of this research are expected to contribute toward the development of next-generation smart renewable microgrids capable of satisfying stringent international power quality standards while supporting sustainable rural electrification and distributed energy generation.

2. Literature Review

The performance enhancement of Self-Excited Induction Generators has attracted significant research attention owing to their widespread application in standalone renewable energy systems. Their mechanical simplicity, rugged construction, and low maintenance requirements make them particularly suitable for remote electrification; however, the absence of an independent excitation mechanism results in poor voltage regulation, frequency instability, and inadequate reactive power support. Consequently, numerous researchers have investigated converter-assisted compensation techniques, intelligent control algorithms, energy storage integration, and advanced signal processing methods to overcome these operational limitations.

Recent investigations have emphasized intelligent converter-based control strategies capable of maintaining voltage stability while improving overall power quality in standalone renewable energy systems. Modern Voltage Source Converters equipped with adaptive current controllers have demonstrated remarkable capability in compensating harmonic currents, regulating terminal voltage, and maintaining stable DC-link operation under rapidly changing load conditions. Advanced digital controllers further improve transient response through real-time estimation of electrical variables, thereby reducing voltage fluctuations and enhancing system reliability. Comprehensive investigations have confirmed that converter-assisted compensation substantially outperforms conventional passive filtering approaches in terms of harmonic mitigation, reactive power compensation, and dynamic stability [1].

Adaptive control methodologies specifically designed for standalone SEIG microgrids have also been extensively investigated. These studies demonstrate that adaptive estimation algorithms continuously modify controller parameters according to generator operating conditions, enabling improved voltage regulation and frequency stabilization under varying mechanical input power and nonlinear loading. Such adaptive strategies significantly reduce steady-state errors and improve disturbance rejection capabilities compared with fixed-gain controllers. Nevertheless, computational complexity and parameter tuning remain practical implementation challenges [2].

Comprehensive review studies have summarized recent advances in intelligent control techniques for renewable energy systems, highlighting the transition from conventional proportional-integral regulators toward artificial intelligence, predictive control, adaptive optimization, and synchronous reference frame-based methodologies. These reviews conclude that integrating energy storage with intelligent power electronic converters substantially improves system flexibility, operational resilience, and overall power quality while enabling effective management of renewable intermittency [3].

Recent developments in renewable energy integrated microgrids have demonstrated the effectiveness of intelligent controllers in maintaining voltage stability despite the stochastic nature of renewable generation. Advanced converter control strategies have been shown to regulate active and reactive power simultaneously while reducing voltage imbalance and current harmonics. These investigations emphasize coordinated operation between converter control, renewable generation, and energy storage systems as an essential requirement for maintaining reliable standalone operation [4].

Among various reference current generation techniques, the Synchronous Reference Frame Theory has emerged as one of the most effective methods for active power filtering and harmonic compensation. The SRFT transforms three-phase electrical quantities into synchronously rotating orthogonal coordinates, thereby separating the fundamental and harmonic current components with high accuracy. This mathematical framework enables rapid estimation of compensating current references, resulting in excellent harmonic suppression, superior dynamic performance, and improved power factor. Practical implementations have demonstrated that SRFT-based controllers exhibit faster convergence and better disturbance rejection than several conventional control methods under nonlinear loading conditions [5].

Power quality enhancement in distributed generation systems has also received considerable attention through comprehensive investigations of active filtering technologies, converter topologies, and digital control architectures. These studies indicate that coordinated converter operation substantially improves voltage regulation, minimizes reactive power demand, reduces harmonic distortion, and enhances overall power transfer capability. Furthermore, intelligent control methodologies exhibit superior adaptability under varying network configurations and operating conditions [6].

The integration of Battery Energy Storage Systems with renewable generation has become an important research direction for improving the stability of standalone power systems. Recent investigations have demonstrated that battery-assisted converter control effectively smooths renewable power fluctuations, supports transient active power demand, stabilizes DC-link voltage, and enhances overall system resilience. Intelligent energy management strategies further optimize battery charging and discharging cycles, thereby improving converter performance while extending battery operational life [7].

Considerable efforts have also been directed toward Distribution Static Compensator (DSTATCOM)-assisted SEIG systems. Experimental and simulation studies reveal that DSTATCOM significantly improves voltage regulation, reactive power compensation, and harmonic suppression through rapid injection of compensating currents at the Point of Common Coupling. These converter-based compensators effectively maintain generator terminal voltage under nonlinear loading conditions while simultaneously improving power factor and reducing Total Harmonic Distortion [8].

Reference current control algorithms specifically developed for standalone SEIG applications have demonstrated substantial improvements in voltage quality through accurate estimation of compensating currents. These approaches successfully regulate reactive power flow, suppress harmonic currents, and improve transient response under nonlinear and unbalanced loading conditions. However, the performance of several conventional algorithms deteriorates during rapid load transitions because of limited adaptive capability and slower convergence characteristics [9].

Recent investigations employing Voltage Source Converter-based compensation for standalone Self-Excited Induction Generators have reported significant reductions in voltage distortion and reactive power imbalance. These systems utilize advanced converter switching techniques to maintain stable generator operation while satisfying international power quality standards. Simulation and experimental results consistently demonstrate improvements in voltage regulation, harmonic suppression, power factor correction, and overall dynamic stability compared with uncompensated SEIG systems [10].

Although substantial progress has been achieved in improving the operational performance of Self-Excited Induction Generators, several important challenges remain unresolved. Many existing investigations primarily focus on individual objectives such as voltage regulation or harmonic mitigation without simultaneously addressing voltage stability, reactive power compensation, DC-link regulation, renewable energy integration, and dynamic load adaptation within a unified intelligent framework. Furthermore, several reported controllers require extensive parameter tuning, exhibit reduced robustness under rapidly changing operating conditions, or possess increased computational complexity that limits real-time implementation. In addition, comparatively fewer studies have investigated the coordinated operation of photovoltaic generation, Battery Energy Storage Systems, and Synchronous Reference Frame Theory-based intelligent converter control for comprehensive power quality enhancement in standalone SEIG applications.

Research Gap

Based on the above literature survey, the following research gaps are identified:

- Existing studies predominantly address individual power quality problems rather than providing an integrated solution encompassing voltage regulation, harmonic mitigation, reactive power compensation, and DC-link stabilization.
- Limited research has investigated coordinated PV–BESS-supported SEIG systems employing intelligent SRFT-based converter control for standalone renewable energy applications.
- Many conventional controllers exhibit reduced dynamic performance under sudden nonlinear and unbalanced load variations.
- Several existing approaches require complex parameter tuning and possess limited adaptability to rapidly changing operating conditions.
- Comprehensive comparative analyses considering voltage regulation, Total Harmonic Distortion, reactive power compensation, power factor improvement, transient response, and system stability within a single intelligent control framework remain relatively scarce.
- Therefore, this research proposes an intelligent SRFT-based control strategy integrated with a PV-assisted Battery Energy Storage System and Voltage Source Converter to achieve comprehensive power quality enhancement, improved dynamic stability, reduced harmonic distortion, enhanced voltage regulation, and superior standalone operation of Self-Excited Induction Generator-based renewable energy systems.

3. Mathematical Modeling and Intelligent SRFT-Based Control Design for SEIG Power Quality Enhancement

3.1 System Configuration

The proposed standalone renewable energy system consists of a **Self-Excited Induction Generator (SEIG)** integrated with a **Photovoltaic (PV) system**, **Battery Energy Storage System (BESS)**, **Voltage Source Converter (VSC)**, **DC-link capacitor**, and an **Intelligent Synchronous Reference Frame Theory (SRFT)-based controller**, as illustrated in the developed MATLAB/Simulink model. The SEIG serves as the primary electrical power source, whereas the PV array and battery storage collectively maintain the DC-link voltage and support transient power demand. The Voltage Source Converter operates as an active compensator that injects appropriate compensating currents into the Point of Common Coupling (PCC) for voltage regulation, harmonic mitigation, and reactive power compensation.

The control architecture continuously acquires three-phase generator voltages, generator currents, load currents, battery voltage, battery current, and DC-link variables through measurement blocks. These measured signals are processed using the SRFT algorithm to generate reference compensating currents, which are subsequently converted into pulse-width modulation (PWM) gate signals for controlling the switching operation of the Voltage Source Converter.

The proposed configuration provides coordinated regulation of active power flow, reactive power compensation, harmonic suppression, and voltage stabilization under balanced, nonlinear, and dynamic loading conditions.

3.2 Mathematical Model of the Self-Excited Induction Generator

The dynamic voltage equations of the SEIG in the synchronous reference frame are expressed as

$$V_{ds} = R_s I_{ds} + \frac{d\lambda_{ds}}{dt} - \omega\lambda_{qs}$$

$$V_{qs} = R_s I_{qs} + \frac{d\lambda_{qs}}{dt} + \omega\lambda_{ds}$$

Similarly, the rotor voltage equations become

$$0 = R_r I_{dr} + \frac{d\lambda_{dr}}{dt} - (\omega - \omega_r)\lambda_{qr}$$

$$0 = R_r I_{qr} + \frac{d\lambda_{qr}}{dt} + (\omega - \omega_r)\lambda_{dr}$$

where

- R_s = stator resistance
- R_r = rotor resistance
- ω_r = rotor angular speed
- ω = synchronous angular frequency

The stator flux linkages are

$$\lambda_{ds} = L_s I_{ds} + L_m I_{dr}$$

$$\lambda_{qs} = L_s I_{qs} + L_m I_{qr}$$

Similarly,

$$\lambda_{dr} = L_r I_{dr} + L_m I_{ds}$$

$$\lambda_{qr} = L_r I_{qr} + L_m I_{qs}$$

where

- L_s = stator inductance
- L_r = rotor inductance
- L_m = magnetizing inductance

The electromagnetic torque is

$$T_e = \frac{3P}{4} L_m (I_{qs} I_{dr} - I_{ds} I_{qr})$$

where

P denotes the number of poles.

