International Journal of Power Electronics and Drive System (IJPEDS)
Vol. 16, No. 2, June 2025, pp. 1298~1305
ISSN: 2088-8694, DOI: 10.11591/ijpeds.v16.i2.pp1298-1305

Power quality improvement in grid connected hybrid renewable energy system using UPQC

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Article Info

Article history:

Received Nov 21, 2024
Revised Apr 12, 2025
Accepted May 6, 2025

Keywords:

D-FACTS
Power quality
Renewable energy sources
Total harmonic distortion
Unified power quality conditioner

ABSTRACT

The detection and mitigation of power quality issues have become essential due to the increased interest in integrating renewable energy sources to the power system. There are various methods to mitigate the power quality issues that arise due to the integration of composite renewable sources into the current power system. Distribution flexible alternating current transmission system (D-FACTS) devices are widely used for this purpose. Unified power quality conditioner (UPQC), due to its superior performance over other conditioners, has been used in the proposed system. The primary objective of this paper is to implement the UPQC to enhance power quality in grid-integrated photovoltaic-wind system by reducing total harmonic distortion (THD). MATLAB Simulink is utilized to verify the results of the proposed system. Total harmonic distortion analysis for a grid-connected photovoltaic-wind system without and with UPQC is compared. The efficacy of UPQC in reducing THD in a grid-integrated photovoltaic-wind system is presented. THD decreases from 24.06% to 11.19% when UPQC is linked to the proposed system. To validate the implementation of the proposed system, the results are compared with already published work.

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1. INTRODUCTION

Increasing worries about the exhaustion of fossil fuels and their effects on climate change have amplified the significance of renewable energy sources. Photovoltaic and wind are the top two green energy sources in use. All these sources of renewable electricity are very volatile due to their dependency on external factors such as sunlight and wind [1]. Although renewable energy sources are currently crucial components of electricity networks, there are persistent challenges with their integration, especially discrepancies between generation capacity and load demand [2]. Despite the power quality (PQ) problems caused by these integrations, grid-interconnection of renewable energy sources is need of hours [3]. In recent years, renewable energy has started to spread to almost all countries. Switching over to renewable energy sources because of distributed generation (DG), discarding the traditional energy sources due to their insufficiencies in the form of environmental degradation, fossil fuel exhaustion, non-flexibility, ageing, and also very low energy efficiency. Based on the trends, the majority of wind and solar hybrid generating systems will meet future energy requirements [4].

In the coming decades, half of the world's energy needs will be satisfied by renewable sources. Because wind and photovoltaic systems rely on nature, their power inputs vary greatly as well. The PQ improvement in the ac-bus and constant power at the DC-link are significant problems [5]. Several distribution flexible alternating current transmission system (D-FACTS) devices with suitable control algorithms have been implemented to alleviate these PQ problems. By accurately adjusting a number of factors, including active and reactive power, impedances, and the voltage at the point of common coupling (PCC), these D-FACTS devices can enhance the dynamic behavior and dependability of the system [6], [7]. While examining the smart grid, the primary criterion is power quality, because of some active correction and quick filtration. Active power filters are therefore mostly chosen to compensate for power quality issues. Reduced power factor, high total harmonic distortion (THD) level, and power unbalance are some of the variables that must be taken into account while addressing the power quality problems. The voltage adjustment at the DC-link capacitor is crucial for achieving the optimal efficiency on a unified power quality conditioner (UPQC) [8].

