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Research Article

Radiation Shielding Properties of Barite Coated Terry-Cotton Fabric Enhancing the Quality and Stability of Solar Photovoltaic (PV) Energy Integrated into Electrical Networks through an Advanced Active Filtering Technique

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Abstract:

This study proposes a dynamic filtering based framework aimed at improving the performance and reliability of power grid control systems. To achieve this, several distortion identification techniques are first examined to determine the most efficient method for real-time operation. The selected dynamic filter is subsequently incorporated into a photovoltaic generator (PVG) to support the delivery of high quality electrical energy and to optimize power flow supervision. The obtained results confirm that integrating renewable generation with intelligent energy management significantly enhances grid stability, control accuracy, and overall system efficiency.

1. Introduction

The global pursuit of cleaner energy has accelerated the adoption of renewable technologies, with solar power emerging as one of the most promising options. Among various systems, photovoltaic generators (PVGs) have become increasingly popular thanks to their flexible scalability, environmental advantages, and continuously decreasing installation costs [1]. Driven by international policies aiming to curb green house gas emissions and dependence on fossil fuels, major investments are being directed toward solar power infrastructure by governments and energy providers world wide. Despite these benefits, integrating PVGs into conventional electrical grids introduces new operational and technical concerns [2]. Unlike traditional synchronous generators, PVGs rely on power electronic interfaces primarily. Inverters that can inject distorted currents into the network, there by generating harmonic disturbances [3]. Such harmonics impair power quality, reduce power factor, and can lead to increase losses and overheating in electrical equipment [4]. They may also accelerate component wear and cause mal functions in sensitive electronic devices such as communication or medical systems [5]. As PVG penetration continues to rise, the magnitude of these disturbances becomes more critical.

To sustain reliable and high quality power delivery, advanced mitigation strategies must be deployed. A particularly effective method involves the use of Shunt Active Power Filters (SAPFs) [6], which detect and compensate harmonic currents in real time by injecting inverse current components into the grid. The overall performance of these systems, however, relies strongly on the precision and rapid response of the harmonic detection algorithms applied [7].

This work introduces a hybrid configuration that integrates a photovoltaic generator (PVG) with a shunt active power filter (SAPF) governed by an adaptive harmonic detection mechanism. The proposed design aims to ensure high quality power delivery to the electrical grid while promoting the generation of clean and sustainable energy [6]. By merging real-time harmonic compensation with renewable power production, the system contributes to ongoing efforts toward energy transition achieving environmental sustainability without compromising grid efficiency or reliability. The main objectives of this approach are twin: to mitigate harmonic distortion injected into the grid and to provide instantaneous active and reactive power support. PV installations have become a dominant component of decentralized power generation [1], yet their interfacing through power electronic converters such as inverters and rectifiers frequently introduces unwanted harmonics [1], [4]. To overcome this limitation, Our study proposes an active filtering system coupled to a PVG and equipped with an intelligent control algorithm capable of performing harmonic mitigation and reactive power compensation simultaneously within the distribution network.

2. Harmonics and compensation techniques

2.1 Origin of harmonics in electrical networks

Ideally, an electrical network should deliver voltage and current waveforms that are perfectly sinusoidal. In practice, the increasing presence of nonlinear equipment such as photovoltaic inverters, variable speed drives, and various switching converters distorts these waveforms by generating harmonic components within the grid current [3], [5]. These harmonics, which are multiples of the system's fundamental frequency (50 Hz or 60 Hz depending on regional standards), can negatively affect the network's operation. They may produce resonance with grid impedances, cause overvoltages, lead to overheating of transformers and conductors, and disturb the performance of automation or communication devices. Additionally, they deteriorate the power factor [8], [9], resulting in higher power losses and reduced efficiency.

The Total Harmonic Distortion (THD) index is commonly used to quantify such waveform distortion. It expresses the degree to which current or voltage deviates from its ideal sinusoidal form, providing a key metric for evaluating power quality and harmonic contamination levels in electrical systems [7].

$$THD(\%) = \frac{I_h}{I} \quad (1)$$

In equation (1), I and I_h represent the source current and the harmonic component load current successively.

2.2 Harmonic identification technique

The first step in any harmonic compensation strategy is to correctly identify the harmonic components within the system. Several reliable techniques can be used for this purpose [10]. One of the most common is the Fast Fourier Transform (FFT)**,** which provides an accurate spectral analysis for signals that remain steady over time. However, its accuracy decreases when the system experiences sudden changes or non-stationary conditions [4].
Another effective approach is the Phase-Locked Loop (PLL) method. This dynamic technique tracks the fundamental frequency of the signal in real time, allowing it to isolate harmonic distortions even when the system's operating conditions fluctuate [6].

