Ain Shams Engineering Journal 16 (2025) 103479

Contents lists available at ScienceDirect

Ain Shams Engineering Journal

journal homepage: www.sciencedirect.com

Full Length Article

Bi-Level Multi-Objective optimization of harmonic filters for PV penetration and harmonics mitigation in power distribution using Autism-Based Optimizer

Asmaa Elhussiny [a,b], Shady H.E. Abdel Aleem [c], E.E. El-Kholy [c], Ahmed F. Zobaa [d,*], Ahmed M. Zobaa [e]

[a] National Organization for Potable Water and Sanitary Drainage, Egypt
[b] Electrical Engineering Department, Faculty of Engineering, Menoufia University, Shibin El Kom, Menoufia 6132711, Egypt
[c] Department of Electrical Engineering, Institute of Aviation Engineering and Technology, Giza 12658, Egypt
[d] Electronic and Electrical Engineering Department, Brunel University of London, Uxbridge UB8 3PH, UK
[e] Electrical Power Engineering Department, Faculty of Engineering, Cairo University, Giza 12613, Egypt

ARTICLE INFO

Keywords:
Harmonics mitigation
Distributed generation systems
Photovoltaic systems
damped passive Filters
Harmonic Blocking Filter
Harmonic pollution
Total harmonic distortion
Optimization

ABSTRACT

The rising usage of power electronic converters linked to renewable energy sources has become a major source of harmonics in power systems. Passive harmonic filters are an excellent solution for addressing this issue. However, these traditional filters have a problem linked to resonance frequency, which needs damping. This paper introduces a Harmonic Blocking Filter (HBF) that consists of a shunt-connected Damped Double-Tuned Passive Filter (DDTF) and a series component. Six different DDTF schemes are investigated: four single-resistor DDTFs (SR-DDTF) and two double-resistor DDTFs (DR-DDTF). This study intends to perform harmonic mitigation and increase PV penetration levels by obtaining parameters for each HBF system using the Autism-Based Optimizer (ABO). The Harmonic Pollution Factor (HPF) is a power quality indicator used to assess and reduce the system's harmonic content. The findings show that the proposed HBF filter efficiently increases PV penetration in the system while lowering harmonic levels.

1. Introduction

Harmonic distortions have a substantial impact on power system components and customer devices. Harmonics reduce power quality and increase system losses by up to 20 %. According to recent studies, incremental power losses in distribution networks might vary from 4 to 8.5 % for different values of harmonics. Losses of the distribution system change with nonlinear loads and can reach 110 % with 100 % harmonic loads. A smart grid with 1–8 % Voltage Total Harmonic Distortion (THD_V) may experience losses ranging from 4.7 to 42.2 %. Harmonics can be captured at the building, device, and levels of distribution and inserted back into the system to fix deformed wave patterns, improving the quality of power [1].

Several techniques of harmonic mitigation have been suggested and used in recent years. Many industrial establishments use harmonic filters to guarantee that they meet the harmonic restrictions set by the supply utilities [2]. Passive harmonic filtering is the most frequent harmonic mitigation technology in power systems [3–10]. Its simplest form is the single-tuned filter (STF) and its primary premise is to generate a low-impedance path by resonance between the filter capacitor and reactor, thereby preventing harmonics from penetrating the network. Various filter topologies have been proposed to accommodate different applications, such as single-tuned, high-pass, c-type, double-tuned, triple-tuned, etc [11–23]. The researchers are still working on other promising topologies. Active harmonic filtering is a new harmonic elimination technology that can provide a more flexible performance than passive filtering [24–29]. The most basic active filtering is to extract the undesired harmonics and inject an opposite signal back into the line for cancellation. Although active harmonic filtering has been studied for years, the number of projects applying this new technique is still limited. The main reason is its high cost, low reliability, and excessive switching loss; finally, hybrid harmonic filtering is proposed as a combination of

* Corresponding author.
E-mail addresses: Asmaaaelhosainy@gmail.com (A. Elhussiny), engyshady@ieee.org (S.H.E. Abdel Aleem), eelkholy63@yahoo.com (E.E. El-Kholy), azobaa@ieee.org (A.F. Zobaa), a.mzobaa@cu.edu.eg, a.m.zobaa@ieee.org (A.M. Zobaa).

https://doi.org/10.1016/j.asej.2025.103479
Received 28 December 2024; Received in revised form 18 April 2025; Accepted 6 May 2025
Available online 13 May 2025

passive and active harmonic filters [30–34]. The research's main intention is to minimize the capacity of the active filter and optimize the performance of the passive filter. The passive part is generally designed to reduce the dominant harmonics and support reactive power. The active part addresses non-characteristic and high-frequency harmonics with a low content. Among the above methods, passive harmonic filtering is still preferable due to its simplicity, reliability, and economic advantages, especially for the harmonic-producing loads above 1 MW [35].

Among these solutions, passive harmonic filters remain the most effective and feasible option for decreasing the distortions of harmonics in systems of medium and high voltage (12 kV). Passive filters arise in a variety of topologies, each with a unique frequency response. The single-tuned and high-pass filters are considered the most prevalent. A single-tuned filter filters a single harmonic, whereas high-pass filters remove harmonics above specific frequencies. There are several categories of high-pass filters, containing various orders such as first, second, and third orders. The industrial practice utilizes multiple filter topologies to get the desired harmonic filtering performance [2].

The traditional filter damping resistance design is insufficient to ensure optimal leakage current attenuation and control system stability. In comparison to the high-cost and complex active control methods, passive damping is regarded as the simplest, most commonly used, and least expensive method of reducing the filter resonance peak. In this situation, the damping resistance is set to provide the appropriate attenuation of the filter resonance peak, thereby enhancing the stability [36].

The damping resistance is connected based on two methods, including the parallel connections of resistors (LCL-P-R) and the series connection of filter-based LCL and resistors (LCL-S-R) [37]. This research has shown that introducing parallel damping resistors suppresses the effect of resonance and the component of THD better than the type of series configuration [38].

Power networks have conventionally implemented harmonic filters to minimize the effects of harmonic distortion and to diminish the harmonic levels [37,39,40]. For example, research in [39] compared the abilities and performance of passive and active filters in reducing harmonics. Furthermore, it has demonstrated the merits and drawbacks of each type. To choose the optimal filter design for domestic single-phase applications, several strategies and various mitigating methods have been examined [40]. The study assessed the dynamic and steady-state outputs for the filters of active power, as well as the performance of two regularly utilized methods of reference current extraction. According to the results, minimizing the %THD to less than 5 % was attainable under the standard of IEEE-519 recommendations [41]. To reduce the harmonic voltage, the researchers in [37] addressed the issue in a power system that included the motor drives for both the roughing mill and the finishing mill. By compensating for reactive power and absorbing harmonics, a system of passive harmonic filters with suitable and optimal size and capacity in a power system that includes a drive of mill motor can offer a cost-effective solution. In [42], the diagnostic technique is based on simulation, which investigates the effects of environmental factors such as humidity and pollution levels and utilizes LC equivalent circuits of various insulator types. The first stage in developing LC waveforms is to experiment with different insulator materials, such as advanced composite insulators, standard ceramic and glass insulators, and hybrid RTV silicone rubber-coated and conducting glazed insulators. The LC circuits of Suwarno's and Kizilcay's models are then simulated, providing equivalent LC waveforms and properties. The properties of each insulator and its environmental impacts are then diagnosed using the values of the corresponding circuit parameters. The findings indicate that composite insulators composed of SiR or epoxy resin have a nonlinear resistance ranging from a few MΩ to tens of GΩ and a greater intrinsic resistance of around 40 GΩ. This suggests that the insulators are very resistant to water and impurities on their surface. The degree of severity of the insulator issue is expected to be revealed by comparing these attributes. Another approach to decreasing Total Harmonic Distortion (THD) in the context of 5G VCO design is explored in [43]. The study describes a unique Complementary Metal Oxide Silicon (CMOS) ring oscillator that functions as a voltage controlled oscillator. By combining the advantages of a current-starved ring oscillator with a negative-skewed delay, the proposed design maximizes their respective benefits. The suggested design uses a 1.15 V control voltage and a 2 V supply voltage to produce a 9.35 GHz dominant frequency with a 13.82 % harmonic distortion between the inputs and outputs. The suggested architecture may execute 5 G-based applications requiring high frequency and low power by carefully selecting passive components within the design.

