The Eurasia Proceedings of Science, Technology, Engineering and Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering and Mathematics (EPSTEM), 2026

Volume 40, Pages 54-65

ICBAST 2026: International Conference on Basic Sciences and Technology

Analyzing Energy Quality in the Integration of Renewable Sources into Algeria's Remote Southwest Network

Dehini Rachid
University of Bechar - Tahri Mohamed

Benchikh Lehocine Iftikhar
University of Bechar - Tahri Mohamed

Glaoui Hachemi
University of Bechar - Tahri Mohamed

Bediar Samira
University of Bechar - Tahri Mohamed

Abstract: Independent electricity grids with multiple renewable energy sources face several challenges in ensuring the quality of electricity. This type of network offers the benefits of reliability, efficiency and sustainability. However, the management of such networks requires producers or distributors to deal with issues such as the consequences of the pollution of harmonic currents, the change of renewable energy sources, the challenges of connectivity, and cybersecurity risks. This work examines the consequences of the flow of harmonic currents in an independent, multi-source grid of energy in the far south-west of Algeria (Tindouf area). This research also focuses on understanding the effect of short circuit energy on this type of currents generated by non-linear loads. Through the simulation of this study and analysis, it was observed that harmonic currents, resulting from loads or non-linear intermediates such as converters, have effects on network performance and deterioration of the voltage curve. This results in a decrease in the quality of the electrical product. This work suggests using one of the most reliable solutions, the parallel active filter, in order to reduce harmonic currents, which helps improve network currents and voltage. It also enhances the quality of energy directed to consumers. The results of this study confirmed the importance of proactive measures to manage this type of electrical grid to meet the needs of consumers for this energy, while maintaining its quality and reliability.

Keywords: Renewable energy, Energy quality, Multi-source, Harmonic pollution, Parallel active filters

Introduction

Multi-source electrical grids are systems that simultaneously integrate multiple energy sources to meet the needs of consumers (Hota & Mohanty, 2016). These networks typically involve several power generation technologies such as wind, chemical (fuel cell), solar and hydropower, as well as energy from fossil fuels (Mu et al., 2020). This type of network helps to increase the level of reliability, efficiency and flexibility in the process of supplying energy from the product to the consumers. One of the main advantages of this network is its superior ability to harness several sources of renewable energy along with traditional fossil sources. It also reduces total reliance on fossil fuel energy and contributes to the reduction of unwanted gas emissions (Chen et al., 2024). The regular distribution of electricity generation through various sources ensures continuity of service, in other words, minimizing the effects of supply and demand fluctuations or interruptions from an individual source. These systems are the cornerstone of their operation,) and help make appropriate choices of energy sources from a variety of sources based on factors including abundance, cost and environmental considerations (Navarro et al., 2020. In addition, it has the ability to store and distribute this energy efficiently, which helps the flexibility and stability of the network (Barukcic et al., 2023). In general, multi-source power grids are promising solutions to meet today's increasing demand for electricity, while addressing environmental concerns and enhancing energy security (Potrc et al., 2021).

Although this type of network has many good advantages, it faces some problems (Baqar et al., 2022). One of these important challenges is the complexity of the control systems that manage the various energy sources within the same network. This control system must simultaneously provide: generation, transmission and distribution of electricity from multiple sources and coordinate between them, which can be expensive in terms of implementation and maintenance (Bakare et al., 2023; Mel et al., 2022; Strbac, 2008). Demand side management is also a key component that can significantly affect system operation costs and flexibility (Strbac, 2008).. Unlike traditional sources such as coal or natural gas, among other challenges facing this network, is the diversity of energy sources such as wind and solar energy; their generation is controlled by weather conditions and fluctuations during the day, and these changes can pose challenges to ensuring the stability of the network and the continuity of supply of this energy, especially with the lack of sufficient storage solutions for the latter (Bird et al., 2013; Deguenon et al., 2023; Hana, 2023; Oyekale et al., 2020).

