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Research Article

Contribution to the Reduction of the Harmonic Distortions and of the Current Unbalance in a Distribution Network

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Abstract

Today, the challenge of electricity distribution is to ensure the quality of electrical energy to balance production and demand. However, many of these disturbances can be found in an electrical network. Traditional and modern solutions have been proposed in the literature to reduce these disturbances. Among these solutions, active filtering has proven to be the most effective. There are active series filters designed to compensate for parasitic voltages, active parallel filters designed to compensate for parasitic currents and hybrid filters designed to compensate for both parasitic voltages and currents. In fact, several innovative solutions have been implemented to improve the reliability of these active filters. This research focuses on the simultaneous reduction of electrical harmonics and current imbalance in electrical power distributed to customers. The objective is to model and simulate in the Matlab/Simulink environment a four-wire active filter adapted to a public power distribution network. The integration of the parallel active filter will result in a simultaneous reduction of the harmonic rate and the unbalance. At the end of the simulation, the parallel active filter contributed significantly to reducing the harmonic rate in the different phases from 46% to 1.50% and the current unbalance rate from 14.78% to 0.14%.

Keywords

Active Filter, Unbalance, Harmonics, Power Quality, Hysteresis Control

1. Introduction

The introduction plays an important role in providing background information (including relevant references), emphasizing the importance of the study, and outlining its Electricity is ubiquitous in our lives. It is generated by power plants, transmitted through transmission and distribution networks, and delivered to end users. Today, we are witnessing the proliferation of non-linear loads, which consume little electrical energy from power users. Electronic converters and non-linear loads generate disturbances in the network, such as increased harmonics, current unbalance and reactive energy. These disturbances affect the fundamental electrical characteristics: frequency, voltage amplitude and waveform. Deterioration in any or all of these factors indicates an anomaly in the reliability of the distributed power [1]. In order to guarantee power quality in accordance with the EN 50160 and IEEE 1159-2009 standards, it has become indispensable to use network pollution control techniques, the most important of which is the use of active filters [2-4]. The performance of the active filter is based on three criteria: the type of inverter, the estimation of the reference current and the choice of the inverter current control [5, 6]. To this end, this article deals with the design of an active filter that takes into

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account the unbalances and harmonics in a public distribution network. Four-wire parallel active filters are a suitable solution in this case.

2. Electrical Network Parallel Active Filtering Techniques

The principle of the filter and the methods used to configure and estimate the parameters are applied to the distribution network, which is a subsystem of the electricity network where energy is distributed at medium voltage (MV) for customers requiring high power and at low voltage (LV) to ensure service to customers connected to the network. MV/LV substations are the basic devices in this system [7]. The waveform of electrical energy in this electrical system is subject to degradation, so additional devices such as active filters are required should be written in English.

2.1. Configuration of an Active Filter with Four Lines in Parallel

Active power shunt filters in an electrical system can be represented by Figure 1, which shows two main parts: a control part and a power part connected to the network via a passive L-R filter (known as a coupling filter) to attenuate harmonic distortion and current unbalance in the network [8].

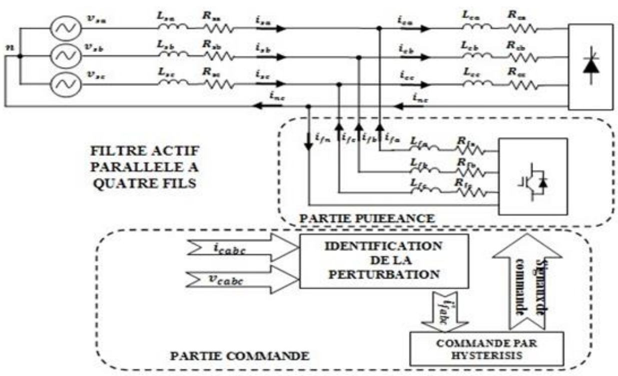

Figure 1. *General view of the FAP with the four wires [6].*

IGBT thyristors are currently the most widely used in power applications. It's have been chosen for their performance, i.e. low forward voltage drop, fast switching time and high power handling [1]. The switching state of thyristors depends on the control signal provided by the control circuit [9]. The filter described above can be used in a variety of contexts simply by setting the appropriate values.