In recent years, sources of renewable energy have received enormous attention. Renewable energy is derived from natural resources that are continually replenished and have a lesser environmental effect than fossil fuels. The primary sources include: (solar energy, wind energy, hydroelectric power, biomass energy, and so on). [44] Investigates the potential of hydropower as a renewable energy source for the Macaronesian islands, which include the Azores, Madeira, the Canary Islands, and Cape Verde. Because of their distant location and existing reliance on imported fossil fuels, these islands require an ecological shift to renewable energy sources. The technique employed in this research includes a SWOT analysis and a survey of relevant literature. The SWOT analysis assesses the strengths, weaknesses, opportunities, and threats to hydropower development on each island. The findings suggest that each island has unique characteristics that influence its hydropower potential. Because of its rainfall and volcanic properties, the Azores already has mini-hydropower plants and the potential for pumped storage systems. Madeira also uses hydropower, including the world's first underground pumped storage facility (UPHS) in Socorridos. However, there are restrictions owing to the steep terrain and the struggle for water supplies. The Canary Islands highlight the success story of El Hierro Island, which greatly expanded renewable energy penetration with a wind farm and pumped storage hydropower plant. Cape Verde's geography and lack of rainfall make hydroelectric production a substantial issue, thus, the focus has switched to wind generation. The study finds that hydropower can play an important role in the ecological change of these islands. However, careful planning and awareness of environmental elements are required to maximize advantages while minimizing potential negatives. The report underlines the significance of conducting island-specific studies and investigating possibilities for pumped storage systems.

PV systems are recognized as a widely utilized and promising generation system across the world. Because these generators are connected to the grid via power electronics converters, they may present some harmonic level challenges, particularly in high penetration cases [45,46]. Harmonic distortion in the PV system may be generated due to intrinsic and extrinsic effects. Harmonics generated by such power electronics-based technologies used in PV systems are regarded as one of the most serious concerns that may arise, particularly when integrating PVs at high penetration rates. Intrinsic harmonic distortions are caused by inverter defects such as components and control loop nonlinearities, measurement inaccuracies, and limited PWM resolution. Connection to a weak and distorted electrical grid could be regarded as an extrinsic influence on the PV system's output waveform. The current waveform that the inverter produces is distorted by a distorted voltage in the control system.

PV systems use switching devices such as diodes, IGBTs, and thyristors at the interface of the grid to send produced DC power to the network of AC distribution. Because these devices are linked to nonlinear loads, they generate harmonic voltages and currents at far higher frequencies than the fundamental frequency, often many times the fundamental frequency. Thus, it is vital to reduce these harmonics that influence the system and might create various difficulties, such as losses of power and limit the equipment life [47].

Several factors influence the power quality of the PV inverter's current. Both current THD and reactive power are related to the output active power levels, which vary with the solar irradiance levels. When the level of irradiation is low, the value of current THD value increases rapidly. But it decreases significantly as the output power of the inverters of PV growths and extends its nominal value, as the factor of THD is inversely proportional to the inverters' output for the PV. The current distortion behavior in the PV system will be stated by the intrinsic characteristics of the circuit of control and nonlinear components of the PV inverter [48].

A detailed study of hybrid renewable microgrids' harmonic analysis, including the best passive filter design and uncertainties, was conducted in [49]. Another area of research focuses on creating a filter-based shunt active power in a practical test platform to enhance the quality of power in a hybrid renewable energy system [50]. Similar studies in RES often use filters and harmonic reduction techniques [51–53]. Issues with power quality resulting from the integration of RESs' wind and solar energy systems have been examined in [54]. Research in [47] aims to provide effective Passive harmonic filter modeling and application in systems of power distribution, taking into account the influence of high penetration of PV with non-linear loads. All previous methods and techniques have a gap in reducing the THD for voltage and current simultaneously with the presence of a high share of DGs.

Meshack Magaji Ishaya et al in [55] introduced a novel single-tuned passive filter (STPF) that minimizes harmonics of the 5th, 7th, 11th, 13th, 17th, and 19th sequences in a three-phase power system. The measurements were collected at the point of common connection. To evaluate the filter's performance, the system and STPF were developed in MATLAB/Simulink, and the simulated results, with and without the STPF, were examined. The STPF lowered THDI from 14.93 % to 4.87 %, meeting the IEEE 519–2022 standard and effectively reducing harmonics to the target level. The STPF was successfully adjusted to reduce the harmonics of the fifth, seventh, eleventh, thirteenth, seventeenth, and nineteenth sequences. Difficulties faced when designing the system are mostly connected to the individual and overall harmonic distortion restrictions for current and voltage at the PCC. As a result, the STPF had the constraint of only eliminating harmonics one at a time and was designed for a fixed nonlinear load, although the load frequency might change quickly.

Similar to Aashish Jaiswal's research in [56], this work presents innovative harmonic mitigation approaches adapted for islanding settings. These solutions include improved control algorithms, filter designs, and modulation schemes that reduce harmonics and improve overall system performance during islanded operation. Comparative assessments of several mitigation options are offered, assessing their effectiveness in reducing harmonic distortions while preserving grid code compliance. The study adds new insights to the area of grid-connected PV systems by providing a thorough knowledge of harmonic difficulties during islanding occurrences and presenting novel ways for mitigating them. The findings of this study are critical for improving the dependability, stability, and power quality of PV systems linked to the grid, allowing green energy sources to be added to the grid without issue. The results show that the THD reduction is around 3 % when compared to the present passive technique and existing active/hybrid approaches, which have THD reductions of 4.5 % and 3.5 %, respectively.

Bonolata Biswas Taya et al in [57] conducted this study by comparing data from D-STATCOM and HAPF, with a focus on voltage wave measurements, 3rd and 5th harmonics, and total harmonic distortion. Three distinct capacitor banks with capacities of 40-kilovolt ampere reactive (KVAR), 60 KVAR, and 80 KVAR were chosen as benchmarks. MATLAB/Simulink software was used to collect all required data for each of the capacitor banks mentioned above. HAPF outperforms D-STATCOM in all areas of data analysis in this investigation. Although a simulation was run to see whether there would be any differences with varying loads, no changes were found. This study intends to make it easier to pick a suitable device for industrialization, as failing to do so might have negative consequences for the system. The study's disadvantage is that, while the research was effective, it only looked at one type of renewable energy system, in this case, wind power. The research establishes the fixed specifications of this power system.