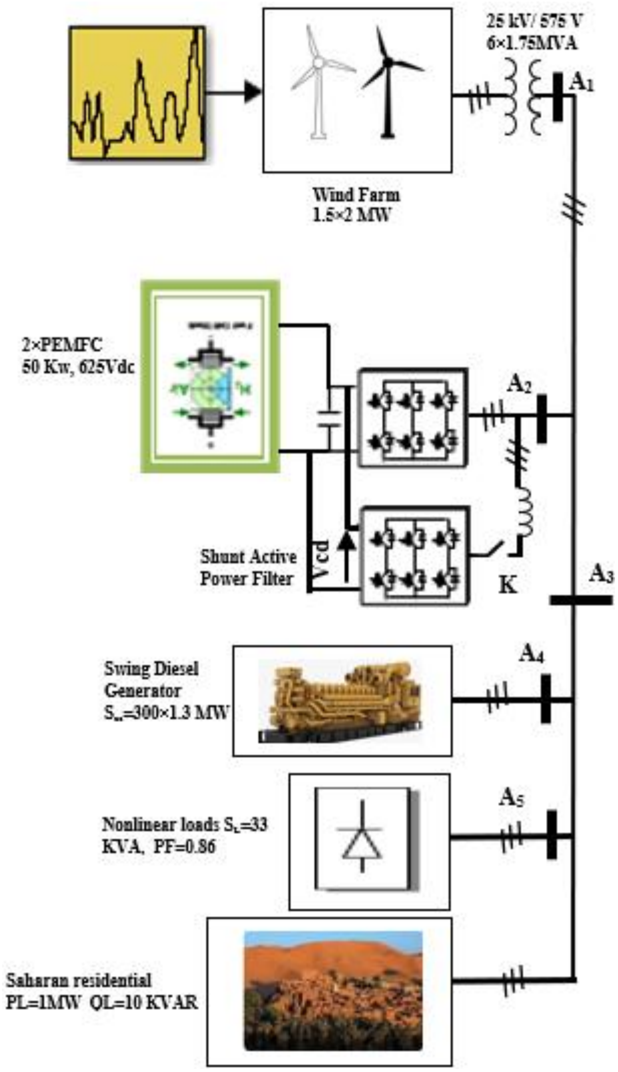

Figure 1. Various energy sources in an independent (Tindouf region in central Algeria).

Multisource electricity grids also, in terms of interconnection, share some challenges; upgrading the existing infrastructure or constructing new transmission lines to weave different energy sources might be snarled in regulatory challenges and opposition from local communities. Additionally, striking a balance between the varied interests (that is, energy producers, consumers as well as policymakers) can complicate the decision-making which in turn slows the shift to multisource grids. Moreover, multisource electricity grids may face cybersecurity risks owing to the digital control systems and communications networks. These systems are susceptible to cyber-attacks that could result in disruptions of power supplies or even compromise data integrity and confidentiality about stability (Bouramdane, 2023; Krause et al., 2021).

Because of the widespread use of semiconductor based electronic equipment in renewable sources i.e. converters and digital controllers and because of proliferation of non-linear loads in electrical networks, it seems that problem of harmonic current pollution is very clear in these networks. This harmonic current type causes the generation of harmonic voltage when flowing through the network impedance, to be added on the fundamental line-to-line voltage of power system with a non-sinusoidal distorted shape. However, in time, when technology and interests allow these reasons to be removed by using multi-source electrical networks then they will provide an efficient solution for the transition from centralized grids toward a more sustainable and flexible energy future (Eroglu et al., 2021).

In this work, we try to show the pollution due to harmonic currents resulting from the use of various energy sources in an independent network in the Tindouf region (Saharan zone) in west Algeria. In our case, traditional energy, fuel cells and wind energy as shown in figure 1, we also try to compensate these currents and reduce them using the parallel active filter, to obtain the sinusoidal form of the currents and voltages, in order to ensure the quality conditions of the electrical product supplied to consumers (Eroglu et al., 2021; Gbadamosi et al., 2022; Zec & Mikulovic, 2022).

Impact of the Electrical Network's Short-Circuit Power

This study does not focus on the efficiency of smart grid source controls or their configurations. Instead, they delve into how these sources behave within a fault-prone grid, with a particular focus on how short-circuit power in the grid affects harmonic currents generated by nonlinear loads and renewable energy converters. This study aims to highlight the effectiveness of parallel active filters in addressing one of the challenges within networks exposed to the risk of harmonic voltage surge. In addition, we focus our attention on the significant impact that fluctuations in network parameters such as frequency, short-circuit power and load variation have on the proper operation of the network.

To conduct our study objectively and determine appropriate load and network short-circuit power values for analyzing the active filtering of harmonic currents generated by nonlinear loads like static converters, we manipulate the SCC/SN power ratio and observe changes in network parameters. Our findings are visually represented in the following figures:

- SCC refers to the short-circuit power of an electrical network where it connects, known as the Point of Common Coupling (PCC).
- SN stands for the nominal power of the load, which in this case is specified as 1.3 MVA.

