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Article

Improved power quality in distribution system with renewable energy sources integration

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Abstract: Customers of electric utilities are increasingly concerned with meeting the growing energy demand. Petroleum derivatives account for 75% of global energy consumption, but issues like air pollution, global warming, and depleting petroleum supplies make sustainable energy sources a vital alternative. Distributed generation (DG) refers to renewable energy sources (RES) integrated at the distribution level, which can introduce challenges in power quality (PQ), voltage regulation, and system stability due to the intermittent nature of RES. Inverters, acting as active inductors, help mitigate harmonic currents in the system. This paper proposes a method where a shunt active filter reduces harmonic distortion in the distribution network using a control strategy based on SRF (Synchronous Reference Frame) computation. The method compensates for load current harmonics and imbalance, improving power quality at the point of common coupling (PCC) without additional power conditioning equipment. The system employs an inverter integrated with advanced control to function as both a power filter and a source of real power for the grid. The SRF technique helps detect and compensate for non-linear load currents and voltage imbalances. Simulation results using MATLAB/Simulink demonstrate the effectiveness of the proposed system across various non-linear load conditions. The PI regulator efficiently maintains the inverter's capacitance voltage, ensuring balanced grid-side flows. This method simplifies the implementation of power conditioning and enhances the system's performance at the PCC.

1. Introduction

Energy needs are growing, and electric utilities and end users of electricity are becoming increasingly concerned about meeting those needs. Petroleum product consumption provides for 75% of the world's energy needs. However, growing concerns about unnatural weather change, dwindling petroleum products, and their increasing cost have made it necessary to consider sustainable energy sources as a viable alternative

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for the future. Many countries have shown enormous interest in environmentally friendly power for the power age throughout the past 10 years. The development of the sustainable power domain has also been accelerated by government incentives and market innovation.

Distributed generation (DG) is the term for renewable energy sources (RES) that are included at the appropriation level. Because of the high entry level of irregular renewable energy sources (RES) in circulation frameworks, the utility is concerned about potential organisational risks related to power-quality (PQ), voltage guidelines, and stability. Consequently, in order to provide safe, stable, and fruitful operations within the broader organisation, the DG frameworks are anticipated to align with strict administrative and specialised structures. The advancement of power devices and computerised control technology has made it possible to efficiently regulate the DG frameworks, allowing for the upgrading of framework activity with more developed PQ at PCC.

However, the widespread use of force-based devices and non-direct loads at PCC results in consonant fluxes that have the potential to destroy the essence of force. For the most part, current controlled voltage source inverters are used in distributed systems to transmit irregular reconfigured energy sources. Recently, there have been a few control systems for network-associated inverters that combine PQ layout. To absorb the consonant current, an inverter functions as a dynamic inductor at a particular recurrence. However, it can be difficult to precisely estimate organisation inductance over time, which could lead to the failure of control execution. A comparable methodology is suggested that uses a shunt dynamic channel as dynamic conductance to muffle the noises in a dispersion network. In light of the theory, a control system for an endless communicating inverter is suggested. The heap current sounds are predicted to be compensated in this manner by both burden and inverter current detection. The non-linear load current noises have the potential to cause voltage harmonics and pose a significant power quality risk to the power grid infrastructure.

In order to compensate for heap current sounds and burden imbalance at the appropriation level, active power filters (APF) are commonly utilised. This resulted in additional equipment expenses. However, the authors of this work have integrated the APF components into a standard inverter that communicates sustainably with the lattice while essentially requiring no additional equipment. The key idea here is to make the most of the inverter rating, which is frequently underutilised due to the discontinuous nature of RES. This project demonstrates how the framework linking the inverter may actually be utilized to fulfill the following important roles:

- Move of dynamic power gathered from the sustainable assets (wind, sun oriented, and so forth.)
- Load reactive power request support
- Current harmonics compensation pay at PCC
- Current unbalance and nonpartisan current pay in the event of 3-stage 4-wire framework.

In addition, with satisfactory control of matrix communicating inverter, every one of the four targets can be achieved either separately or all the while. The PQ imperatives at the PCC can in this manner be totally kept up with inside the utility principles without extra equipment cost.

Thanks to advancements in power devices and computerised control technology, DG frameworks may now be efficiently managed to enhance framework activity and achieve significantly improved PQ at PCC. However, the widespread use of force devices, base gear, and non-direct loads at PCC produce symphonious flows that have the potential to destroy the essence of force [1–3].In a circulating structure, the discontinuous RES are often connected via current regulated voltage source inverters. Recently, a few control strategies that integrate PQ arrangement for framework-associated inverters have been proposed. Within [4] A similar approach is suggested in [5], where a shunt dynamic filter functions as dynamic conductance to reduce the harmonics in the conveyance network.

The suggested system in [6] includes RES connected to a network communicating inverter's dc-connection. A distributed generation (DG) system must have a voltage source inverter, which connects the renewable energy source to the grid and transfers the generated electricity. A DC source or an air conditioner source with a rectifier connected to a DC interface could be the RES. Variable speed wind turbines generate power at variable ac voltage, whereas energy components and solar energy sources typically produce power at changeable low dc voltage.

Therefore, before connecting on a dc-connect, the power generated from these endless sources needs to be power moulded (i.e., dc/dcor ac/dc) [7–9].The reference lattice flows are created by augmenting the dynamic current portion with solidarity framework voltage vector forms. The quick amount of adjusted network flows is the reference matrix unbiased current, which is set to zero. To generate a solidarity vector pattern, the lattice synchronising point obtained from the phase locked loop (PLL) is used as [10, 11]. [12] "Displaying and Control of a Coordinated Energy unit Wind Turbine Framework A," by B. Delfino and F. Fornari.Rowe and X. Li, "Prot Trade Film Fuel Cells: Numerical Displaying." "Specialised and Monetary Appraisal of Framework autonomous Crossover Photovoltaic-Diesel-Battery Power Frameworks for Business Burdens in Desert Conditions," by S. M. Shaahid and M. A. Elhadidy, Sustainable and Practical Energy O. Ulleberg "Sun-oriented Hydrogen Energy Frameworks: Optimal Design, Control and Operation for Future Power Systems" Improvement of a Limited Scale Hydrogen Creation Stockpiling Framework for Hydrogen Applications, K. Sapura, N. T. Stetson, and S. R. Ovshinsky. "Dynamic Displaying and Reproduction of a Little Wind-Power device Cross breed Energy Framework," by J. Khan and M. T. Iqbal, Environmentally friendly power [13–16].