A. Passive filters

Passive filters are built using tuned LC components designed to suppress specific harmonic frequencies within the system. They are appreciated for their simplicity**,** low implementation cost**,** and reliability. However, their main drawbacks lie in their limited adaptability to load variations and the potential occurrence of resonance with the network impedance, which can negatively affect system stability [4], [6].

B. Active Filters

Active filters operate using a controlled power inverter that injects a compensating current into the electrical system. In addition to correcting reactive power**,** these filters can simultaneously suppress multiple harmonic components**.** Compared to passive filters, they offer greater flexibility**,** dynamic response**,** and improved overall performance**,** although they come at a higher cost and system complexity [8], [9].Among the different configurations, the shunt active power filter (SAPF) is the most widely used for harmonic current mitigation [10], [13]. It functions by generating a current waveform that counteracts the harmonic components present in the system, connecting in parallel at the Point of Common Coupling (PCC) to achieve real-time compensation [10].

3. Modelling of the GVP system with active filter

3.1 Photovoltaic generator architecture

A photovoltaic generator (PVG) converts sunlight into direct current (DC) electricity through photovoltaic (PV) panels that are usually connected in a mix of series and parallel arrangements. To draw the maximum possible energy from the available solar radiation, the output power passes through a DC–DC converter**,** often a Boost converter, managed by a Maximum Power Point Tracking (MPPT) algorithm [1]. The regulated DC voltage is then converted into alternating current (AC) using an inverter, which ensures proper synchronization with the utility grid [1], [4]. Figure 1 shows a basic representation of a typical photovoltaic generator setup.

3.2 Connection to low-voltage distribution network

The Point of Common Coupling (PCC) is the junction where the photovoltaic generator (PVG) connects to the low-voltage, three-phase distribution network. It is at this point that harmonic distortions usually begin to appear, mainly due to the switching actions of the inverter. To detect and minimize these unwanted effects, a shunt active power filter (SAPF) is placed in parallel with the PCC [1], [13], as shown in Figure 1.

The shunt active power filter (SAPF) is mainly composed of the following key elements:

- A three-phase bidirectional inverter (figure 2) built with IGBT switches, responsible for generating the compensating current injected into the grid.
- A coupling inductance, which links the inverter to the electrical network and ensures smooth current flow while reducing switching ripples.
- A DC-link capacitor, serving as an energy storage element that facilitates the exchange of power between the inverter and the grid during the compensation process.

- The PCC has a current sensor to measure the harmonics that need to be adjusted.

The harmonic component of the load current, denoted as I_h is identified and then compensated by the shunt active power filter. The filter injects an equal but opposite current into the system.

where $\boldsymbol{I_f}$ represents the compensating current generated by the filter.

$$I_f = I_h \qquad (1)$$

As a result, the total current drawn from the source becomes nearly sinusoidal, significantly improving the overall power quality.

3.3 control strategy of the active power filter

The effectiveness of the shunt active power filter depends greatly on the control strategy applied. In this work, we use a closed-loop control approach that relies on the Clarke transformation to detect harmonics and to generate the reference compensating current to be injected into the system. This transformation is particularly well suited for three-phase systems because it is simple to implement and computationally efficient [3, 4].

The inverter switches are operated using either hysteresis control or pulse-width modulation (PWM). These control methods allow the system to respond quickly and to follow reference signals accurately, even when the network experiences disturbances or load variations [3].

4. Application in active power filtering

4.1 Instantaneous active power

Equation (2) represents the active power transferred between source and load.

$$P(t)=v_\alpha . i_\alpha + v_\beta . i_\beta \qquad (2)$$

- v_α, v_β, i_α and i_β repesent voltage and current's com pounds in Clarke referential.

The shunt active power filter (SAPF) [6], [9] works by calculating the instantaneous active p and reactive q power of the load. Through this analysis, the filter can detect the unwanted components of the power mainly the oscillating parts of p and q and then generate compensating currents to cancel them.
The method used to compute p and q is presented in Equation (3).

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ V_\beta & -V_\alpha \end{bmatrix} \times \begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} \qquad (3)$$

An active power filter (SAPF), generates and injects compensation currents to disprove undesired components in the load current, including: harmonics currents, reactive currents, unbalanced components.

The goal is to make the source current drawn from the grid, sinusoidal in phase with the source voltage, free of harmonics and non-active components, mathematical expression.

$$i_s = i_{load} - i_f \qquad (4)$$

Where: i_{load} is the total load current, i_s represents the source current and i_f is the compensation current injected by the filter.

If the compensation is ideal then: $i_s = i_1$

i_1 is the fundamental active component of the load current.