Published in previous articles that as the ratio of SCC to SN increases, the active power of the load increases, while the reactive power decreases. According to these studies, it becomes apparent that as the ratio of SCC to SN increases, the active power of the load increases, while the reactive power decreases. This suggests that at a sufficiently high short-circuit power of the electrical network, the diode rectifier bridge consumes practically no reactive power (Hao et al., 2023).

Research depict an improvement in voltage drop with the increase in the SCC/SN ratio. At SCC/SN = 2000, there is a greater voltage drop. There's an enhancement in displacement factor with the rise in the SCC/SN ratio. At SCC/SN = 2000, the displacement factor can be considered to be equal to one. Once again, the same reference explains how the SCC/SN ratio has a vital influence on THDv and THDi. Therefore, the limit does not make any sense in the context of the establishment of harmonic injection limits into the electrical network and design of either passive or active filters. This observation was noted by the IEEE 519-1992, which divided into five different intervals and proposed the restrictions to the harmonic currents permitted to be injected into the electrical supply system by devices that are non-linear. Understanding the importance of the SCC/SN ratio on THDV and THDI, a decision was made to study the reliability and efficiency of the passive filter based on a selected case from the intervals specified by the IEEE 519-1992 standard. This case involves harmonic filtering in a weak network where the SCC/SN ratio belongs to the first interval of the IEEE 519-1992 standard (SCC/SN = 10).

Study of Installation of a Wind Farm Technical Part

The aim of the study is to develop a wind power project in Tindouf, Algeria, and three possible sites have been suggested focusing on the wind farm onsite including topography, distance to power networks, area available, site accessibility, and restrictions. Site A, on a plateau to the north of the City, is favored by its location in regard to the wind regime, issues of transportation that include proximity to major highways and the power grid and adequate land for the setup of the wind farm as well as good land for the laying of construction bases. An open area, flat ground, and available space for further expansion of the wind farm provides Site B pressed against the rear wall of the diesel producing unit. It carries the prospects of a through-road and connection to the electrical distribution line. The nearby diesel power plant may aid in operation balancing for instance. Site C is further southwest of the power plant than site A, more wind potential may be obtained because site C is at the top of the small hill existing. Its location far away from the main road and the electrical grid makes the development costs of the wind farm higher than other sites, however, as the site contains more space than most of the sites. A met mast has been erected on the front of the Tindouf gate with the purpose of cutting wind speed measurement's reasons, going against the expectation it probably could suffer from some minor disturbance. In the end, it will be the examination of the merits and demerits of a given place in the long run which will be critical in choosing that place.

Table 1. Coordinates of the three sites

Coordinates	North	West	Altitude
Site A	27°44,741'	8°08,660'	445m
Site B	27°37,8768'	8°6,43359'	377,3m
Site C	27°36,8366'	8°6,9744'	401,4m

Pem Fuel Cell and Reference Currents Generation Control

This research focuses on one of the aspects of a system configuration in which Proton Exchange Membrane (PEM) fuel cells and a shunt active power filter are engaged harmoniously. A major emphasis is made on providing utility grid with integrated fuel cell power considering that the fuel cell power is at times fixed. In particular, the setup is able to go beyond injecting chemical energy to the grid, to operate as active power filter parallel type (PAPF) in eliminating reactive current generated from nonlinear load as well as reducing current harmonics.

The purpose is to increase the power of the system and reduce the impact from harmonic currents. In other words, this means that apart from installing a 100KW fuel cell power system, a shunt active power filter is also installed, these three systems are collectively linked to a three-phase grid with nonlinear loads. What is the means of generating the load current harmonic so as to determine its harmonic component? An injected current which is made up has to be produced. This involves taking what is gross current and deducting the reference filter current. In this study, the approach of using the stationary αβ frame also referred to as the p-q theory is utilized in the evaluation of both active and reactive power. The source voltages and load currents in the αβ frame are expressed in the following manner:

$$\begin{bmatrix} \dot{i}_\alpha \\ \dot{i}_\beta \end{bmatrix} = \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} \dot{i}_a \\ \dot{i}_b \\ \dot{i}_c \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} e_\alpha \\ e_\beta \end{bmatrix} = \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (2)$$

