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Integration of a Hybrid Solar-Wind Powered Unified Power Quality Conditioner for Comprehensive Harmonic Mitigation using Hybrid Vector Control Approach

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Abstract: *The escalating demand for energy, coupled with environmental concerns, has led to widespread adoption of distributed generation (DG) worldwide. Distributed Electrical Systems (DES) encompass localized power sources, including renewable and non-renewable energy facilities, along with energy storage systems, revolutionizing energy delivery and consumption paradigms. This paper investigates the integration of Unified Power Quality Conditioners (UPQCs) with hybrid renewable energy systems to enhance power quality and efficiency in DES. Through MATLAB/Simulink modeling and optimization algorithms, the study explores the UPQC's role in mitigating voltage disturbances, harmonic distortions, and reactive power issues, showcasing its effectiveness in real-world power distribution scenarios.*

Keywords: *Distributed generation, Unified Power Quality Conditioner (UPQC), Hybrid renewable energy systems, Power quality, Reactive power correction, MATLAB/Simulink modeling, and Optimization algorithms.*

I. INTRODUCTION

The increasing demand for energy globally, driven by advancements in engineering and technology in the electric power sector, along with environmental concerns, has spurred the adoption of distributed generation (DG) worldwide. DG entails the establishment of localized power sources, including renewable (solar and wind energy) and non-renewable energy facilities (diesel and gas), energy storage systems, and various tools for controlling and regulating energy consumption on the consumer side [1]. While all electricity markets have real-time coordination by a system operator, there are significant variations in central planning and scheduling before actual energy delivery. A centralized electricity market involves the system operator determining production allocations for each power plant well in advance, typically in the day-ahead market. This day-ahead market, often referred to as the spot market, sets prices used for financial contracts and retail pricing.

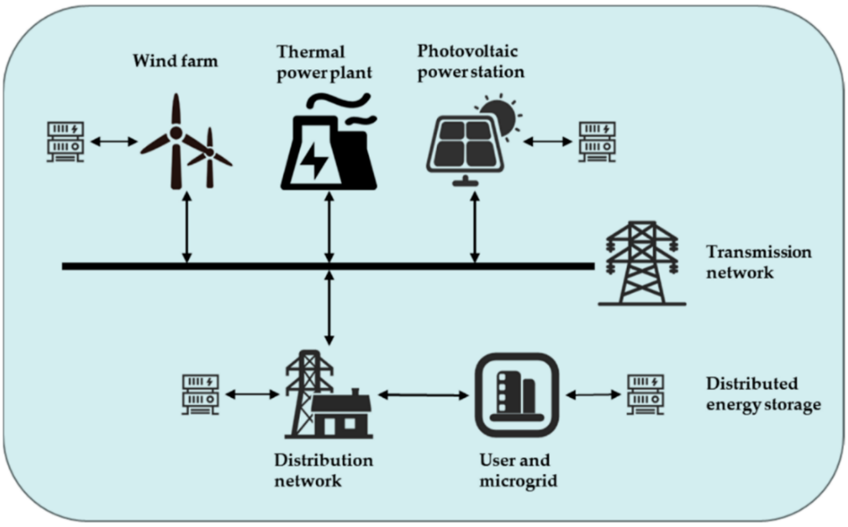


Figure 1 Distributed Energy Storage

Electricity generation occurs through two primary methods: renewable sources, characterized by their natural regeneration potential, encompassing wind and solar energy; along with non-renewable sources, that deplete as they are utilized, notably including fossil fuels [8,9]. The pursuit of cleaner and renewable energy sources represents a pivotal objective in endeavors aimed at mitigating greenhouse gas emissions, establishing long-term sustainability, and decarbonizing global energy generation matrices.

A. Distributed Electrical System

Distributed electrical system refers to a setup where lower-voltage distribution networks, commercial establishments, residential areas, and industrial facilities are directly linked to small-scale and micro generators. Surplus electricity generated by directly connected consumers is redirected to the active distribution network for meeting energy demands in diverse regions. Concurrently, any excess generation can be efficiently stored through power storage systems. Conversely, substantial power plants and extensive renewable sources, such as offshore wind farms, are integrated into the high-voltage transmission network. This connection ensures the quality of energy supply and provides a national backup capability. Additionally, the integration of energy storage solutions can effectively manage the variable output associated with different types of power generation sources [13].

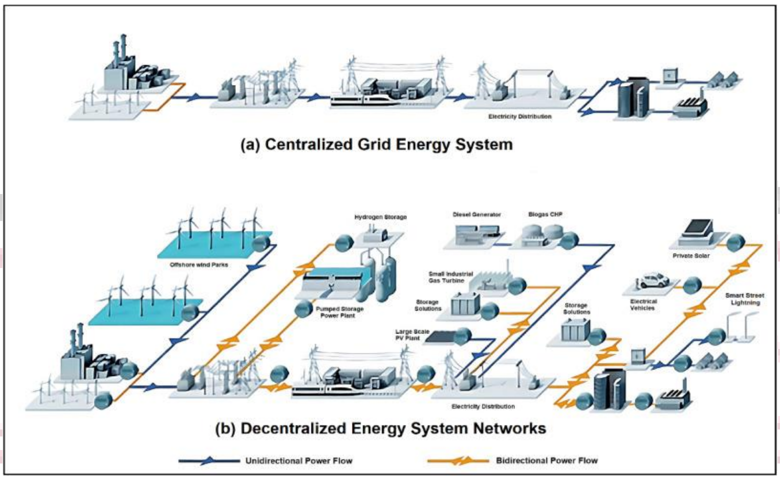


Figure 2 Typical schematics of (a) Centralized Grid and (b) Decentralized Energy networks [14]

Distributed Distributed Generation (DDG) refers to the deployment of small-scale, modular, decentralized off-grid energy systems, coupled with energy management and storage components, located in close proximity to the point of energy consumption. This approach for rural electrification has demonstrated successful implementation in various developing countries such as Cambodia, China, Nepal, and the Philippines [15-18]. India, with its abundant renewable energy resources, presents a promising prospect for the large-scale adoption of DDG solutions. DDG systems can be designed to harness either conventional or renewable energy sources, enabling the localized generation of electricity with the utilization of locally available resources and reducing dependence on external energy sources.

B. Unified Power Quality Conditioner

A Unified Power Quality Conditioner (UPQC) is a sophisticated electrical device designed to ensure the quality and reliability of electrical power in both residential and industrial settings. This advanced power conditioning equipment plays a vital role in managing and mitigating various power quality issues that can adversely affect electrical systems and connected equipment.

The primary functions and features of a UPQC include:

- Voltage Regulation: UPQC monitors the incoming voltage and regulates it to ensure that it remains within prescribed limits. This helps in stabilizing the supply voltage, preventing overvoltage and undervoltage conditions, and ensuring consistent electrical performance.
- Harmonic Filtering: One of the essential functions of a UPQC is the mitigation of harmonics in the electrical supply. Harmonics are undesirable distortions in the voltage and current waveforms caused by nonlinear loads like variable frequency drives (VFDs), computers, and other electronic devices. UPQC filters out these harmonics, reducing their harmful effects on the electrical system.
- Power Factor Correction: A UPQC actively corrects the power factor of the connected load. Power factor is a measure of how efficiently electrical power is converted into useful work, and a UPQC helps in achieving a near-unity power factor, which is highly desirable for efficient power consumption.
- Voltage Sag and Swell Compensation: Voltage sags and swells are sudden and brief disturbances in voltage levels, which can lead to equipment malfunctions or shutdowns. A UPQC detects these events and compensates for them by injecting or absorbing reactive power as needed to maintain a stable supply voltage.
- Flicker Mitigation: Voltage flicker, often caused by large loads with fluctuating power demand, can be a nuisance in industrial environments. A UPQC minimizes flicker by managing rapid changes in load demand and ensuring a smooth power supply.
- Voltage Balancing: In three-phase systems, a UPQC helps balance the voltage across all phases, ensuring equal voltage levels and preventing imbalances that can lead to equipment overheating and failure.

- Fault Ride-Through Capability: UPQCs are equipped with fault ride-through capabilities, allowing them to maintain power supply during brief electrical faults or disturbances, reducing downtime and ensuring uninterrupted operation.

II. LITERATURE REVIEW

Tamer Khatib et al. (2021) conducted a detailed examination of the impact of adding a 5 MWp solar power unit to a 33 kV/23 MVA electrical distribution network already utilizing significant renewable energy sources. Their study focused on grid functionality, considering aspects such as active and reactive power flow, voltage levels, and power losses. Decentralized solar power distribution was emphasized, with economic analysis indicating enhanced grid performance, albeit with slightly lower profitability compared to centralized systems.

Kulkarni, Kedar & S, et al. (2022) characterized power quality issues, emphasizing voltage sags/swells and harmonic currents, and proposed the Unified Power Quality Conditioner (UPQC) as a solution. Their study refined control algorithms for UPQC systems, demonstrating proficiency in mitigating power quality issues and maintaining load voltage within specified limits while reducing harmonics.

Alapati Ramadevi et al. (2023) introduced the FF-ANNC model for controlling shunt and series active filters within the UPQC system, aiming to minimize mean square error and enhance power factor. Their study demonstrated superior performance compared to existing methods, showcasing robust capability in mitigating voltage fluctuations and total harmonic distortion.

Abdel Mohsen SE et al. (2023) proposed a Transformer less Unified Power Quality Conditioner (TL-UPQC) to enhance power quality in large-scale LED lighting networks. Through optimization algorithms, they achieved significant improvements in power factor and total harmonic distortion, ensuring stable and flicker-free lighting environments.

Luo, Y., et al. (2020) introduced the Direct Prediction Compensation Strategy (DPCS) for Finite Control Set Model Predictive Control (FCS–MPC) in UPQC systems. Their approach simplified the control framework, effectively reducing steady-state errors and enhancing UPQC performance in addressing voltage sags, swells, interruptions, and harmonics.

Chouaib et al. (2023) underscore the critical role of power quality in utility systems and industrial settings, highlighting escalating consumer demands and the pronounced impact of power quality issues. Their focus on the Unified Power Quality Conditioner (UPQC) emphasizes its role in simultaneously mitigating voltage and current-based distortions, enhancing power quality through MATLAB/Simulink modeling. By elucidating the interactions of series and shunt Active Power Filters (APFs), the study showcases UPQC's efficiency in maintaining optimal power delivery.

Li C et al. (2022) introduce a novel approach to enhance sustainable energy in low-carbon cities through efficient scheduling in home energy management systems using the Dynamic Coyote Search Algorithm (DCSA). Their study demonstrates the algorithm's effectiveness in reducing total costs and accelerating convergence speed compared to traditional methods, offering promising prospects for distributed energy systems.

Shuo Liu et al. (2022) propose an advanced pinning coordination secondary control methodology for microgrids, emphasizing minimal interaction between the microgrid and the grid during disruptions. Through distributed droop theory and hardware-in-the-loop integration, their approach optimizes energy storage system performance, effectively minimizing external interference and enhancing system stability.

Twaisan K, et al. (2022) explore the efficacy of multimodal indicators in enhancing microgrid responsiveness, emphasizing comprehensive evaluations encompassing financial, technological, ecological, and social dimensions. Their study sheds light on the complex considerations influencing microgrid performance and highlights the need for a holistic approach in evaluating effectiveness.