Harmonics produced during the working of an induction furnace under non-linear variable load have been mitigated using UPQC and distributed static compensator (DSTATCOM) by Saggu *et al.* [9], [10]. Grid integration of renewable energy sources introduces power quality issues in the system. The implementation of DSTATCOM for improving power quality in grid-integrated wind energy systems has been proposed by Hussain *et al.* [11]. Malik *et al.* [12] implemented three-level inverters for the improvement of power quality in a hybrid photovoltaic-wind energy system. Poongothai *et al.* [13] proposed UPQC to enhance the power quality problems in grid-integrated solar power systems. Further, the power quality improvement in grid-connected solar-wind system employing genetic-based ANFIS controller is presented by Sree and Ankarao [14]. Mishra *et al.* [15] implemented the grid-connected PV system with a lymphoblastoid cell line filter for reducing power quality issues. Chapala *et al.* [16] mitigated the power quality issues in a solar-battery connected UPQC grid-integrated system. Further, power quality improvement in a grid-integrated PV system by using a series filter is presented by Hadi *et al.* [17]. The number of research papers has already been published on UPQC to improve the power quality in different kinds of systems, such as grid-connected PV systems or grid-connected wind systems alone. Considering the research gap in the reviewed literature, this paper presents the implementation of UPQC in the grid-connected hybrid photovoltaic-wind system to improve the THD level.

2. STRUCTURE OF UNIFIED POWER QUALITY CONDITIONER

A device called a UPQC fixes problems with voltage and current to enhance power quality [18]. Compensation for PQ problems with source voltage and load current is the main function of a UPQC [19]. In industrial power distribution systems, the UPQC can improve PQ at the PCC [20]. Series and shunt active power filters (APF) are combined to create UPQC. Shunt APF reduces distortions based on current, whereas series APF reduces distortions based on voltage [21]. The main components of UPQC are:

(i) Voltage source inverters (VSI), both shunt and series [22]. Through its series connection with the line, the VSI structure functions as a voltage source [23]. However, by connecting it in parallel with the load, the shunt VSI structure serves as a source of current;
(ii) Shunt inductor acts as the shunt inverter's network link; and
(iii) To establish a common DC link, a capacitor is used. By connecting the two inverters, a capacitor maintains a constant and self-sustaining DC bus voltage across them.

The transformer links a series converter in the network [24]. Figure 1 shows the block diagram of UPQC.

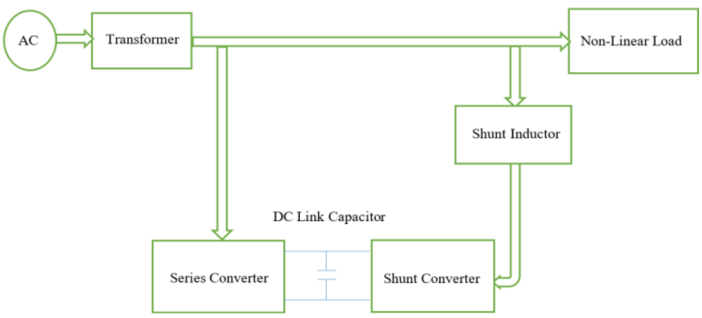

Figure 1. Block diagram of UPQC

3. WORKING OF UNIFIED POWER QUALITY CONDITIONER

The UPQC combines two converters that operate as active power filters in series and shunt, sharing a DC capacitor. When the load demands it, a shunt-connected active power filter can inject reactive current to adjust the power factor, harmonic current to rectify load current harmonics, and negative and zero-sequence components to balance supply currents. It has the capability to control the DC bus voltage. To compensate for the voltages in the source, a series active power filter injects negative and zero sequence voltages at the load bus. It also injects the required active power components to control the magnitude of load voltage and isolates the load bus from source voltage harmonics by injecting harmonic voltage [25].

4. MODELS OF PROPOSED GRID-CONNECTED HYBRID RENEWABLE ENERGY SYSTEM

The UPQC and the whole hybrid system are implemented in MATLAB/Simulink. To assess how well the UPQC performs in reducing power quality problems, two scenarios are simulated: (i) a grid-connected hybrid renewable energy system without UPQC and (ii) a grid-connected hybrid renewable energy system with UPQC. To ascertain the THD values, the proposed grid-connected hybrid renewable energy distributed system has been modelled both with and without UPQC. In order to feed power into the grid, an integrated PV-wind system has been used. A boost converter is then utilized to maintain DC voltages. Moreover, an inverter is used to transform DC input into AC so that it may be sent to the grid. The Simulink models of the grid-connected hybrid PV-wind system without UPQC and with UPQC are shown in Figures 2 and 3, respectively. The internal structure or subsystems of UPQC are depicted in Figures 4 and 5. Simulation parameters used for the proposed system are given in Table 1 [26].