In this scenario, ea, eb, and ec stand for the three-phase grid voltages, while ia, ib, and ic represent the load currents. To determine the instantaneous active and reactive powers in the **α−β** coordinates, the following formulas are applicable:

$$p_l(t) = e_\alpha(t) i_\alpha(t) + e_\beta(t) i_\beta(t) \quad (3)$$

$$q_l(t) = e_\beta(t) i_\alpha(t) - e_\alpha(t) i_\beta(t) \quad (4)$$

From the aforementioned equation, the instantaneous active and reactive powers may be represented in terms of the dc and ac components, that is:

$$p_l = \overline{p_l} + \widetilde{p}_l \quad (5)$$

$$q_l = \overline{q_l} + \widetilde{q}_l \quad (6)$$

While $\overline{p}_1$ and $\overline{q}_1$ correspond to AC components due to harmonic currents, $\widetilde{p}_1$ and $\widetilde{q}_1$ are attributed to DC components stemming from fundamental currents. Estimating the reference currents necessitates $\widetilde{q}_1$ computing the instantaneous powers provided by both the source and the Parallel Active Power Filter (PAPF) to the load. If the utility furnishes real and imaginary instantaneous powers pg and qg, then the main supply should offer $p_g = \overline{p}_1$, while ensuring qg=0. Concurrently, the PAPF delivers the harmonic component and ql. Conversely, to offset reactive power and harmonic current, the PAPF provides the real and imaginary instantaneous powers pf and qf. Maintaining its sinusoidal waveform, the source current ensures that the PAPF supplies the oscillatory portion of pl to the nonlinear load.

$$\begin{aligned} p_g &= \overline{p_l} \\ q_g &= 0 \\ p_f &= p_l - p_g = p_l - \overline{p_l} = \widetilde{p}_l \\ q_f &= q_l - q_g = q_l \end{aligned} \quad (7)$$

Only the reactive power is provided under these circumstances by the PAPF.As a result, during the steady state, the capacitor voltage level remains constant. Active power balancing between the grid, load, and PAPF must be controlled since the load only absorbs exactly $\overline{p}_1$ of the total power, and if $\boldsymbol{p_g \prec \overline{p_l}}$, the PAPF delivers the remaining portion to maintain the DC voltage level.

We have: $\overline{p_g} + \overline{p_f} = \overline{p_l}$

As a result, a gain factor k must be added to the previous equations (7) in order to manage the appropriate amount of active power provided by the PAPF [3].

$$\boldsymbol{k = \frac{\overline{p_g}}{\overline{p_l}}} \quad (8)$$

If the gain factor is more than unity, the grid must provide the PAPF with additional active power in order to recharge the capacitor value required at the VDC voltage. The instantaneous reference powers for the PAPF are as follows:

$$\boldsymbol{\begin{aligned} p_f^* &= \widetilde{p}_l + (1-k)\overline{p_l} \\ q_f^* &= q_l \end{aligned}} \quad (9)$$

In the event that the gain factor is less than unity, the capacitor voltage is too high, resulting in a grid power that is less than $\overline{p}_1$ and the remaining portion of $\overline{p}_1$ being delivered by the PAPF to the load. In this instance, the following equation is used to determine the reference currents mandated by the PAPF:

$$\begin{bmatrix} i_{f\alpha} \\ i_{f\beta} \end{bmatrix} = \begin{bmatrix} e_\alpha & e_\beta \\ -e_\beta & e_\alpha \end{bmatrix}^{-1} \begin{bmatrix} p_f \\ q_f \end{bmatrix} \qquad (10)$$