Generally, distant channels have been used to compensate for sounds and responsiveness; nevertheless, distant channels are very large; there are maturation and tuning problems that might cause problems with the stock impedance. These days, responsive power and flowing sounds are meant to be compensated for with active power line conditioners (APLC) or active power filters (APF). A coordinated reference outline idea was given by Bhattacharya for the computation of the d-q components of the momentary three stage flows. The SRF technique is a basic calculation with very potent reactions that consists of an ABC-DQO change and a stage locked circle (PLL) circuit [17]. The SRF's ability to return noise and responsive power from the fluxes of mutilation load The voltage, recurrence guideline angle, and power quality tests are important ones in these kinds of designs. Furthermore, the simultaneous location method. To separate the reference pay flows, a modification of Instantaneous Reactive Power Theory (IRPT) connected to the Discrete Fourier Transform (DFT) has been suggested. The circuits and calculation procedures in each of the aforementioned computations remain complex.

Objectives

- Interconnection of renewable energy sources with and without SRF algorithm
- Reduction harmonics in the load currents by using SRF Algorithm and 4-leg interfacing inverter
- Hysteresis Current controlling technique is used to compare the load current and grid current to generate pulses for the interfacing inverter
- Power quality improvement with renewable energy sources.

2. Integrated circuit

2.1. Schematic of proposed inexhaustible-based grid-connected distributed generation system

A proposed schematic for an inexhaustible grid-connected distributed generation (DG) system typically integrates renewable sources like solar PV or wind—considered "inexhaustible" due to their perpetual availability—with power electronics for stable grid injection. One advanced configuration uses a large-scale PV array.

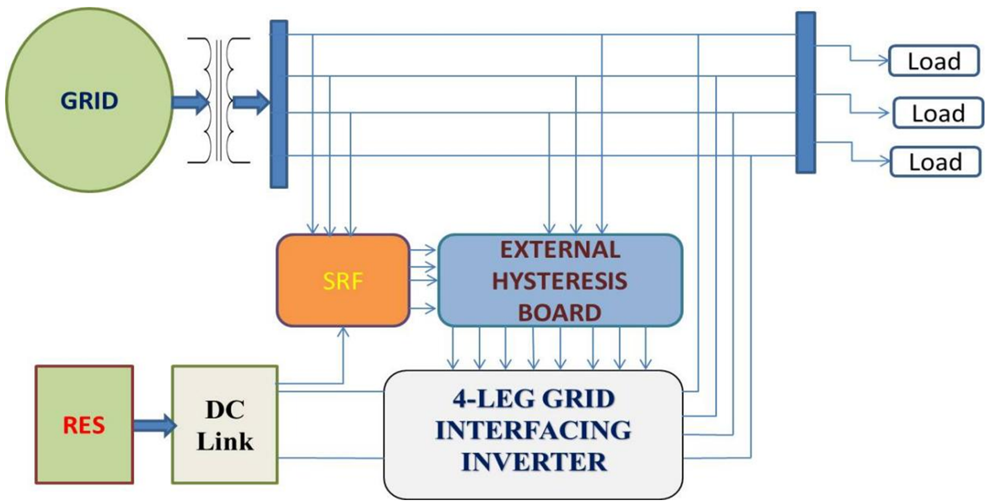

Figure 1. Schematic of proposed grid connected system.

2.2. Renewable energy sources

Photovoltaic model: A photovoltaic, or sun-oriented, cell is a device that directly converts light from the sun into electricity. The amount of current and voltage it produces depends on a number of factors, including temperature, the amount of light it receives from the sun, the frequency at which photons occur, and so on. The sun-powered cell generates a direct current supply.

Power modules: An energy unit is a device that uses hydrogen as fuel to produce water, protons, electrons, and intensity. Power modules are electrochemical devices that directly transform synthetic response energy into electrical energy. It should respond quickly to load variations, require little maintenance, and have a long cell life.

Wind energy: The conversion of wind energy into a useful form of energy, like producing electricity by using wind turbines, is known as wind power. Both wind direction and speed are constantly changing. In addition, the breeze will vary with the climate settings over a longer period of time. Locations with higher wind speeds will generate more electricity. The breeze turbine's power removal is based on the cross-sectional area.

Nickel-metal hydride battery: Similar to a nickel-cadmium cell, a nickel-metal hydride cell, or NiMH, is a battery-powered device. The negative terminal of the NiMH battery is made of a composite that absorbs hydrogen instead of cadmium.

The rectifier connected to the DC interface on the RES could be an AC or DC source. Because of its unpredictability, the power generated by the RES is varied.

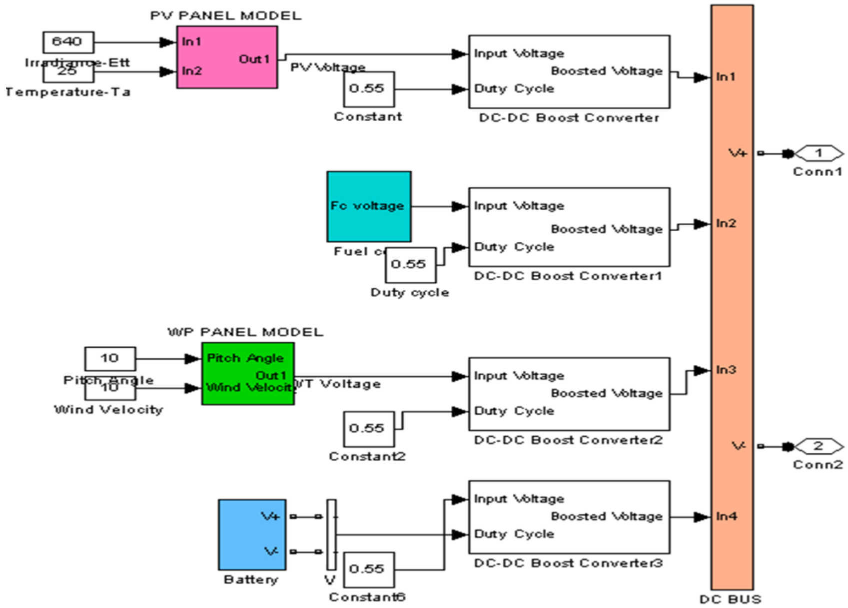

Figure 2. DC bus with varies RES.