4.2 characteristics of compensation currents

Their accuracy and response time are highly dependent on the control strategy and current sensing quality. They are dynamically modified in real time, depending on the load conditions [5]. They are non-sinusoidal, reflecting the harmonics and reactive components present in the load. The index c indicates charge or load.

$$\begin{bmatrix} I_{c\alpha} \\ I_{c\beta} \end{bmatrix} = \frac{1}{V_\alpha^2 + V_\beta^2} \times \begin{bmatrix} V_\alpha & V_\beta \\ V_\beta & -V_\alpha \end{bmatrix} \times \begin{bmatrix} p_c \\ q_c \end{bmatrix}$$

4.3 Proposed compensation strategy

We suggest implementing a Shunt Active Power Filter (SAPF) that is connected to the grid via a coupling inductor in order to preserve excellent power quality at the Point of Common Coupling (PCC) and effectively compensate for the harmonic currents introduced by nonlinear loads [10].

- Two key creeds form the foundation of the chosen control strategy:
- The dynamic identification of the harmonic components of the load current
- The generation and injection of an appropriate compensating current
- The generation and injection of a compensating current, controlled by an inverter operating in PWM mode (Figure 2) [11].

4.4 Inventer control (PWM Modulation)

Sinusoidal PWM, or pulse width modulation, is used to precisely control the injected waveform and a fixed switching frequency in the three-phase inverter that injects the compensatory current i_f. This lowers losses and makes filtering easier.
In order to ensure quick and reliable compensation, a regulation loop modifies the injected current in real-time based on the difference between the measured i_f and its reference value.

4.5 Kaximum power tracking (MPPT)

The PV system is combined by an MPPT controller that maximizes power extraction from the solar generator by utilizing a DC-DC converter.The operating point is continuously adjusted by the MPPT controller to match the Maximum Power Point which varies in response to temperature variations and sun irradiation at maximal position k.

$$P_{pv}(k)=V_{pv}(k)\times I_{pv}(k) \qquad (6)$$

The control technique used in our case is disturbance and observation (P&O). This is the most widely used PPM tracking algorithm. As its name suggests, it is based on disturbing the system by increasing or decreasing V reference (V_{ref}) or by directly acting on the duty cycle of the DC-DC converter, and then observing the effects of these disturbances on the panel output power [1, 3]. If the value of the current power P(k) of the panel is greater than the previous value P(k-1) then the same direction of the previous disturbance is kept, otherwise the disturbance of the previous cycle is reversed [1]. DC-DC converter (figure 3) is controlled to dynamically adjust the operating point along the I-V curve of the solar panels. The MPPT controller measures the voltage V_{pv}_and current I_{pv}_of the PV generator and adjusts its operation to maximize the output power:

$$P_{pv}=V_{pv}\times I_{pv} \qquad (7)$$

By continuously monitoring these parameters, the controller shifts the duty cycle of the converter to track the Maximum Power Point in real time, adapting to changing environmental conditions such as sunlight and temperature.

The output current of a photovoltaic cell is expressed in the following mathematical form :

$$I_{pv} = I_{ph} - I_d - I_p \qquad (8)$$

$$I_{pv} = I_{ph} - I_0\left(e^{\frac{V_d}{nV_t}} - 1\right) - \frac{V_d}{R_p} \qquad (9)$$

$$I_{pv} = I_{ph} - I_0\left(e^{\frac{V_{pv}+R_sI_{pv}}{nV_t}} - 1\right) - \frac{V_{pv}+R_sI_{pv}}{R_s}$$
(10)

I_{pv}: Current generated by the photovoltaic cell;

I_{ph}: Photocurrent created by the cell (proportional to the incident radiation);

I_d: Current flowing through the diode.

$$I_d = I_0\left(e^{\frac{V_d}{V_t}} - 1\right) \qquad (11)$$

Figure 4 represents a model of basic block diagram of boost chopper. It is a direct DC-DC converter. The input source is of the direct current type (inductor in series with a voltage source) and the output load is of the direct voltage type (capacitor in parallel with the resistive load). The switch K can be replaced by a transistor since the current is always positive and the switching operations must be controlled (at blocking and at starting). Its typical application is to convert its input voltage into a higher output voltage [10].

$$V_L(t) = L\frac{dIL(t)}{dt} \quad (12)$$

$$V_L(t) = V_i(t) - V_0(t) \quad (13)$$

BOOST chopper parameters:

- Inductance: L = $3.5\times1e^{-3}$ H;
- IGBT is a power diode;
- Capacitance $C_1 = 20\times10$^(-6) F, $C_2 = 100\times1e^{-6}$ F
- Resistive load R = 70 Ohms.

5. Simulation results and Discussion

The photovoltaic compensation system consists of a GPV, a BOOST chopper and a parallel active filter that ensures the connection to the grid. The latter supplies a non-linear load figure 5. The suggested compensation system acts as a reactive compensator in case of low illumination, and as a shunt active filter that actually injects power into the electrical grid produced by the photovoltaic conversion chain in case of high illumination. The photovoltaic module (BP MSX-60) [9]. It contains (36) multi-crystalline silicon solar cells, and provides a maximum nominal power of 60W. The physical and electrical characteristics of this photovoltaic panel are given in the table 1. Figure 6 describes variation of current and power of PV vs voltage at various values of temperature. In figure 7 it is seen the variation of current and power of PV vs voltage at various values of irradiation.