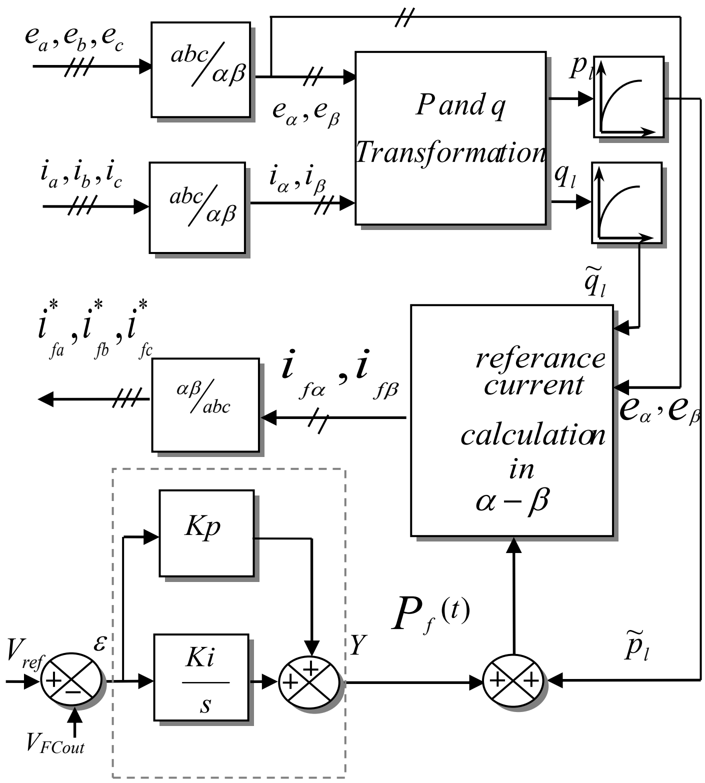

Figure 2. Block diagram for the instantaneous active and reactive power

Results and Discussion

Simulations were undertaken to assess the efficacy of an electrical grid featuring multiple energy sources, operating autonomously from the national grid. Additionally, we aimed to investigate the challenges encountered by this autonomous network under conditions closely resembling real-world scenarios. We introduce a proposed detection and control methodology to the system. The Shunt Active Power Filter (SAPF) is deployed to alleviate harmonics induced by non-linear loads or power supply components like semiconductor-based transformers, especially when the load is in moderate proximity to the grid (Ssc/SN = 300), where Nominal power of the load (SN = 1.3MVA). Detailed parameters of the system model are outlined in Table 2,3.

Table 2. Units for magnetic properties

Parameters	
Supply phase voltage U	220 V
Supply frequency fs	50 Hz
Filter inductor Lf	0.7 mH
Dc link capacitor Cf	0.768474 mF
Vdc	857V
Smoothing inductor Lsmooth	70 µH

Table 3. Parameters of the DFIG

Parameters	
Rated generator power	1.5 MW
Rated voltage	575 V
Rated mechanical speed	12 m/s
Rated frequency	50 Hz
Pole pairs	3
Stator D-axis inductance	0.0136 H
Rotor Q-axis inductance	0.0137 H
Mutual inductance	0.0135 H
Stator resistance	0.012 Ω
Rotor resistance	0.021 Ω
Radius of wind turbine	35.25 m
Number of blades	3
Nominal rotational speed	10 m/s
Optimum power coefficient constant	8.1
Maximum Cp	0.42
Density of air	1.225 kg m−3
Dry friction torque	953 N m
Total inertia of the mechanical	50 kg m2
Radius of wind turbine	35.25 m

Initially, we'll assess the system's performance without the filter. This involves examining the quality of voltage, current, and power transfer among the system's components.

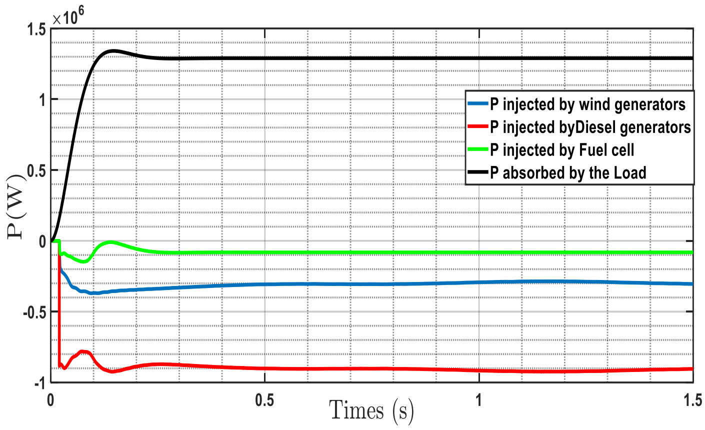

Figure 3. The dynamic exchange of actives powers among the components within the system.

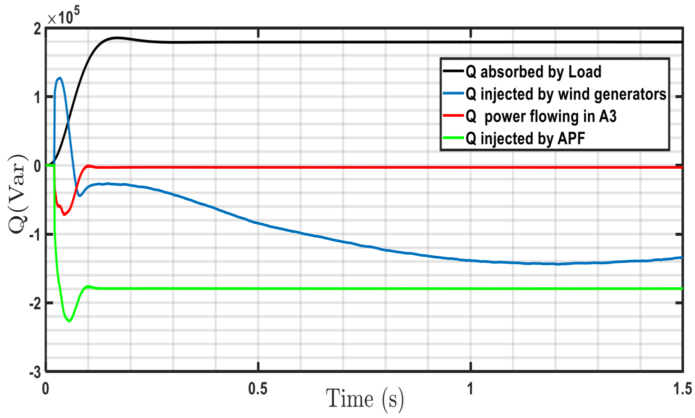

Figure 4. The dynamic exchange of reactive powers among the components within the system.