3. Implementation of Synchronous Reference Frame Algorithm

3.1. With Base Model

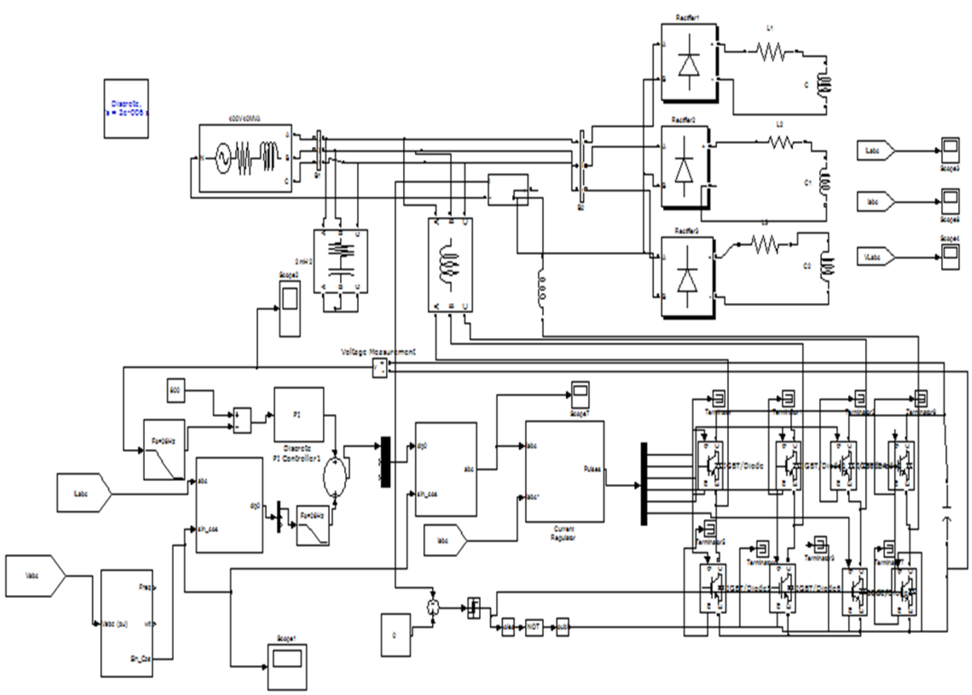

Figure 3. Simulink model of Synchronous Reference Frame Controller(without RES).

3.2. FFT Analysis: Input Voltages (v) & Current (A) Waveforms

The figure below shows input voltage and current at the grid side to analyze the THD.

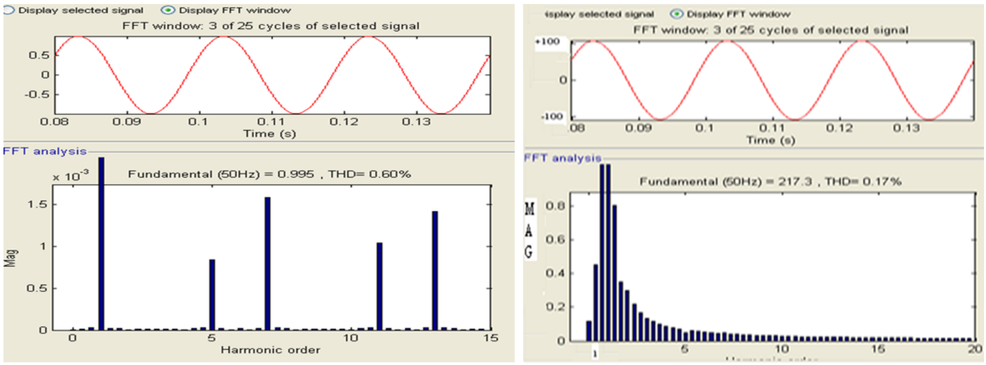

Figure 4. Input Voltages(V) & Current(A) Waveforms.

Load Current(A) RYB Phases: The following figure shows that load currents of RYB phase to find the THD at load side.

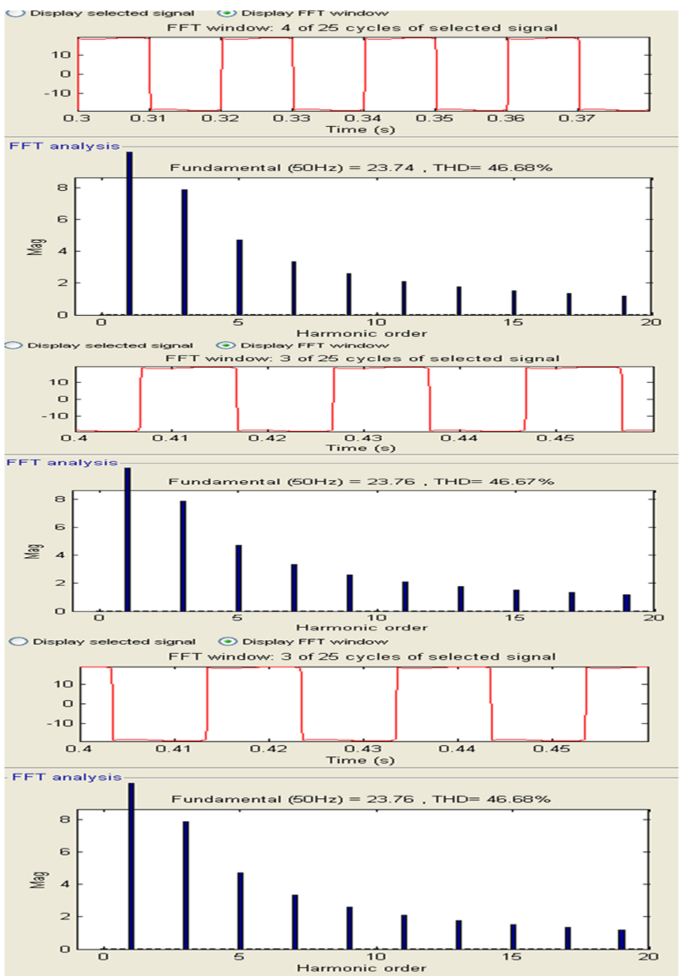

Figure 5. Load Current(A) RYB Phases.