2.1.1. Determination of Parameters for the Control of Harmonic Pollution

The passive coupling filter is calculated using the equation:

$$\frac{di_f}{dt} = \frac{di_h}{dt} \tag{1}$$

Where i_f is the filter current and i_h non-linear load current.

In practice and in general, the first order filter used is L OR LC. The size of this filter depends on the compromise to be found between the dynamics and the efficiency of the parallel active filter. In fact, only a relatively low value of L can achieve the dynamic range of the active filter to satisfy the equation 2 [9]. If the resistance of this coupling filter is neglected, the equation 2 has obtained:

$$\left(\frac{di_f}{dt}\right) max = \frac{V_{fmax} - V_{Smax}}{L_f} \tag{2}$$

$Vfmax$: The maximum value of the voltage at the inverter input.

$Vsmax$: The maximum value of the single voltage at the filter connection point.

2.1.2. Energy Storage System

In the four-wire active shunt filter topology, the capacitor is the energy storage element on the DC side of the inverter.

2.2. Command and Control System

The non-linear load absorbs a harmonic and sometimes unbalanced current in the three-phase case. In order to ensure that sinusoidal alternating current flows in the network, it is necessary to identify the disturbance currents of the load and then to estimate the reference currents that the active filter must inject into the network, with the same amplitude but in phase opposition to those consumed by the load. Several techniques have been presented in the literature, both in the time and frequency domain, to identify the reference currents. The power method is chosen for its simplicity and speed of implementation [4].

The active shunt filter is supplied on the DC side by a capacitor. However, the DC voltage across this capacitor is not constant.

In order to improve this steady state DC voltage without degrading the transient state, the PI regulator is used as a solution that achieves zero static error [10, 11]. The relationship between the power absorbed by the capacitor and the voltage across its terminals can be written as [2].

$$P_{dc} = \frac{d}{dt}\left(\frac{1}{2} C_{dc} V_{dc}^2\right) \tag{3}$$

Applying Laplace to equation 4 that give:

$$P_{dc} = \frac{1}{2} s C_{dc} V_{dc}^2 \tag{4}$$

The voltage across the capacitor is expressed as follows:

$$V_{dc}^2 = \frac{2P_{dc}}{sC_{dc}} \quad (5)$$

2.3. Method for the Development of a Parallel Active Filter for an Electrical System

The procedure for designing the electrical network for the selected hospital is based on four phases. The diagram in the following figure illustrates these four phases.

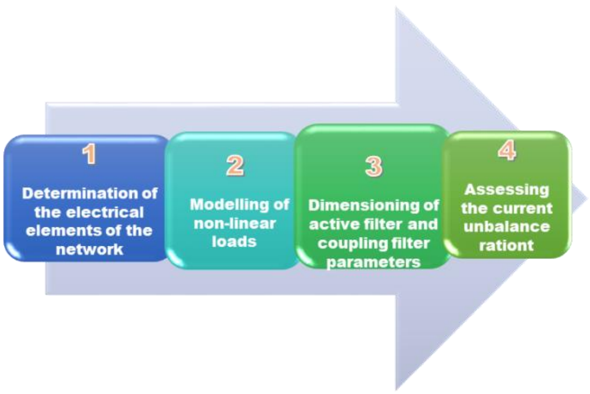

Figure 2. Steps in developing the parallel active filter.

The determination of the power system elements Ls and Rs is based on the IEC 61000-3-12 standard, which defines the relationship between the apparent short-circuit power by the equation:

$$\frac{S_{cc}}{S_{ch}} \geq 30 \quad (6)$$

In addition, the short-circuit impedance can be determined using the equation [8]:

$$Z_S = \frac{3V_S^2}{S_{cc}} \quad (7)$$

With

$$Z_S = \sqrt{R_S^2 + X_S^2} \quad (8)$$

In practice, the impedance X_S is selected between $0.01Z_S$ and $0.1Z_S$ [12].

In the active filter design, the coil is the coupling element between the filter system and its power supply. The inductance of the coil is determined by the following equation:

$$L_f = \frac{V_{fmax} - V_{Smax}}{0.25 i_{Smax} f_{ond}} \quad (9)$$

With:

$$V_{fmax} = \frac{2}{3} V_{DC} \quad (10)$$

V_{fmax}: the maximum value of the inverter input voltage.