As seen in Figure 3, many energy sources help in meeting the load demand with respect to the current design so as to bring down the use of polluting gases. Wind energy constitutes 24% of the load energy while that of fuel cell energy comes in at 6%. Loosely speaking, fossil energy has been the major contributor to the energy load range of about 70 percent including losses. This system has helped abate about 30 percent of these harmful emissions. Power flow of reactive nature greatly affects the choice of equipment… and the stability of the grid. Moreover, it has an impact on the finances. This flow enhances the apparent currents which result in:

- Overreaching and excessive heating of the transformers and cables, and thus active power loss.
- Voltage sags, which increase the reactive power flow and stress the use of electrical equipment on the whole power system. Therefore, it is necessary to reduce its flow through the network, owing to [name] an active filter, which compensates this energy.

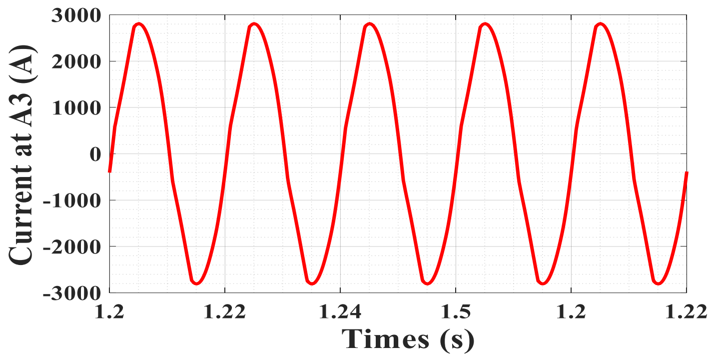

Figure 5. Current at level A3 without A. P. F.

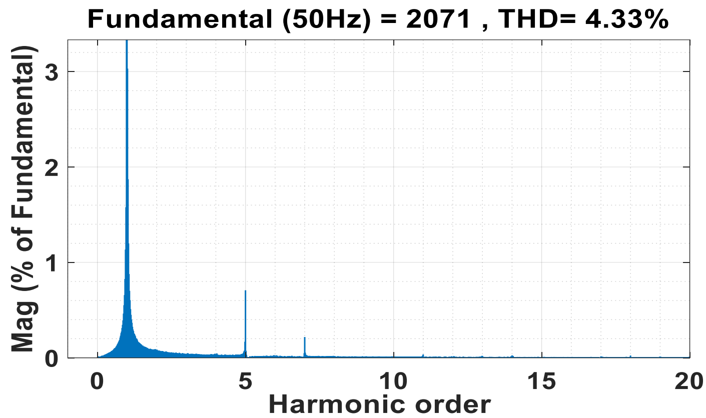

Figure 6. Current at level A3 spectral breakdown without A. P. F.

However, the far more worrying trend is revealed in figures 5 and 6: The electrical current at network level is decreasing; and their distortion factor (harmonic currents) having increased up to a rate of 4.33%! This is above the tolerable limit of international standard IEEE 519-1992. In addition, these harmonic currents flowing in the network impedance cause an attenuation of the magnitude of harmonic voltages. This results in a non-sinusoidal 6.15% voltage with reference to the nominal voltage of the network (Figures 7 and 8). Therefore, the quality of energy is discounted due to this and disturbing the way we are supposed to exist in balance between energy consumer and producer.

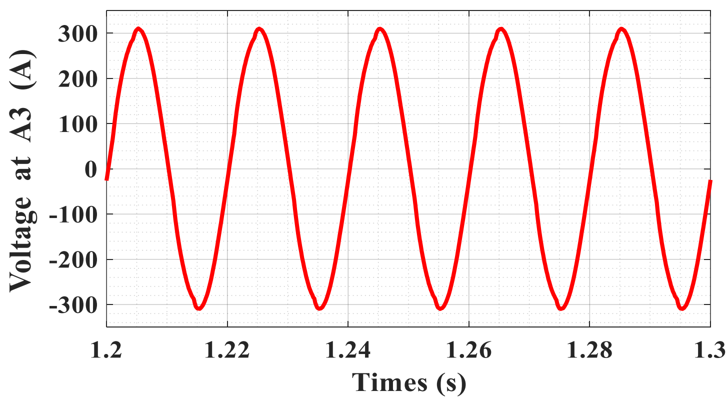

Figure 7. Voltage at level A3 without A. P. F.