Therefore, this paper presents a comprehensive methodology for designing a damped Harmonic Blocking Filter (HBF) as a harmonic mitigation technology to be used after recognizing harmonics as a critical issue affecting PQ due to its benefits of cheap component cost, small size, simplicity of design, affordability, and enhanced power quality. The paper presents the design of HBF, which consists of two parts: a series part and a shunt-connected part. The series part of the HBF is a series inductor-capacitor combination for blocking harmonic currents. The shunt part is a damped double-tuned filter (DDTF) with six schemes of single and double resistors. The HBF provides an effective solution for harmonic mitigation of power systems with a high share of DGs, such as inverter-based PVs integrated with linear and non-linear loads. The results show that the THD for voltage for all DDTF schemes is about 1 %, whereas the THD for current is less than 0.001 % for all schemes except scheme D. As a result, the suggested HBF outperformed earlier techniques in terms of harmonics reduction while maintaining high PV penetration.

The rest of the paper is structured as follows: Section 2 describes the system under study, the approach for modelling and designing the HBF, and the problem formulation. Section 3 depicts the optimization technique. Section 4 examines the results and explains them in three scenarios: 1. when the system is not compensated, 2. with a shunt filter, and 3. with both a shunt and a series component filter. The paper is finally concluded, and the future work is given in Section 5.

2. System formulation

Harmonics in power networks are caused by the integration of renewable energy sources. To address this issue, passive filters are commonly used for harmonic mitigation. This study introduces a novel HBF that solves this problem and overcomes the limitations of traditional passive filters by combining a shunt-connected DDTF with a series component, allowing for robust harmonic suppression while facilitating higher PV integration. To enhance performance under diverse grid circumstances, the suggested HBF design analyzes six distinct DDTF schemes, four single-resistor (SR-DDTF) and two double-resistor (DR-DDTF). A crucial novelty is the use of the Autism-Based Optimizer (ABO), a recently developed metaheuristic algorithm, to systematically modify HBF parameters. This optimization method prioritizes two goals: reducing harmonic distortion, as measure by the Harmonic Pollution Factor (HPF), and increasing PV hosting capacity. Simulation findings show that the proposed HBF not only dramatically decreases harmonic levels, but also raises the PV penetration threshold, filling a major gap in existing passive filter designs. The paper contributes to the field of power quality management by proposing a scalable, optimization-driven strategy to harmonic reduction, which directly supports worldwide efforts to improve renewable energy integration in current grids.

2.1. System under study

The system under study and used in this paper is presented in Fig. 1. In which the grid-connected combination of linear and non-linear load is integrated with a high share of PV. This system has 49 harmonic signatures. As shown in Fig. 1, the HBF consists of two parts: the series part (Z_{fs}) and the parallel part (Z_{fp}), which is a DDTF. Apart from the HBF, the system was utilized before to investigate the harmonic mitigation and hosting capacity enhancement capabilities in [10], where the detailed system parameters and harmonic signatures can be found.

2.2. HBF design

Passive filters will be employed in this investigation because they are

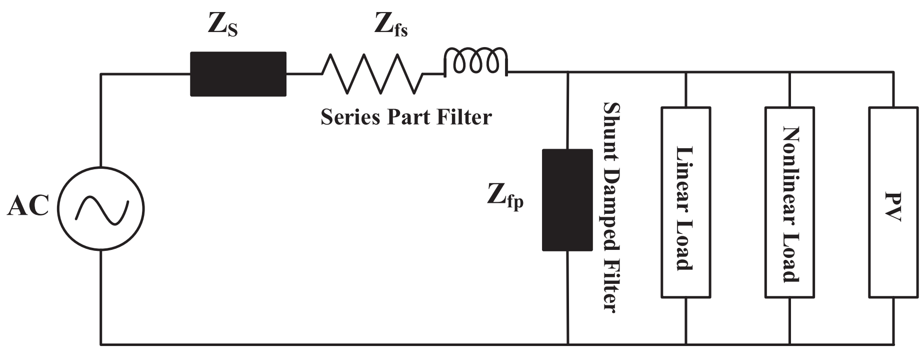

Fig. 1. The circuit of the system under study.

simple and inexpensive. They are defined as a resonant circuit having a low impedance at its tuned frequency that is trapped. Passive filters can be linked in series, shunt, or parallel. Passive filters are often tuned at frequencies with tolerable values of $\pm$ 3 % to $\pm$ 15 %, which differ from the expected harmonic frequencies for suppression. The ratings of inductors and capacitors may alter due to manufacturing tolerances (usually $\pm$ 8 % and $\pm$ 5 % in capacitance and inductance, respectively), which are sufficient for harmonic filtering [49]. The most important criterion for designing this passive damping filter is that it does not affect any other grid part. Therefore, the stability of the control system should be guaranteed first [58]. Fig. 2 shows the six different schemes of DDTFs. Schemes A, B, C, and D have a single damping resistor (SR-DDTF), but schemes E and F have a double damping resistor (DR-DDTF).

The series part of the HBF is designed to act as a short-circuit at the fundamental frequency. Hence, the series inductance (L_s) is optimized, and then the series capacitance (C_s) is calculated to satisfy this condition as follows:

$$Z_{fs}(\omega_f) = j\left(\omega_f L_s - \frac{1}{\omega_f C_s}\right) = 0 \tag{1}$$

Where ω_f is the fundamental angular frequency.

The parallel part may be one of the six DDTF schemes (Schemes A-F); hence, the DDTF is firstly designed as an undamped DTF described in detail in [8], and then the DDTF is designed by narrowing the difference between the DTF and DDTF impedance–frequency characteristics. This is performed using a bi-level optimization algorithm as described in [8]. The parallel part parameters can be calculated as follows:

$$C_1 = \left(\omega_f\left(\frac{\omega_p}{\omega_1\omega_2}\right) - \frac{1}{\omega_f} + \frac{\omega_f}{\omega_1^2\omega_2^2}\left[\frac{\left(\omega_1^2+\omega_2^2-\omega_p^2\right)\omega_p^2 - \omega_1^2\omega_2^2}{\omega_p^2-\omega_f^2}\right]\right) \times \left(\frac{Q_f}{V^2}\right) \tag{2}$$

$$C_2 = C_1\left(\frac{\omega_1^2+\omega_2^2-\omega_p^2}{\omega_s^2} - 1\right)^{-1} \tag{3}$$

$$L_1 = \frac{1}{\omega_s^2 C_1} \tag{4}$$

$$L_2 = \frac{1}{\omega_p^2 C_2} \tag{5}$$

The source current (I_s) and Point of Common Coupling (PCC) voltage (V_L) can be formulated as follows:

$$I_s = \sqrt{\sum\nolimits_{h\geq 1} I_{sh}^2} \tag{6}$$

$$V_L = \sqrt{\sum\nolimits_{h\geq 1} V_{Lh}^2} \tag{7}$$

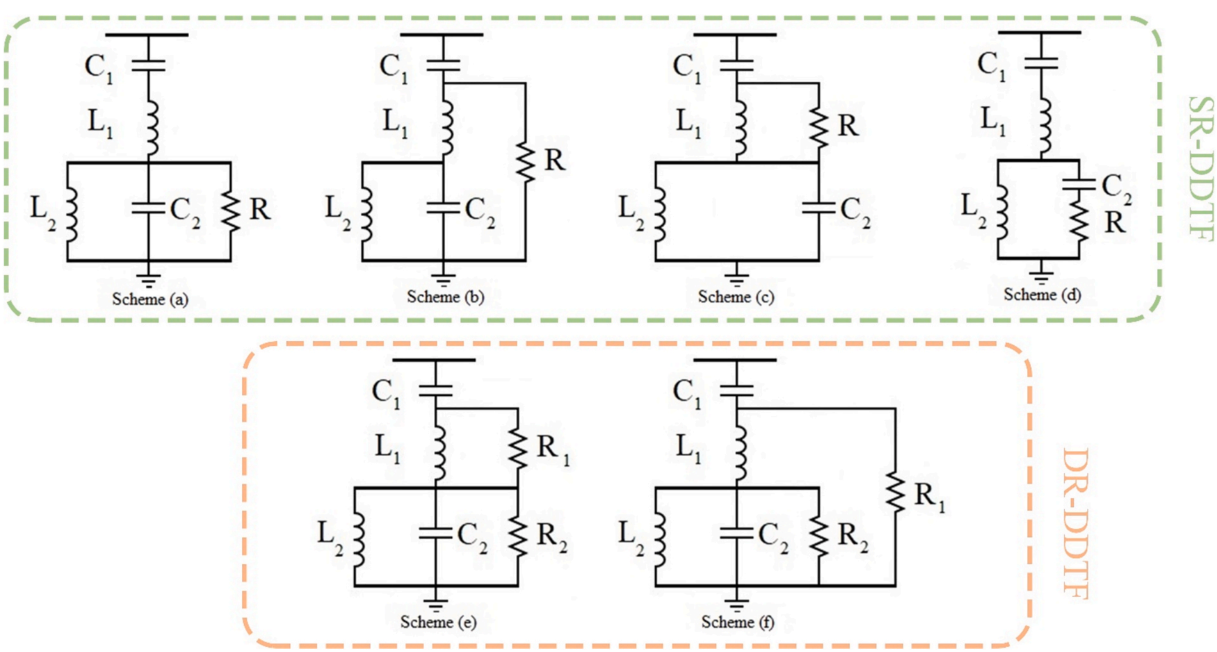

Fig. 2. Various configurations of DDTFs.

Where h is the harmonic order.

The system Power Quality (PQ) indices are mathematically formulated as follows:

$$PF = \frac{\sum_{h\geq 1}(V_{Lh} \times I_{sh} \times cos(\varnothing_h))}{V_L \times I_s} \times 100\% \tag{8}$$

$$THD_V = \frac{\sqrt{\sum_{h\geq 2} V_{Lh}^2}}{V_{L1}} \tag{9}$$

$$TDD_I = \frac{\sqrt{\sum_{h\geq 2} I_{sh}^2}}{I_{ML}} \tag{10}$$

The Harmonic Pollution Factor (*HPF*) was previously introduced in [59]. It is considered a more generalized PQ metric as it depends on both THD_V and TDD_I. Hence, minimizing *HPF* leads to the minimization of both metrics. The *HPF* can be formulated as follows:

$$HPF = \sqrt{THD_V^2 + TDD_I^2 + (THD_V^2 * TDD_I^2)} \tag{11}$$

The PV penetration level (*PVP*) is defined as the ratio between the PV generator's total apparent power (S_{PV}) and the total system's base power (S_{base}) and can be expressed as follows:

$$PVP = \frac{S_{PV}}{S_{base}} \tag{11}$$

2.3. Problem formulation

The optimization is divided into two levels: higher-level and lower-level objective functions. The lower-level objective function (OF_{LL}) and the higher-level objective function (OF_{HL}) can be expressed as follows:

$$OF_{LL}(L_1, C_1, L_2, C_2, R_1, R_2, L_S, C_S) = Min(\max(\Delta\omega_{x1}, \Delta\omega_{x2}, \Delta\omega_{z1}, \Delta\omega_{z2})) \tag{12}$$

$$OF_{HL}(L_1, C_1, L_2, C_2, R_1, R_2, L_S, C_S) = Min\left(W_1 \times HPF + \frac{W_2}{PVP}\right) \tag{13}$$

where $\Delta\omega_{x1}$ is the difference between the shunt filter's first tuning frequency as an undamped filter and the first tuning frequency at which its reactance is minimal, while $\Delta\omega_{z1}$ is the difference between the shunt filter's first tuning frequency as an undamped filter and the first tuning frequency at which its impedance is minimal, and W_1 and W_2 are weighting factors. There are seven parameters for the first four schemes (A, B, C, D) of the shunt HBF part, as they are SR-DDTF. However, there are eight parameters for the other two schemes (E, F), as they are DR-DDTF, hence, R_2 is omitted from the optimization problem.

The optimization constraints (*Cons*) include the following:

$$Con_1 : 0 < L_1, C_1, L_2, C_2, R_1, R_2, L_S, C_S < 1 \tag{14}$$

$$Con_2 : PF \geq 92\% \tag{15}$$

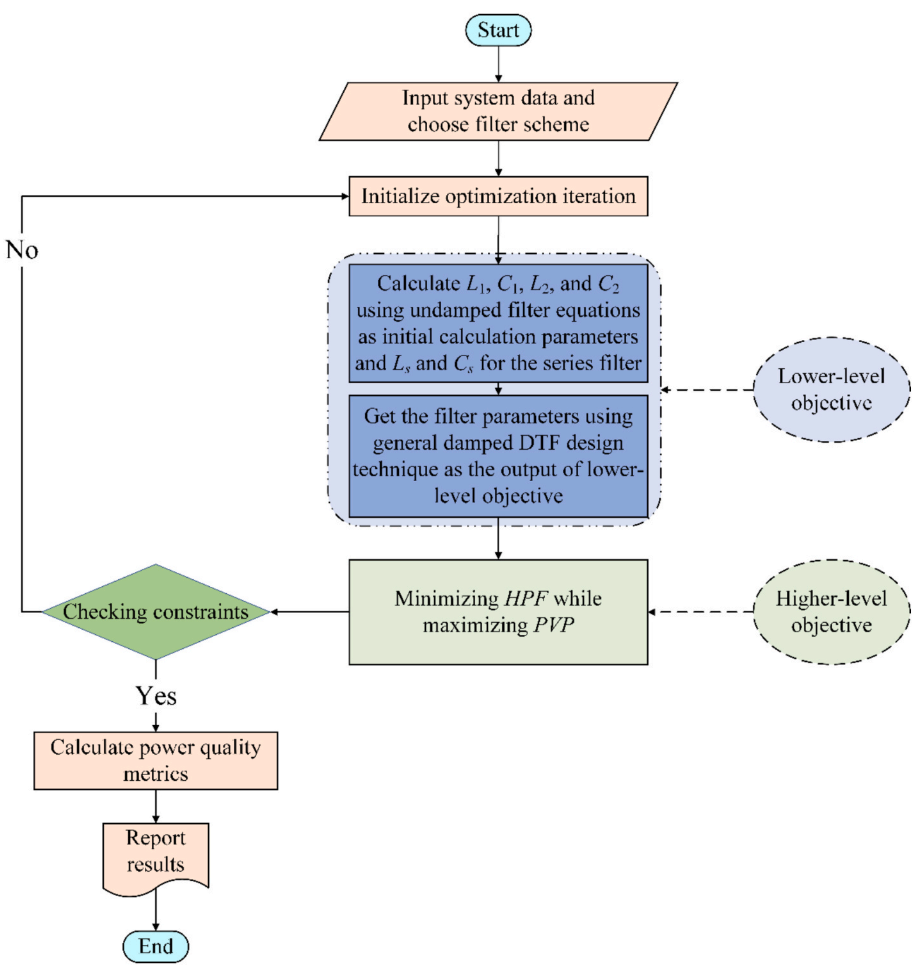

Fig. 3. Bi-Level optimization problem for the HBF design.

$$Con_3 : THD_V < 5\% \tag{16}$$

$$Con_4 : TDD_I < 8\% \tag{17}$$

The following flow chart, shown in Fig. 3, better explains the bi-level optimization process for designing the HBF.