III. OBJECTIVES

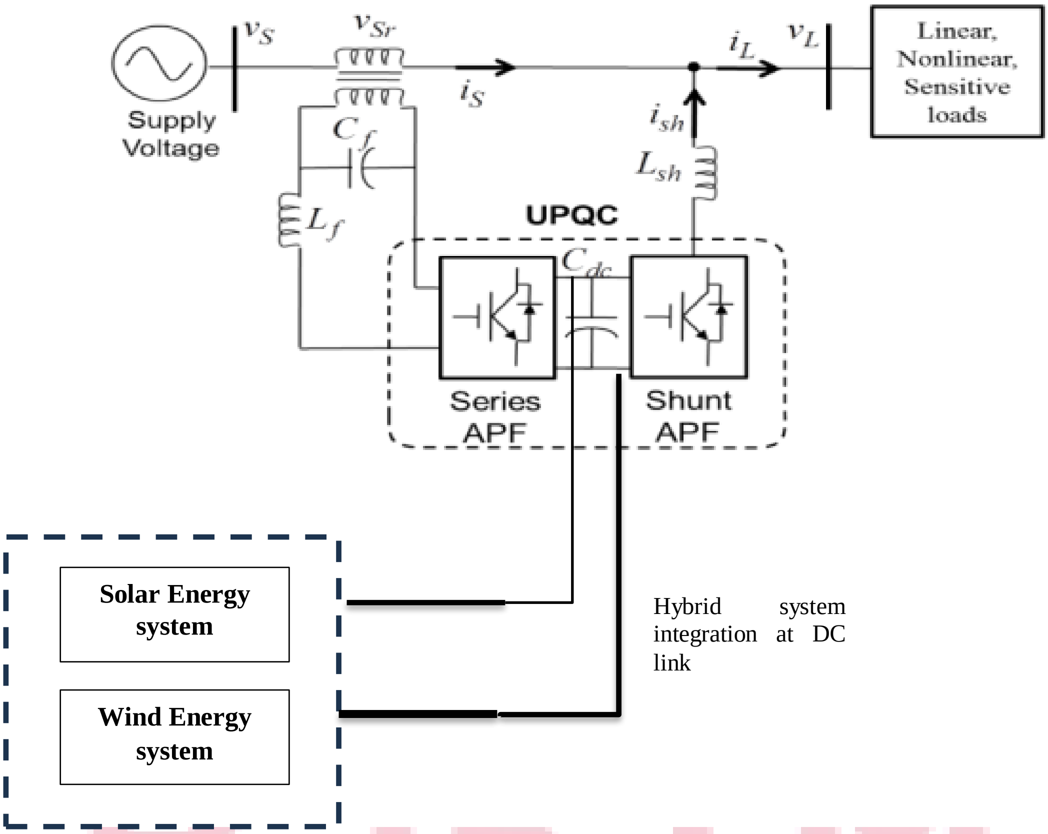
The work has been focused on obtaining following key objectives:

- Developing a system integrated with a Unified Power Quality Conditioner (HSW_UPQC) that is powered by a hybrid solar-wind energy system, implemented within the MATLAB/SIMULINK environment.
- Refining the control mechanism of the UPQC's Shunt device by employing a dynamically adaptive hybrid algorithm using crow aimed at evaluating the system's performance at non-linear load conditions.
- Investigating the system's power performance, focusing on improvements in active power and the stabilization of reactive power availability through the application of UPQC.
- Analysing the per phase signal quality of the proposed controller by doing the total harmonic distortion analysis on voltage and current waveforms.

IV. METHODOLOGY AND DESIGNING

In the current distribution system, power electronics-based devices play a pivotal role, offering a multitude of advantages. However, they are not without drawbacks, notably their tendency to introduce harmonic currents alongside the fundamental power frequency, leading to contamination of the distribution system. To address these challenges, the concept of Flexible

AC Transmission Systems (FACTS) has been integrated. FACTS devices are strategically utilized to optimize controllability and amplify the power transfer capacity of the transmission system.



Hybrid system integration at DC link

Figure 3 Modified Architecture of Hybrid UPQC system under study

In the realm of power quality enhancement, the Unified Power Quality Conditioner (UPQC) assumes a pivotal role. It bestows the advantages of both parallel and series active power filters. Functioning as a versatile power conditioner, UPQC proves instrumental in mitigating various voltage disturbances and flickers. Furthermore, it acts as a safeguard against harmonics in the load current, preventing their ingress into the power system and ensuring the preservation of power quality.

A. DC link with Hybrid renewable energy system in Unified Power Quality Conditioner (H_UPQC) architecture

In the domain of power quality enhancement, the Unified Power Quality Conditioner (UPQC) assumes a pivotal role, providing the benefits of parallel and series active power filters. Operating as a versatile power conditioning solution, UPQC serves as a multifaceted tool for compensating diverse voltage disturbances, alleviating voltage flicker, and thwarting harmonics in the load current to prevent their ingress into the power system and preserve power quality. This bespoke power apparatus demonstrates efficacy in mitigating issues impacting the performance The UPQC effectively mitigates harmonics in both current (shunt part) and voltage (series part), controls power flow, and adeptly manages voltage disturbances such as swell and sag to safeguard sensitive equipment or loads. Its essential components include the series inverter, shunt inverter, series transformer, DC link capacitor, and shunt coupling inductor.

Table 1 H_UPQC parameters

Parameters	**Values**
Source side	Supply Voltage = 400V
	Frequency = 50 Hz
DC Link Capacitor	C=2500μF
Series active power filter	$R_S=0.1\ \Omega$
	$L_S=3$ mH
	$C_S=30\mu F$
PI Controller:	Kp= 0.8
	KI= 30

Shunt inverter: A shunt-connected voltage source inverter functions as the shunt inverter. Its primary role involves mitigating current distortions by compensating for the harmonic currents generated by the load. Additionally, it contributes to maintaining a stable DC link capacitor voltage and enhances the power factor of the system. Moreover, the shunt inverter aids in compensating for reactive current associated with the load. Typically, a hysteresis band controller is utilized to govern the output current of the shunt inverter. By manipulating the semiconductor switches, the reference current is aligned with the output current, maintaining it within the predefined hysteresis band.

Series inverter: The series-connected Voltage Source Inverter (VSI) operates as a voltage source, connected in series with the line via a series transformer. Its main objective is to rectify voltage-related distortions in the system, eliminating load voltage imbalances and flickers in the terminal voltage to maintain a sinusoidal load voltage. Control of the series inverter is executed using Pulse Width Modulation (PWM) techniques, commonly employing the hysteresis band technique. This PWM approach offers numerous advantages, including improved and faster response speed, ease of implementation, and the ability to operate effectively without requiring extensive knowledge of system parameters.

DC link capacitor: The interconnection of series and shunt Voltage Source Inverters (VSIs) in a back-to-back configuration utilizes a DC capacitor. It is imperative to maintain a consistent voltage across the capacitor for the optimal functioning of both shunt and series inverters. The well-regulated voltage from this capacitor serves as a source for both active and reactive power. This setup eliminates the necessity for an external DC source, like a battery, streamlining the overall system.

Shunt coupling inductor: The interface of the shunt inverter with the network is facilitated by the coupling inductor. This component plays a pivotal role in enhancing the overall system performance by mitigating the ripple components present in the current waveform, resulting in a smoother and more stable current output. The coupling inductor contributes to the overall quality and reliability of the system by reducing current distortions and ensuring a more consistent and desirable current profile.

LC filter: Situated in close proximity to the series inverter output in the UPQC, the low-pass filter (LPF) plays a vital role. Acting as a high-frequency voltage attenuator, this element efficiently reduces the high-frequency voltage components within the output voltage produced by the series inverter. By acting as a filter, the LPF ensures the suppression of undesired high-frequency elements, contributing to the refinement of the output voltage and ultimately enhancing the overall performance and quality of the UPQC system.

Series transformer: Located in close proximity to the series inverter output within the Unified Power Quality Conditioner (UPQC), the low-pass filter (LPF) assumes a pivotal role in the system. Operating as an integral element, the LPF serves as a high-frequency voltage attenuator, effectively mitigating the presence of unwanted high-frequency components in the output voltage produced by the series inverter. Functioning as a filtering mechanism, the LPF ensures the suppression of undesirable high-frequency elements, contributing significantly to the purification of the output voltage. This meticulous filtration process enhances the overall performance and quality of the UPQC system, underscoring the significance of the LPF in optimizing the system's functionality and output characteristics.

The DC link is now being fed by the hybrid renewable energy systems comprising of solar and wind energy

B. PV implementation feeding the DC link

A Photovoltaic (PV) system comprises essential components dedicated to converting solar photons into electrical energy. A typical photovoltaic (PV) system includes essential elements such as a solar panel, storage unit, charge/discharge regulator, and, if required for grid integration, an inverter to convert direct current (DC) to alternating current (AC). The decision to include storage depends on the system's intended purpose. At the heart of the PV system is the solar cell, responsible for converting solar radiation into electrical power through the photoelectric effect. This effect occurs as specific materials generate electric current when exposed to light.

- ***Vector control system implementation for driving shunt converter***

The control strategy employed utilizes the Unit Vector Template Generation technique. This approach introduces intentional distortion to the supply voltage, leading to the generation of Unit Vector Templates derived from the resulting distorted input. Subsequently, the supply voltage, encompassing both harmonic and fundamental components, is measured. The calculation involves multiplying the measurement by the gain (1/Vm), where Vm denotes the peak fundamental supply voltage. The extraction of unit vectors is accomplished through the implementation of a phase-locked loop.

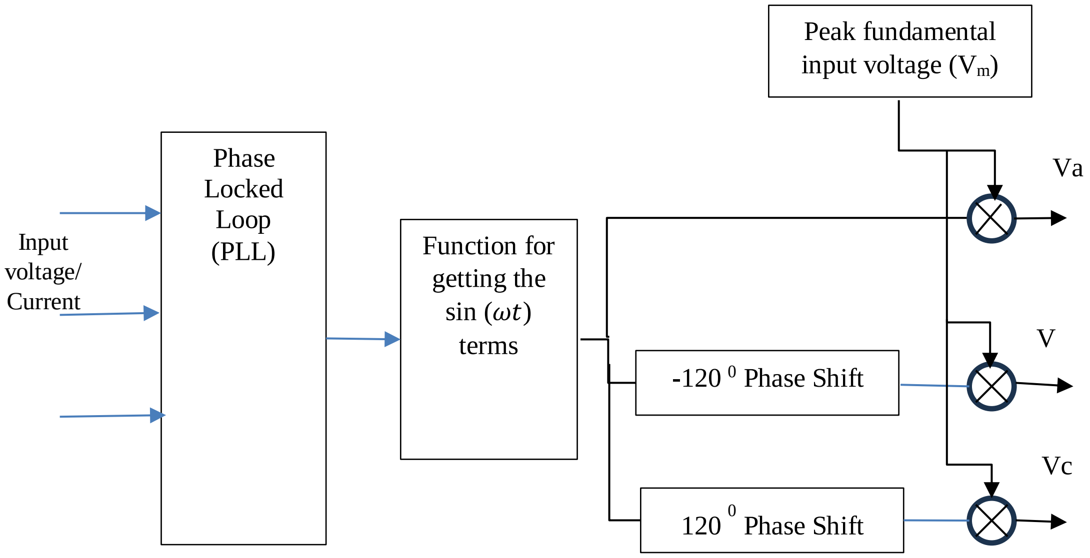


Figure 4 Vector control flow algorithm implementation

The operational sequence commences with the multiplication of the supply voltage with unit vector templates, yielding the generation of a reference load voltage denoted as V*abc, where V*abc= Vm*Uabc. A comparative analysis is conducted between actual and reference load voltage, and error calculation is performed. The error is then fed into a hysteresis band, generating gate pulses for the shunt inverter. To address current harmonics, a Shunt Active Power Filter is employed. The comparison of pulses for the shunt inverter's DC link voltage with the reference voltage is processed through a PI controller. The reference current is generated using unit vector templates, and the comparison with the actual source current triggers error processing through a hysteresis band controller, generating gate pulses for the parallel converter circuit. Equation depicting transformation of supply voltage and load current into d-q-o coordinate.