5.1 Simulation of the system before the introduction of the photovoltaic compensation system

The waveforms of the three-phase source current and the current consumed by the nonlinear load, as well as the active and reactive powers of the three-phase source, are shown in Figure 8 and Figure 9 before the introduction of the photovoltaic compensation system.At the beginning of the system, there is no SAPF, the load uses an active power of 300W (figure 9), the source currents are the same as those of the non-linear load ($is=i_{load}$=3.8A) and a THDi of 26.12% (figure 10).

5.2 Simulation of the system before the activtion of the photovoltaic compensation device

Figures 11 and 12 show that the SAPF operates, and produces currents i_f after a transient of t=0.04s, making the source currents sinusoidal, the active power between the value 240w and the value 320w (figure 11) while the reactive energy continues to oscillate around zero. Therefore, the harmonic distortion rate of the source current is improved and is worth THDi= 2.18% (figure 13).This rewording offers more information about the function of the active filter, the dynamics of the system both before and after the filter was added, and the effects on distortion rate and energy quality.Prior to correction, the current's Total Harmonic Distortion (THD) was above 22% (figure 10), which is much higher than the IEEE 519 standard's upper bounds. Following Active Power Filter activation, THD (post-compensation) equals 2.18% (figure 13) which is permissible under IEEE 519.

5.3. Photovoltaic Energy Injection

PV system injected an average power of 1.5 kW during periods of maximum sunlight. Figure 7 shows the real-time tracking of the Maximum Power Point (MPPT). The strategy of dual inverter usage (filtering + injection) has led to a significant reduction in the system's cost.Turning on the shunt active filter in this setup allows one to introduce compensating currents (i_f) into the system. After a brief transition period of 0. 04 seconds, as shown in the accompanying figure (Figure 11), the source currents start to resemble sine waves. The active filter creates a compensatory current to oppose the harmonics in the source current, therefore explaining this. This adjustment improves the form of the source current quite a lot. As a result, the Total Harmonic Distortion (THDi) of the source current is 2.18%, as shown in the attached figure 13. This demonstrates a notable increase in power quality, hence confirming the efficacy of the active filter's PWM modulating control for minimizing harmonics. The active filter's capacity to reduce the major harmonic components and at the same time improve the waveform of the source currents suggests that it aided grid stability in addition to decreasing them. This result shows how the chosen control method manages nonlinear load-induced perturbations effectively, and it also emphasizes how the hybrid system might maximize power quality in trying circumstances [11-13]. In this rephrasing one may learn more about the goal of the active filter, the system's behavior before and after it was installed, and the effect on the distortion rate and energy quality. This reduction in harmonic distortion shows how well the active filter improves power quality and ensures that standards are encountered.