3. Autism-Based Optimizer (ABO)

The Autism-Based Optimization (ABO) algorithm is an innovative computational method that draws inspiration from certain cognitive patterns associated with the autism spectrum, particularly the characteristics of focused attention and systematic information processing. The algorithm begins by creating a set of potential solutions distributed across the search space, similar to how an individual might systematically scan their environment for information. It then employs two main search strategies: a global search that explores broadly across the solution space and a local search that focuses intensely on promising areas, mirroring the ability to shift between broad and focused attention patterns.

The algorithm draws inspiration from several cognitive patterns commonly observed in autism without making judgments about these traits. One key characteristic is the ability to pay intense attention to specific details while processing information systematically. In the algorithm, this is reflected in how it searches through the solution space – it can focus intensely on promising areas (exploitation phase) while maintaining the ability to systematically explore new regions (exploration phase). This mirrors how some autistic individuals might thoroughly examine specific aspects of a subject that interests them while maintaining a systematic approach to understanding the whole.

The algorithm's memory and update mechanism is inspired by the often-observed pattern-processing abilities and strong systematic thinking associated with autism. Just as some autistic individuals excel at recognizing patterns and maintaining detailed information about their interests, the algorithm maintains and updates a detailed memory of the best solutions it finds. The transition between broad and focused search behaviors in the algorithm is analogous to how attention patterns can shift between different levels of focus – from broad environmental awareness to intense concentration on specific details.

The social learning aspect of the algorithm, where solutions are influenced by both individual experiences (local best) and group information (global best), takes inspiration from how information processing can involve both individual detailed observation and broader pattern recognition. The control parameters that guide the algorithm's behavior parallel the way information processing can be regulated and adjusted based on the specific needs of the situation.

The algorithm's effectiveness comes from its ability to balance between exploration and exploitation phases, guided by certain control parameters that gradually shift the focus from broad searching to fine-tuning solutions. This transition is similar to how attention can be initially broad but then become highly focused on specific details. The algorithm maintains a memory of the best solutions it has found and continuously updates this memory as better solutions are discovered. The search process is further enhanced by incorporating information from both the best-known solution and the average position of all solutions, helping to maintain diversity while still converging toward optimal results. This combination of features makes ABO particularly effective for solving complex optimization problems in various fields, from engineering design to feature selection in machine learning. The optimizer code is available in [60].

Due to its distinctive bio-inspired design that mimics cognitive patterns associated with autism, the Autism-Based Optimizer (ABO) offers several advantages over conventional optimization algorithms. These include: a dynamic balance between exploration and exploitation (which outperforms algorithms such as Particle Swarm Optimization (PSO) and Genetic Algorithms (GA), which may depend on static parameters or heuristics like fixed mutation rates that can lead to premature convergence or inefficient resource allocation), memory retention and continuous updates (which enhance stability in dynamic environments, where algorithms like Ant Colony Optimization (ACO) might overlook valuable historical data due to pheromone evaporation), systematic and focused local search (which minimizes the risk of becoming trapped in local optima compared to Simulated Annealing (SA) or hill-climbing methods, which may lack systematic exploration following initial exploitation), diversity maintenance through adaptive parameter control (ABO is more user-friendly and robust across various problem domains compared to algorithms like GA, which require user input for mutation and crossover rates), and hybrid information (ABO successfully prevents the premature convergence common in PSO and GA by preserving population diversity longer, which is crucial for complex, multi-modal problems). Consequently, ABO's strengths lie in its powerful memory processes, methodical yet adaptable search tactics, and an adaptive balance of exploration and exploitation, all influenced by cognitive qualities associated with autism. These characteristics enable it to excel in complex, multi-modal optimization problems where conventional algorithms may falter due to strict parameterization, low variety, or premature convergence. ABO provides a unique perspective on bio-inspired optimization by transforming human cognitive strategies into a computational framework [60].

4. Results and discussion

The MATLAB software is utilized to simulate the studied problem, which is depicted in Fig. 1. In this paper, an HBF with a parallel part of a DDTF filter with its six schemes in a distribution system with a PV grid-connected generator is designed. Three scenarios are examined. Scenario 1: the uncompensated system; Scenario 2: when a shunt DDTF filter only is connected to the system; and Scenario 3: when the system harmonics are mitigated using HBF (both the shunt and series components of the HBF are present). All these scenarios utilize ABO to obtain the optimal HBF parameters. Those scenarios are better illustrated in Fig. 4 as follows:

Scenario 1: The uncompensated system.

The uncompensated case scenario of the system is simulated such that it does not include any DGs and with a gradual increase of DGs penetration ratio specifically at 20 %, 40 %, 60 %, and 80 % to investigate the effect of increasing the inverter-based DGs penetration on the system's power quality and other performance indices. The obtained results are shown in Table 1.

The PV generator (DG) is assumed to have a 0.95 PF lagging in all cases. One can notice that as the penetration level increases, the PCC voltage V_L increases, *THDV* increases, *TDDI* increases, HPF increases as a result, and finally, the *PF* decreases. There cannot be any PV penetration in the first place, as the uncompensated case scenario without the addition of any PV has system performance indices violating the IEEE 519 standards, and the penetration of PV will only make them worse. Hence, this comparison is performed to verify this concept for this system.

Scenario 2: Shunt only.

Six different DDFT filter schemes will be introduced in shunt to the system, and a high share of DGs as PVs will be integrated with loads that are both linear and non-linear to enhance the system performance and power quality by reducing the voltage and current THD at the same time. The ABO optimization technique is used to find the optimal solution for each scheme of the shunt filter. Table 2 displays the parameters for each scheme of the shunt filter. The results of the system utilizing a shunt filter only are tabulated in Table 3.

After connecting six different schemes of DDTF, we can notice that the value of *THDV* and *TDDI* decreases compared to the uncompensated system. For instance, if we see the results of Scheme A, we can noticed that, the *THDV* decreases from 16.0514 % to 1.455 %, and *TDDI* decreases from 4.4561 % to 1.8291 %. This means that the new DDTF filter

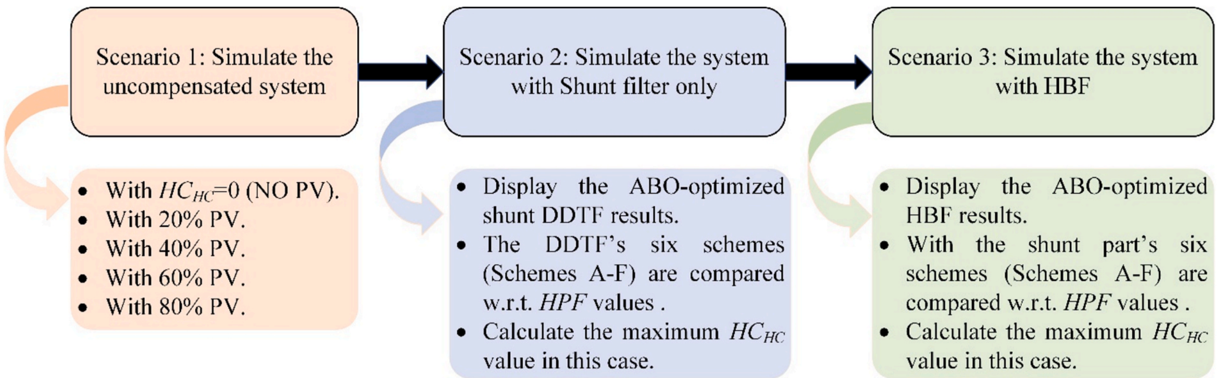

Fig. 4. The three investigated scenarios are in the manuscript.