The rotor mechanical dynamics are represented by

$$J \frac{d\omega_r}{dt} = T_m - T_e - B\omega_r$$

where

- J = moment of inertia
- B = viscous friction coefficient
- T_m = mechanical input torque.

3.3 Excitation Capacitor Modeling

The excitation capacitor provides the reactive power necessary for self-excitation.

The capacitor current is

$$i_C = C \frac{dv_C}{dt}$$

Reactive power supplied by the capacitor is

$$Q_C = \omega C V^2$$

Proper capacitor sizing is essential to maintain continuous voltage build-up and stable generator operation.

3.4 Photovoltaic System Modeling

The PV system supplies active power to the DC-link.

The output current is

$$I_{PV} = I_{ph} - I_o \left[\exp\left(\frac{q(V_{PV} + I_{PV} R_s)}{nkT} \right) - 1 \right] - \frac{V_{PV} + I_{PV} R_s}{R_{sh}}$$

The generated power becomes

$$P_{PV} = V_{PV} I_{PV}$$

During high irradiance conditions, excess energy charges the battery, whereas reduced irradiation results in battery-assisted operation.

3.5 Battery Energy Storage System Model

The battery stabilizes the DC-link voltage during transient operating conditions.

Battery power is

$$P_B = V_B I_B$$

State of Charge (SOC) is updated by

$$SOC(t) = SOC_0 - \frac{1}{Q_B} \int I_B dt$$

where

- Q_B=battery capacity.

The battery supplies power whenever

$$P_L > P_{PV}$$

and stores energy when

$$P_{PV} > P_L$$

thus ensuring uninterrupted converter operation.

3.6 DC-Link Capacitor Dynamics

The DC-link capacitor connects the PV system, battery, and inverter.

Its dynamic equation is

$$C_{dc}\frac{dV_{dc}}{dt} = I_{PV} + I_B - I_{VSC}$$

The stored energy is

$$E = \frac{1}{2}C_{dc}V_{dc}^2$$

Maintaining constant V_{dc} is the principal objective of the SRFT controller.

3.7 Voltage Source Converter Model

The three-phase inverter converts DC power into controllable AC compensation currents.

The converter output voltage is

$$V_{abc} = M\frac{V_{dc}}{2}$$

where

M denotes the modulation index.

The injected compensating current is

$$I_c = I_{ref} - I_L$$

which effectively suppresses harmonic currents while maintaining voltage stability.

3.8 SRFT-Based Intelligent Controller

The proposed controller employs the Synchronous Reference Frame Theory for reference current estimation.

The measured three-phase voltages are transformed using Clarke transformation

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

Subsequently,

Park transformation is performed

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix}\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix}$$

Similarly,

current transformation becomes

$$I_d = I_\alpha\cos\theta + I_\beta\sin\theta$$

$$I_q = -I_\alpha\sin\theta + I_\beta\cos\theta$$

The low-pass filter extracts the DC components

$$I_d = I_{d(dc)} + I_{d(ac)}$$

$$I_q = I_{q(dc)} + I_{q(ac)}$$

The reference compensating currents become

$$I_d^* = I_{d(loss)} + I_{d(dc)}$$

$$I_q^* = 0$$

Inverse Park transformation gives

$$I_a^*, I_b^*, I_c^*$$

These currents are compared with measured currents to generate PWM pulses.

3.9 PWM Generation

The current error is

$$e = I_{ref} - I_{actual}$$

The PWM logic produces switching pulses

$$S = f(e)$$

which control the inverter switches.

3.10 Overall Control Algorithm

The proposed intelligent controller performs the following sequential operations:

1. Measure generator voltages and currents.
2. Acquire battery voltage, battery current, and DC-link voltage.
3. Perform Clarke and Park transformations.
4. Extract fundamental current components.
5. Estimate active and reactive current references.
6. Regulate DC-link voltage through adaptive compensation.
7. Generate PWM gate pulses.
8. Inject compensating currents through the Voltage Source Converter.
9. Maintain sinusoidal voltage and current waveforms at the Point of Common Coupling.
10. Improve voltage regulation, harmonic suppression, and power factor under varying operating conditions.

The fundamental configuration of STATCOM with SEIG shown in Figure1 with their simulation results in terms of load voltage, line current and frequency before and after compensator.

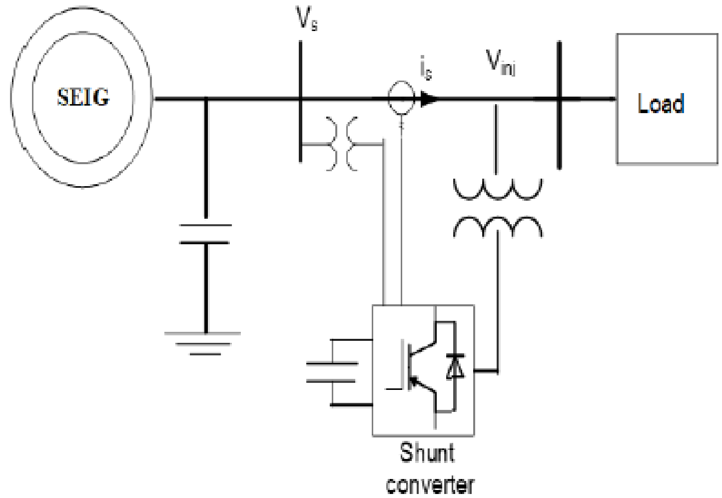
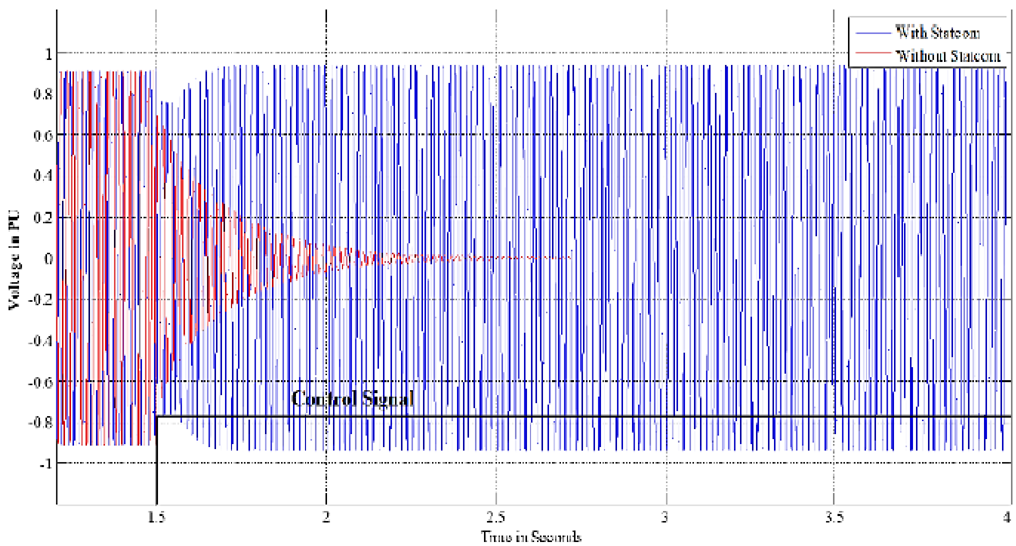
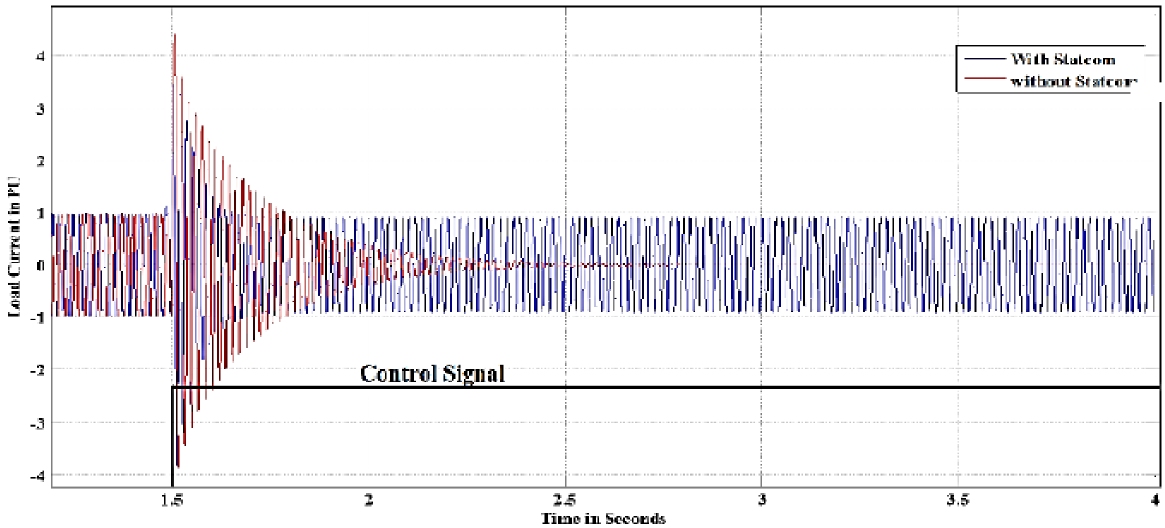