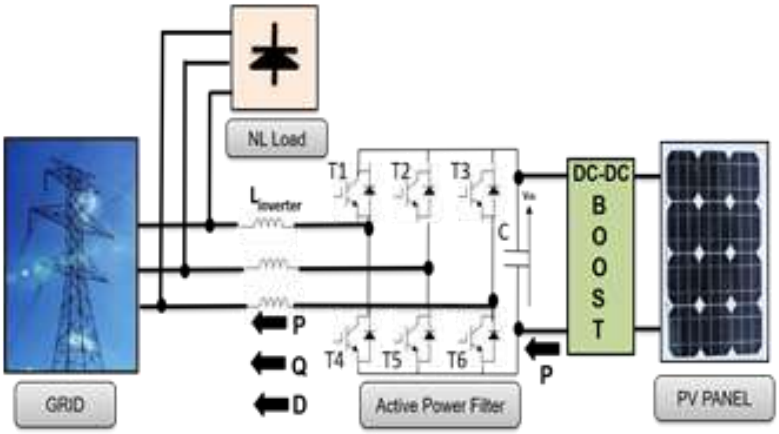

Figure 1. *Photovoltaic generator architecture*

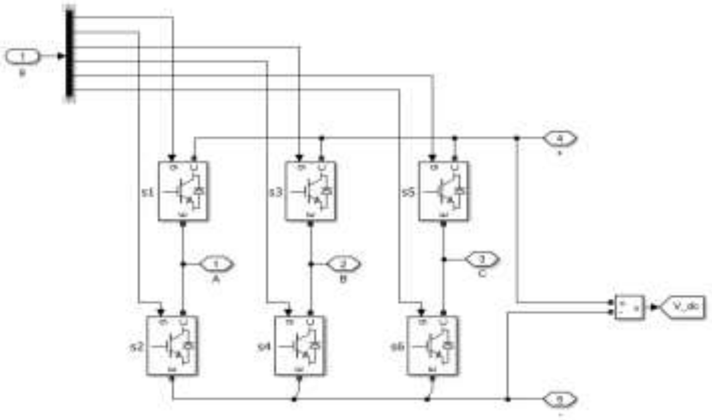

Figure 2. *Inverter simulation diagram*

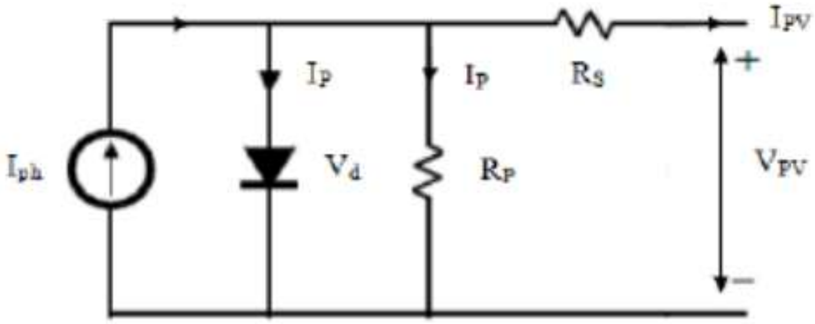

***Figure** 3. Equivalent circuit of a photovoltaic Cell*

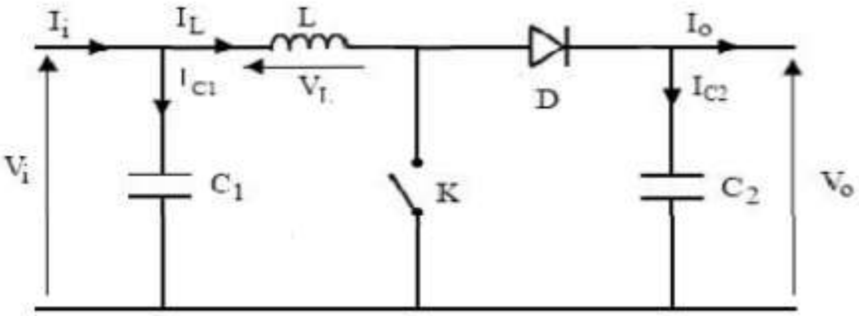

Figure 4. *Model of a boost chopper*

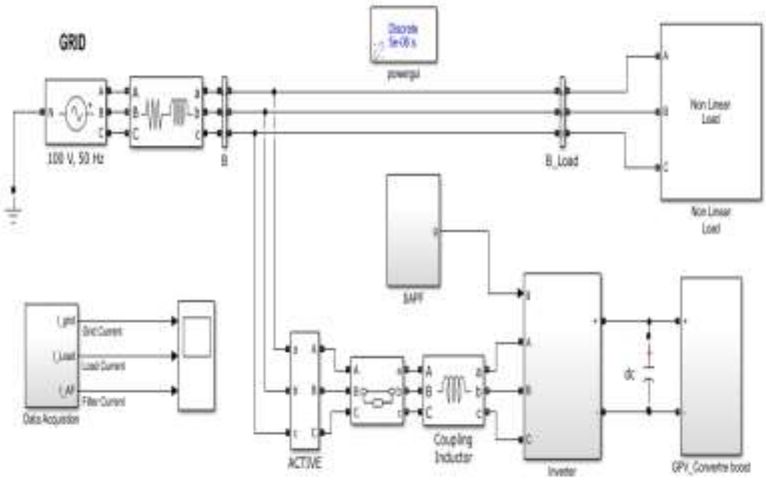

Figure 5. *Simulation Model of the Photovoltaic Compensation System*

Table 1*: Physical and electrical characteristics of the PV generator chosen for modeling and simulation.*

Physical characteristics	**BP MSX-60**
Number of cells in series (Ns) Number of cells in parallel (Np)	N_s = 36 N_p = 1
Electrical characteristics (STC)	Ga=1000w/m^2, 25°C, AM 1.5
Maximum Power (P_{max}) Peak Point Voltage (V_{mpp}) Peak Point Current (I_{mpp}) Open Circuit Voltage (V_{oc}) Short Circuit Current (I_{sc})	60 W 17.1 Volt 3.5 A 21.1 Volt 3.8 A

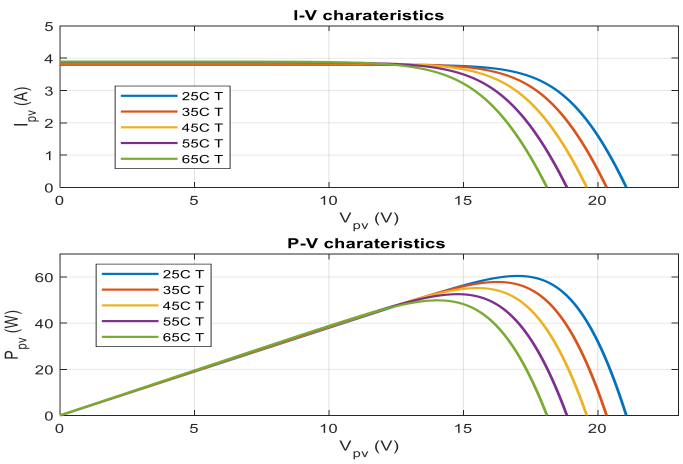

Figure 6. *Variation of current and power of PV vs voltage at various values of temperature*