Compensation Current(A) of RYB Phase: The following figure shows the compensation of RYB phase to find the THD at compensation.

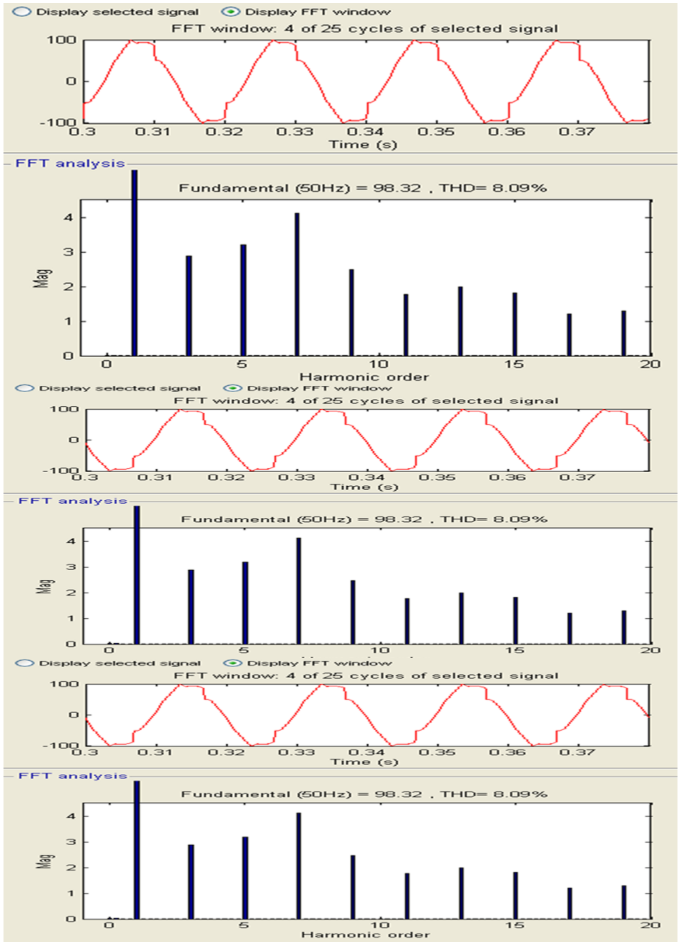

Figure 6. Compensation current(A) of RYB phase

3.3. Simulation Results: V_{dc} Voltage (V) vs Time (S)

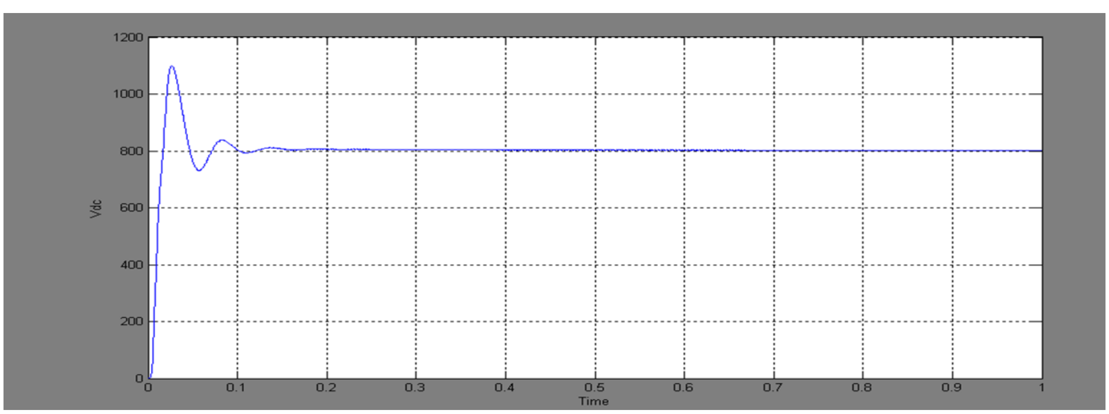

Figure 7. V_{dc} voltage vs time.

The PI-regulator, limits the voltage of the DC-side capacitors. It serves as a component for energy storage so that a three-stage, four-wire inverter can be operated. Voltage (V) of Input Unit The figure shows that the voltage per unit with particular time.

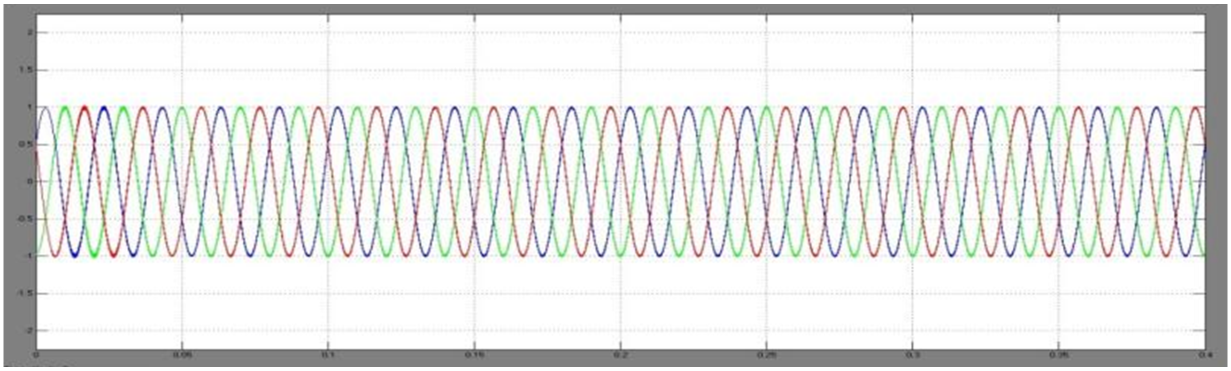

Figure 8. Input voltage vs time

The following figure shows that load currents of RYB phase to find the THD at load side.