Table 1. Simulation parameters

Sr. No.	Description	Parameters	Values
1.	Wind Turbine	Base torque (Nm)	8000
		Mechanical output power (kW)	75
		The base-power-electrical generator (kW/pf)	75/0.9
		Base speed of wind (m/s)	10
2.	Photovoltaic	Irradiance	950
		Real power generated (kW)	30
3.	Connected Grid	System phase voltage (V)	440
		System frequency (Hz)	50
4.	Non-linear Load	Nominal system voltage (V)	440

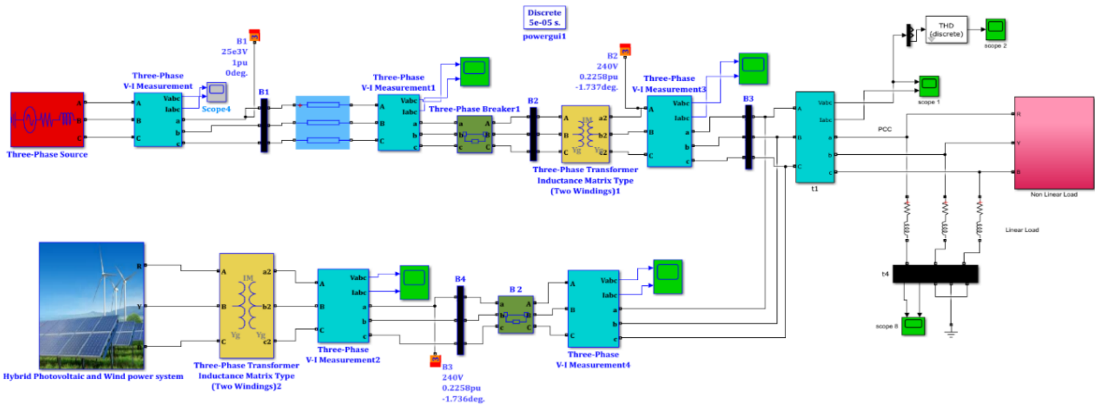

Figure 2. Simulink model of a grid-connected hybrid renewable energy system without UPQC

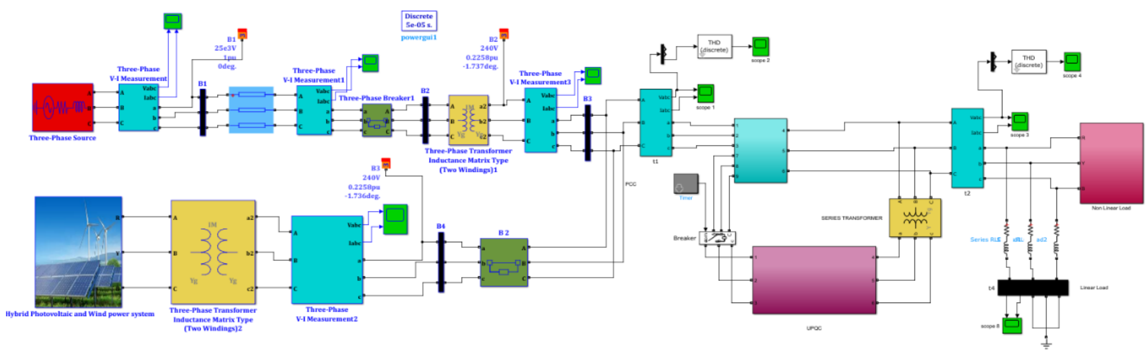

Figure 3. Simulink model of grid-connected hybrid renewable energy system with UPQC