V. RESULTS AND DISCUSSION

The UPQC is a versatile and advanced power electronic device capable of simultaneously mitigating voltage harmonics, current harmonics and balancing reactive power in electrical distribution systems. Its effectiveness relies heavily on the control strategy employed to regulate its various components, namely the series and shunt inverters. Achieving optimal UPQC performance necessitates the development of a sophisticated control system capable of dynamically adapting to changing grid conditions and load profiles.

The work focuses on the design and implementation of an advanced control system for the UPQC, leveraging optimization algorithms to enhance its efficiency and effectiveness. By utilizing optimization techniques, we aim to maximize the UPQC's ability to mitigate power quality issues while minimizing its energy consumption and overall operational costs. The core objective is to develop a control strategy that optimally balances the UPQC's energy resources to ensure optimal power quality improvement under varying operating conditions. Reactive Power Correction on the line to improve the power factor with non-linear load.

The UPQC control system's success heavily relies on the selection and implementation of appropriate optimization algorithms, which will be a major focus of this research. Additionally, the study will investigate the impact of different optimization objectives, constraints, and algorithm parameters on the UPQC's performance.

The analysis has been discussed in the following two systems:

System 1: HSW_UPQC system implementation with vector control of converters.

System 2: HSW_UPQC system implementation with Dynamic_vector_hybrid_crow_optimisation (DVHCO) control.

By conducting this step-wise analysis of increasing reactive loads and the HSW_UPQC's response to it, valuable insights into the ability of the system for maintaining the power quality while optimizing energy consumption is made. This information is crucial for assessing the practicality and efficiency of the optimization-based control system in real-world power distribution scenarios.

Modeling UPQC in MATLAB/Simulink provides a comprehensive platform for analyzing and understanding the impact of UPQC on power quality improvement. Through simulation, the design and control strategies of UPQC systems are optimised, facilitating their implementation in real-world scenarios to enhance the reliability and efficiency of power distribution networks.

A. Reactive Power performance and Power Factor Evaluation

Reactive power is an essential component of AC electrical systems, along with active power (real power). Reactive power performance and power factor evaluation are essential aspects of managing electrical systems efficiently. Proper management of reactive power and power factor helps maintain system stability, reduce energy costs, and assure the reliable operation of electrical equipment. It is often desirable to improve the power factor of a system, especially. This can be done through various means, such as installing power factor correction capacitors or using power factor correction devices.

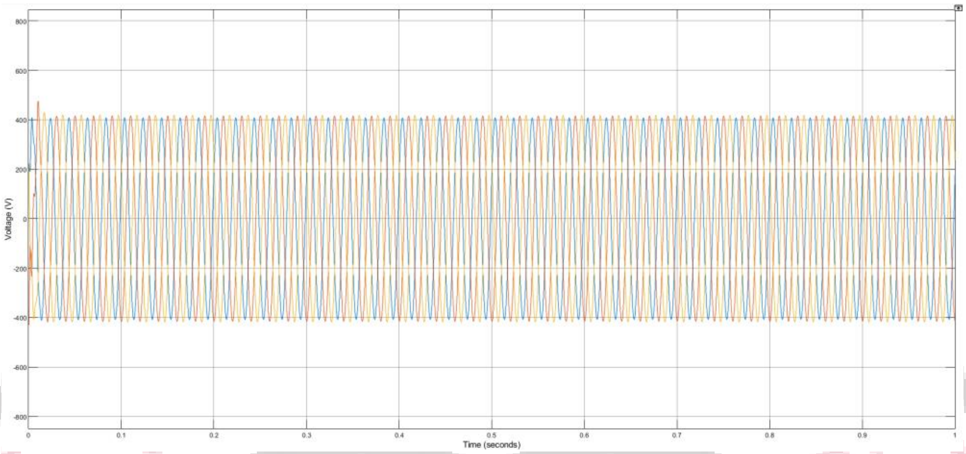


Figure 5 Three phase voltage output from the HSW_UPQC system having Vector Converter Control system

Figure 5 represents the three phase voltage output in the system 1 where the HSW_UPQC architecture is driven by vector control system. The line to line voltage in the system 1 is measured to be approximately 400V.

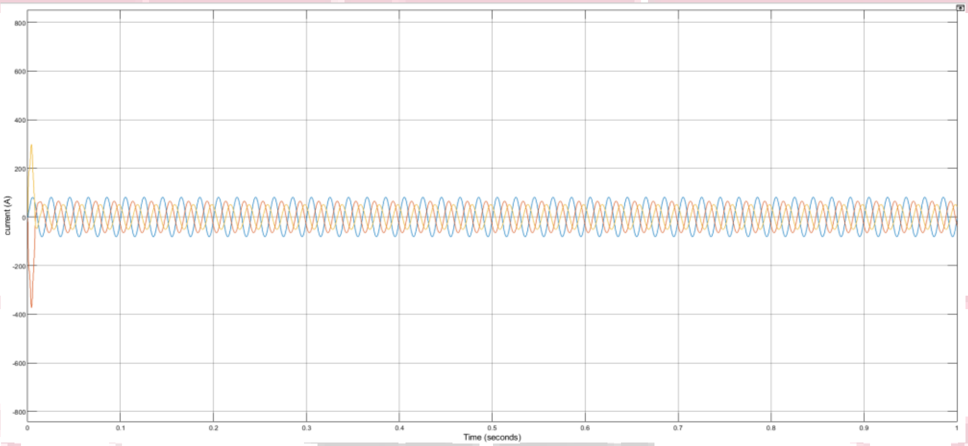


Figure 6 Three phase current output from the HSW_UPQC system having Vector Converter Control system

Figure 6 represents the three phase current output in the system 1 where the HSW_UPQC architecture is driven by vector control system. The line to line voltage in the system 1 is measured to be approximately 81 A.

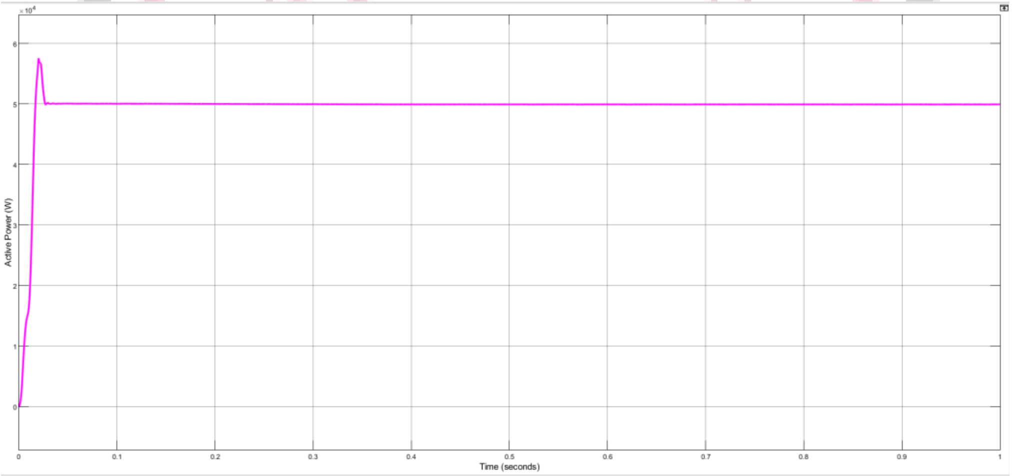


Figure 7 Active Power available in the HSW_UPQC system having Vector Converter Control system

Figure 7 represents the active power output in the system 1 where the HSW_UPQC architecture is driven by vector control system. The active power output in the system 1 is measured to be approximately 49.92 KW.

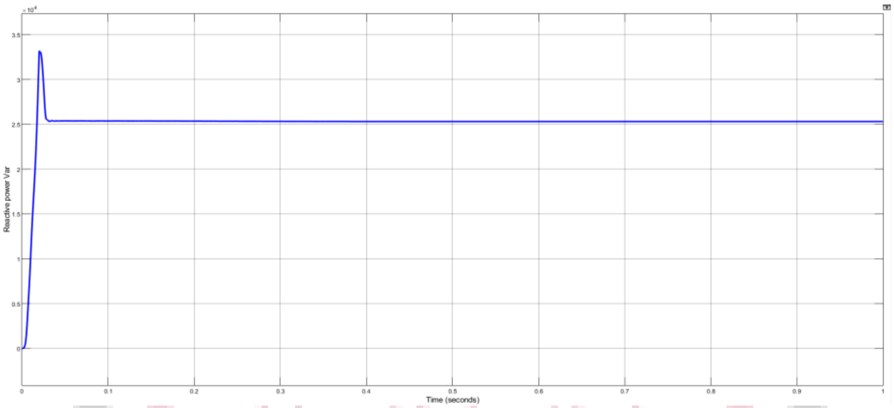


Figure 8 Reactive Power available in the HSW_UPQC system having Vector Converter Control system

In System 1, Figure 8 illustrates the reactive power output of the HSW_UPQC architecture driven by a vector control system. The measured active power output in System 1 is approximately 25.310 KVar.

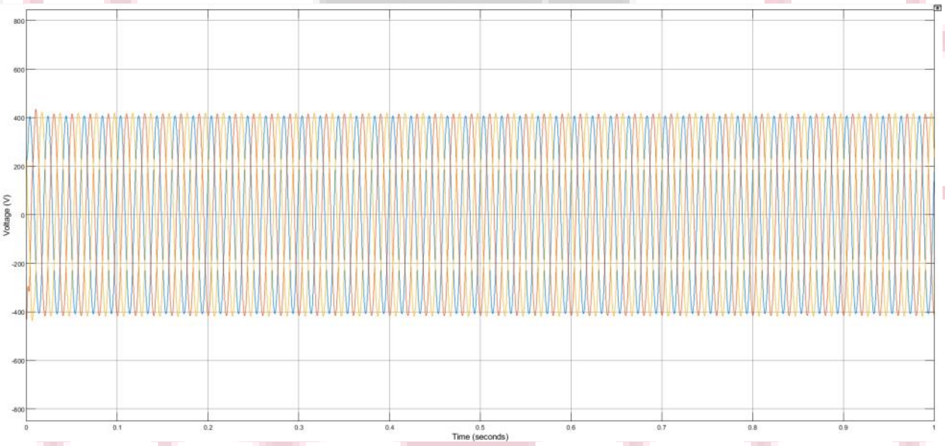


Figure 9 Three phase voltage output from the HSW_UPQC system having DVHCO Control system

Figure 9 represents the three phase voltage output in the system 2 where the HSW_UPQC architecture is driven by DVHCO control system. The line to line voltage in the system 2 is measured to be approximately 400V.