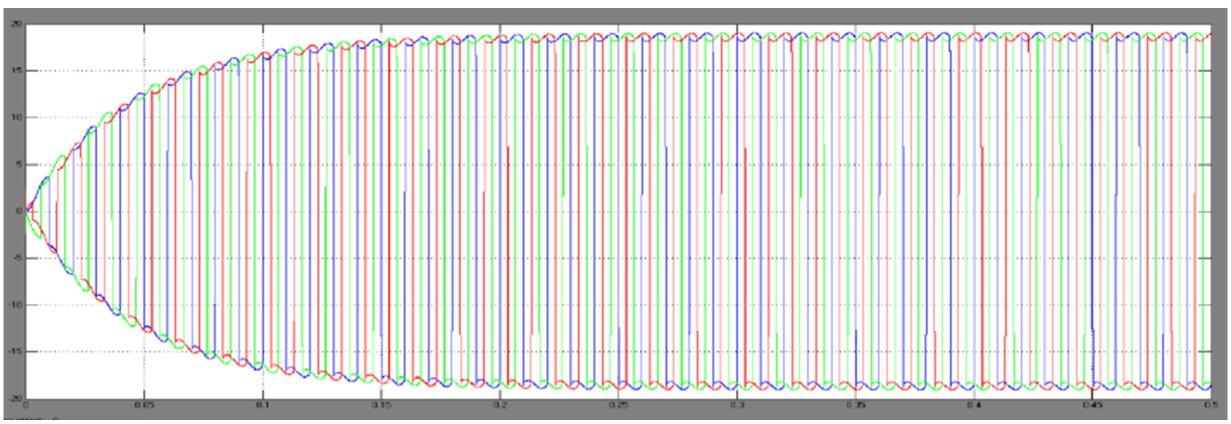

Figure 9. Load Current(A) Vs Time.

3.4. Compensation Current of RYB

The figure shows that compensation of RYB phase VS time at compensation.

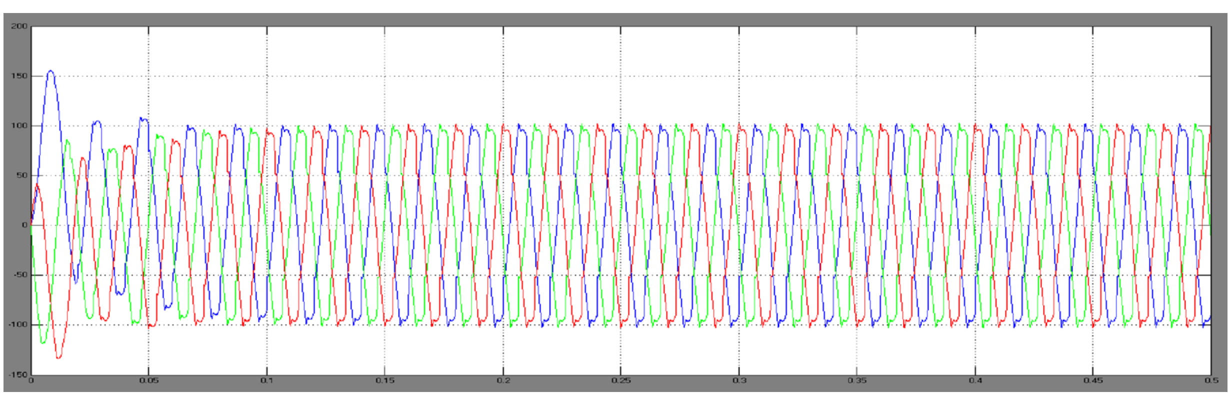

Figure 10. Current(A) Vs Time.

Table 1. Synchronous reference frame algorithm with controlled column width.

I/P Phase Voltage (V) -THD%			I/P Phase Current (A) -THD%			O/P Phase Current (A) -THD%			Compensation Current (A) -THD%		
V_{a1}	V_{b1}	V_{c1}	I_{a1}	I_{b1}	I_{c1}	I_{a01}	I_{b01}	I_{c01}	I_{a01}	I_{b01}	I_{c01}
0.60	0.62	0.61	0.17	0.18	0.19	46.66	46.67	46.68	8.09	8.09	8.10

The mains flows in the three stages four wire after remuneration are supposed to be absolutely sinusoidal and in stage with the mains voltages. The outcomes acquired for every one of the three stages four wire for both the previously mentioned control calculation show that the shunt pay has been accomplished. The FFT examination (Figures 4 to 6) of the source flows when pay show that the harmonics decline definitely from around 46.6% to under 8.09% after compensation. Table 1 records the %THD of the mains current when shunt remuneration in light of the SRF hypothesis yields improved brings about terms of THD of repaid source current.

4. Synchronous reference frame algorithm with renewable energy sources

4.1. Simulation model

Similar procedure is adopted for this circuit which involves the incorporation of renewable energy sources.