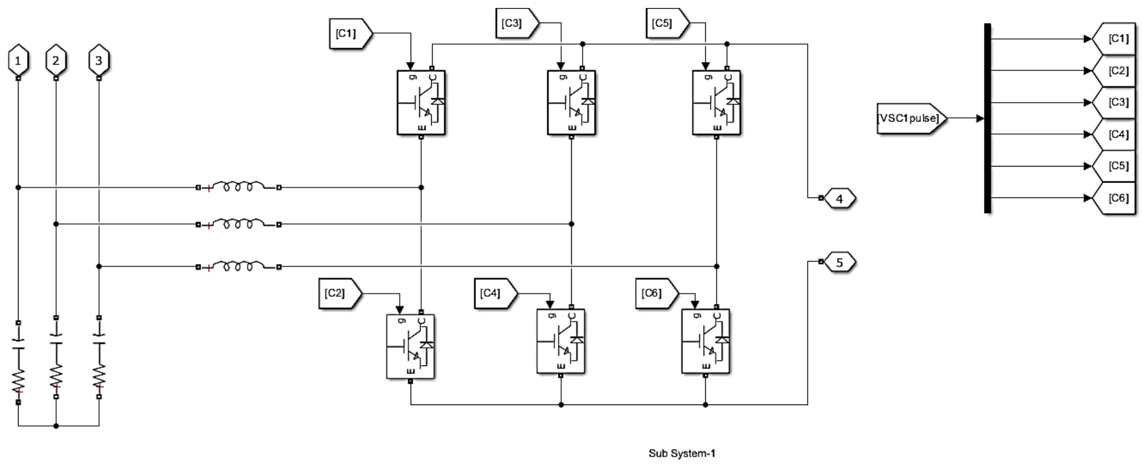

Figure 4. Sub-system 1 of UPQC

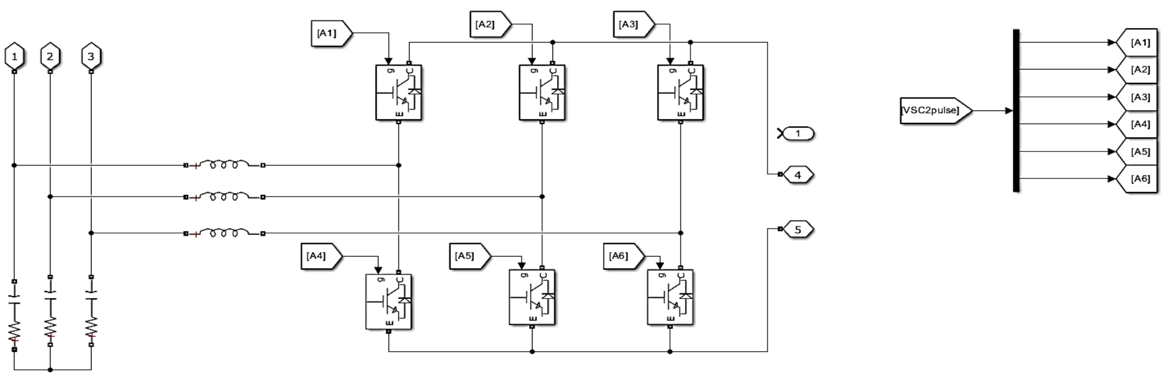

Figure 5. Sub-system 2 of UPQC

5. RESULTS AND DISCUSSION

Prior to UPQC integration, the first set of THD measurements was obtained. Due to the non-linear nature of the solar and wind energy sources, harmonics were introduced into the system. Figures 6 and 7 (see Appendix) depict the THD measurements and load voltage and current waveforms of the proposed system without UPQC. The THD levels were re-measured under the same operating conditions following the integration of the UPQC into the system. Figures 8 and 9 (see Appendix) represent the THD measurements and load current and voltage waveforms of the proposed system with UPQC. In all the figures, time is represented on the x-axis and the magnitude of respective parameters is represented on the y-axis. The outcomes of both scenarios, in which grid-connected hybrid PV-Wind systems without and with UPQC are considered. The comparison of results depicts the reduction of THD from 24.06 % to 11.19 %. For further validation, the obtained results are also compared with [26], which shows the reduction of THD from 25 % to 13 % for UPQC integrated hybrid solar-wind systems for 11th order harmonics.