V_{smax}: the maximum value of the simple voltage at the filter connection point.

i_{Smax}: the maximum current delivered by the source.

2.4. Application to the Power Supply Network of a Hospital

The simulation of the network, pollutant loads, three-phase rectifiers and three- or four-arm parallel active filters is carried out using the Matlab-Simulink environment. The case study is a hospital in Niamey, the CHR source substation has the following characteristics: apparent power S=1000 KVA; voltage system: 230/400 V; Dyn11 coupling and a secondary current of 1443 A.

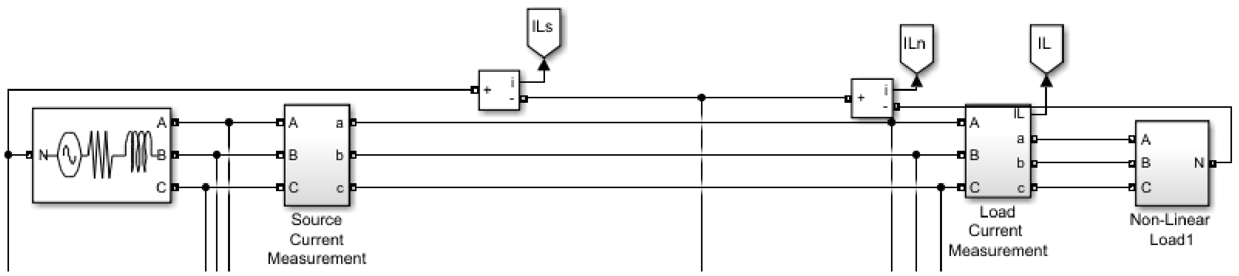

Figure 3. Model implemented.

2.4.1. Capacitor Reference Voltage

Several approaches have been formulated to determine this voltage. There is an assumption-based method, which is very simple and provides the best power quality [13]. According to this approach, the V_dcref voltage is equal to 700 V because, within the constraints of the switches, the minimum value of the Vdc voltage is twice the maximum value of the simple mains voltage to ensure the controllability of the output filter current at all times [14].

2.4.2. Value of the Capacity of the Capacitor

The calculation of the capacitance is based on the measurement of the highest harmonic current Ih in the network. The capacitance Cdc is calculated as follows [4, 13]:

$$C_{dc} = \frac{I_h}{\Delta V_{dc} \omega_h V_{dc}} \quad (11)$$

With ω_h the lowest pulsation of the harmonics to be compensated and ΔV_{dc_h}.

2.4.3. Current Umbalance Evaluation

The approximate formula for the unbalance rate according to IEEE std. 141-1993 is [15]:

$$T_{DI} = \frac{Max(I_1;I_2;I_3) - I_{moy}}{I_{moy}} \quad (12)$$

With:

$$I_{moy} = \frac{\sum_{i=1}^{n} I_i}{3} \quad (13)$$

The simulation diagram for all model elements is shown in Figure 4.