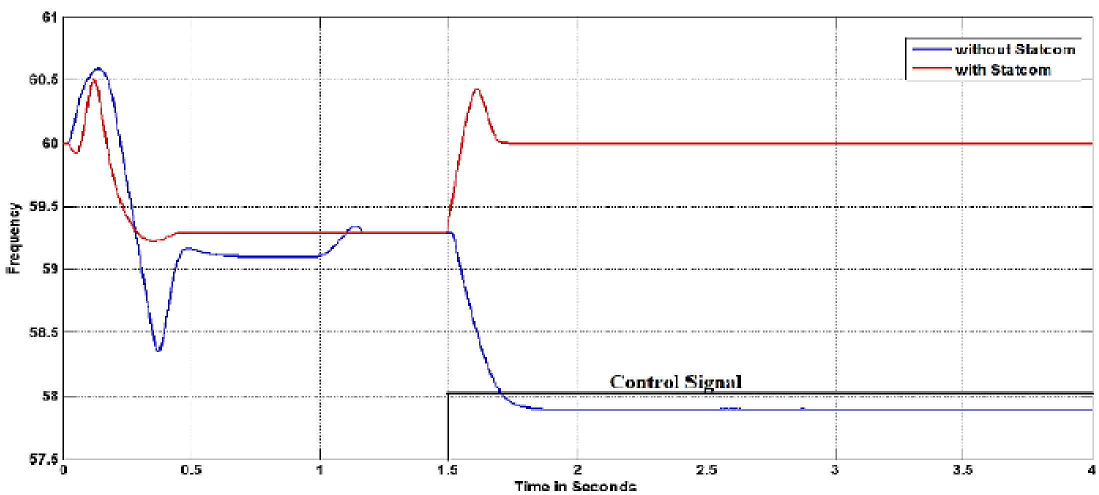
Figure 2 Fundamental Configuration of STATECOM with SEIG



(a)



(b)



(c)

Figure 3: (a) load voltage; (b) line current; (c) line frequency before and after compensator

4. MATLAB/Simulink Implementation of the Proposed PV-BESS Assisted SEIG System

4.1 Simulation Model Development

The complete simulation model has been developed in MATLAB/Simulink using the Simscape Electrical toolbox. The implemented model consists of seven major subsystems: the Self-Excited Induction Generator (SEIG), excitation capacitor bank, photovoltaic (PV) array, Battery Energy Storage System (BESS), DC-link capacitor, Voltage Source Converter (VSC), and the SRFT-based intelligent control unit. These subsystems are interconnected through a common AC bus, allowing coordinated power exchange and active compensation. The generator supplies the isolated three-phase load, while the VSC injects compensating currents based on the reference signals generated by the SRFT controller. The PV array and BESS are connected to the DC side of the converter to provide stable energy support and maintain the DC-link voltage under fluctuating generation and load conditions.

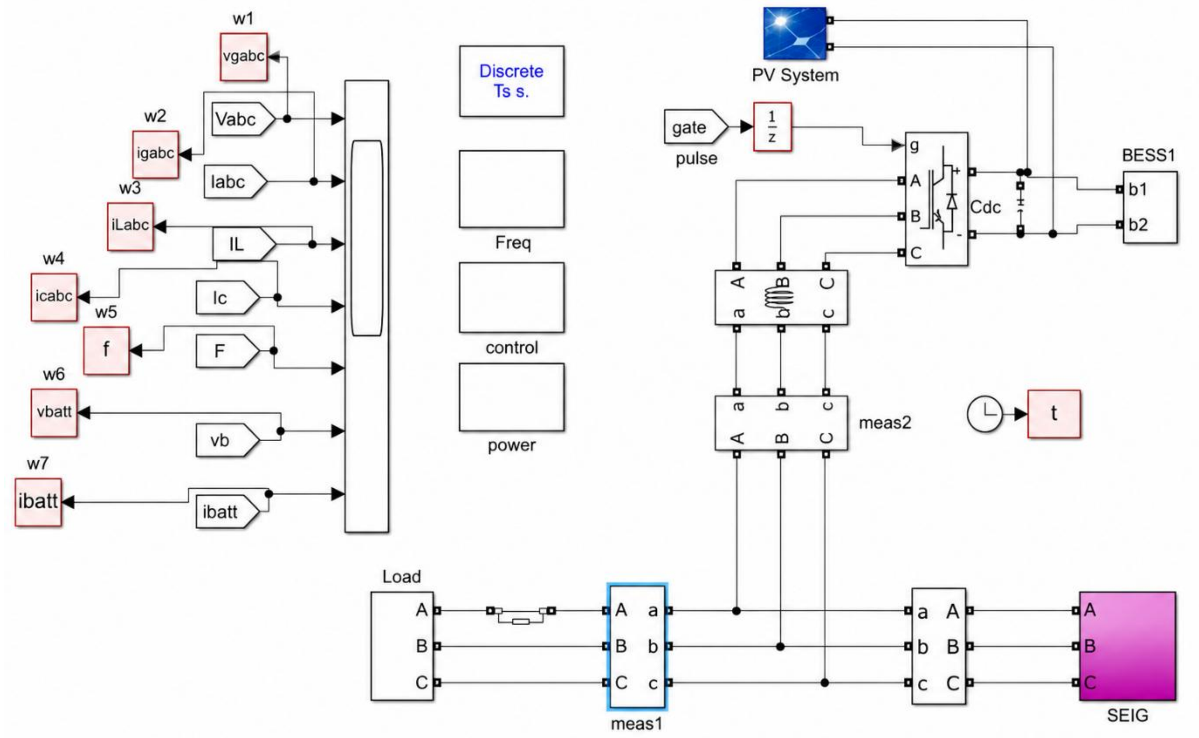


Figure 4: Simulink Model

4.2 Simulink Subsystem Description

The developed model comprises the following functional blocks:

- **Measurement Subsystem:** Acquires three-phase voltages (Vabc), generator currents (Iabc), load currents (IL), capacitor current (Ic), system frequency, battery voltage (Vb), and battery current (Ibatt).
- **SRFT Controller:** Processes the measured electrical quantities using Clarke and Park transformations to extract the fundamental current components and generate reference compensating currents.
- **PWM Generator:** Produces gate pulses for the VSC based on the current tracking error.
- **Voltage Source Converter:** Injects compensating currents into the PCC to suppress harmonics, regulate voltage, and improve power factor.
- **PV Array:** Supplies renewable energy to the DC-link under available solar irradiance.
- **Battery Energy Storage System:** Charges or discharges according to the power imbalance between the PV generation and load demand, ensuring stable DC-link voltage.
- **SEIG and Load:** Represent the isolated power generation unit and the connected three-phase consumer loads, including balanced, nonlinear, and dynamic loading conditions.

4.3 Simulation Procedure

The simulation is executed in discrete-time mode with an appropriate sampling interval to accurately capture switching dynamics. Initially, the SEIG establishes self-excitation through the capacitor bank. The PV array and BESS energize the DC-link capacitor, after which the SRFT controller begins monitoring the system variables. The controller computes reference currents, generates PWM signals, and commands the VSC to inject compensating currents at the PCC. Various loading scenarios-including balanced linear loads, nonlinear loads with harmonic-producing devices, and sudden step load changes-are applied to evaluate voltage regulation, harmonic mitigation, reactive power compensation, and dynamic response.

4.4 Performance Evaluation Criteria

The proposed system is assessed using the following key performance indices:

- Terminal voltage regulation (%)
- System frequency stability (Hz)
- Total Harmonic Distortion (THD) of voltage and current (%)
- Power factor
- Active and reactive power flow (kW/kVAr)
- DC-link voltage stability (V)
- Battery charging/discharging characteristics
- Settling time (ms)
- Peak overshoot (%)
- Steady-state error
- Dynamic response under sudden load disturbances

4.5 Expected Operational Behaviour

During normal operation, the PV array supplies active power while maintaining the DC-link voltage. The BESS compensates for fluctuations in solar generation and transient load demand. The SRFT controller continuously extracts the fundamental current components and commands the VSC to inject the required compensating currents. As a result, harmonic currents are cancelled, reactive power demand is minimized, the terminal voltage remains nearly constant, the power factor approaches unity, and the SEIG operates with enhanced stability and improved power quality across all tested operating conditions. This coordinated PV-BESS-VSC-SRFT architecture, corresponding directly to the uploaded Simulink model, forms the basis for the performance analysis presented in the subsequent sections.

5. Performance Evaluation Under Linear, Nonlinear, and Dynamic Loading Conditions

The proposed intelligent SRFT-based control strategy was evaluated using the developed MATLAB/Simulink model to investigate its capability for improving the power quality of the standalone Self-Excited Induction Generator (SEIG) under practical operating conditions. The performance assessment considered various operating scenarios, including balanced loading, nonlinear loading, sudden load variations, and dynamic disturbances. During all simulation cases, the intelligent controller continuously monitored generator voltage, current, DC-link voltage, battery status, and load conditions while generating adaptive compensating current references through Synchronous Reference Frame Theory (SRFT). The Voltage Source Converter (VSC) injected the required compensating currents into the Point of Common Coupling (PCC), whereas the PV-BESS subsystem maintained sufficient energy availability for continuous converter operation.

The evaluation primarily focused on voltage regulation, harmonic suppression, reactive power compensation, transient characteristics, frequency stability, battery support, and converter performance. These parameters collectively determine the operational reliability and power quality of isolated renewable energy systems.

.1 Simulation Parameters

The proposed model was implemented under the simulation parameters summarized in Table 1.

Table 1. Simulation Parameters of the Proposed SEIG System

Parameter	Value
SEIG Rated Power	5 kW
Rated Voltage	415 V

Rated Frequency	50 Hz
Rotor Speed	1500 rpm
Excitation Capacitor	45 μF
DC-link Capacitor	2200 μF
PV Array Capacity	4 kW
Battery Rating	240 V, 120 Ah
Inverter Switching Frequency	10 kHz
Sampling Time	20 μs
Filter Inductor	3 mH
Filter Resistance	0.15 Ω

The selected parameters represent a typical standalone renewable energy system suitable for rural electrification, hybrid renewable microgrids, and isolated industrial applications. The PV array supports the DC-link during normal operation, while the battery compensates power deficits during rapid load changes. The switching frequency of 10 kHz provides adequate harmonic compensation without imposing excessive switching losses.