Table 1
Scenario 1: Uncompensated system results without any DGs in the system.

Parameters	Uncompensated Case				
	Without any DGs	20 %	40 %	60 %	80 %
V_L *(p.u.)*	0.95757	0.96585	0.97322	0.98015	0.98684
THDV (%)	16.0514	16.3195	16.1398	15.8159	15.4633
TDDI (%)	4.4561	4.6064	4.7431	4.8675	4.9817
HPF (%)	73.4404	77.0633	78.3791	78.7423	78.7286
PF (%)	87.1501	81.39	70.997	51.3863	17.5933

is very appropriate for mitigating the harmonics and enhancing the system's power quality.

Scenario 3: HBF-compensated system.

In this scenario, a hybrid damping method that combines a shunt DDTF and a series part is connected to the system with a high share of DGs such as PV systems, which ensures the stability of the system by reducing THD for voltage and current at the same time and improving the power factor of the system. Tables 4 and 5 show the filter parameters and the results of the compensated case.

The THD results in Tables 3 and 5 for voltage and current harmonic distortion show that the current and voltage THD after applying the hybrid filters is lower than the scenario of the shunt filter only. For instance, in scheme A, the value of TDD_I was 1.8291 % in the case of the shunt filter only and fell to 0.00031563 % after adding the series part. The THD_V value was 1.4551 % and has now dropped to 1.086 %. All THD values for current and voltage are reduced in the other schemes, and they are all less than the IEEE-519 standard's acceptable limit of 5—8 %, according to the IEEE-519 standards. As a result, our proposed techniques demonstrate the effectiveness of using a hybrid damping approach that combines a shunt DDTF and series component harmonic filters to reduce harmonics even in cases with high penetration of DG, such as systems of PV.

Figs. 5 and 6 illustrate the THD_V in the six schemes in two cases: shunt filter only and with the HBF. In Fig. 5, the uncompensated case's THD_V as well as the maximum allowable limit implied by IEEE 519 are also shown. It is evident that Scheme D is the worst scheme in THD_V; hence, it will not be included in Fig. 6. The maximum allowable limit and the uncompensated case will also be excluded from Fig. 6 for better clarification of the values of the other schemes (Schemes A, B, C, E, F). From Fig. 6, it is evident that for the shunt filter case, Scheme F is superior compared to the other schemes in lowering THD_V value, while all the schemes achieve lower values of THD_V in the HBF case compared to

Table 2
Scenario 2: Shunt Filter parameters.

Components	ABO optimizer					
	Scheme A	Scheme B	Scheme C	Scheme D	Scheme E	Scheme F
L_1 *(H)*	$7.3598*10^{-6}$	$7.0433*10^{-6}$	$2.4105*10^{-5}$	0.001988	$8.3613*10^{-6}$	$7.1646*10^{-6}$
L_2 *(H)*	$5.9843*10^{-8}$	$2.7641*10^{-4}$	$1.1830*10^{-4}$	0.00670	$6.5623*10^{-7}$	$6.9474*10^{-6}$
C_1 *(F)*	0.001056	0.001483	0.001097	$6.5300*10^{-4}$	0.001054	0.0011435
C_2 *(F)*	0.1076399	0.0091639	$8.9386*10^{-4}$	$3.3674*10^{-6}$	0.011449	0.00901
R_1 *(Ω)*	$1.1950*10^{5}$	$6.1526*10^{5}$	$10*10^{5}$	1	$8.6411*10^{5}$	$10*10^{5}$
R_2 *(Ω)*	–	–	–	–	$8.7652*10^{5}$	$2.2631*10^{5}$
h_1	35.3945	1.85499	6.3553	1.3340	30.3448	31.4552
h_2	40.4446	33.5752	30.1447	44.3646	41.0151	44.9555
Inverter phase angle	−13.1704	−15.9470	−17.7224	−16.9334	−14.7820	−15.65445
Q_{shunt}	4.8944	5.1530	5.0136	2.9559	4.8753	5.30319
$m_{parallel}$	39.6602	2	9.7885	21.1861	36.7227	40.2118

Table 3
Scenario 2: Shunt filter only results.

Scheme	ABO Optimizer					
	V_L *(p.u.)*	THD_V *%*	TDD_I *%*	*P.F%*	*HPF%*	*PV Penetration %*
Scheme A	0.99259	1.4551	1.8291	98.0143	3.5421	72.4946
Scheme B	0.99213	1.3273	1.8135	98.0814	3.2931	72.3107
Scheme C	0.98906	2.3956	1.8251	97.7642	5.3093	65.7546
Scheme D	0.97428	7.2603	2.6757	91.8429	20.9104	38.3161
Scheme E	0.99043	1.4771	1.8021	98.0251	3.5377	68.0171
Scheme F	0.99374	1.305	1.8115	98.7497	3.2515	75.0256

Table 4
Scenario 3: HBF parameters.

Components	ABO optimizer					
	Scheme A	Scheme B	Scheme C	Scheme D	Scheme E	Scheme F
L_1 (H)	$5.8817*10^{-6}$	$5.3689*10^{-6}$	$5.3913*10^{-6}$	0.002417	$4.8724*10^{-6}$	$5.7721*10^{-6}$
L_2 (H)	$1.1397*10^{-6}$	$1.1804*10^{-6}$	$9.5099*10^{-7}$	0.01445	$5.8055*10^{-7}$	$4.3020*10^{-7}$
C_1 (F)	0.00117	0.0012	0.0011	$3.3489*10^{-4}$	0.00116	0.00109
C_2 (F)	0.00655	0.00648	0.0094	$2.9748*10^{-6}$	0.01562	0.0227
R_1 (Ω)	$7.4610*10^{5}$	$7.24741*10^{5}$	$10*10^{5}$	1	$10*10^{5}$	$9.8129*10^{4}$
R_2 (Ω)	–	–	–	–	$9.8403*10^{5}$	$3.3013*10^{5}$
h_1	30.3150	30.275	30.0249	1.3348	31.0245	30.4947
h_2	46.5949	47.6452	46.1248	40.685	45.5953	42.2548
Inverter phase angle	−17.5847	−16.22719	−12.0943	17.7268	−15.5279	−14.4739
Q_{shunt}	5.4273	5.58348	5.1165	1.5530	5.3924	5.0834
$m_{parallel}$	36.8125	36.39199	33.5094	15.3520	33.4234	32.2028

Table 5
Fully compensated system Results.

Scheme	ABO Optimizer				
	THD_V %	TDD_I %	P.F%	HPF%	PV Penetration %
Scheme A	1.086	0.00031563	93.5118	1.086	80.6631
Scheme B	1.0561	0.00026932	99.6823	1.0561	81.3394
Scheme C	1.1978	0.0010927	99.3911	1.1978	81.699
Scheme D	9.036	0.3765	97.5876	9.036	86.8494
Scheme E	1.0255	0.00026438	97.7009	1.0255	81.3095
Scheme F	1.1884	0.00026532	96.1889	1.1884	96.1889

the shunt filter scenario. All schemes in Fig. 6 achieve very close values of THD_V; however, Scheme E is proven superior in this regard.