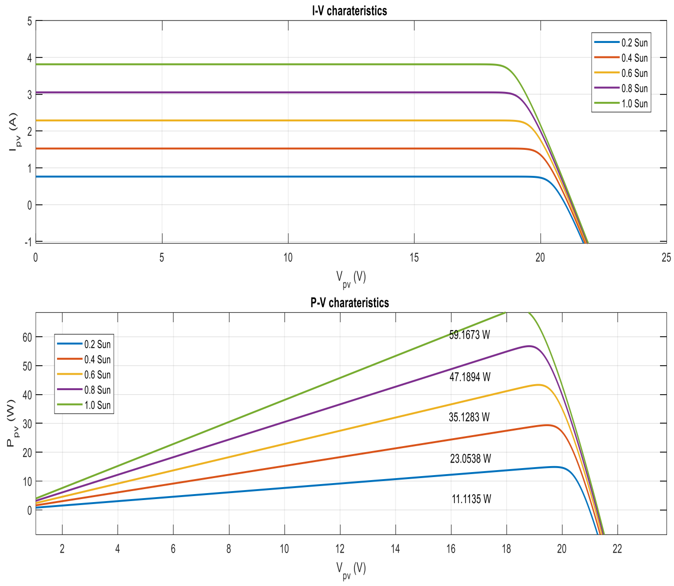

Figure 7. *Variation of current and power of PV vs voltage at various values of irradiation.*

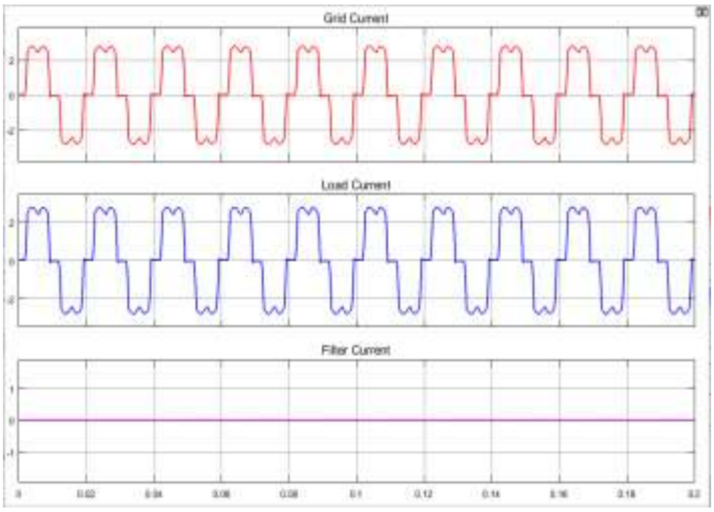

Figure 8. *Illustrates the temporal evolution of the line current before compensation,*