6. CONCLUSION

In grid-integrated wind and solar distributed energy systems, the use of UPQC has been implemented. This work focuses on the design, simulation, and analysis of the performance of UPQC in mitigating power quality problems in terms of THD. It is evident from the results that the overall THD decreases from 24.06 % to 11.19 % when UPQC is linked to the grid-integrated wind and solar renewable energy system. Further, the results are compared with the already published work, which depicts the improved performance of UPQC in integrated hybrid solar-wind systems and validates the novelty of the proposed research paper. Further, the research can be performed on the implementation of UPQC with hybrid optimization techniques in hybrid solar/wind/battery/fuel cells or any other suitable combinations of renewable energy systems.

ACKNOWLEDGMENTS

The authors are indebted to the I.K.G. Punjab Technical University Jalandhar, Kapurthala for providing the advanced research facilities for this research work.

FUNDING INFORMATION

Authors state no funding involved.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Manpreet Singh	✓	✓	✓	✓	✓	✓			✓	✓				
Lakhwinder Singh		✓			✓	✓			✓	✓	✓	✓		

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest to declare.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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APPENDIX

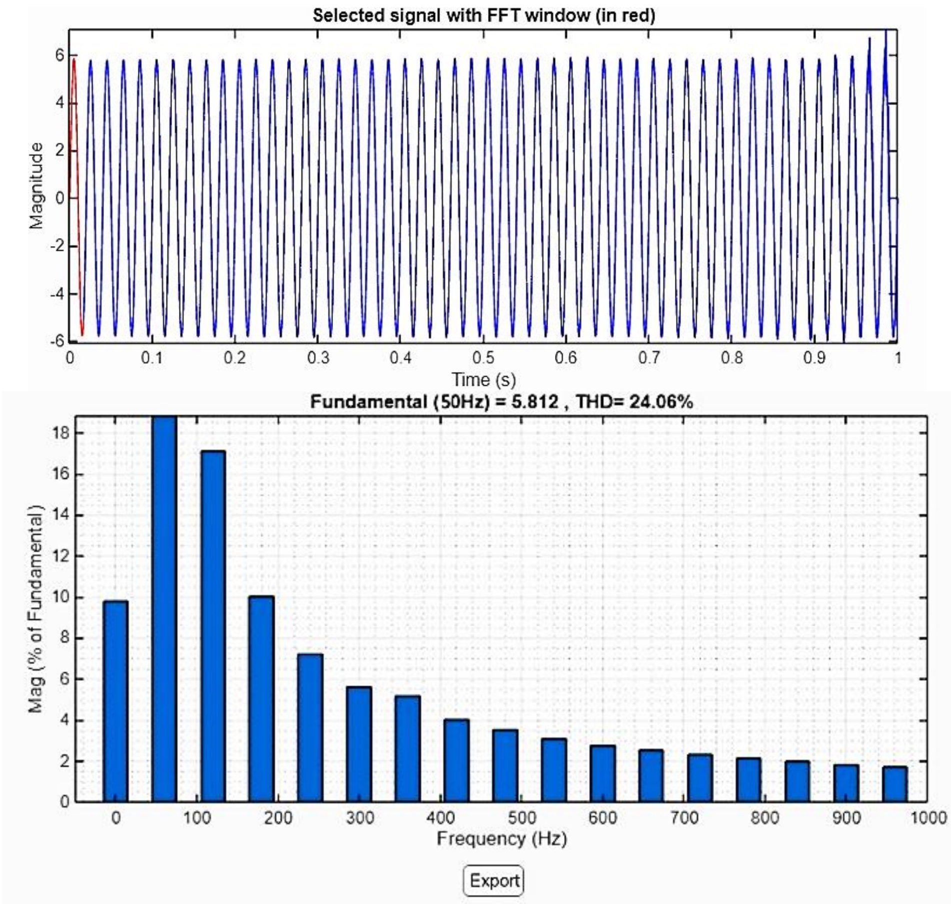

Figure 6. THD measurements of a grid-connected hybrid renewable energy system without UPQC