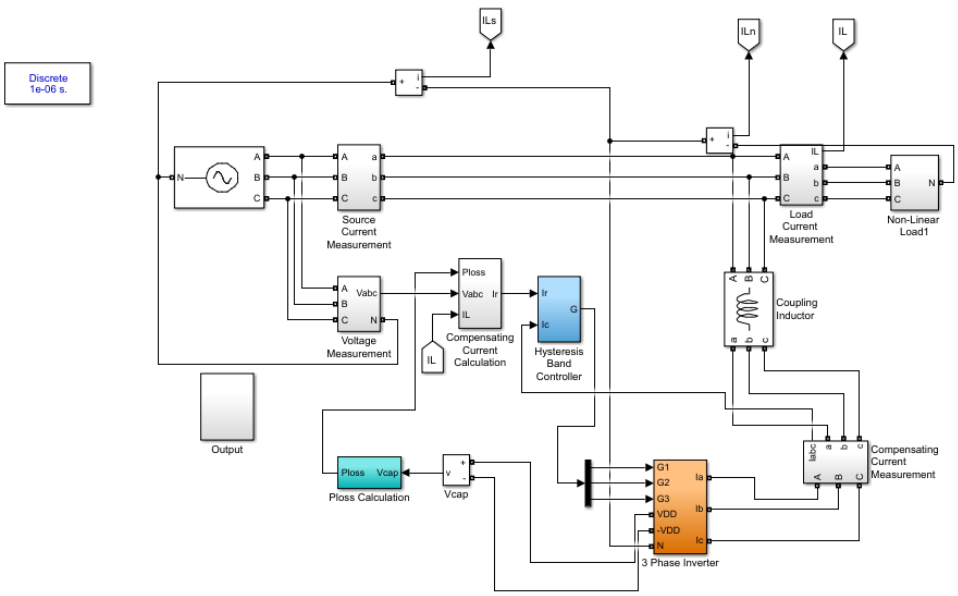

Figure 4. *Simulation model.*

Based on this model, two scenarios are developed:

1) The first scenario involves simulating the model without filter;
2) The second scenario involves inserting the active filter into the simulation model.

3. Results

In accordance with the assumptions made in the first scenario, the results obtained are shown in the following two figures. The waveform of the currents drawn by the non-linear loads is shown in Figure 5.

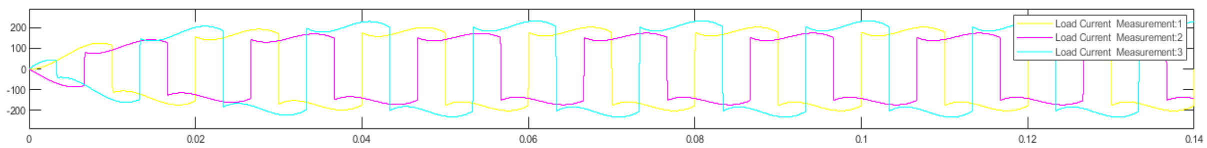

Figure 5. *Plots of three non-linear load currents.*

A spectral analysis of Figure 5 allowed us to quantify the rate of harmonic distortion on the three phases shown in Figure 6.