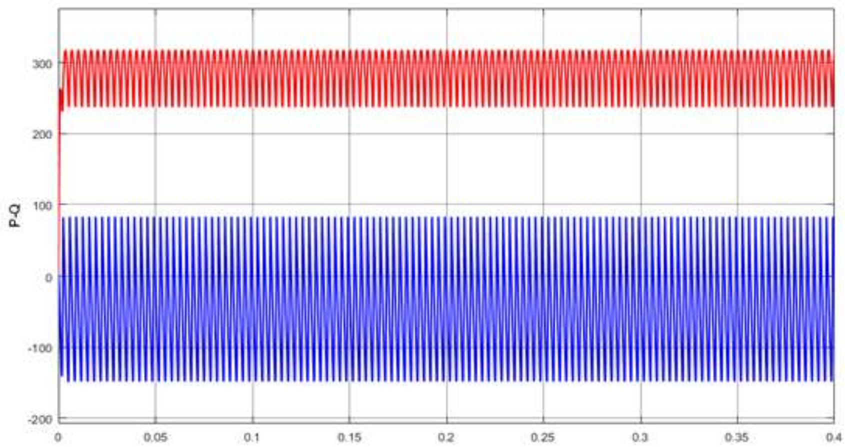

Figure 9: *Active and reactive power characteristic.*

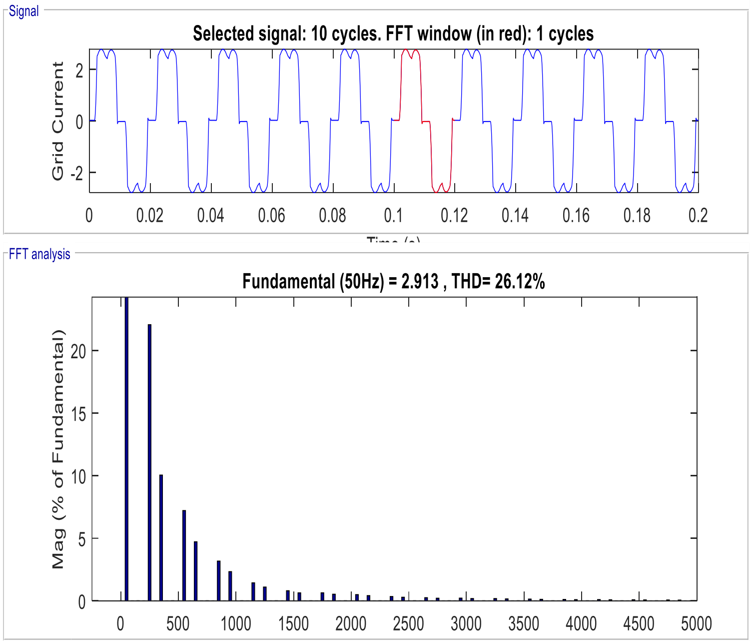

Figure 10. *Spectral analysis of the source current before accouplement of the SAPF.*

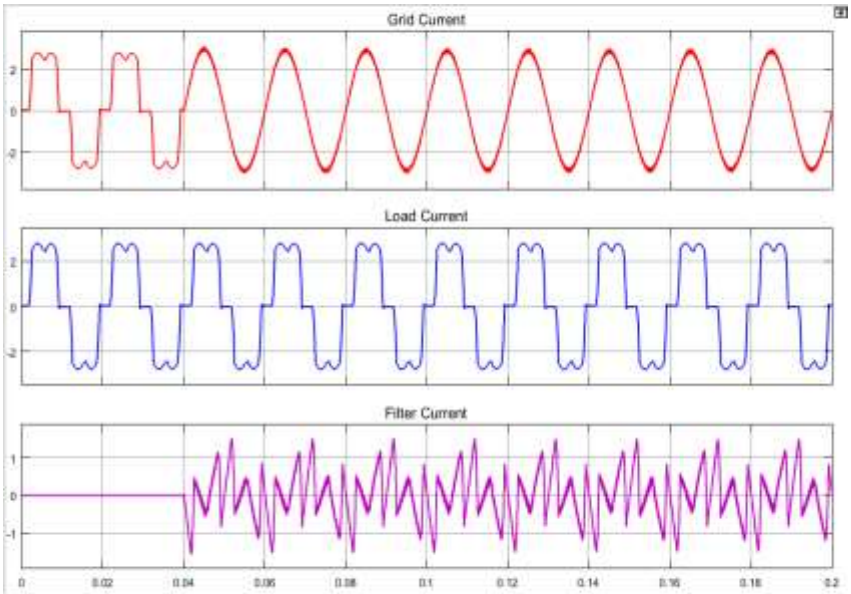

Figure 11. *Source current and load current and filter current (SAPF integrated) for non-linear load*