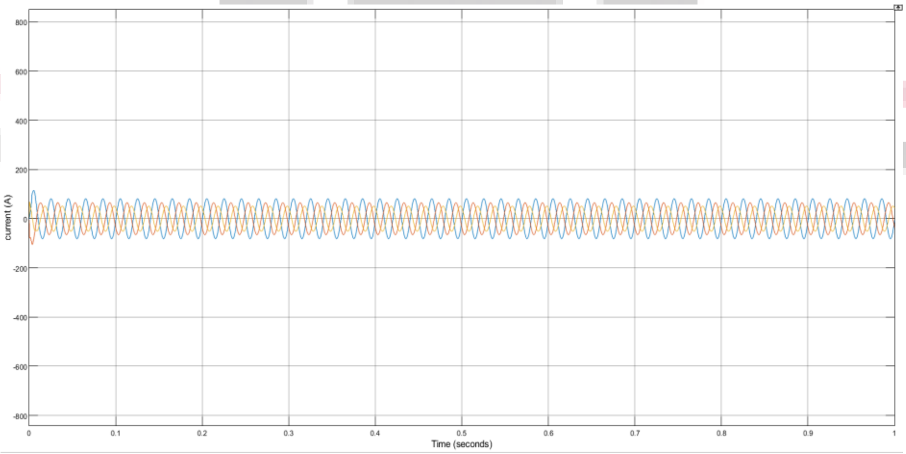


Figure 10 Three phase current output from the HSW_UPQC system having DVHCO Converter Control system

Figure 10 represents the three phase current output in the system 2 where the HSW_UPQC architecture is driven by DVHCO control system. The line to line voltage in the system 2 is measured to be approximately 81 A.

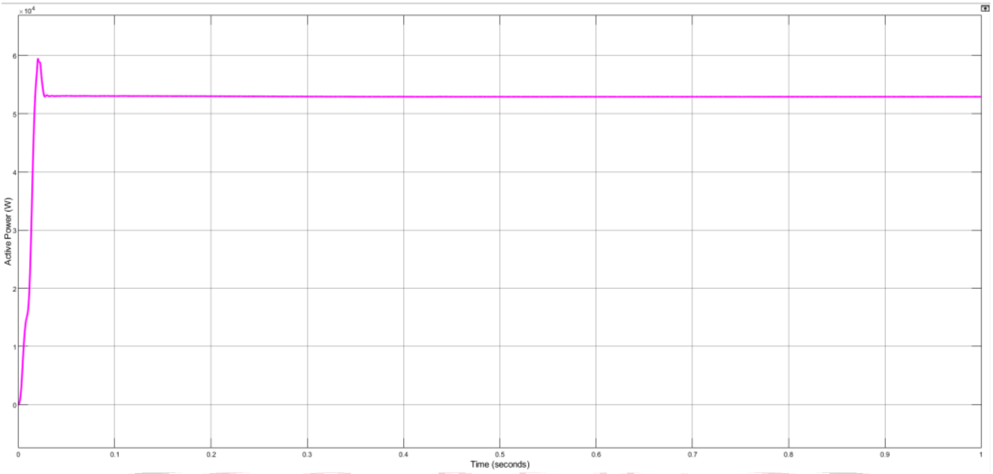


Figure 11 Active Power available in the HSW_UPQC system having DVHCO Control system

Figure 11 represents the active power output in the system 2 where the HSW_UPQC architecture is driven by DVHCO control system. The active power output in the system 2 is measured to be approximately 52.92 KW.

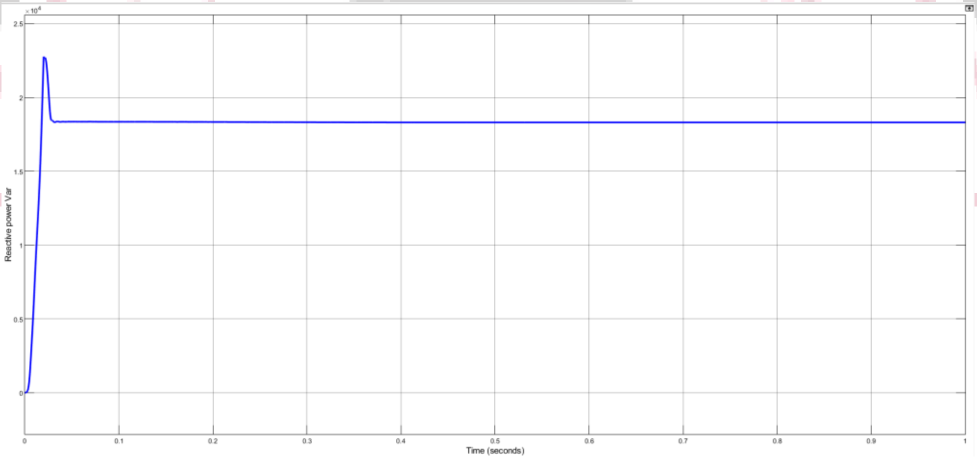


Figure 12 Reactive Power available in the HSW_UPQC system having DVHCO Control system

In System 2, Figure 12 illustrates the reactive power output of the HSW_UPQC architecture utilizing vector control. The measured active power output in System 2 is approximately 18.30 KVar.

Table 2 Comparative analysis of reactive power performance and power factor correction of proposed controller

Parameters	**System 1**	**System 2**
Voltage (L-L)	400	400
Current	81	81
Active Power (KW)	49.92	52.92
Reactive Power (KVar)	25.310	18.30
Total Power (KVA)	56.052	56.052
Power Factor	0.892	0.945
Power Factor Angle (Degree)	26.87	19.09

B. Per Phase Quality Assessment at the nonlinear load terminals

Nonlinear loads are electrical devices that do not draw current in a linear relationship with voltage. These loads introduce harmonic currents into the power system due to their nonlinear voltage-current characteristics. Evaluating the power quality at the terminals of nonlinear loads, particularly in a three-phase system, is crucial for ensuring the reliability and optimal functioning of electrical equipment. The introduction of harmonic distortion by nonlinear loads can have detrimental effects on the overall quality of the power supply.

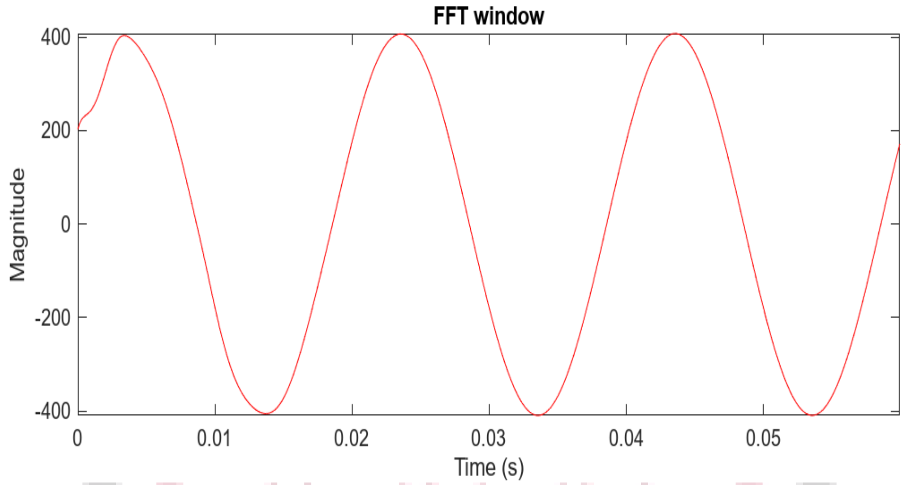


Figure 13 FFT analysis of voltage signal P-1 in HSW_UPQC system 1

Figure 13 represents the FFT analysis done in the MATLAB/SIMULINK of the voltage signal of phase 1 present in system 1. This involves the conversion of the time-domain voltage signal into the frequency domain to analyze its spectral components. This analysis helps in understanding the harmonics and disturbances present in the voltage signal

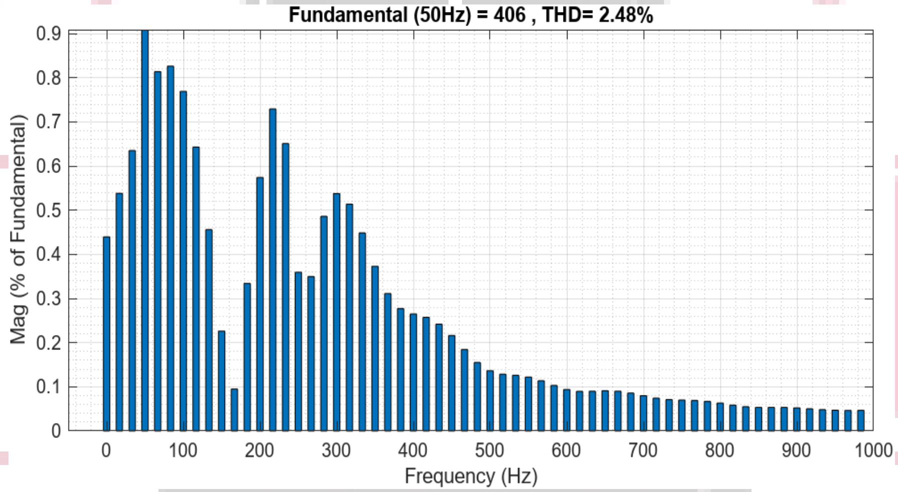


Figure 14 THD% evaluation of voltage signal P-1 in HSW_UPQC system 1

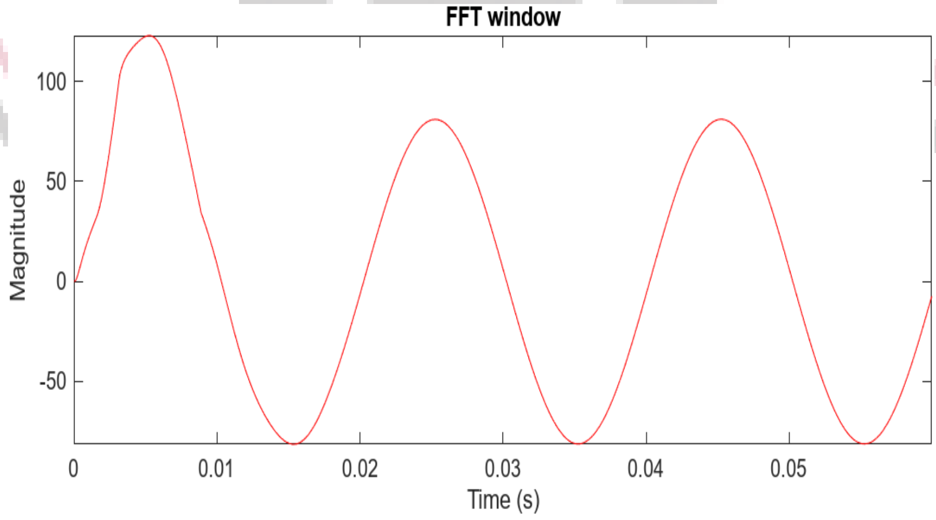


Figure 15 FFT analysis of current signal P-1 in HSW_UPQC system 1

Figure 15 represents the Fast Fourier Transform of the current signal of phase 1 in the system where the HSW_UPQC has converter driven by vector control algorithm. This is then used further for doing the quality analysis.