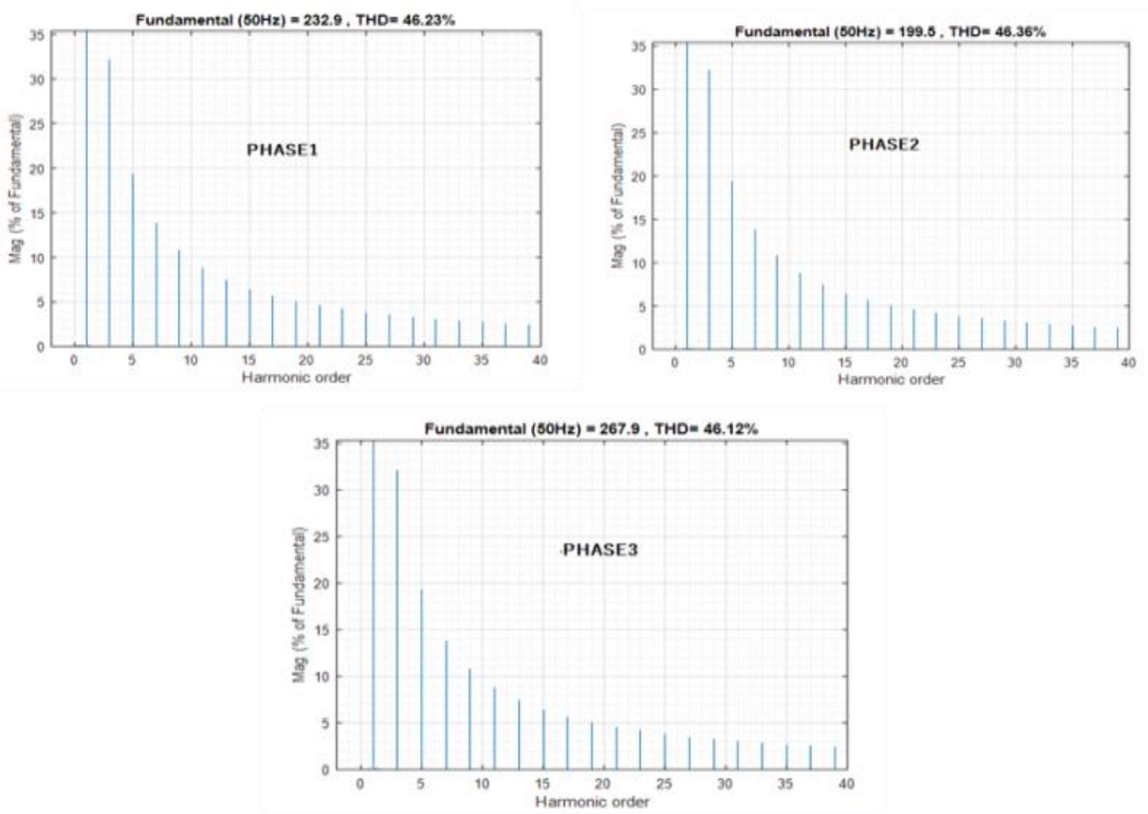

Figure 6. *Current harmonic rate before integrating the active filter.*

The harmonic distortion rates by electrical phase order are THD1=46.27%; THD1=46.40%; THD1=46.15%. In addition, the recorded current unbalance rate is 14.78%. When the active filter is integrated to reduce the harmonic distortion levels and the current imbalance rate, the results shown below are obtained.

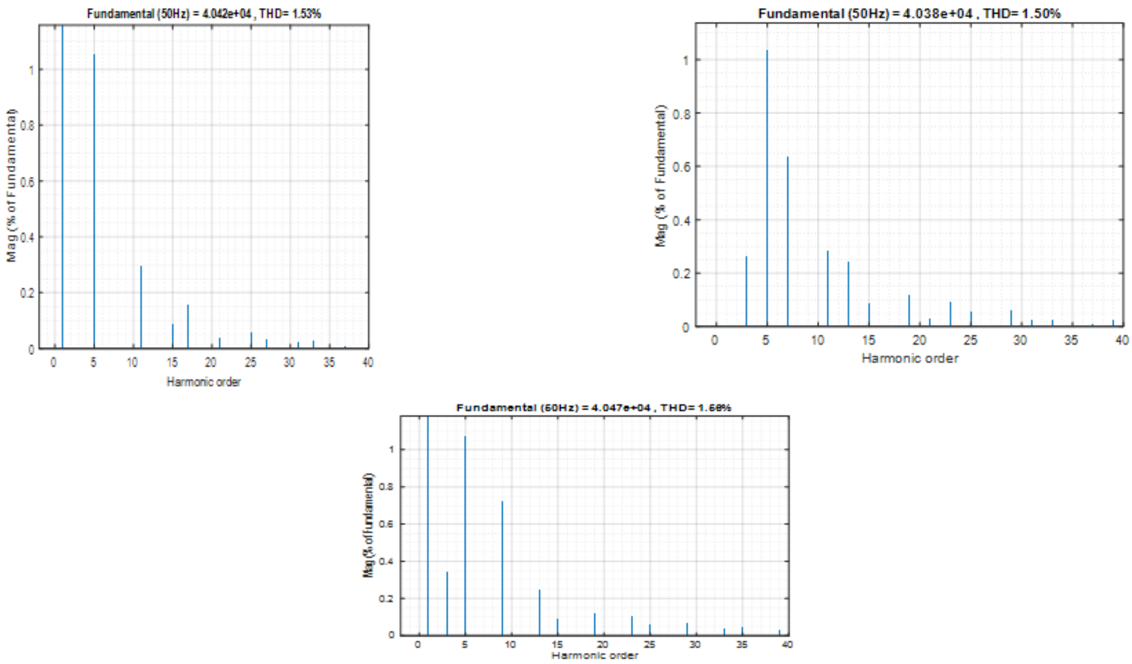

Figure 7. *Current harmonic rate after integrating the active filter.*

4. Discussion

Initially, before filtering, the harmonic distortion rate of the different phases is about 46% and the current unbalance rate is 14.78%, indicating the presence of harmonics and unbalance in the three-phase load. At this point, the current flowing through the three-phase load is the same as that supplied by the three-phase source (transformer secondary).

In order to assess the effectiveness of the filter, a table has been drawn up comparing the rates of harmonic distortion and unbalance before and after integration of the FAP.

The summary table shows that, overall, the use of the active filter has made a significant contribution to reducing the THD in the various phases.