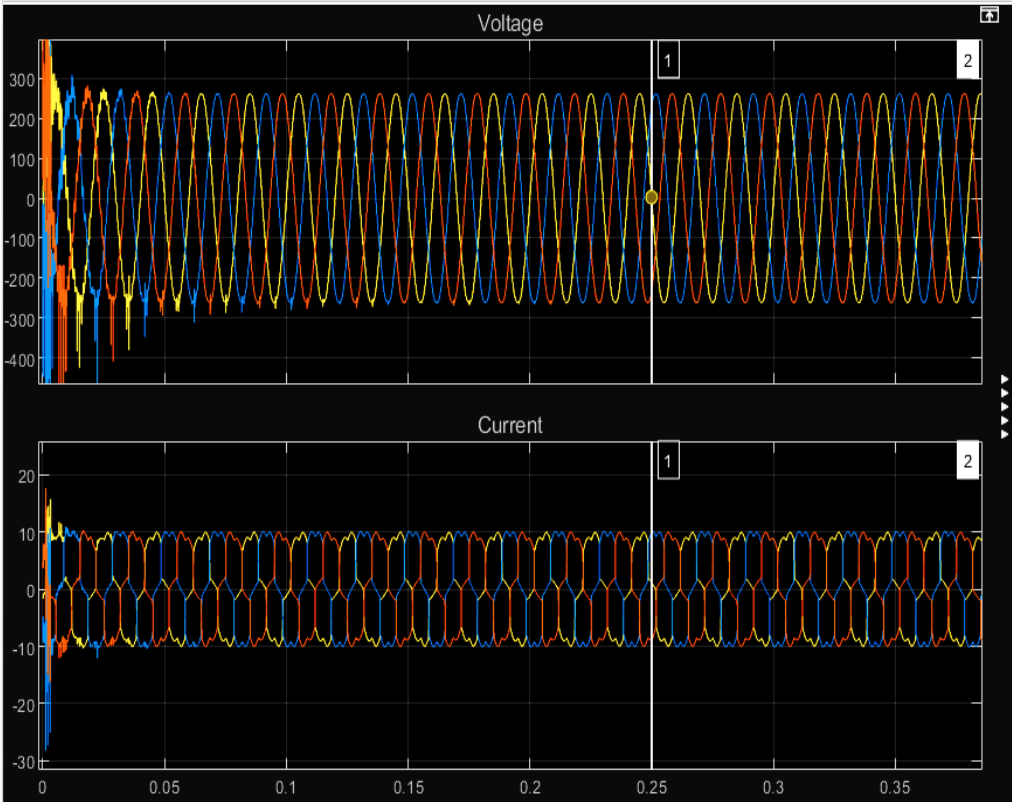

Figure 7. Load voltage and current waveforms (magnitude versus time) for a grid-connected hybrid renewable energy system without UPQC