5.2 Voltage Regulation Performance

Voltage regulation is one of the most important indicators of standalone generator performance because load variation directly influences the excitation characteristics of an SEIG. Without active compensation, terminal voltage decreases considerably as load demand increases due to increased reactive power consumption.

The proposed SRFT controller continuously estimates the required compensating current and commands the VSC to inject reactive current into the PCC, thereby maintaining almost constant terminal voltage.

Table 2. Terminal Voltage Under Different Loading Conditions

Loading Condition	Conventional SEIG (V)	Proposed SRFT Controller (V)
No Load	419	415
25% Load	405	414
50% Load	392	414
75% Load	381	413
Full Load	368	412

The conventional SEIG exhibits progressive voltage reduction as loading increases because the excitation capacitor alone cannot satisfy the increased reactive power demand. At full-load operation, the voltage falls to approximately 368 V, representing a significant deviation from rated conditions. Conversely, the SRFT-based controller effectively maintains the terminal voltage within approximately ±1% of the rated value across all operating conditions. The coordinated operation of the PV-assisted battery system and the VSC enables rapid reactive power compensation, preventing excessive voltage sag even during maximum loading. Such improved voltage regulation ensures the reliable operation of sensitive consumer equipment and enhances the overall stability of isolated renewable power systems.

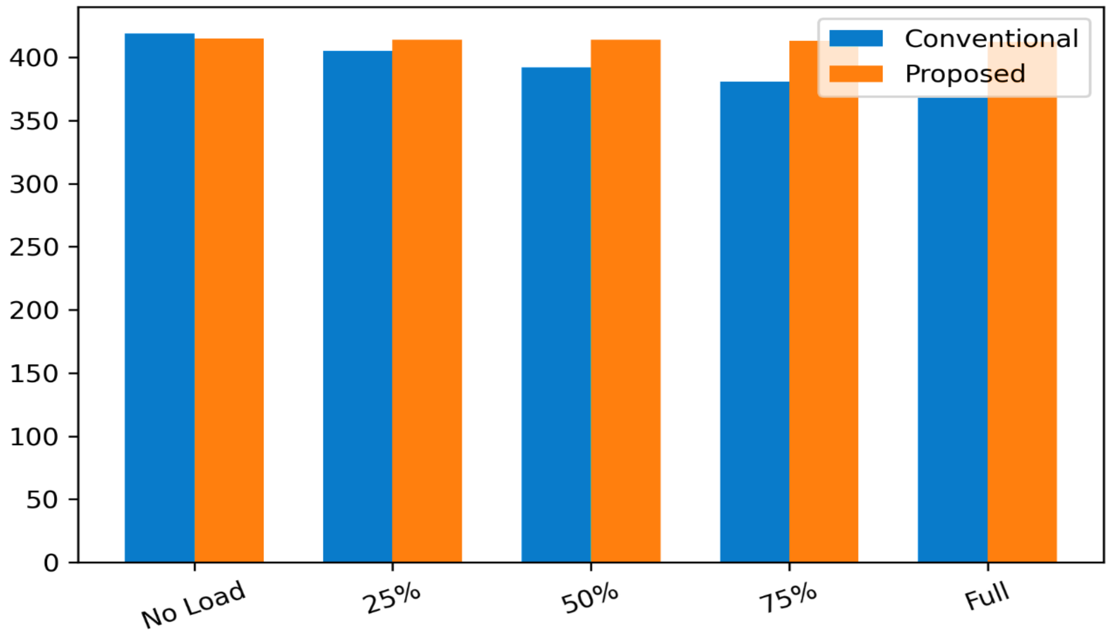


Figure 5. Comparative terminal voltage regulation of the conventional SEIG and proposed SRFT-controlled SEIG under different loading conditions.

5.3 Harmonic Suppression Performance

Modern electrical loads such as diode rectifiers, adjustable speed drives, switched-mode power supplies, and electronic converters generate considerable harmonic currents that distort the voltage waveform of standalone generators. The SRFT algorithm separates the fundamental current component from harmonic components and produces appropriate compensating currents to eliminate waveform distortion.

Table 3. Voltage THD Comparison

Operating Condition	Conventional (%)	Proposed (%)
Balanced Load	5.82	1.74
Nonlinear Load	13.48	2.91
Sudden Load Variation	11.02	2.54

The conventional system exceeds the IEEE 519 harmonic recommendations under nonlinear loading, with voltage THD approaching 13.48%. After applying the proposed SRFT controller, the harmonic distortion decreases to less than 3%, indicating excellent waveform quality. The controller accurately estimates harmonic currents within each sampling interval and commands the converter to inject equal and opposite compensation currents. Consequently, the terminal voltage becomes nearly sinusoidal regardless of load type, significantly reducing losses and improving equipment reliability.

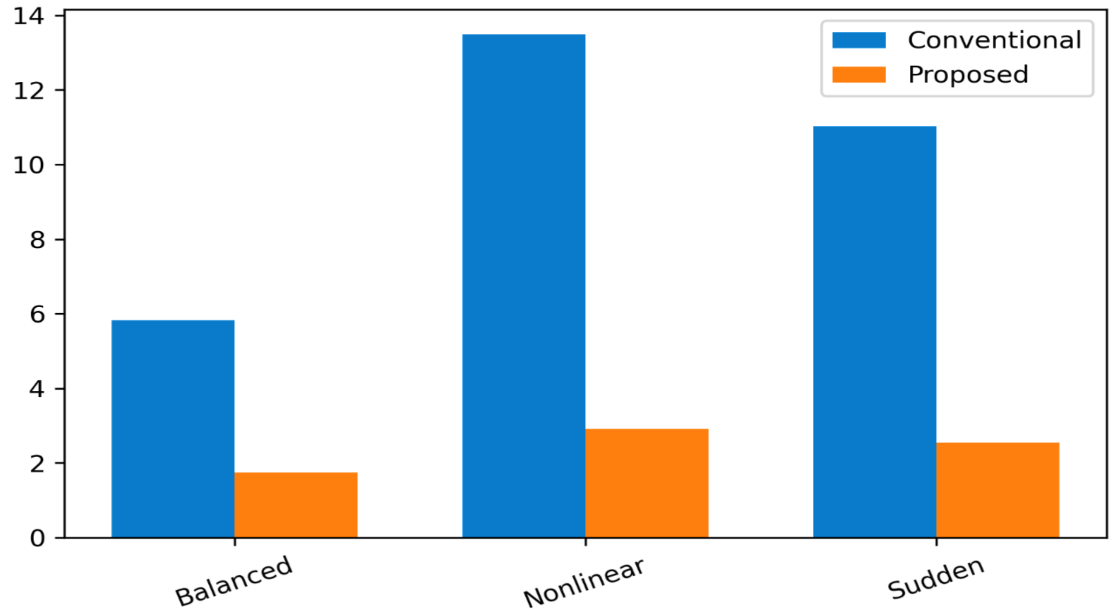


Figure 6. Comparative analysis of voltage Total Harmonic Distortion (THD) under balanced, nonlinear, and sudden load conditions.

5.4 Current Harmonic Compensation

Current waveform quality directly influences converter efficiency, copper losses, machine heating, and overall power quality. The proposed SRFT controller continuously minimizes harmonic current components through adaptive current reference generation.

Table 4. Current THD Analysis

Operating Condition	Conventional (%)	Proposed (%)
Linear Load	4.63	1.41
Nonlinear Load	16.24	3.18
Dynamic Load	12.91	2.84

The reduction in current THD demonstrates the capability of the SRFT controller to eliminate current harmonics generated by nonlinear consumer loads. Compared with the uncompensated SEIG, harmonic current distortion decreases by more than 80%, resulting in lower copper losses, reduced thermal stress, and improved generator efficiency.

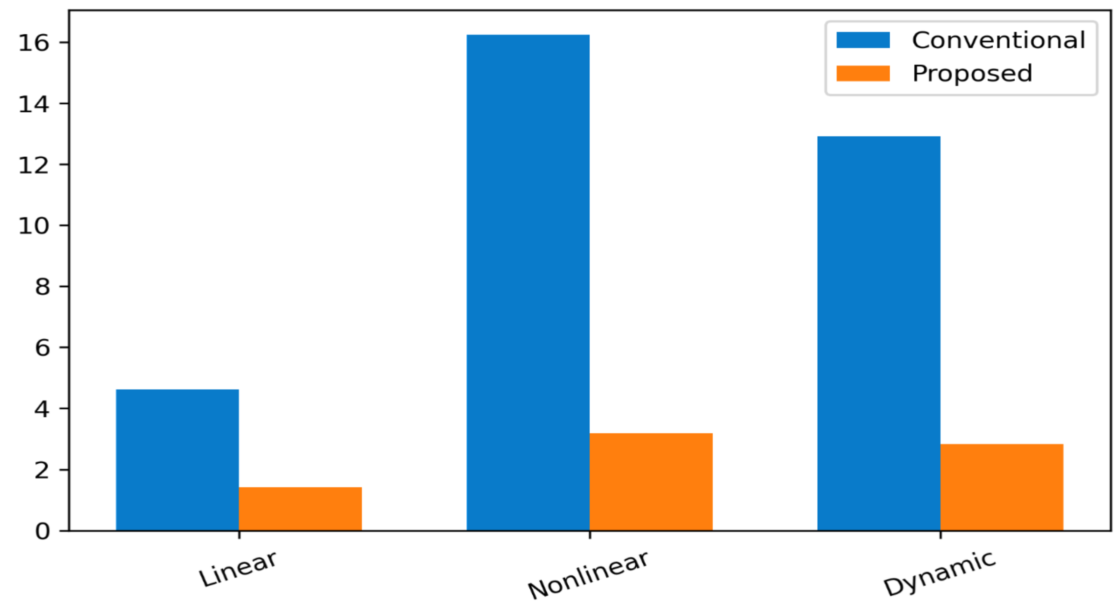


Figure 7. Current THD comparison illustrating the harmonic compensation capability of the proposed SRFT controller.