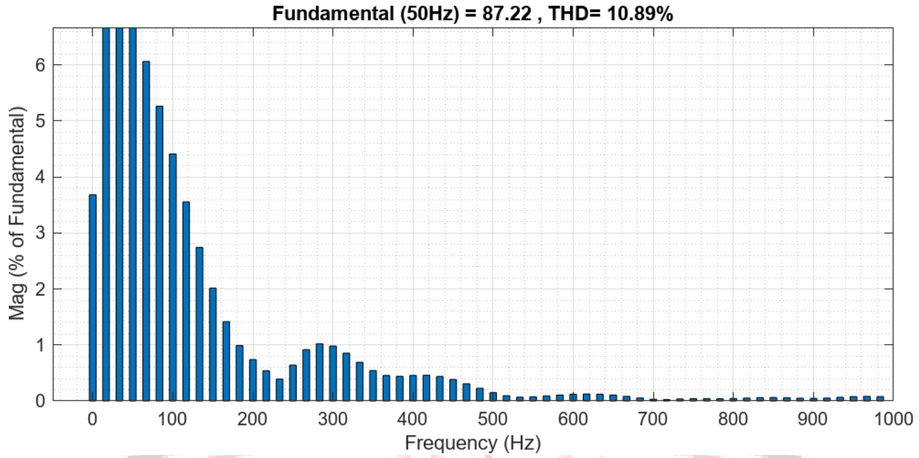


Figure 16 THD% evaluation of current signal P-1 in HSW_UPQC system 1

Figure 16 represents the total harmonic distortion percentage present in the current signal of phase 1 in the system where the HSW_UPQC has converter driven by vector control algorithm. The THD% was found to be 10.89% at 50 hz fundamental frequency

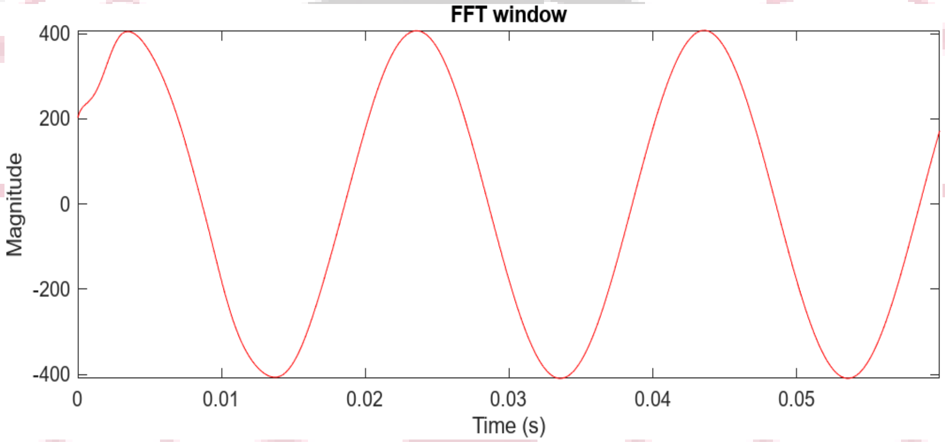


Figure 17 FFT analysis of voltage signal P-1 in HSW_UPQC system 2

Figure 17 represents the FFT analysis done in the MATLAB/SIMULINK of the voltage signal of phase 1 present in system 2. This involves the conversion of the time-domain voltage signal into the frequency domain to analyze its spectral components. This analysis helps in understanding the harmonics and disturbances present in the voltage signal

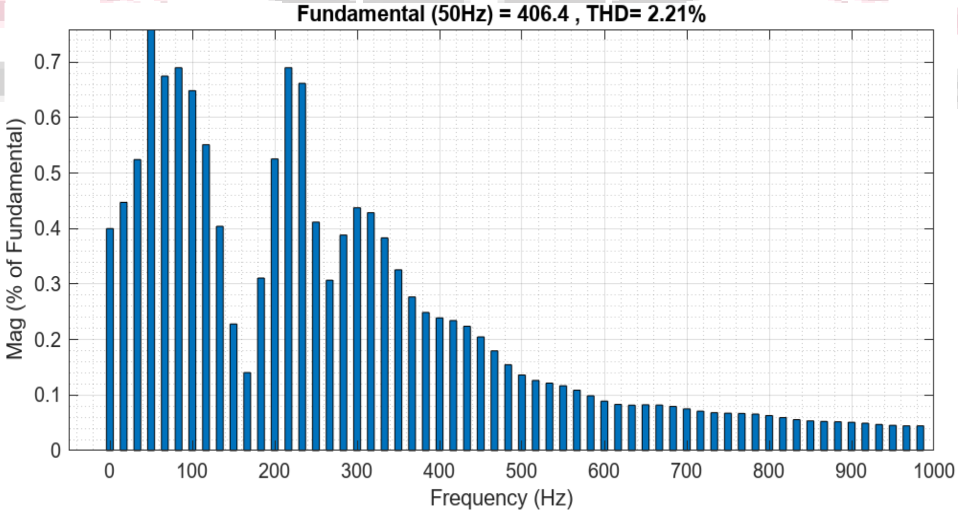


Figure 18 THD% evaluation of voltage signal P-1 in HSW_UPQC system 2

Figure 18 represents the total harmonic distortion percentage present in the voltage signal of phase 1 in the system where the HSW_UPQC has converter driven by proposed DVHCO algorithm. The THD% was found to be 2.21% at 50 hz fundamental frequency

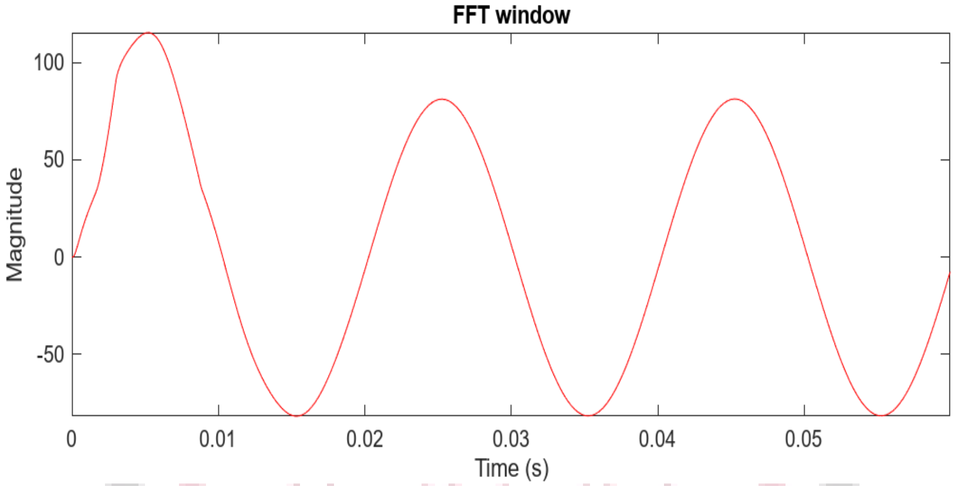


Figure 19 FFT analysis of current signal P-1 in HSW_UPQC system 2

Figure 19 represents the Fast Fourier Transform of the current signal of phase 1 in the system where the HSW_UPQC has converter driven by proposed DVHCO algorithm. This is then used further for doing the quality analysis.

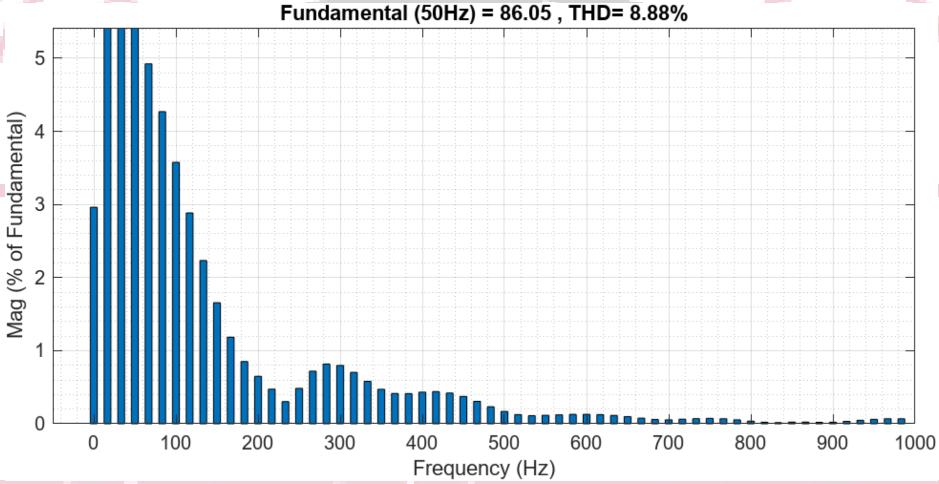


Figure 20 THD% evaluation of current signal P-1 in HSW_UPQC system 2

Figure 20 represents the total harmonic distortion percentage present in the current signal of phase 1 in the system where the HSW_UPQC has converter driven by proposed DVHCO algorithm. The THD% was found to be 8.88% at 50 hz fundamental frequency

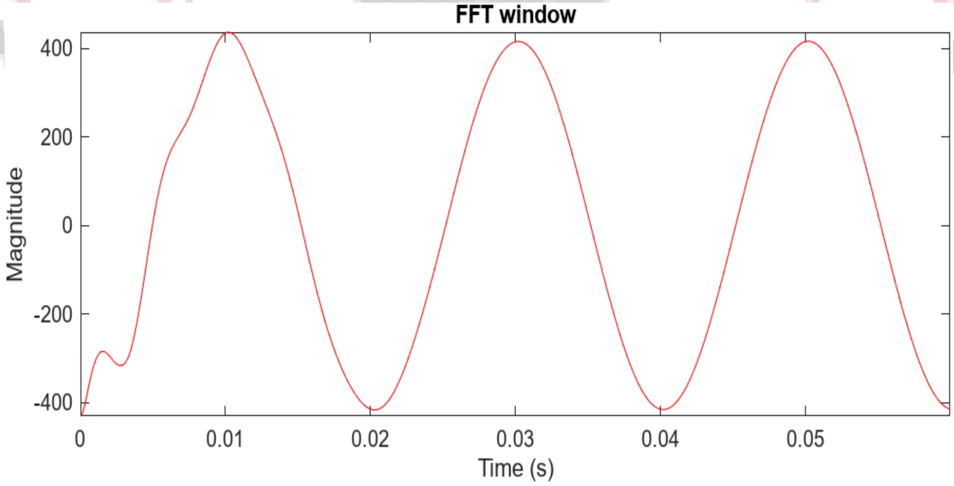


Figure 21 FFT analysis of voltage signal P-2 in HSW_UPQC system 1

Figure 21 represents the FFT analysis done in the MATLAB/SIMULINK of the voltage signal of phase 2 present in system 1. This involves the conversion of the time-domain voltage signal into the frequency domain to analyze its spectral components. This analysis helps in understanding the harmonics and disturbances present in the voltage signal

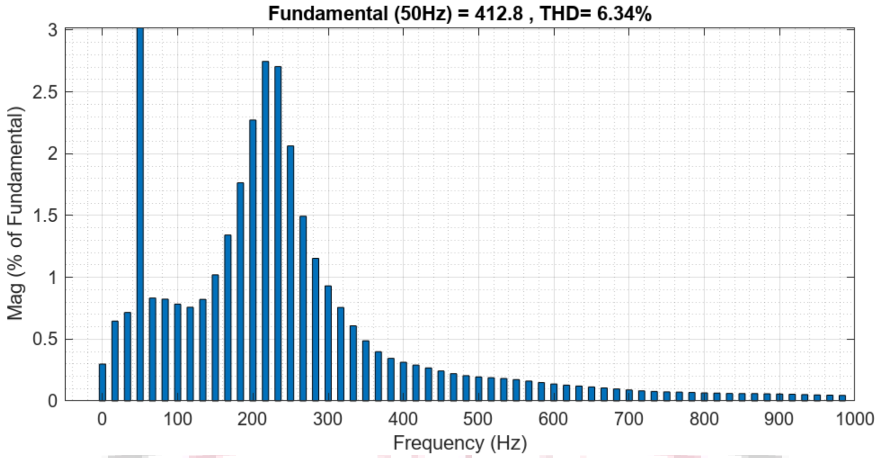


Figure 22 THD% evaluation of voltage signal P-2 in HSW_UPQC system 1

Figure 22 represents the total harmonic distortion percentage present in the voltage signal of phase 2 in the system where the HSW_UPQC has converter driven by vector control algorithm. The THD% in the phase 2 voltage was found to be 6.34% at 50 hz fundamental frequency