With regard to the rate of current unbalance after filtering, the satisfaction is all the greater in that, on the one hand, it is lower than the rate of unbalance allowed in a distribution substation in Algeria, which is 15% [13] and, on the other hand, the TDi obtained is very low compared with that allowed in Madagascar, which is set at 10% in the work of raherimihaja Henri Josephson [15].

Better still, the TDi obtained is lower than that accepted in France by EDF in low-voltage distribution, in the range [0.5; 2%] [6].

5. Conclusions

The research activity developed in this article consisted in the implementation of a four-wire active filter to reduce both electrical harmonics and current unbalance. The case study of a hospital electrical network was modelled and used to test the designed active filter. The simulation of the electrical system showed that the parallel active filter made a significant contribution to reducing the harmonic rate in the different phases from 46% to 1% and the current unbalance rate from 14.78% to 0.14%. As part of future improvements, research will need to be carried out on optimization of active filter design.

Abbreviations

EN	European Norm
IEEE	Institute of Electrical and Electronics Engineers
MV	Medium Voltage
LV	Low Voltage
IGBT	Insulated-gate Bipolar Transistor
DC	Direct Current
IEC	International Electrotechnical Commission

Author Contributions

Daouda Abdourahimoun: Ressources, Supervision, Investigation, Data curation

Adamou Namata Aboubacar: Format Analysis, Validation, Software

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Data Availability Statement

The data supporting the outcome of this research work has been reported in this manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] YUAN, Wenqian, YUAN, Xiang, XU, Longwei, et al. Analyse des pertes harmoniques d'un réseau de distribution basse tension intégré au photovoltaïque distribué. Sustainability, 2023, vol. 15, no 5, p. 4334. [YUAN, Wenqian, YUAN, Xiang, XU, Longwei, et al. Ana-lysis of harmonic losses in a low-voltage distribution network integrated with distributed photovoltaics. Sustainability, 2023, vol. 15, no. 5, p. 4334] *https://www.mdpi.com/2071-1050/15/5/4334*

[2] BACHRY, A. et STYCZYNSKI, Z. A. An analysis of distribution system power quality problems resulting from load unbalance and harmonics. In: 2003 IEEE PES Transmission and Distribution Conference and Exposition (IEEE Cat. No. 03CH37495). IEEE, 2003. p. 763-766. *https://doi.org/10.1109/TDC.2003.1335371*

[3] DJAZIA, Kamel. Etude des filtres actifs pour réseaux déséquilibrés et distordus. 2015. Thèse de doctorat. Université Ferhat Abbas. [DJAZIA, Kamel. Study of active filters for disequilibrated and distorted networks. 2015. PhD thesis. Université Ferhat Abbas.] *https://www.ccdz.cerist.dz/admin/notice.php?id=000000000903958000369*

[4] BENNAIDJA, Tarek. Filtrage actif pour les réseaux déséquilibrés et distordus. 2018. Thèse de doctorat. [BENNAIDJA, Tarek. Active filtering for unequilibrated and distorted networks. 2018. PhD thesis.] *http://dspace.univ-setif.dz:8888/jspui/handle/123456789/1851*

[5] ZOUKH, Nadjet et RAS GHANEM, Amria. Amélioration de la qualité de l'énergie électrique par l'utilisation d'un filtre actif parallèle dans un réseau électrique. 2023. Thèse de doctorat. Université Ibn Khaldoun. [ZOUKH, Nadjet and RAS GHANEM, Amria. Improving electrical power quality by using a parallel active filter in an electrical network. 2023. PhD thesis. Université Ibn Khaldoun.] *http://dspace.univ-tiaret.dz/handle/123456789/13587*

[6] NOSHAHR, Javad Behkesh, BAGHERI, Mehdi, et KERMANI, Mostafa. The estimation of the influence of each harmonic component in load unbalance of distribution transformers in harmonic loading condition. In: 2019 IEEE International Conference on Environment and Electrical Engineering and 2019 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe). IEEE, 2019. p. 1-6. *https://doi.org/10.1109/EEEIC.2019.8783488*

[7] AMAR, Omeiri. Simulation d'un filtre actif parallèle de puissance pour la compensation des harmoniques de courant. Dirigé par Haddouche Ali, université de Badji Mokhtar Annaba, 2007, vol. 3. [AMAR, Omeiri. Simulation of a parallel active power filter for current harmonics compensation. Diri-gé par Haddouche Ali, université de Badji Mokhtar Annaba, 2007, vol. 3.] *https://biblio.univ-annaba.dz/wp-content/uploads/2014/06/OMEIRI-AMAR.pdf*