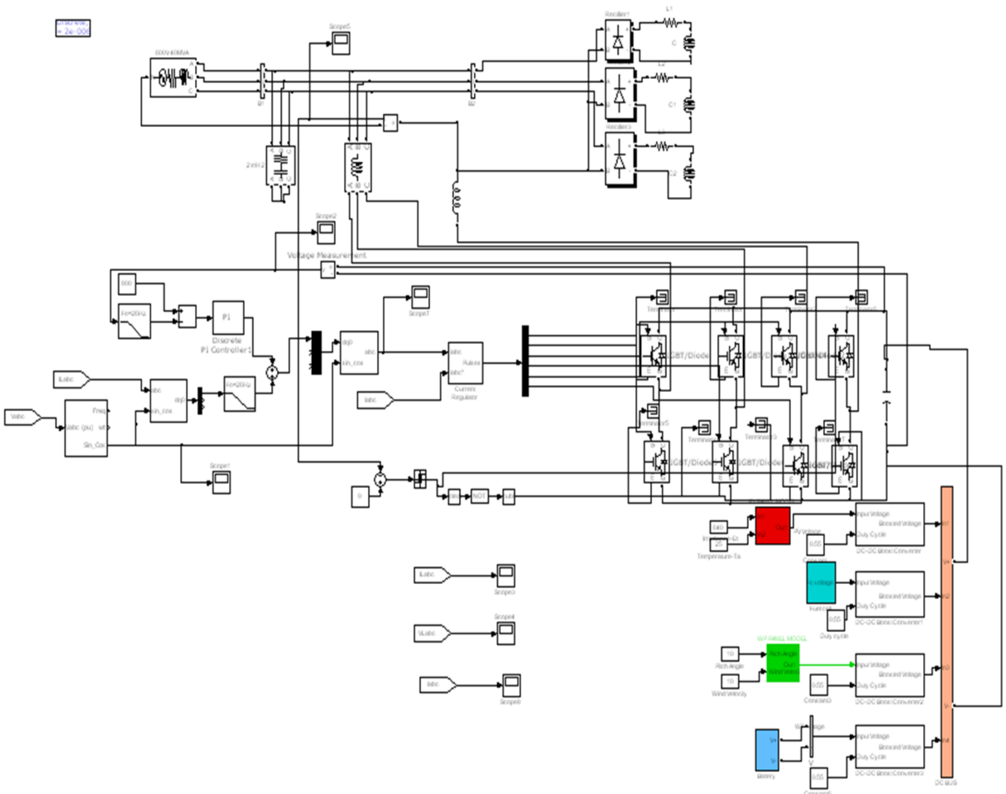

Figure 11. Simulink model of Synchronous Reference Frame Controller(with RES).

4.2. FFT analysis: Input voltages (V) & current (A) waveforms

The figure shows input voltage and current at grid side to analyze the THD.

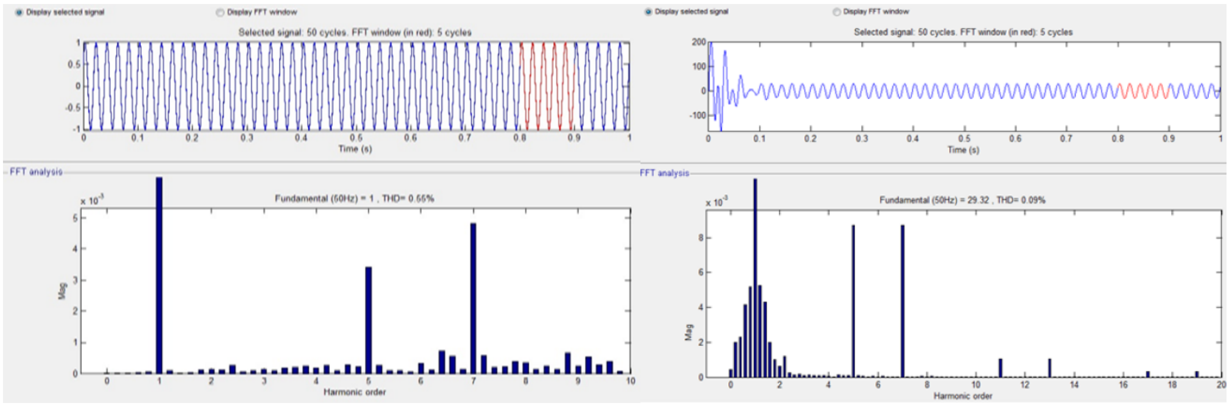

Figure 12. input voltages(V) & current(A) waveform.

The figure shows that load currents of RYB phase to find the THD at load side.

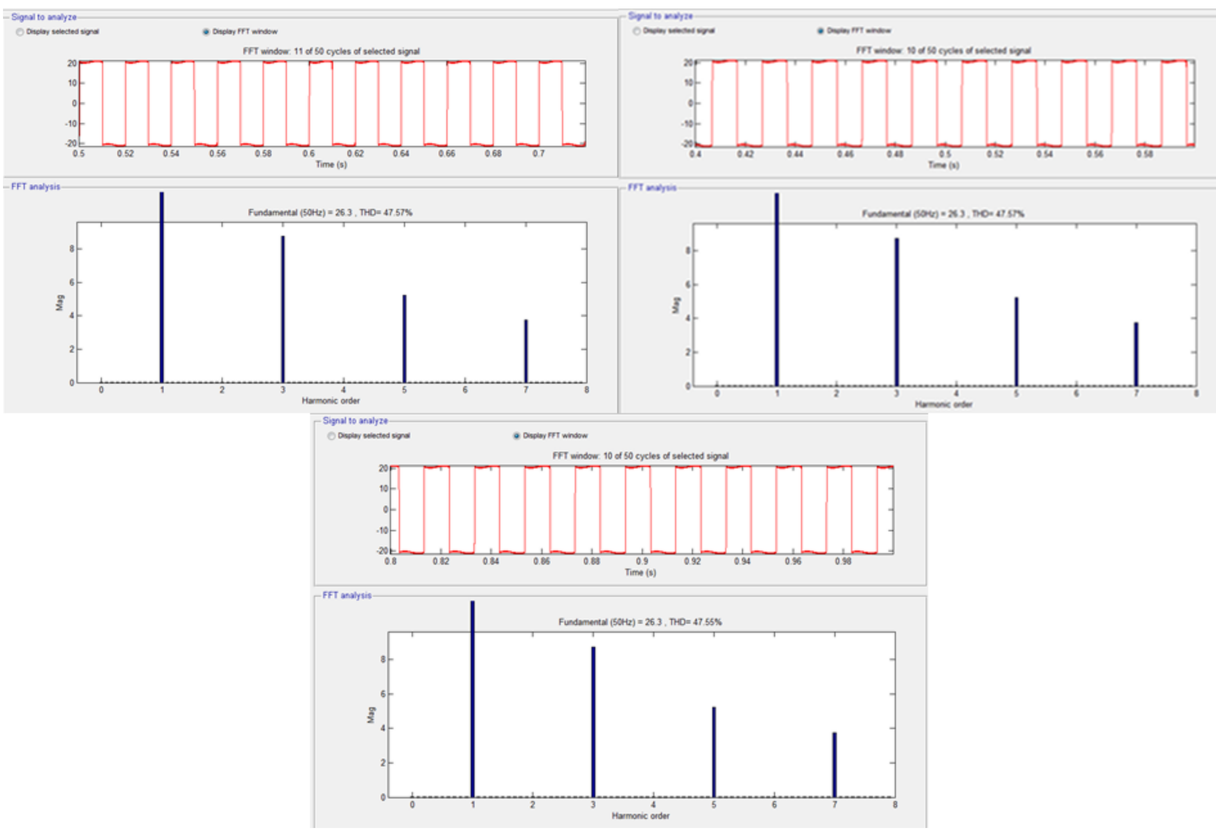

Figure 13. load current(A) RYB phases.