Fig. 7 illustrates the TDD_I in the six schemes in two cases: shunt filter only and with the HBF. In Fig. 7, the uncompensated case's TDD_I as well as the maximum allowable limit implied by IEEE 519 are also illustrated. A logarithmic scale is used for better presentation of both shunt-only and HBF cases, as the values vary over a wide range. Scheme D is the worst scheme in TDD_I. From Fig. 7, it is evident that for the shunt filter case, Scheme E is superior compared with other schemes in lowering TDD_I value with a very small difference between it and the rest of the schemes (A, B, C, F), while all the schemes achieve lower values of TDD_I in HBF scenario compared with the shunt filter scenario. For the HBF scenario,

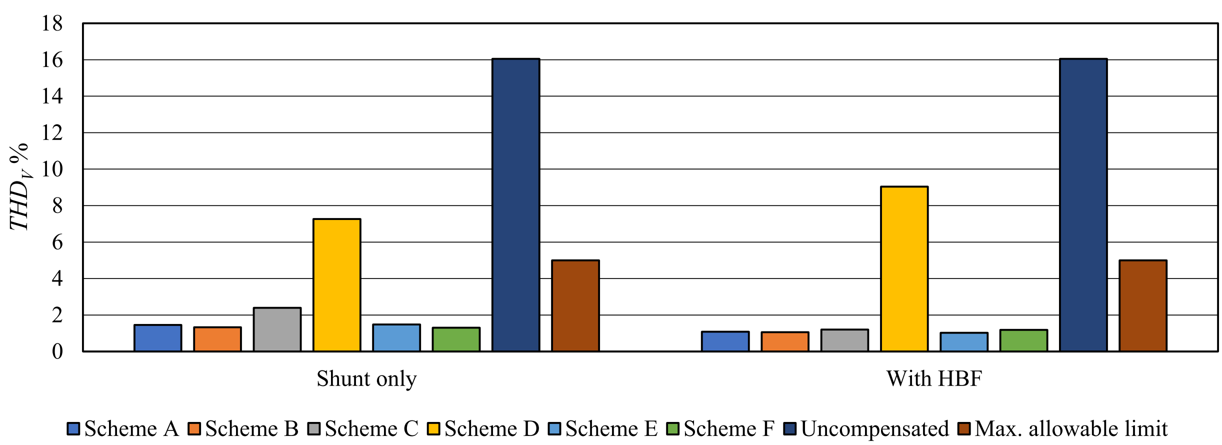

Fig. 5. THD_V comparison in the systems with shunt filter only and with HBF, including all schemes, the uncompensated case, and the maximum allowable limit by IEEE 519.

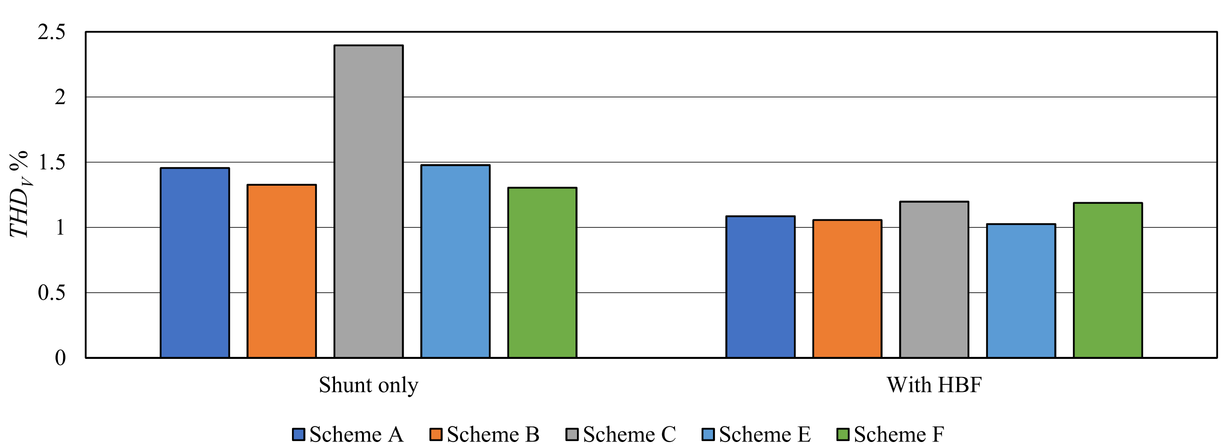

Fig. 6. THD_V comparison in the systems with shunt filter only and with HBF including Schemes A, B, C, E, and F.

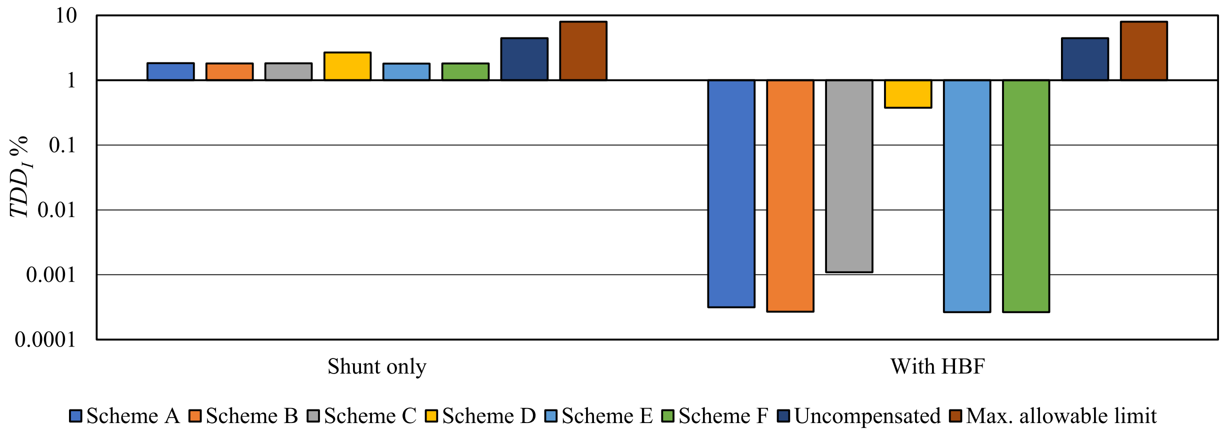

Fig. 7. TDD_I comparison in the systems with shunt filter only and with HBF, including all schemes, the uncompensated case, and the maximum allowable limit by IEEE 519 in logarithmic scale.

Scheme E is proven superior.

Fig. 8 illustrates the *HPF* in the six schemes in two cases: shunt filter only and with the HBF. In Fig. 8, the uncompensated case's *HPF* as well as the maximum allowable limit are also illustrated. The maximum allowable limit of *HPF* is calculated from the IEEE 519 maximum allowable limits for THD_V and TDD_I. A logarithmic scale is used for better presentation of both shunt only and HBF cases, as the values vary over a wide range. It is evident that Scheme D achieves the highest *HPF* value. From Fig. 8, it is evident that for the shunt filter case, Scheme F is superior compared with other schemes in lowering *HPF* value with a very small difference between it and schemes (A, B, C, E), while all the schemes achieve lower values of *HPF* in HBF scenario compared with the shunt filter scenario.

For better displaying the differences between the schemes, especially in the HBF scenario, Fig. 9 illustrates the HPF in all schemes except Scheme D in two cases: shunt filter only and with the HBF. All Schemes displayed in Fig. 9 achieve low *HPF* values; however, Scheme E is the best by a relatively small difference between the other schemes.

The comparison between the different schemes with respect to the PVP is illustrated in Fig. 10. Scheme F is shown to be superior in both scenarios. Scheme D is the worst scheme in the shunt filter case. While all the schemes achieve a high PVP value due to the low value of HPF in the HBF case.