[8] THOMAS, Jaime Prieto, REVUELTA, Patricio Salmerón, VALLÉS, Alejandro Pérez, et al. Practical evaluation of unbalance and harmonic distortion in power conditioning. Electric Power Systems Research, 2016, vol. 141, p. 487-499. *https://doi.org/10.1016/j.epsr.2016.08.012*

[9] BOUKADOUM, Aziz. Contribution à l'analyse et la redaction de la pollution harmonique dans le réseau électrique. 2007. Thèse de doctorat. Annaba. [BOUKADOUM, Aziz. Contribution to the analysis and drafting of harmonic pollution in the electrical network. 2007. PhD thesis. Annaba.] *https://www.ccdz.cerist.dz/admin/notice.php?id=00000000000000733867000632*

[10] KEBIRI, Samia. Modélisation et simulation d'un filtre actif multiniveaux. 2009. Thèse de doctorat. Université Mouloud Mammeri. [Modeling and simulation of a multilevel active filter. 2009. PhD thesis. Université Mouloud Mammeri.] *https://fdsp.ummto.dz/500*

[11] KHADEM, Shafiuzzaman Khan, BASU, Malabika, et CONLON, Michael F. Fonctionnement parallèle des onduleurs et des filtres de puissance active dans un système de production décentralisée – Une revue. Revue des énergies renouvelables et durables, 2011, vol. 15, no 9, p. 5155-5168. [KHADEM, Shafiuzzaman Khan, BASU, Malabika, et CONLON, Michael F. Parallel operation of inverters and active power filters in a distributed generation system - A review. Renewable and Sustainable Energy Review, 2011, vol. 15, no. 9, pp. 5155-5168.] *https://doi.org/10.1016/j.rser.2011.06.011*

[12] CHAOUI, Abdelmadjid. Filtrage actif triphasé pour charges non linéaires. 2018. Thèse de doctorat. [CHAOUI, Abdelmadjid. Three-phase active filtering for nonlinear loads. 2018. PhD thesis.] *http://dspace.univ-setif.dz:8888/jspui/handle/123456789/2409*

[13] GHADBANE, Ismail. Commande d'un filtre actif triphasé parallèle par différents régulateurs. 2011. Thèse de doctorat. Faculté des sciences et de la technologie UMKBiskra. [GHADBANE, Ismail. Control of a parallel three-phase active filter by different controllers. 2011. Doctoral thesis. Faculty of Science and Technology UMKBiskra.] *http://thesis.univ-biskra.dz/1743/*

[14] ORJUELA, Julian Alberto Fernandez. Intégration des Véhicules Electriques dans le réseau électrique résidentiel: impact sur le déséquilibre et stratégies V2G innovantes. 2014. Thèse de doctorat. Université de Grenoble. [ORJUELA, Julian Alberto Fernandez. Integration of Electric Vehi-cules in the residential power grid: impact on imbalance and innovative V2G strategies. 2014. PhD thesis. University of Grenoble.] *https://hal.science/tel-01076835/*

[15] KOUTOU, Alidou. Contribution à la résolution des déséquilibres de tension sur les réseaux à câbles de garde isolés par l'utilisation des compensateurs statiques (STATCOM). 2023. Thèse de doctorat. Université du Québec à Trois-Rivières. [KOUTOU, Alidou. Contribution to the resolution of voltage unbalances on insulated earth cable networks using static compensators (STATCOM). 2023. PhD thesis. Université du Québec à Trois-Rivières.] *https://depot-e.uqtr.ca/id/eprint/10759/1/eprint10759.pdf*

Biography

Daouda Abdourahimoun is a teacher and researcher at the Faculty of Science and Technology. He is an Assistant Professor specialising in Electrical and Electronic Engineering. His research focuses mainly on the behaviour and constraints of electrical systems. He holds a patent for the invention of a multifunctional agro-industrial machine. He is also a biomedical maintenance engineer.

Research Field

Daouda Abdourahimoun: Energy quality, Resilience, Flexibility of electrical systems, Smart grid, Energy planning.