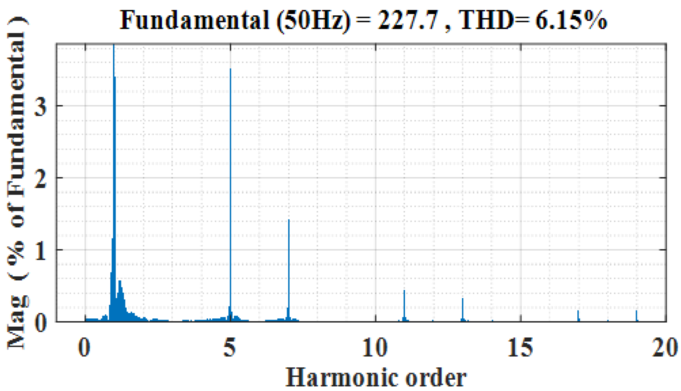

Figure 8. Voltage at level A3's spectral breakdown without A. P. F.

Then, we go on perform a transformer in parallel with the output of the power cell transformer. This clever ingenious addition introduces harmonic currents that are the exact opposite of those present in the network thereby cancelling them out. Consequently, the network stress is increase and thus power transmission quality improves, losses of power getting reduced.

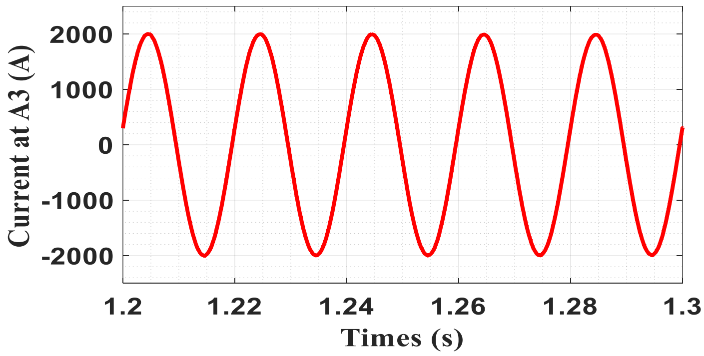

Figure 9. Current at level A3 with A. P. F.

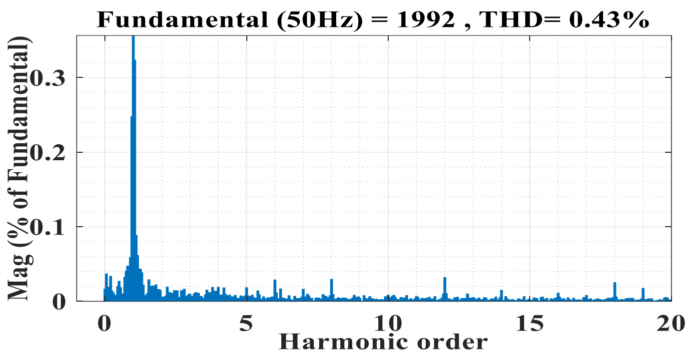

Figure 10. Current at level A3 spectral breakdown with A. P. F.

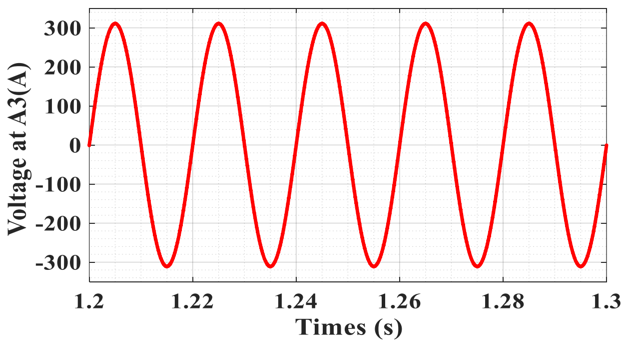

Figure 11. Voltage at level A3 with A. P. F.

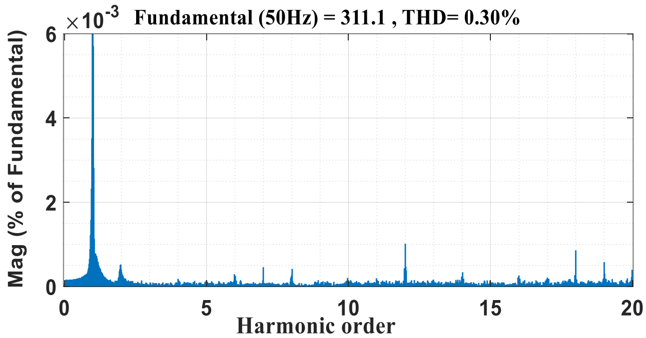

Figure 12. Voltage at level A3's spectral breakdown with A. P. F.