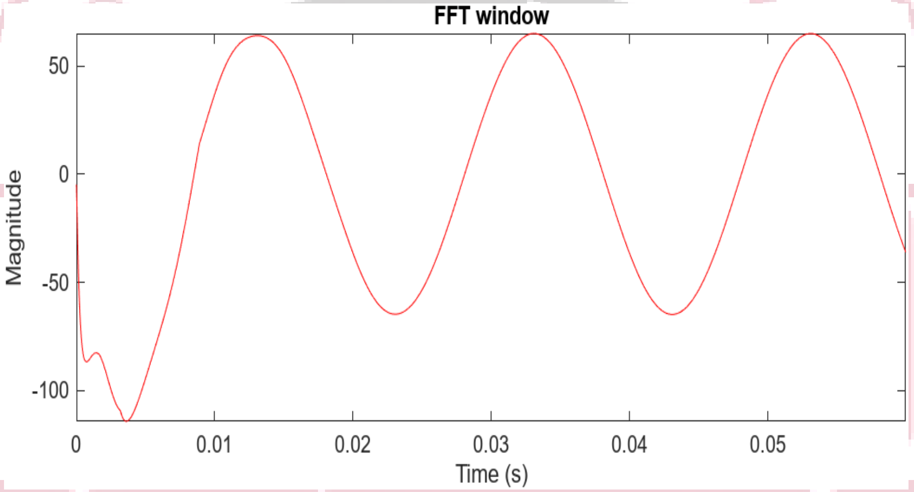


Figure 23 FFT analysis of current signal P-2 in HSW_UPQC system 1

Figure 23 represents the Fast Fourier Transform of the current signal of phase 2 in the system where the HSW_UPQC has converter driven by vector control algorithm. This is then used further for doing the quality analysis.

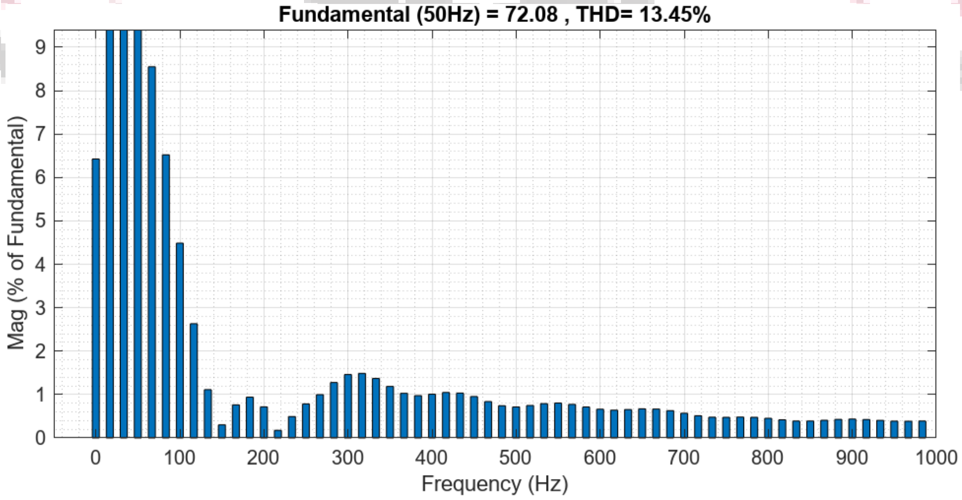


Figure 24 THD% evaluation of current signal P-2 in HSW_UPQC system 1

Figure 24 represents the total harmonic distortion percentage present in the current signal of phase 2 in the system where the HSW_UPQC has converter driven by vector control algorithm. The THD% was found to be 13.45% at 50 hz fundamental frequency

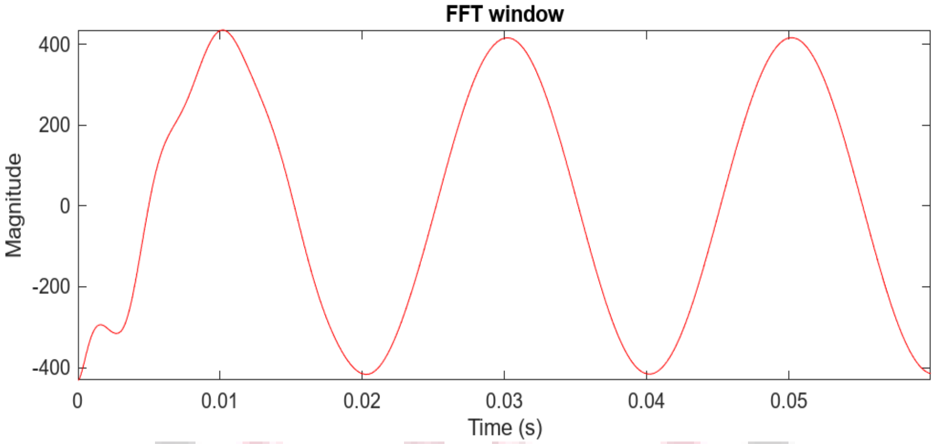


Figure 25 FFT analysis of voltage signal P-2 in HSW_UPQC system 2

Figure 25 represents the FFT analysis done in the MATLAB/SIMULINK of the voltage signal of phase 2 present in system 2. This entails the conversion of the voltage signal's time-domain representation into the frequency domain to scrutinize its spectral elements. This analysis serves the purpose of gaining insights into the presence of harmonics and disruptions in the voltage signal.

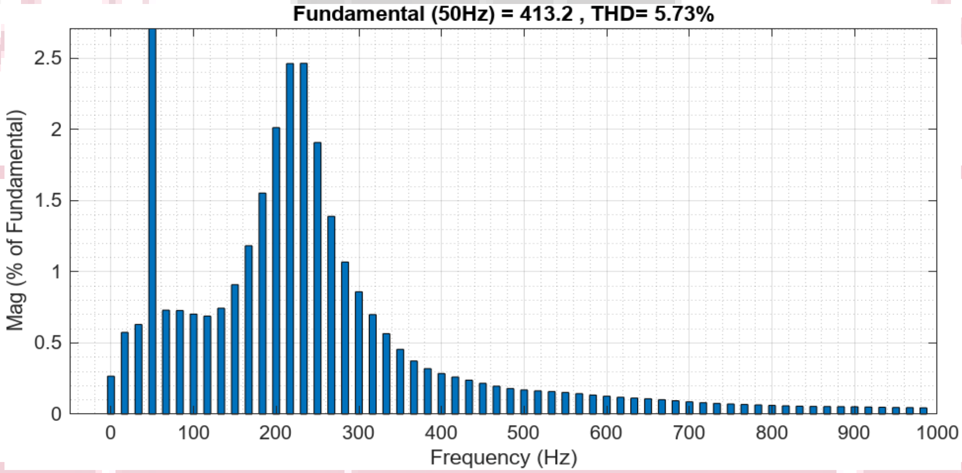


Figure 26 THD% Evaluation of voltage signal P-2 in HSW_UPQC system 2

Figure 26 represents the total harmonic distortion percentage present in the voltage signal of phase 2 in the system where the HSW_UPQC has converter driven by proposed DVHCO algorithm. The THD% was found to be 5.73 % at 50 hz fundamental frequency

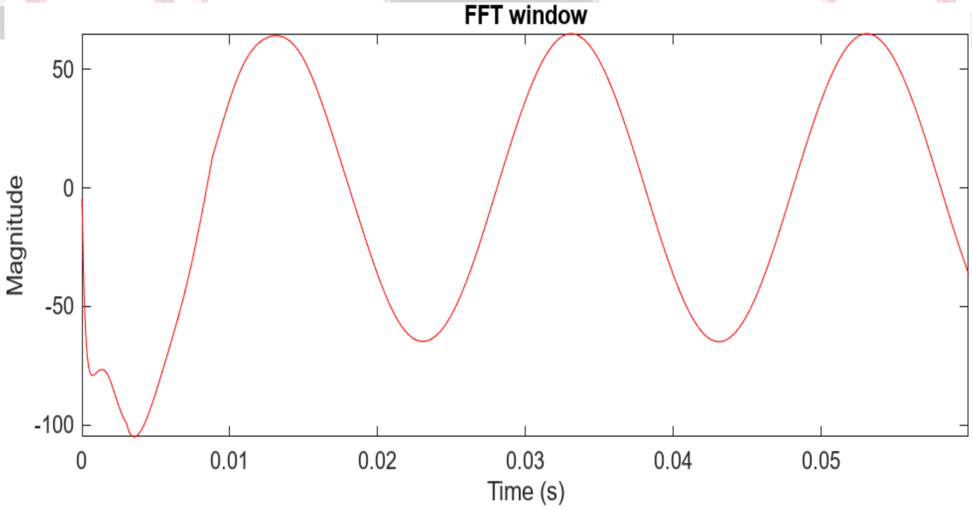


Figure 27 FFT analysis of current signal P-2 in HSW_UPQC system 2

Figure 27 represents the Fast Fourier Transform of the current signal of phase 2 in the system where the HSW_UPQC has converter driven by proposed DVHCO algorithm. This is then used further for doing the quality analysis.

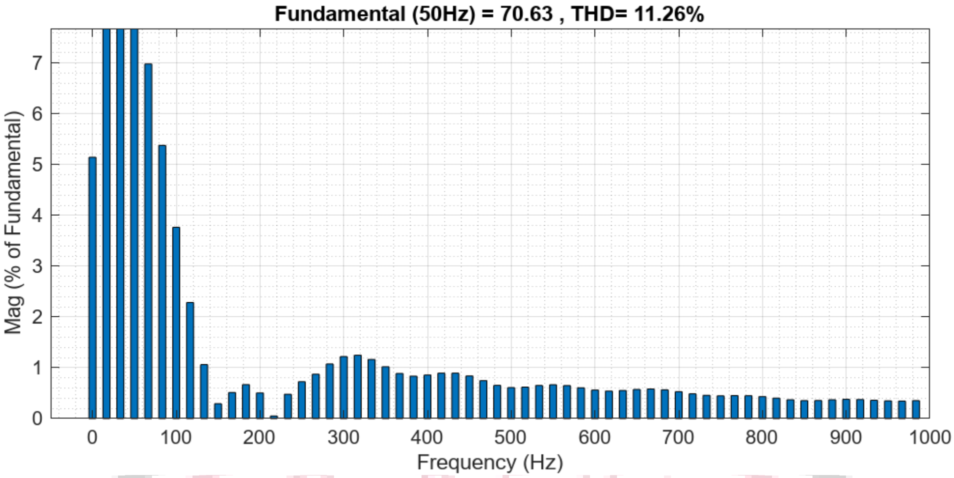


Figure 28 THD% evaluation of current signal P-2 in HSW_UPQC system 2

Figure 28 represents the total harmonic distortion percentage present in the current signal of phase 2 in the system where the HSW_UPQC has converter driven by proposed DVHCO algorithm. The THD% was found to be 11.26% at 50 hz fundamental frequency

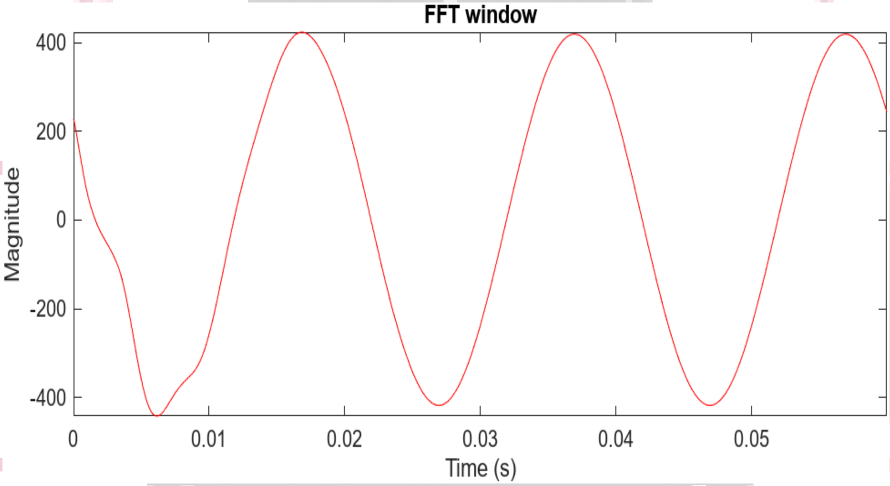


Figure 29 FFT analysis of voltage signal P-3 in HSW_UPQC system 1

Figure 29 illustrates the FFT analysis conducted within MATLAB/SIMULINK for the voltage signal of phase 3 within system 1. This analysis entails the transformation of the time-domain voltage signal into the frequency domain to examine its spectral elements. Such analysis serves the purpose of gaining insights into the harmonics and disturbances that exist within the voltage signal.