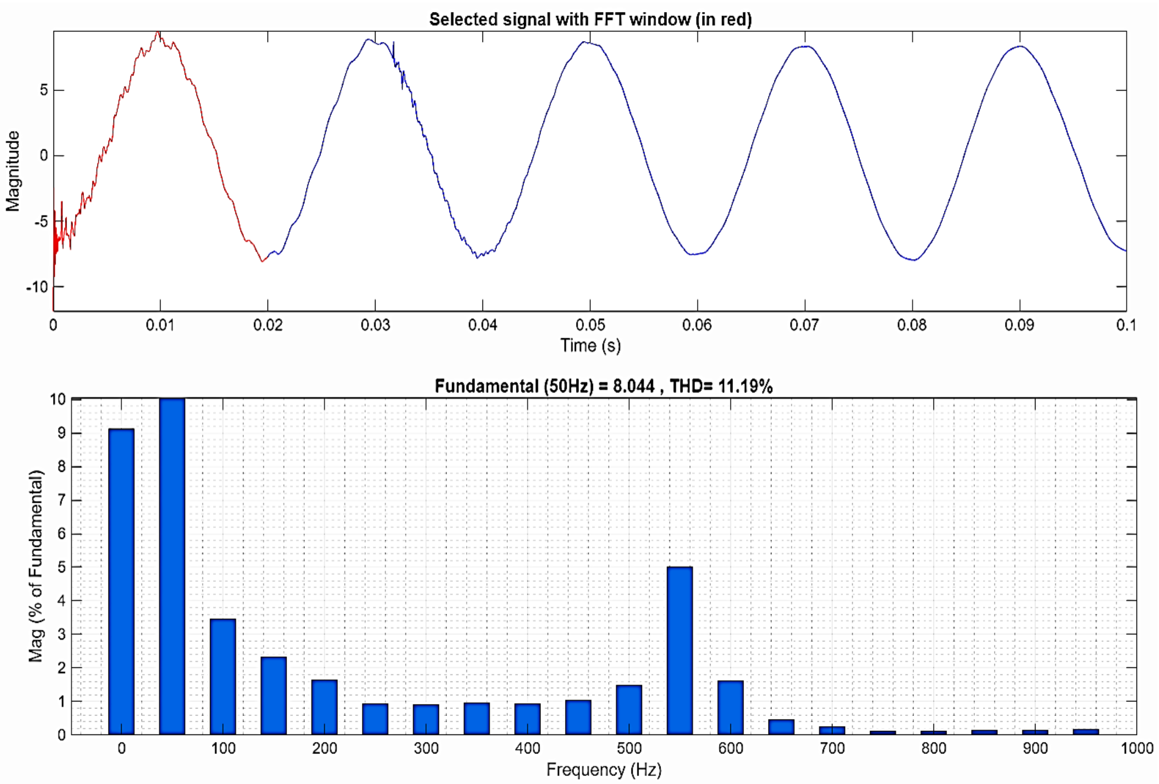

Figure 8. THD measurements of grid-connected hybrid renewable energy system with UPQC

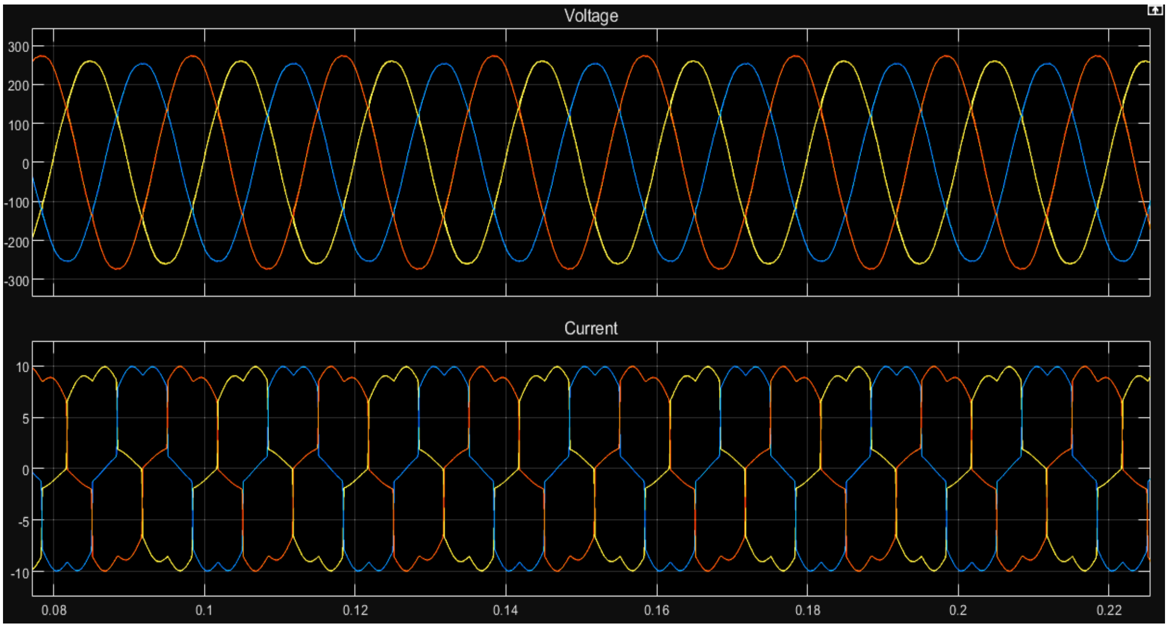

Figure 9. Load voltage and current waveforms (magnitude versus time) of grid-connected hybrid renewable energy system with UPQC

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