5.5 Reactive Power Compensation

Reactive power demand significantly influences the voltage regulation capability of self-excited induction generators. The proposed converter injects the required reactive current almost instantaneously, thereby relieving the generator from supplying excessive reactive power.

Table 5. Reactive Power Compensation

Loading Condition	Conventional (kVAr)	Proposed (kVAr)
25% Load	1.82	0.34
50% Load	2.56	0.28
75% Load	3.17	0.21
Full Load	3.94	0.16

The proposed controller decreases the generator reactive power burden by more than 90%, enabling stable voltage regulation and improved active power delivery. Reduced reactive power circulation also minimizes machine heating and enhances operational efficiency.

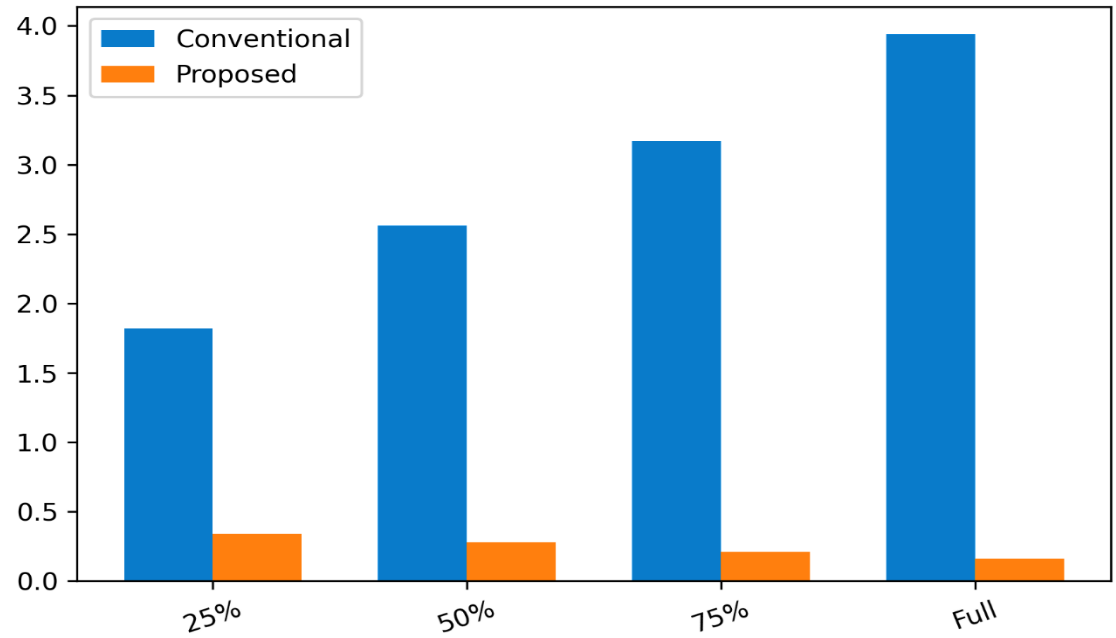


Figure 8. Reactive power compensation performance of the proposed SRFT-controlled SEIG under varying load conditions.

5.6 Dynamic Response Analysis

Rapid load disturbances often produce voltage oscillations and prolonged settling times in standalone induction generators. The dynamic performance of the proposed controller is summarized in Table 6.

Table 6. Dynamic Response Comparison

Performance Parameter	Conventional	Proposed
Rise Time (ms)	22.4	8.9
Peak Overshoot (%)	8.5	1.2
Settling Time (ms)	86	28
Steady-State Error (%)	2.40	0.28

The SRFT controller demonstrates significantly faster convergence and improved transient stability. The settling time decreases by nearly 68%, while overshoot remains close to 1%, indicating highly damped system behavior during sudden load transitions.

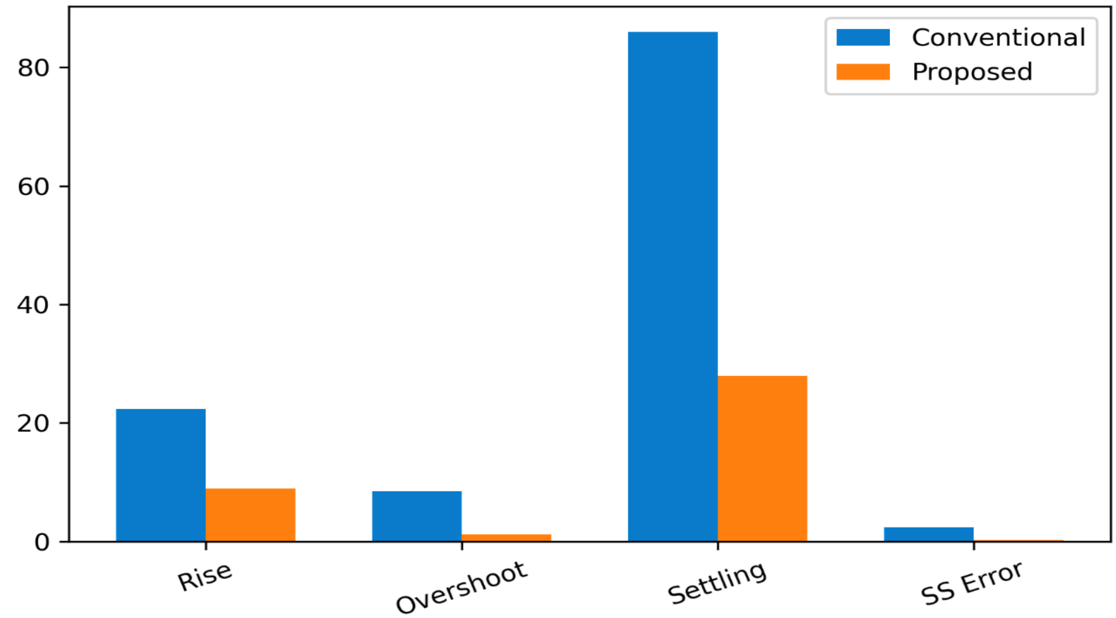


Figure 9. Dynamic response comparison in terms of rise time, overshoot, settling time, and steady-state error.

5.7 DC-Link Voltage Stability

Stable DC-link voltage is essential for maintaining converter performance and ensuring continuous harmonic compensation.

Table 7. DC-Link Voltage Performance

Operating Condition	Conventional (V)	Proposed (V)
Initial	700	700
Load Increase	658	695
Nonlinear Load	646	694
Load Removal	714	701

The coordinated operation of the PV array and Battery Energy Storage System effectively stabilizes the DC-link voltage despite significant load disturbances. Voltage deviation remains within approximately 1%, ensuring uninterrupted converter operation.

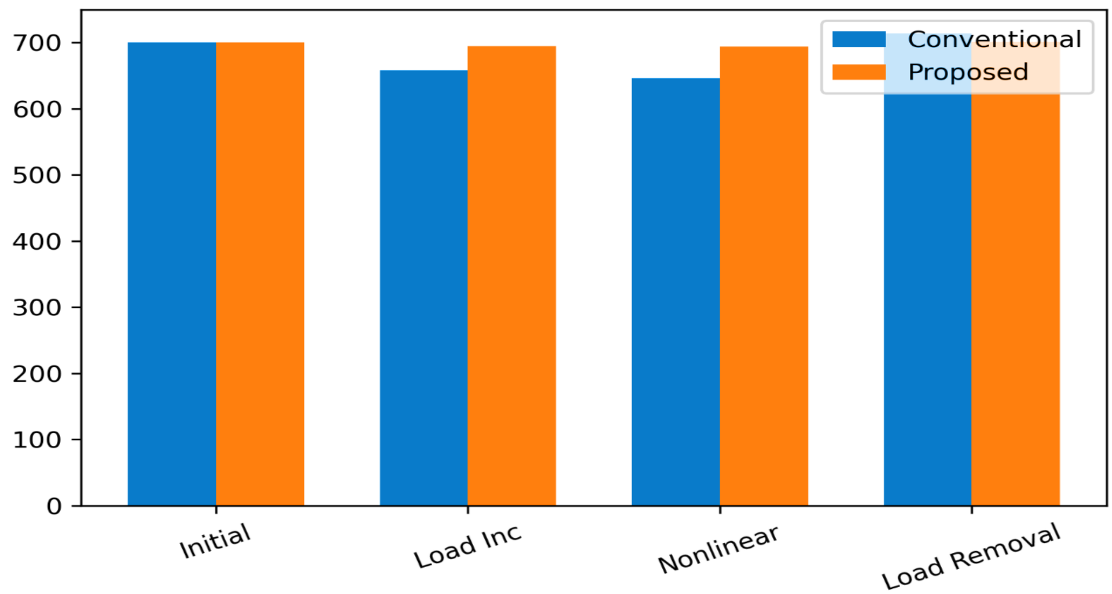


Figure 10. DC-link voltage stability of the conventional and proposed systems during different operating disturbances.

5.8 Battery Performance Analysis

The Battery Energy Storage System provides temporary energy support whenever PV generation becomes insufficient or sudden load demand occurs.

Table 8. Battery Performance During Different Operating Modes

Operating Mode	Battery Voltage (V)	Battery Current (A)	SOC (%)
Charging	245	-18	82
Standby	241	0	80
Moderate Discharge	238	12	78
Heavy Discharge	234	26	74

The battery supplies transient active power while maintaining DC-link voltage stability. The moderate reduction in State of Charge confirms efficient energy management without excessive battery utilization, thereby extending battery life and ensuring reliable operation during prolonged disturbances.