Compensation Current(A) of RYB Phase: The figure shows that compensation of RYB phase to find the THD at compensation

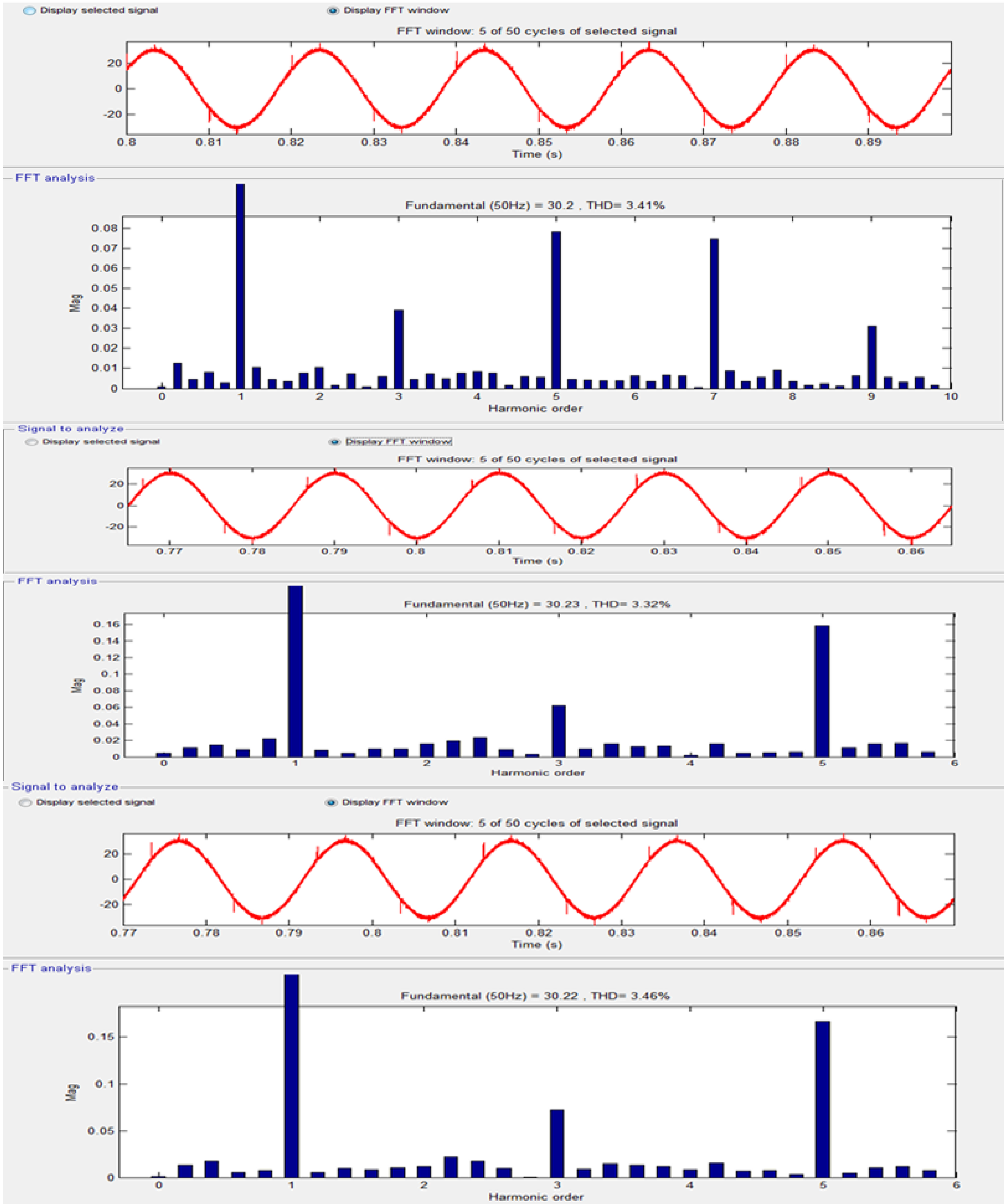

Figure 14. Compensation Current of RYB Phase.

4.3. Simulation results: Neutral current (A) vs time (s)

The graphic illustrates how, following the simulation, the ground current of the three-phase, four-wire goes to zero. In = 0.

Figure 15. V_{dc} voltage vs time.

Input Voltage(V) in Per Unit the figure shows that the voltage per unit with respective time.

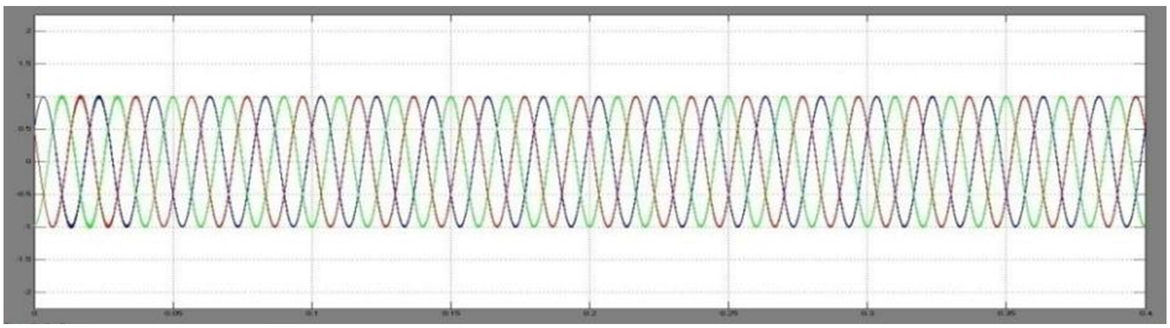

Figure 16. Input voltage vs time.

Load Current(A) Vs Time(S) The figure shows that load currents of RYB phase load side VS Time.