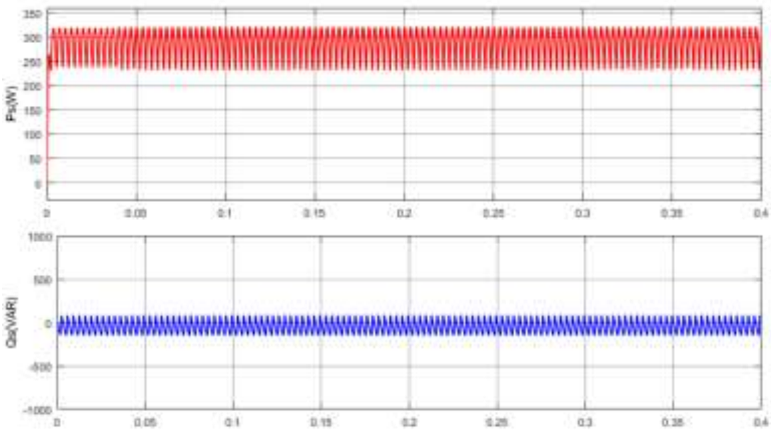

Figure 12. *Instantaneous power figures after SAPF commissioning*

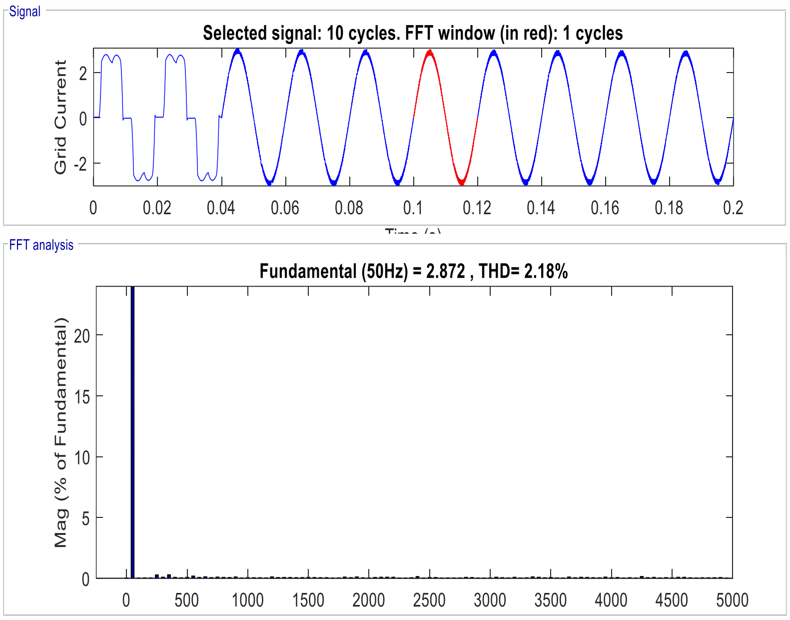

Figure 13: *Spectral analysis of signals after SAPF commissioning: source current*

6. Conclusions

This study demonstrates the strategic value of a hybrid design that improves power quality in distribution networks by integrating a solar generator with an active filter. This method is innovative because the inverter simultaneously manages reactive power. Disturbances and harmonics are corrected during the injection of renewable energy.

Simulation results from numerous tests confirm that this technology stabilizes network operating conditions and maintains harmonic distortion levels within acceptable limits.

This work offers promising prospects for the implementation of smart and sustainable solutions at a time when the energy transition and the development of electrical infrastructure are major challenges.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

References

[1] Y. Tang, S. Sun, B. Zhao, C. Ni, L. Che, and J. Li, *"Distributed Photovoltaic Generation Aggregation Approach Considering Distribution Network Topology,"* Energies, vol. 17, no. 12, article 2990, Jun. 2024.

[2] M. M. Abdusalam, *"Structures and control strategies of parallel and hybrid active filters with experimental validations,"* Ph.D. dissertation, Univ. Henri Poincaré – Nancy 1, Nancy, France, NNT: 2008NAN10016, 2008.

[3] D. K. Dash and P. K. Sadhu, "A Review on the Use of Active Power Filter for Grid-Connected Renewable Energy Conversion Systems," *Processes*, vol. 11, no. 5, Art. no. 1467, May 2023.

[4] S. Srimatha, B. Mallala, and J. Upendar, "A Novel ANFIS-Controlled Customized UPQC Device for Power Quality Enhancement," *Journal of Electrical Systems and Information Technology*, vol. 10, Art. no. 55, Nov. 2023.

[5] M. H. J. Bollen and I. Y. H. Gu, *Signal Processing of Power Quality Disturbances*, Wiley-IEEE Press, 1st ed., Aug. 2006.

[6] Y. Wang, J. Tang, J. Si, D. Tang, "Power quality enhancement in islanded microgrids via closed-loop adaptive virtual impedance control," *Protection and Control of Modern Power Systems*, vol. 8, Art. no. 10, Mar. 2023.

[7] G. J. Wakileh, *Power Systems Harmonics: Fundamentals, Analysis and Filter Design*, Springer-Verlag Berlin Heidelberg, 2010.

[8] E.-H. Mayoral, M. Madrigal-Martínez, J. D. Mina-Antonio, R. Iracheta-Cortez, J. A. Enríquez-Santiago, O. Rodríguez-Rivera, G. Martínez-Reyes, and E. Mendoza-Santos, "A Comprehensive Review on Power-Quality Issues, Optimization Techniques, and Control Strategies of Microgrid Based on Renewable Energy Sources," *Sustainability*, vol. 15, no. 12, art. no. 9847, 2023.

[9] **A.** S. Alhattab, A. N. Alsammak, and H. A. Mohammed**,** "A Review on D-STATCOM for Power Quality Enhancement," *Al-Rafidain Engineering Journal*, vol. 28, no. 1, pp. 207-218, Mar. 2023.

[10] J. He, Y.W. Li, "An Enhanced Microgrid Load Demand Sharing Strategy," *IEEE Trans. Power Electron.*, 2011.

[11] R. Teodorescu, F. Blaabjerg, M. Liserre, *Control of Power Inverters in Renewable Energy and Smart Grid Integration*, Wiley, 2011.

[12] D. K. Dash and P. K. Sadhu, "A Review on the Use of Active Power Filter for Grid-Connected Renewable Energy Conversion Systems," *Processes*, vol. 11, no. 5, Art. no. 1467, May 2023

[13] S. Bhattacharya, D.M. Divan, "Synchronous Frame Harmonic Isolator Using Active Series Filter," *Proc. PESC*, 1993.