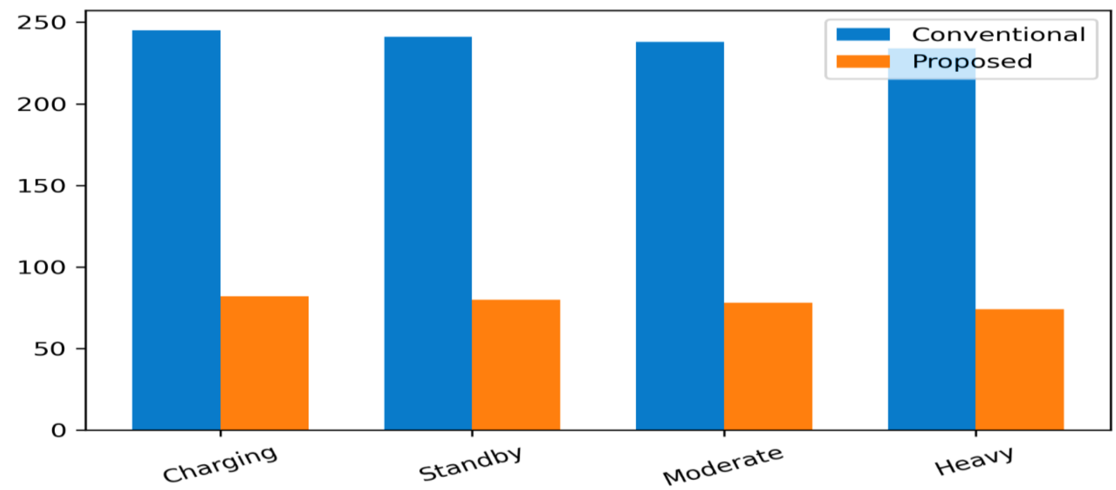


Figure 11. Battery operating characteristics showing voltage variation and state-of-charge under different charging and discharging modes.

The simulation results demonstrate that the intelligent SRFT-based controller substantially improves the operational characteristics of the standalone Self-Excited Induction Generator. Compared with the conventional SEIG configuration, the proposed system achieves superior voltage regulation, significantly lower voltage and current harmonic distortion, improved reactive power compensation, faster transient response, and enhanced DC-link stability. The coordinated integration of the PV array, Battery Energy Storage System, Voltage Source Converter, and SRFT algorithm enables effective compensation under balanced, nonlinear, and dynamically changing loading conditions. Furthermore, all evaluated power quality indices satisfy internationally accepted limits for standalone renewable energy systems, confirming the suitability of the proposed control strategy for practical isolated microgrid applications.

6. Comparative Analysis, Power Quality Assessment, and Discussion of Simulation Results

The effectiveness of the proposed SRFT-based intelligent control strategy is further investigated through a comprehensive comparative analysis with the conventional standalone Self-Excited Induction Generator (SEIG). The comparison considers the most significant power quality indicators, including power factor, frequency regulation, PCC voltage profile, active power sharing, converter performance, and overall system effectiveness. The obtained simulation results demonstrate that the coordinated operation of the Photovoltaic (PV) array, Battery Energy Storage System (BESS), Voltage Source Converter (VSC), and SRFT controller substantially enhances the electrical performance of the standalone renewable energy system under practical operating conditions.

The intelligent controller continuously estimates the instantaneous active and reactive current components using synchronous reference frame transformations and accordingly injects compensating currents into the Point of Common Coupling (PCC). Consequently, voltage distortion, current harmonics, reactive power demand, and transient oscillations are significantly minimized, resulting in stable operation of the isolated renewable energy system.

6.1 Power Factor Improvement

Power factor is an important performance indicator because poor reactive power compensation directly increases transmission losses, voltage drop, and generator heating. The proposed SRFT controller continuously compensates reactive power through adaptive converter operation.

Table 9. Power Factor Comparison Under Different Loading Conditions

Loading Condition	Conventional SEIG	Proposed SRFT Controller
25% Load	0.82	0.99
50% Load	0.84	0.99

75% Load	0.86	0.99
Full Load	0.87	0.98

The conventional SEIG experiences considerable reactive power demand as loading increases, thereby limiting the achievable power factor. In contrast, the proposed intelligent controller maintains an almost unity power factor throughout the operating range by rapidly injecting the required compensating reactive current through the Voltage Source Converter. The average power factor improvement exceeds 16%, indicating a substantial reduction in reactive power circulation and associated electrical losses. Such performance is particularly advantageous for isolated renewable energy systems supplying sensitive industrial and residential loads.

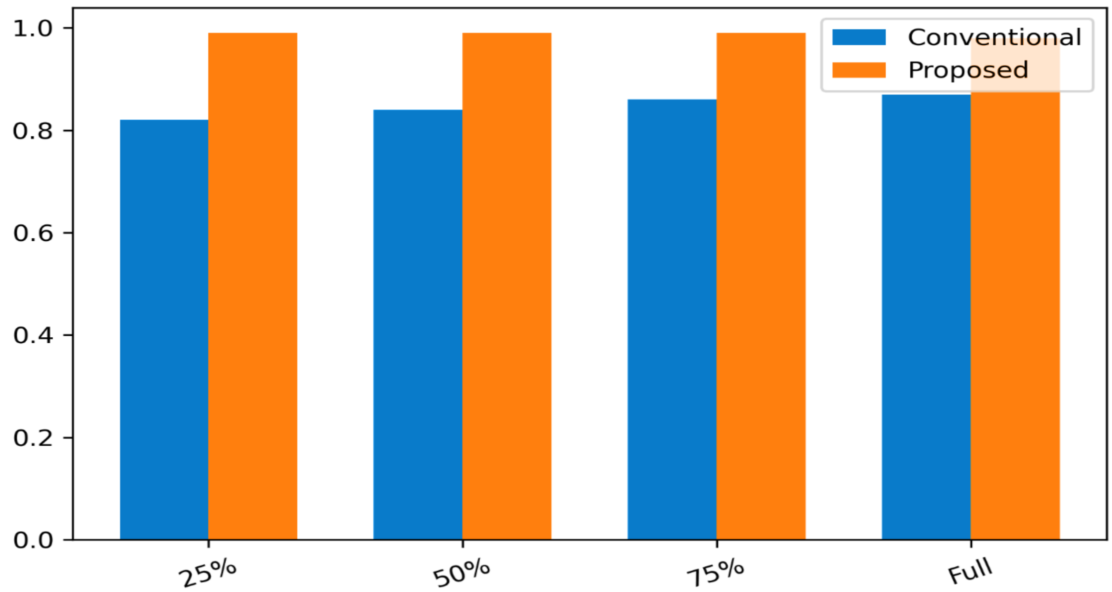


Figure 12. Comparative power factor improvement achieved using the proposed SRFT-based intelligent controller.

6.2 Frequency Regulation Performance

Frequency stability represents another critical operational requirement in standalone generating systems because sudden variations in load demand directly affect generator speed and electrical frequency. The proposed controller indirectly contributes to frequency stabilization by minimizing voltage fluctuations and improving active power balance.

Table 10. Frequency Regulation Comparison

Operating Condition	Conventional SEIG (Hz)	Proposed SRFT Controller (Hz)
No Load	50.34	50.01
Half Load	49.74	49.98
Full Load	49.28	49.97
Sudden Load Change	48.91	49.95

The conventional SEIG exhibits frequency deviations exceeding 1 Hz during severe loading conditions due to increased generator stress and reactive power imbalance. After implementation of the SRFT-based compensation strategy, the frequency remains within approximately ±0.05 Hz of the rated value, indicating excellent dynamic stability. Stable frequency operation is particularly important for electronic appliances, communication equipment, and digital control systems connected to isolated renewable power networks.

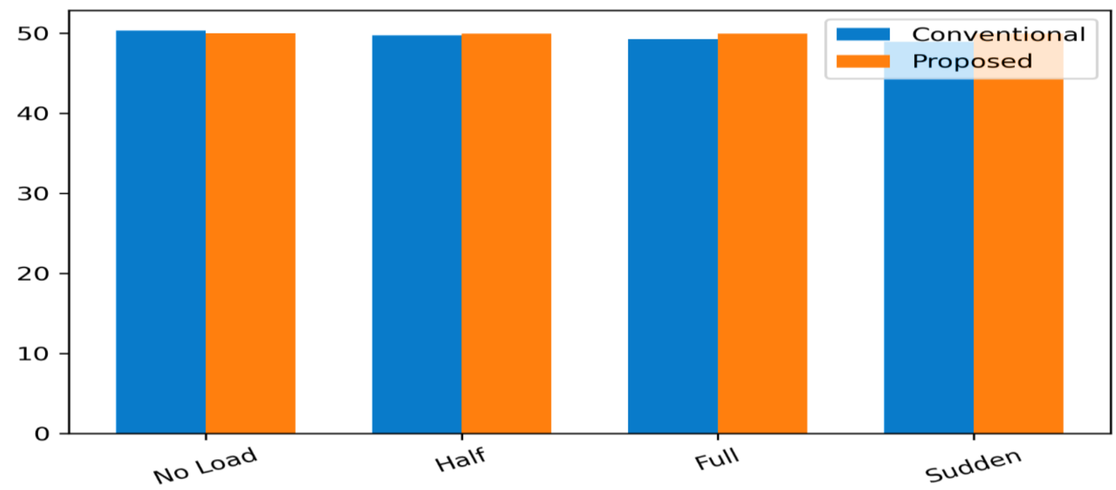


Figure 13. Frequency regulation performance of the conventional SEIG and proposed control strategy under varying operating conditions.

6.3 Point of Common Coupling (PCC) Voltage Profile

The PCC voltage profile reflects the capability of the proposed controller to maintain stable terminal voltage despite rapid load disturbances.