According to the previous figures (see fig 9-10-11-12), after the insertion of the Active Power Filter, in this system with multiple power sources, the network currents improved, becoming THD=0,43%, after removing the harmonic network currents, which represented 4,33% of the fundamental component, with harmonic currents, opposed to them in phase, and injected from the filter. This improvement in performance led to an improvement in network voltages, which decreased from 6,15%to 0,33%, and therefore to a high quality of energy directed to the consumer.

Conclusion

To Sum up, in this article investigate the integration of renewable energy sources to the remote south-west network in Algeria and examine energy quality aspects by showing solutions to improve the quality of electrical product for a consumer. Multi-source electrical networks making use of various energy sources have numerous advantages, primarily linked to their reliability, effectiveness as well as ecological friendliness. But a number of issues need to be resolved — everything from uncontrolled harmonic current pollution through the interconnected grid to dealing with the variability that comes with adding renewables into the generation mix, interconnection problems and cybersecurity risks.

The study aimed to work mainly on the effect of network short circuit power on harmonic current generation by nonlinear loads and renewal power converters. It was determined via simulations and analysis that the harmonic currents were having a big impact on the network's performance, reducing energy product quality.

Consequently, harmonics mitigation was successfully achieved by applying the parallel active filters reducing distortion in network currents and voltages. This improvement in network voltages is main factor to increase the quality of energy transmitted each costumer, resulting from harmonic currents elimination. Results from such a study underscores the imperative of taking preventive method to treat multi-source electrical networks efficiently in order to fulfill energy required levels at elsewheres while keeping up quality and dependability.

Recommendations

In this study, we showed that a multi-source autonomous grid in the Tindouf region can suffer from significant harmonic distortion and voltage issues, especially under weak short-circuit conditions. We therefore recommend that operators of similar remote grids systematically monitor harmonic indices, carefully consider the SCC/SN ratio when connecting new converters, and adopt shunt active power filters to keep current and voltage distortion within acceptable limits. In the longer term, combining wind, fuel cell and conventional units with improved control and storage strategies could further reduce fossil fuel use while maintaining good power quality for local consumers.

Scientific Ethics Declaration

* The authors declare that they are fully responsible for the scientific, ethical, and legal content of this article published in the EPSTEM journal. This work relies on numerical modelling and simulations of power systems and does not involve human or animal subjects, so formal ethics committee approval was not required.

Conflict of Interest

* The authors declare that they have no conflicts of interest related to the research, authorship, or publication of this article.

Funding

* This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Acknowledgements or Notes

*This article was presented as an oral presentation at the International Conference on Basic Sciences and Technology (www.icbast.net) held in Konya, Türkiye, on April 02–05, 2026.

*The authors would like to thank Tahri Mohamed University and the Laboratory of Information Processing and Telecommunications (LTIT) for their support, as well as colleagues who contributed helpful comments and discussions.

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Author(s) Information

Dehini Rachid
Laboratory of Information Processing and Telecommunications (LTIT), Faculty of Technology, University of Bechar - Tahri Mohamed, Bechar 08000, Algeria
ORCID iD: https://orcid.org/0000-0002-8769-218X
Contact e-mail : dehini.rachid@univ-bechar.dz

Benchikh Lehocine Iftikhar
Laboratory of Information Processing and Telecommunications (LTIT), Faculty of Technology, University of Bechar - Tahri Mohamed, Bechar 08000, Algeria
ORCID iD: https://orcid.org/0000-0001-9061-0096

Glaoui Hachemi
Laboratory of Information Processing and Telecommunications (LTIT), Faculty of Technology, University of Bechar - Tahri Mohamed, Bechar 08000, Algeria
ORCID iD: https://orcid.org/0009-0005-0334-8576

Bediar Samira
Electrical engineering Department, University of Bechar - Tahri Mohamed, Bechar 08000, Algeria
ORCID iD: https://orcid.org/0009-0004-0927-4347

*Corresponding author(s) contact email

To cite this article:

Rachid, D., Iftikhar, B.L, Hachemi, G. & Samira, B. (2026). Analyzing energy quality in the integration of renewable sources into Algeria's remote southwest network. *The Eurasia Proceedings of Science, Technology, Engineering and Mathematics (EPSTEM)*, *40*, 54–65.