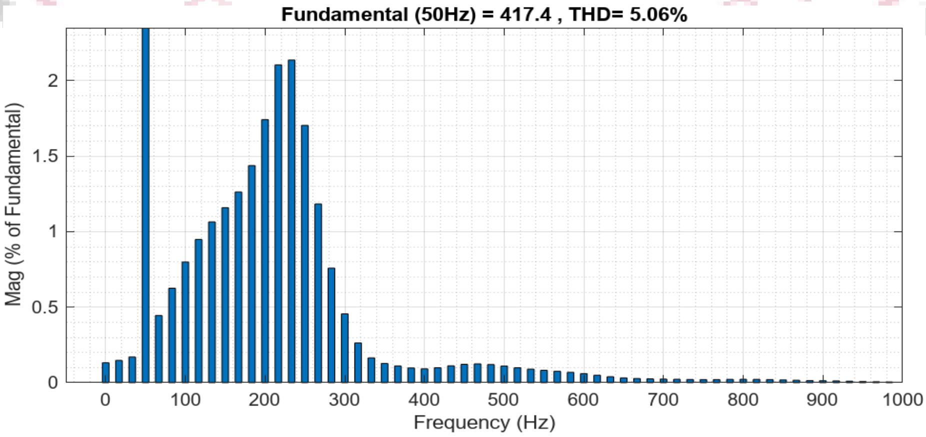


Figure 30 THD% evalaution of voltage signal P-3 in HSW_UPQC system 1

Figure 30 represents the total harmonic distortion percentage present in the voltage signal of phase 3 in the system where the HSW_UPQC has converter driven by vector control algorithm. The THD% in the phase 3 voltage was found to be 5.06% at 50 hz fundamental frequency

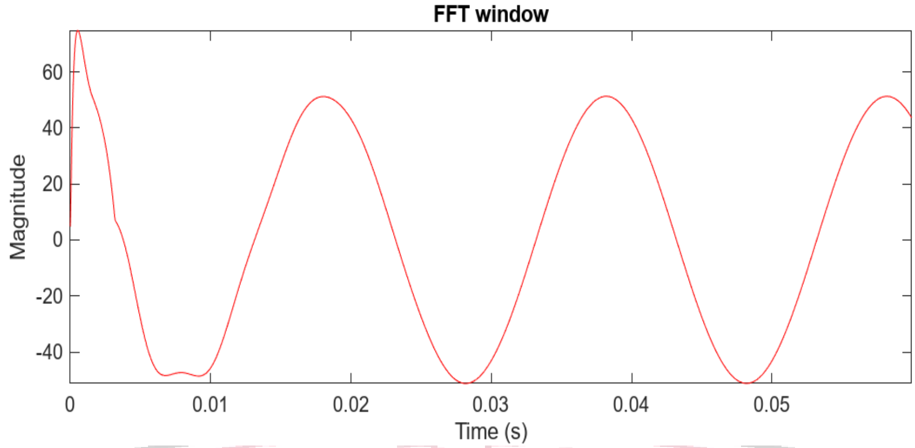


Figure 31 FFT analysis of current signal P-3 in HSW_UPQC system 1

Figure 31 represents the Fast Fourier Transform of the current signal of phase 3 in the system where the HSW_UPQC has converter driven by vector control algorithm. This is then used further for doing the quality analysis.

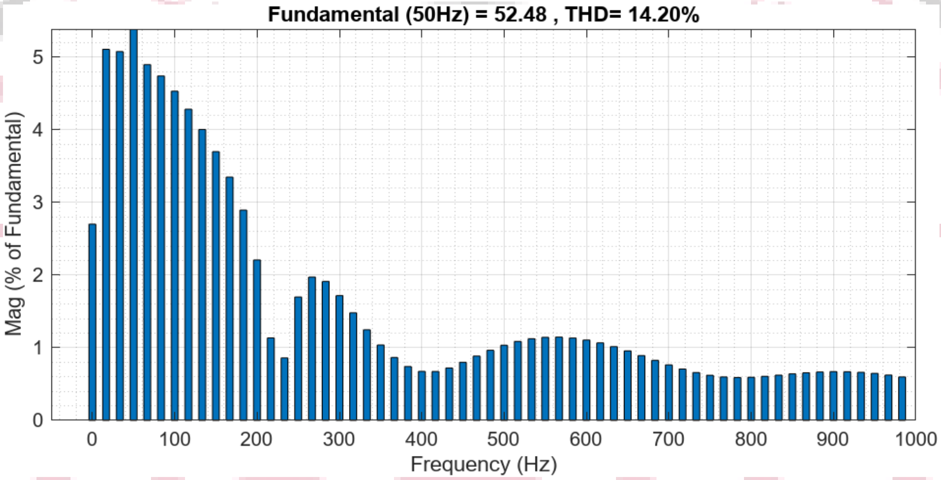


Figure 32 THD% evaluation of current signal P-3 in HSW_UPQC system 1

Figure 32 represents the total harmonic distortion percentage present in the current signal of phase 3 in the system where the HSW_UPQC has converter driven by vector control algorithm. The THD% was found to be 14.20% at 50 hz fundamental frequency

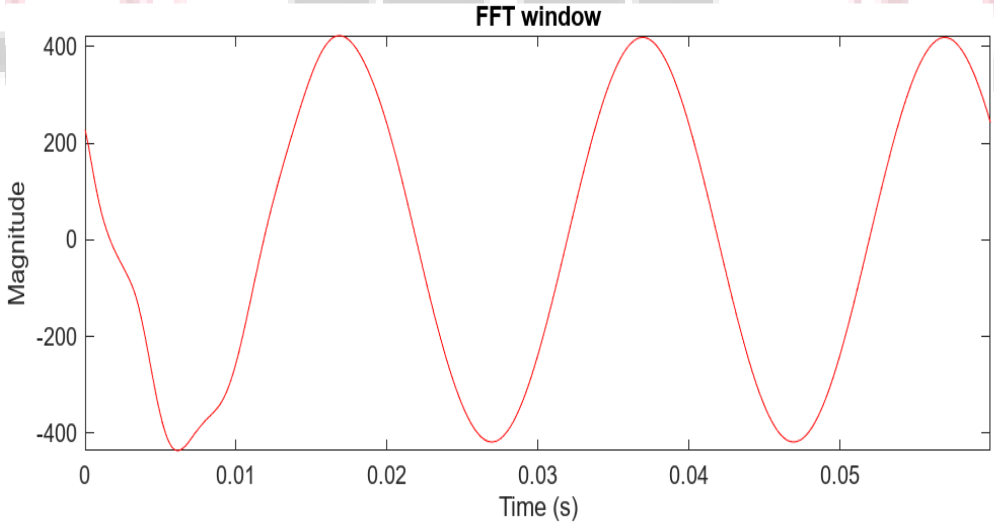


Figure 33 FFT analysis of voltage signal P-3 in HSW_UPQC system 2

Figure 33 represents the FFT analysis done in the MATLAB/SIMULINK of the voltage signal of phase 3 present in system 2. This entails the conversion of the voltage signal's time-domain representation into the frequency domain to scrutinize its spectral elements. This analysis serves the purpose of gaining insights into the presence of harmonics and disruptions in the voltage signal.

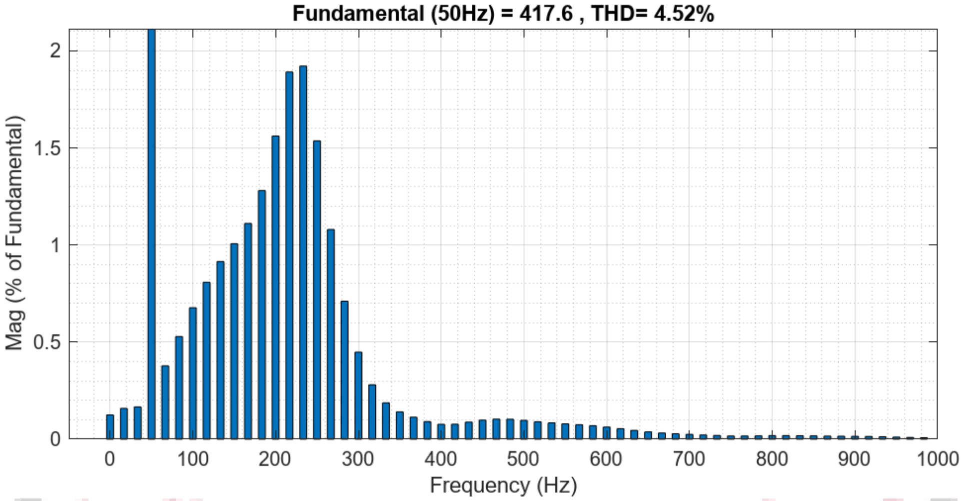


Figure 34 THD% evaluation of voltage signal P-3 in HSW_UPQC system 2

Figure 34 represents the total harmonic distortion percentage present in the voltage signal of phase 3 in the system where the HSW_UPQC has converter driven by proposed DVHCO algorithm. The THD% was found to be 4.52 % at 50 hz fundamental frequency

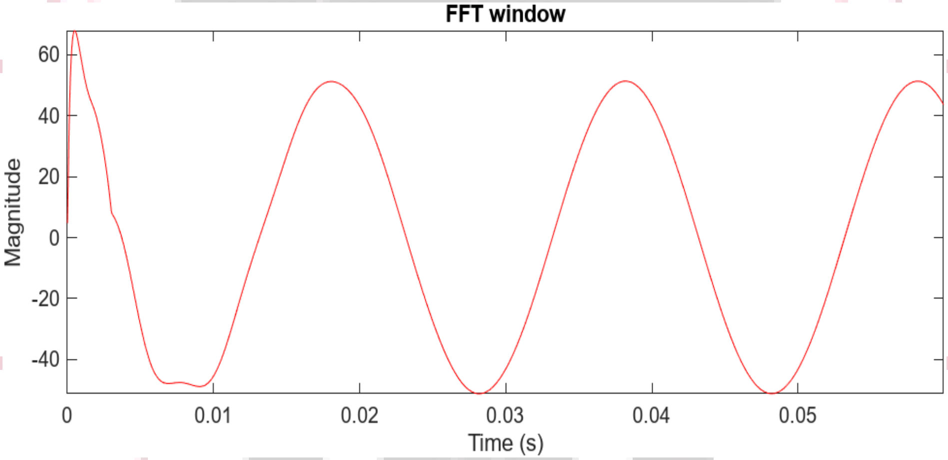


Figure 35 FFT analysis of current signal P-3 in HSW_UPQC system 2

Figure 35 represents the Fast Fourier Transform of the current signal of phase 3 in the system where the HSW_UPQC has converter driven by proposed DVHCO algorithm. This is then used further for doing the quality analysis.