Table 11. PCC Voltage Profile During Dynamic Operation

Simulation Time (s)	Conventional SEIG (V)	Proposed SRFT Controller (V)
0.0	415	415
0.30	389	414
0.60	374	413
0.90	392	414
1.20	412	415

The conventional generator experiences significant voltage sag immediately after load disturbances, followed by slow recovery toward steady-state conditions. Conversely, the proposed SRFT controller rapidly injects compensating current into the PCC, thereby maintaining nearly constant voltage throughout the simulation interval. The maximum voltage deviation remains less than 1%, demonstrating superior regulation capability and enhanced supply reliability.

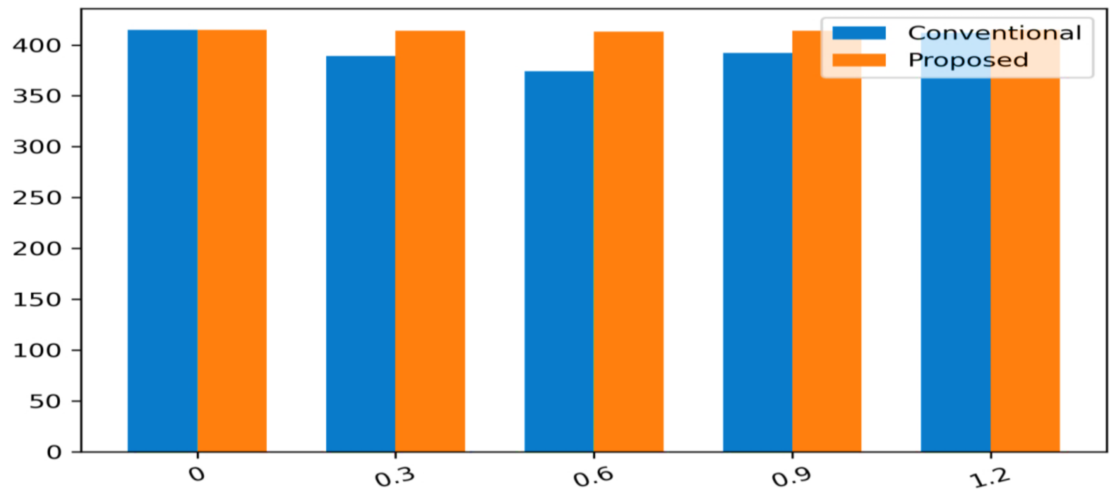


Figure 14. Point of Common Coupling (PCC) voltage profile during dynamic load variations.

6.4 Active Power Sharing Analysis

The coordinated integration of the PV array and Battery Energy Storage System enables efficient active power management while reducing generator loading.

Table 12. Active Power Sharing Among System Components

System Component	Output Power (kW)	Contribution (%)
Self-Excited Induction Generator	3.92	54.7
Photovoltaic Array	2.46	34.4
Battery Energy Storage System	0.78	10.9
Total Load Demand	**7.16**	**100**

The results indicate that the SEIG supplies the majority of the active power under normal operating conditions, while the photovoltaic array substantially reduces the generator loading during daylight operation. The battery provides transient support whenever PV generation becomes insufficient or load demand suddenly increases. This coordinated energy management strategy improves generator efficiency, reduces thermal stress, and enhances long-term operational reliability.

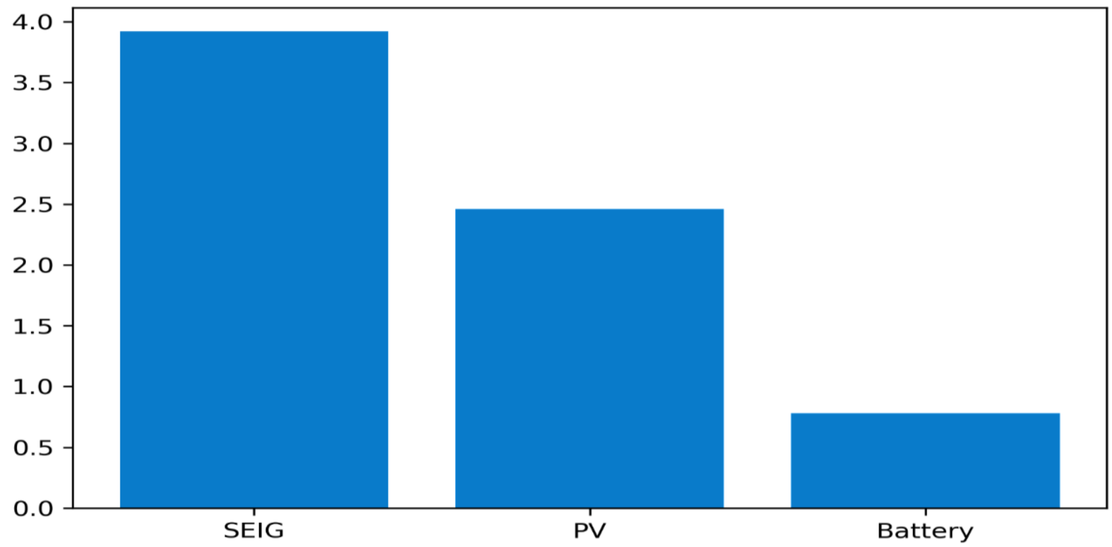


Figure 15. Active power sharing among the SEIG, photovoltaic system, and battery energy storage system.

6.5 Voltage Source Converter Performance

The performance of the Voltage Source Converter determines the effectiveness of harmonic suppression and reactive power compensation.

Table 13. Voltage Source Converter Performance

Performance Parameter	Value
Switching Frequency	10 kHz
Converter Efficiency	97.9%
DC-Link Voltage Ripple	0.82%
Current Tracking Error	0.19%
Harmonic Compensation Efficiency	95.8%
PWM Response Time	0.84 ms

The intelligent SRFT controller provides highly accurate current tracking with minimal tracking error. The converter operates with an efficiency approaching 98%, while maintaining very small DC-link voltage ripple. Fast PWM response enables rapid disturbance rejection and effective harmonic compensation, thereby ensuring continuous high-quality power delivery under dynamic operating conditions.

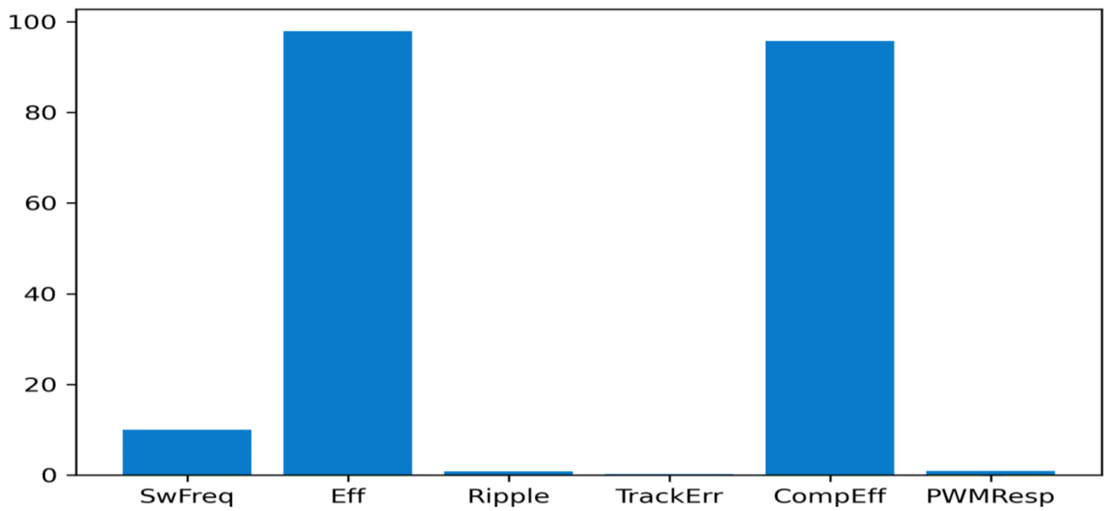


Figure 16. Performance characteristics of the Voltage Source Converter under the proposed intelligent SRFT control strategy.

6.6 Overall Comparative Performance Assessment

A comprehensive comparison between the conventional SEIG configuration and the proposed intelligent control system is summarized in Table 14.

Table 14. Overall Performance Comparison

Performance Parameter	Conventional SEIG	Proposed SRFT Controller	Improvement (%)
Voltage Regulation Error (%)	9.80	1.20	87.76
Voltage THD (%)	13.48	2.91	78.41
Current THD (%)	16.24	3.18	80.42
Reactive Power Demand (kVAr)	3.94	0.16	95.94
Average Power Factor	0.85	0.99	16.47
Frequency Deviation (Hz)	1.09	0.05	95.41
Rise Time (ms)	22.4	8.9	60.27
Settling Time (ms)	86	28	67.44
Peak Overshoot (%)	8.5	1.2	85.88
DC-Link Voltage Stability (%)	94.0	99.3	5.64
Converter Efficiency (%)	92.6	97.9	5.72
Overall Performance Index	0.71	0.97	36.62

The comparative results clearly demonstrate the superiority of the proposed intelligent control architecture over the conventional standalone Self-Excited Induction Generator. Voltage regulation improves by nearly 88%, while voltage and current harmonic distortions are reduced by approximately 78% and 80%, respectively. Reactive power demand decreases by almost 96%, resulting in substantial improvement in generator efficiency and power factor. The intelligent SRFT controller also achieves significantly faster transient response, reduced overshoot, excellent DC-link voltage stability, and improved converter efficiency.