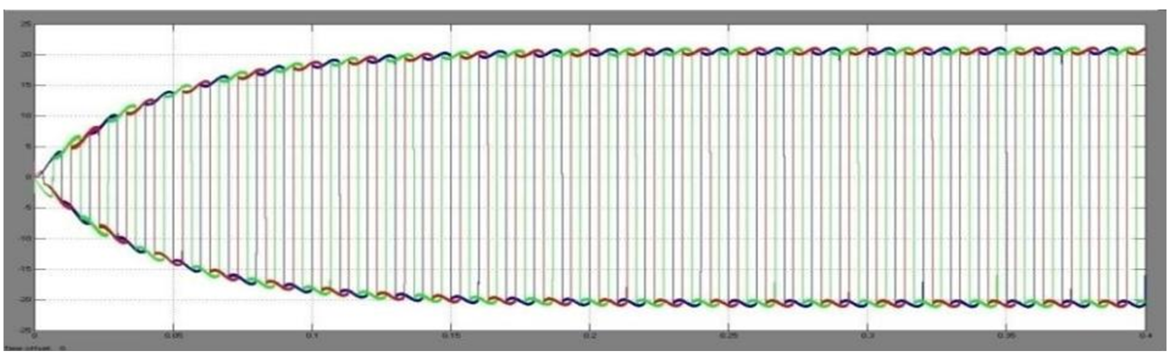

Figure 17. Compensation Current(A) Vs Time(S).

The following figure shows that compensation of RYB phase with respective time.

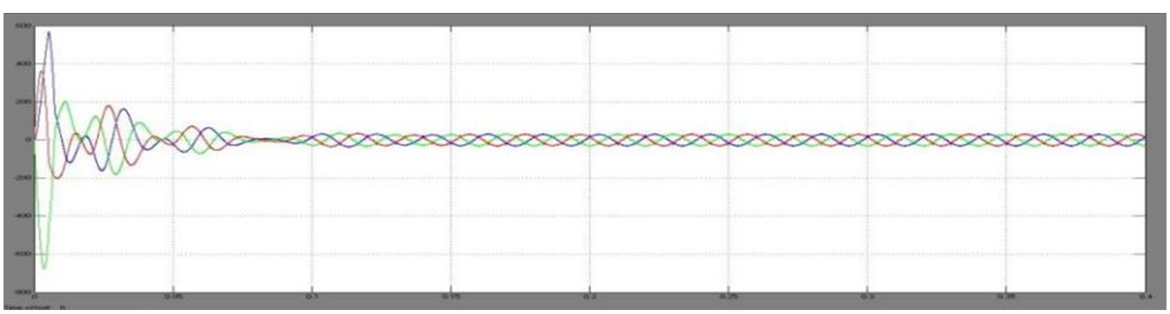

Figure 18. Current (A) Vs Time(S).

Table 2. Synchronous reference frame(srf) algorithm of %thd , i/p voltage, i/p current & load current & compensation current with renewable energy resources (res).

I/P Phase Voltage (V) -THD%			**I/P Phase Current (A) -THD%**			**O/P Phase Current (A) -THD%**			**Compensation Current (A) -THD%**		
V_{a2}	V_{b2}	V_{c2}	I_{a2}	I_{b2}	I_{c2}	I_{a02}	I_{b02}	I_{c02}	I_{a02}	I_{b02}	I_{c02}
0.55	0.56	0.57	0.09	0.10	0.11	47.57	47.57	47.55	3.41	3.32	3.46

For the source current shown in Figures 12 to 14, the Fast Fourier Transform (FFT) is used to quantify the call for sounds with the necessary repetition at 50 Hz. The Total Harmonic Distortion (THD) calculated at the source and load (current) on SRF using a framework for the transmission of environmentally friendly power assets.

The dynamic channel reconstruction based on SRF is completed under various non-linear load situations. According to an FFT analysis, the active filter reduces the load's THD from 47.57% current to 3.32 percent, or less than 5%. This is consistent with the rules for harmonics under non-linear or balanced load conditions outlined in IEEE 519-1992 and IEC 61000-3.

Table 3. Comparative analysis of configurations with and without renewable sources.

Without Renewable Sources											
I/P Phase Voltage (V) -THD%			**I/P Phase Current (A) -THD%**			**O/P Phase Current (A) -THD%**			**Compensation Current (A) -THD%**		
V_{a3}	V_{b3}	V_{c3}	I_{a3}	I_{b3}	I_{c3}	I_{a03}	I_{b03}	I_{c03}	I_{a03}	I_{b03}	I_{c03}
0.60	0.62	0.61	0.17	0.18	0.19	46.66	46.67	46.68	8.09	8.09	8.10
With Renewable Sources											
I/P Phase Voltage (V) -THD%			**I/P Phase Current (A) -THD%**			**O/P Phase Current (A) -THD%**			**Compensation Current (A) -THD%**		
V_{a3}	V_{b3}	V_{c3}	I_{a3}	I_{b3}	I_{c3}	I_{a03}	I_{b03}	I_{c03}	I_{a03}	I_{b03}	I_{c03}
0.55	0.56	0.57	0.09	0.10	0.11	47.57	47.57	46.55	3.41	3.32	3.46

5. Conclusions

The goal of this paper is to enhance the power quality for PCC at a 3-phase, 4-wire DG system by introducing a unique control method for an existing grid-interfacing inverter. It has been demonstrated that power conditioning can be efficiently applied to the grid-interfacing inverter without compromising real power transfer's regular operation. Due to an unbalanced and non-linear load tied to the PCC, current imbalance, current harmonics, and load reactive power are successfully corrected such that grid side currents always remain to be evenly distributed and sinusoidal at the power factor of unity.

The Synchronous Reference Frame (SRF) methodology was used to develop the system, and the resulting findings confirm the efficacy of the suggested SRF-based technique. Additionally, by locally compensating it from the fourth leg of the inverter, the load neutral current is kept from flowing onto the grid side. It is further demonstrated that, when compared to traditional methods, the SRF algorithm's implementation using non-conventional resources performs better at removing harmonics. IEEE519 reports that a significant decrease in THD% (from 47.57% to 3.32%) and power quality is noted in the SRF algorithm using RES.

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Author contributions: B. Devulal has contributed to the conception and design of 3-phase 4-leg grid connected Inverter and SRF control strategy. Material preparation, data collection, simulation, results and analysis were performed by B. Devulal and D. Ravi Kumar. The first draft of the manuscript was written by B. Devulal and D. Ravi Kumar, M. Siva have verified, added some more description and results. All the three authors have verified and approved the final manuscript.

Disclosure statement: The authors declare that they have no competing interest among themselves or others for this work.

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