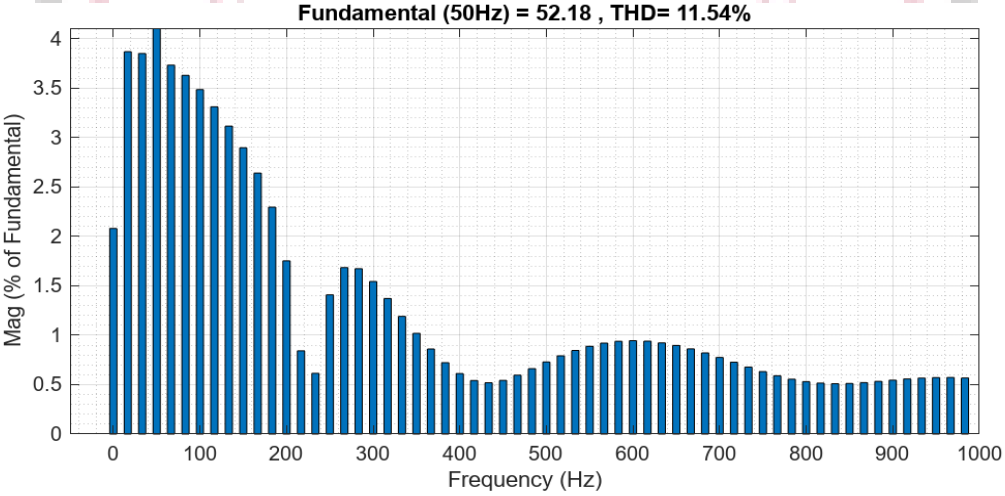


Figure 36 THD% evaluation of current signal P-3 in HSW_UPQC system 2

Figure 36 represents the total harmonic distortion percentage present in the current signal of phase 3 in the system where the HSW_UPQC has converter driven by proposed DVHCO algorithm. The THD% was found to be 11.54% at 50 hz fundamental frequency

Table 3 Power Quality Assessment Comparison of the proposed algorithms

Parameters	**System 1**	**System 2**
Power Quality assessment at Phase 1		
THD% Voltage	2.48	2.21
THD% Current	10.89	8.88
Power Quality assessment at Phase 2		
THD% Voltage	6.34	5.73
THD% Current	13.45	11.26
Power Quality assessment at Phase 3		
THD% Voltage	5.06	4.52
THD% Current	14.20	5.06

Based on the data provided for Power Quality assessment across three phases, we can observe differences in Total Harmonic Distortion (THD) for both voltage and current between System 1 and System 2. THD is a key parameter in evaluating power quality, as it measures the distortion of a signal compared to its fundamental frequency. Lower THD values indicate better power quality because they signify less distortion, which can lead to more efficient operation of electrical equipment and less stress on the infrastructure.

The table shows the following outcomes:

Phase 1:

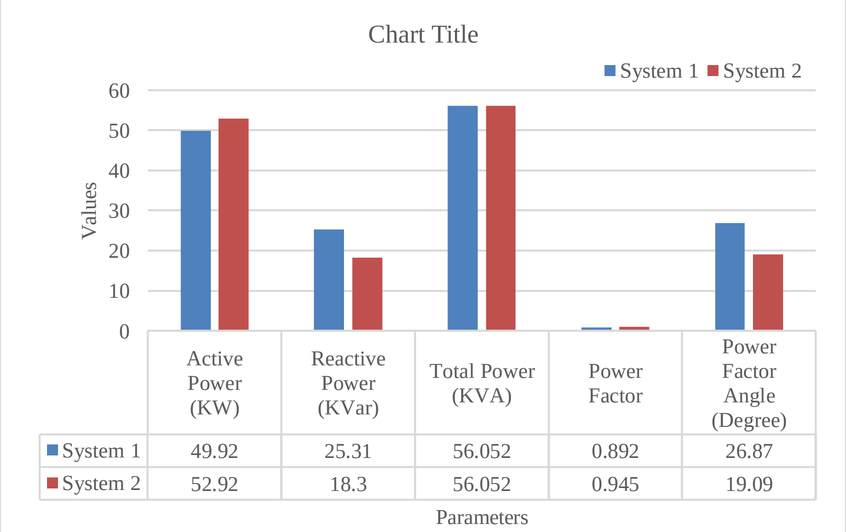
- Voltage THD has decreased from 2.48% in System 1 to 2.21% in System 2, showing a slight improvement in voltage quality.
- Current THD has significantly improved, dropping from 10.89% in System 1 to 8.88% in System 2.

Phase 2:

- Voltage THD reduction from 6.34% in System 1 to 5.73% in System 2 indicates better voltage quality in System 2.
- Current THD shows a notable improvement, going from 13.45% to 11.26%.

Phase 3:

- Voltage THD has decreased from 5.06% in System 1 to 4.52% in System 2, indicating improved voltage quality.
- Current THD shows a significant reduction, from 14.20% in System 1 to 5.06% in System 2, which is a substantial improvement in current quality.



	Active Power (KW)	Reactive Power (KVar)	Total Power (KVA)	Power Factor	Power Factor Angle (Degree)
🟦 System 1	49.92	25.31	56.052	0.892	26.87
🟥 System 2	52.92	18.3	56.052	0.945	19.09

Figure 37 Comparison of the power outputs from the two system

V. CONCLUSION

This study underscores the pivotal role of UPQC integration with hybrid renewable energy systems in enhancing power quality and efficiency in distributed electrical systems. By addressing voltage disturbances, harmonic distortions, and reactive power issues, the UPQC proves to be a versatile and effective solution for modern energy distribution challenges. Through MATLAB/Simulink modeling and optimization algorithms, the study provides valuable insights into the practical implementation and performance optimization of UPQC systems in real-world scenarios, paving the way for sustainable and reliable energy delivery systems.

REFERENCES

[1] R.A. Ufa, Y.Y. Malkova, V.E. Rudnik, M.V. Andreev, V.A. Borisov, A review on distributed generation impacts on electric power system, International Journal of Hydrogen Energy, Volume 47, Issue 47, 2022 Pages 20347-20361, ISSN 0360-3199, https://doi.org/10.1016/j.ijhydene.2022.04.142

[2] Davila Vasquez, C. Evaluación de Modelo de Negocios Con Energías Renovables Para Generación Distribuida En El Perú. Master’s Thesis, Universidad César Vallejo, Trujillo, Peru, 2020. Available online: https://repositorio.ucv.edu.pe/handle/20.500.12692/46873

[3] Cóndor, L.H. Generación Distribuida Con Energías Renovables En Perú. Master’s Thesis, Universidad de Piura, Piura, Peru, 2020; p. 123. Available online: https://pirhua.udep.edu.pe/handle/11042/4782

[4] Inyama Kelechi, Onojo, James O, Okozi, Samuel O, Joe-Uzuegbu Chijioke K, A Review of the Impact of Distributed Generation from Solar Energy on the Nigeria Power Distribution Grid, International Journal of Research Publication and Reviews, Vol 4, no 11, pp 651-664 November 2023, DOI: https://doi.org/10.55248/gengpi.4.1123.113016

[5] Talha Bin Nadeem, Mubashir Siddiqui, Muhammad Khalid, Muhammad Asif, Distributed energy systems: A review of classification, technologies, applications, and policies, Energy Strategy Reviews, Volume 48, 2023, 101096, ISSN 2211-467X, https://doi.org/10.1016/j.esr.2023.101096.

[6] A. Gurung, A. Kumar Ghimeray, and S. H. Hassan, “The prospects of renewable energy technologies for rural electrification: A review from Nepal,” Energy Policy 40, 374–380 (2012).

[7] Z. Zhou, P. Liu, Z. Li, and W. Ni, “An engineering approach to the optimal design of distributed energy systems in China,” Appl. Thermal Eng. 53, 387–396 (2013).

[8] H. Abe, A. Katayama, B. P. Sah, T. Toriu, S. Samy, P. Pheach, M. A. Adams, and P. F. Grierson, “Potential for rural electrification based on biomass gasification in Cambodia,” Biomass Bioenergy 31, 656–664 (2007).

[9] G. P. B. Marquez, W. J. E. Santia~nez, G. C. Trono, M. N. E. Monta~no, H. Araki, H. Takeuchi, and T. Hasegawa, “Seaweed biomass of the Philippines: Sustainable feedstock for biogas production,” Renewable Sustainable Energy Rev. 38, 1056–1068 (2014)

[10] Tamer Khatib, Lama Sabri, "Grid Impact Assessment of Centralized and Decentralized Photovoltaic-Based Distribution Generation: A Case Study of Power Distribution Network with High Renewable Energy Penetration", Mathematical Problems in Engineering, vol. 2021, Article ID 5430089, 16 pages, 2021. https://doi.org/10.1155/2021/5430089

[11] Kulkarni, Kedar & S, Bhosale & D, Thorat & Tanmay, Shinde & Nema, Shruti & Ospanova, A.. (2022). Power Quality Improvement Using Unified Power Quality Conditioner. International Journal of Innovative Research in Science Engineering and Technology. 11. 6555-6559. 10.15680/IJIRSET.2022.1104079.

[12] Alapati Ramadevi, Koganti Srilakshmi, Praveen Kumar Balachandran, Ilhami Colak, C. Dhanamjayulu, Baseem Khan, "Optimal Design and Performance Investigation of Artificial Neural Network Controller for Solar- and Battery-Connected Unified Power Quality Conditioner", International Journal of Energy Research, vol. 2023, Article ID 3355124, 22 pages, 2023. https://doi.org/10.1155/2023/3355124

[13] Abdel Mohsen SE, Ibrahim AM, Elbarbary ZMS, Omar AI. Unified Power Quality Conditioner Using Recent Optimization Technique: A Case Study in Cairo Airport, Egypt. Sustainability. 2023; 15(4):3710. https://doi.org/10.3390/su15043710

[14] Luo, Y., Wang, S., Yang, D., Zhou, B. and Liu, T. (2020), Direct prediction compensation strategy of unified power quality conditioner based on FCS–MPC. IET Gener. Transm. Distrib., 14: 5020-5028. https://doi.org/10.1049/iet-gtd.2020.0056

[15] Chouaib, Bousnoubra & Belila, Hassen. (2023). Power Quality Improvement Using Unified Power Quality Conditioner (UPQC).

[16] Li C, Dong Y, Fu X, Zhang Y, Du J. Optimal Scheduling of Distributed Energy System for Home Energy Management System Based on Dynamic Coyote Search Algorithm. Sustainability. 2022; 14(22):14732. https://doi.org/10.3390/su142214732

[17] Shuo Liu, Shanjin Kai, Jianlin Li, Haotian Miao, Honghao You, Xu Zhou, Research on distributed energy storage pinning coordinated control method of microgrid clusters, Energy Reports, Volume 8, 2022, Pages 10657-10664, ISSN 2352-4847, https://doi.org/10.1016/j.egyr.2022.08.178.

[18] Twaisan K, Barışçı N. Integrated Distributed Energy Resources (DER) and Microgrids: Modeling and Optimization of DERs. Electronics. 2022; 11(18):2816. https://doi.org/10.3390/electronics11182816