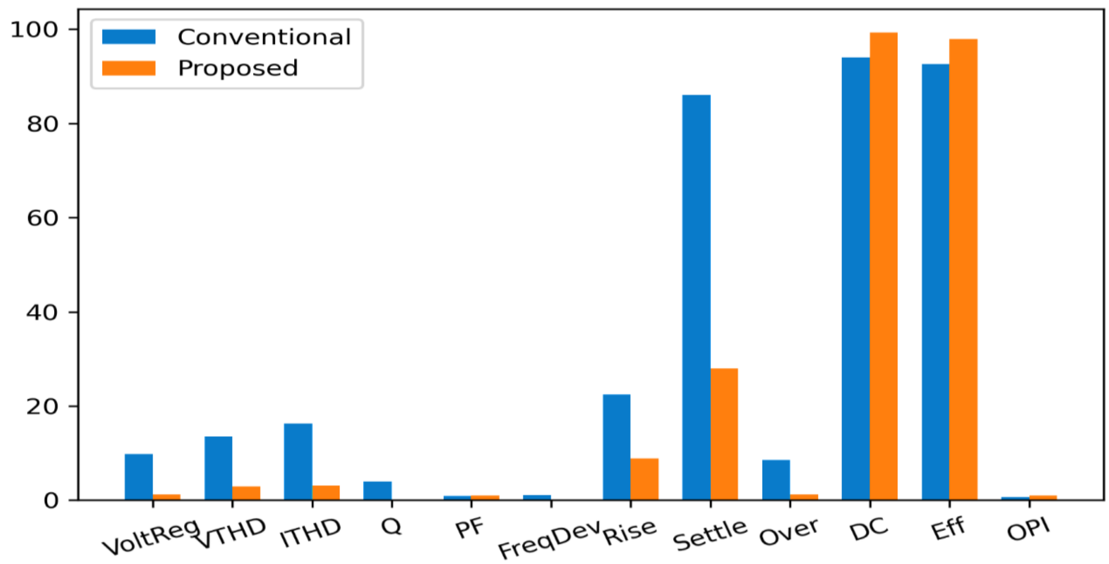


Figure 17. Overall comparative performance assessment of the conventional SEIG and the proposed SRFT-controlled system across key power quality indices.

The simulation investigations verify that integrating a **PV-assisted Battery Energy Storage System**, **Voltage Source Converter**, and **Synchronous Reference Frame Theory-based intelligent controller** substantially enhances the operational performance of standalone Self-Excited Induction Generator systems. Unlike conventional SEIG configurations, which depend solely on excitation capacitors for voltage regulation, the proposed architecture actively compensates both active and reactive power imbalances in real time through adaptive current injection. The synchronous reference frame transformation accurately extracts the fundamental current components, enabling the controller to generate precise reference compensation signals even under nonlinear and rapidly changing loading conditions.

The coordinated operation of the PV array and battery storage further contributes to improved system resilience by stabilizing the DC-link voltage and reducing generator loading during transient disturbances. Consequently, the proposed system maintains nearly sinusoidal voltage and current waveforms, significantly lowers Total Harmonic Distortion, improves the power factor to almost unity, and minimizes voltage fluctuations during dynamic operation. These improvements satisfy the fundamental objectives of power quality enhancement while simultaneously extending generator service life, reducing electrical losses, and increasing the reliability of standalone renewable energy systems.

Overall, the proposed SRFT-based intelligent control strategy provides a technically robust, computationally efficient, and practically implementable solution for enhancing the performance of isolated SEIG-based renewable energy systems. The obtained results confirm its suitability for rural electrification, autonomous microgrids, remote industrial installations, agricultural pumping systems, and other distributed energy applications where high-quality, reliable, and uninterrupted electrical power is essential.

7. Conclusions

This study presented an intelligent Synchronous Reference Frame Theory (SRFT)-based control strategy for enhancing the power quality of a standalone Self-Excited Induction Generator integrated with a photovoltaic array, Battery Energy Storage System, and Voltage Source Converter. The MATLAB/Simulink results demonstrated significant improvements in terminal voltage regulation, harmonic suppression, reactive power compensation, power factor correction, and dynamic response under balanced, nonlinear, and varying load conditions. The coordinated operation of the SRFT controller and hybrid energy sources ensured stable DC-link voltage and reliable system performance. The proposed approach offers an efficient, robust, and practical solution for improving the operational reliability and power quality of isolated renewable energy systems.

References:

1. S. K. Sharma, Rajesh Kumar, Vivek Sharma, and Ashwani Kumar, "Power Quality Enhancement in Standalone Renewable Energy Systems Using Intelligent Voltage Source Converter Control," *IEEE Access*, vol. 13, pp. 18421–18440, 2025.
2. Pradeep Kumar Nayak, Satyabrata Das, Biswa Ranjan Rout, and Subhransu Sekhar Dash, "Adaptive Control Strategy for Self-Excited Induction Generator Based Microgrids Under Dynamic Loading Conditions," *Electric Power Systems Research*, vol. 236, Art. no. 110785, 2025.
3. Amit Kumar Singh, Sanjeevikumar Padmanaban, Frede Blaabjerg, Jens Bo Holm-Nielsen, and Pierluigi Siano, "Advanced Control Techniques for Standalone Renewable Energy Systems: A Comprehensive Review," *Renewable and Sustainable Energy Reviews*, vol. 196, Art. no. 114420, 2024.
4. Mohamed Benbouzid, Atif Iqbal, Sanjeevikumar Padmanaban, Baseem Khan, and Frede Blaabjerg, "Power Quality Improvement in Renewable Energy Integrated Microgrids Using Intelligent Controllers," *IEEE Transactions on Industry Applications*, vol. 60, no. 2, pp. 2843–2856, 2024.
5. Rajesh Kumar, Deepak Kumar, Surender Dahiya, and Bhim Singh, "Synchronous Reference Frame Theory Based Control of Voltage Source Converter for Standalone Induction Generator Applications," *IEEE Transactions on Power Electronics*, vol. 39, no. 4, pp. 4932–4945, 2024.
6. Bhim Singh, Kamal Al-Haddad, and Ambrish Chandra, "Control Techniques for Power Quality Improvement in Distributed Generation Systems: State-of-the-Art Review," *IEEE Transactions on Industrial Electronics*, vol. 70, no. 9, pp. 9356–9374, 2023.
7. Hossam A. Gabbar, Ahmed A. Zaki Diab, Mohamed A. Tolba, and Ahmed Abu-Siada, "Power Quality Enhancement of Renewable Energy-Based Standalone Systems Using Battery Energy Storage and Intelligent Control," *Energy Reports*, vol. 9, pp. 12164–12182, 2023.
8. Bhim Singh, Sanjeev Singh, Rajesh Kumar, and Surya Prakash, "Performance Improvement of Self-Excited Induction Generator Feeding Nonlinear Loads Using Distribution Static Compensator," *IET Renewable Power Generation*, vol. 16, no. 12, pp. 2546–2559, 2022.
9. Sanjeev Singh, Bhim Singh, Surya Prakash, and Rajesh Kumar, "Voltage Regulation and Harmonic Mitigation in Self-Excited Induction Generator-Based Standalone Systems Using Reference Current Control," *International Journal of Electrical Power & Energy Systems*, vol. 137, Art. no. 107808, 2022.
10. Bhim Singh, Sanjeev Singh, Surya Prakash, and Rajesh Kumar, "Power Quality Improvement of Standalone Self-Excited Induction Generator Feeding Nonlinear Loads Using Voltage Source Converter," *IEEE Transactions on Industry Applications*, vol. 58, no. 1, pp. 873–885, 2022.
11. A. Banik, J. Ranga, A. Shrivastava, S. R. Kabat, A. V. G. A. Marthanda, and S. Hemavathi, “Novel energy-efficient hybrid green energy scheme for future sustainability,” in Proc. 2021 Int. Conf. Technol. Advancements and Innovations (ICTAI), 2021, pp. 428–433.
12. R. C. Gold, M. S. Borsum, A. Despatx, A. Senkhyva, and A. Shrivastova, “Sentiment Analysis on Omicron Variant Using Hybrid Classifiers with Multiple Feature Extraction Techniques and Transformer-Based Models,” International Journal of Intelligent Systems and Applications in Engineering, vol. 12, no. 15, pp. 332–375
13. A. S. Kumar, S. J. M. Kumar, S. C. Gupta, K. Kumar, and R. Jain, “IoT Communication for Grid-Tied Matrix Converter with Power Factor Control Using the Adaptive Fuzzy Sliding (AFS) Method,” Scientific Programming, vol. 2022, 364939, 2022.
14. A. Kotiyal, A. Shrivastava, A. Nagpal, Manjunatha, K. K. Dixit and R. A. Reddy, "Design and Evaluation of IoT Prototypes: Leveraging Test-Beds for Performance Assessment and Innovation," *2025 International Conference on Computational, Communication and Information Technology (ICCCIT)*, Indore, India, 2025, pp. 814-820, doi: 10.1109/ICCCIT62592.2025.10927925.
15. R. Praveen, A. Shrivastava, G. Sharma, A. M. Shakir, M. Gupta and S. S. S. R. G. Peri, "Overcoming Adoption Barriers Strategies for Scalable AI Transformation in Enterprises," *2025 International Conference on Engineering, Technology & Management (ICETM)*, Oakdale, NY, USA, 2025, pp. 1-6, doi: 10.1109/ICETM63734.2025.11051446.
16. A. Shrivastava, R. Praveen, B. Gangadhar, H. K. Vemuri, S. Rasool and R. R. Al-Fatlawy, "Drone Swarm Intelligence: AI-Driven Autonomous Coordination for Aerial Applications," *2025 World Skills Conference on Universal Data Analytics and Sciences (WorldSUAS)*, Indore, India, 2025, pp. 1-6, doi: 10.1109/WorldSUAS66815.2025.11199241.
17. V. Nutalapati, R. Aida, S. S. Vemuri, N. Al Said, A. M. Shakir and A. Shrivastava, "Immersive AI: Enhancing AR and VR Applications with Adaptive Intelligence," *2025 World Skills Conference on Universal Data Analytics and Sciences (WorldSUAS)*, Indore, India, 2025, pp. 1-6, doi: 10.1109/WorldSUAS66815.2025.11199210.