5. Conclusions and future work

This paper presented an HBF filter composed of a series part that is an *L-C* combination and a shunt part that is a DDTF with six schemes and with a high penetration of PV DGs. Compared to the conventional composite passive damping method, the proposed hybrid damping method can eliminate almost all current harmonics while also lowering THD_V below the accepted limits of 5 % according to IEEE-519 standard. The harmonic distortion is injected into the system from non-linear loads, grid/source harmonics, and PV harmonics are measured and analyzed before and after the specified filters are applied. Initially, the uncompensated system is studied without any filters connected. Following that, the shunt filter is connected to overcome the issue of high *HPF* levels. Finally, the system is investigated after incorporating the HBF. A single-objective optimization technique was used to design optimal DTF filters. Then a multi-objective optimization technique was used to achieve the objective of minimizing HPF and maximizing PV penetration simultaneously. The optimization technique used was the Autism Based Optimizer (ABO). The programming platform used for this purpose was MATLAB 2016b. The system was initially studied and tested in its base case (uncompensated) without adding DG units, and then increasing gradually. Observations revealed that as demand increased, so did harmonic distortion. A solution was necessary to maintain harmonics at the desired levels, especially considering the growing penetration of PV injected into the grid. The HBF filter was designed to address the issue. From the results, we can notice that all the schemes except scheme D achieve a high PVP value with a low value of HPF in all scenarios of DTFs. Based on the results obtained from these techniques, the best-performing schemes of those six schemes (scheme E and scheme F) will be chosen for real-life implementation. Then, in

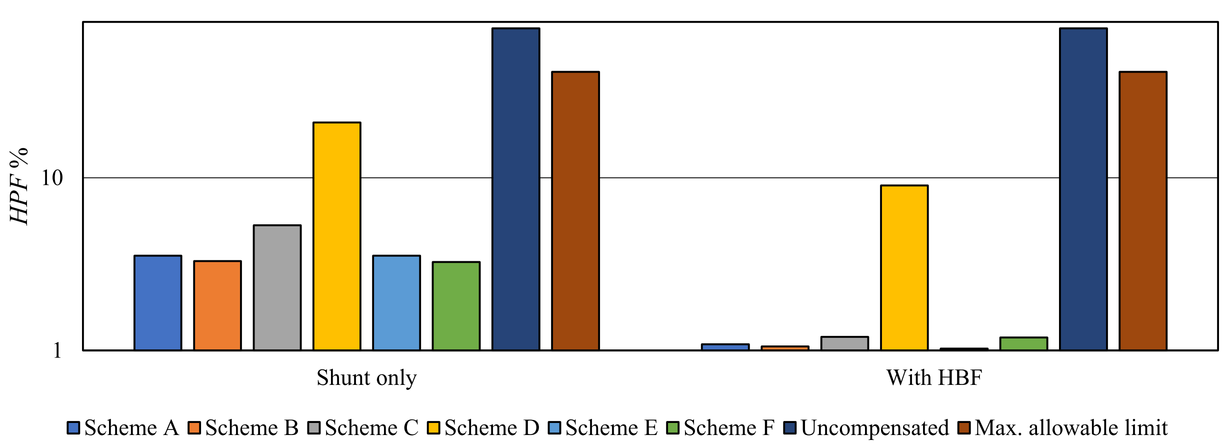

Fig. 8. *HPF* comparison in the systems with shunt filter only and with HBF including all schemes, the uncompensated case, and the maximum allowable limit in logarithmic scale.

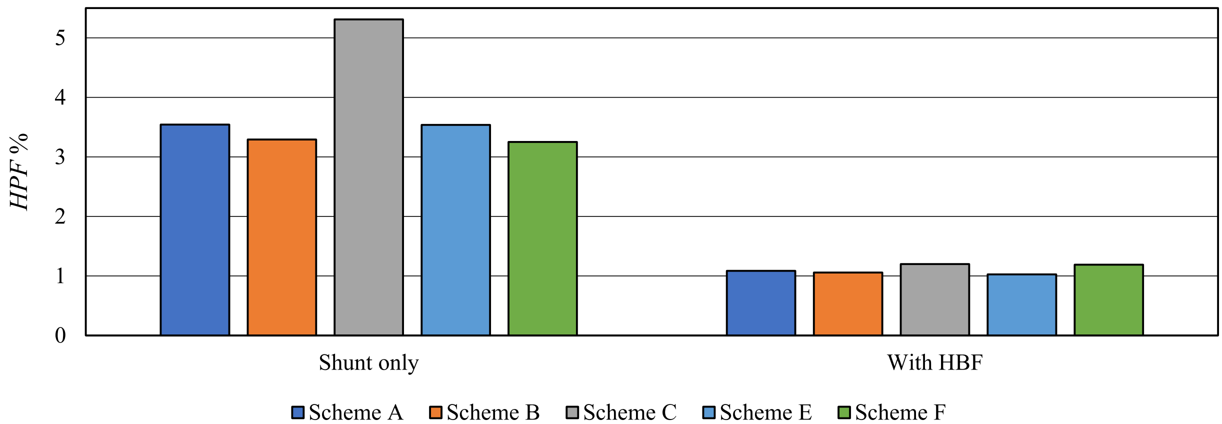

Fig. 9. *HPF* comparison in the systems with shunt filter only and with HBF, including all schemes, various environmental factors, except for Scheme D.

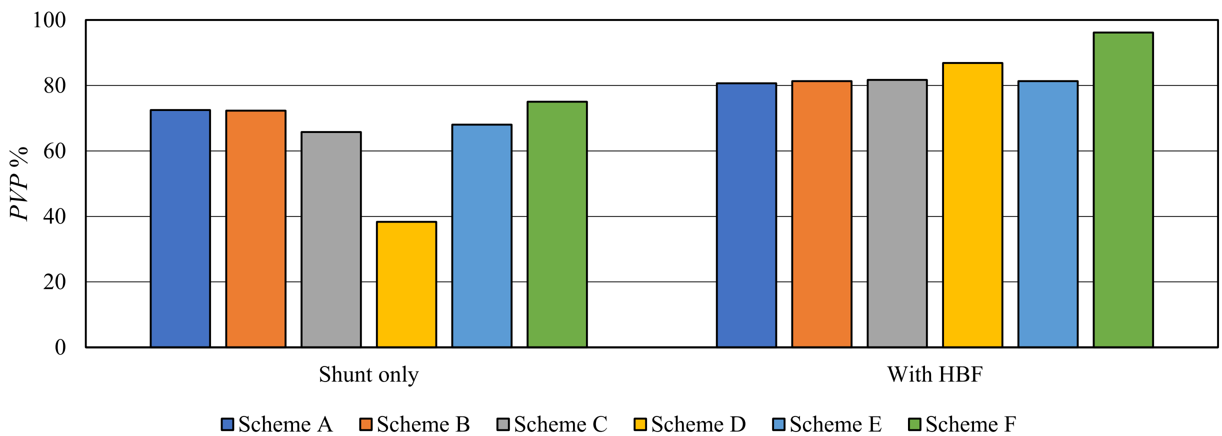

Fig. 10. *PVP* comparison in the systems with shunt filter only and with HBF, including all schemes.

conclusion, it is very clear that by considering the magnitude of HPF, PV penetration level, system PF, and other PQ metrics, HBF proves its superiority. As part of our future work, we want to install and test the proposed filter in a real-world power distribution network to ensure its performance under practical conditions. This procedure will improve and reinforce the reliability and applicability of our results. Moreover, Future works may include harmonic signatures for other DG or distributed storage (DS) systems, such as fuel cells, etc.

CRediT authorship contribution statement

Asmaa Elhussiny: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation. **Shady H.E. Abdel Aleem:** Writing – review & editing. **E.E. El-Kholy:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Ahmed F. Zobaa:** Writing – review & editing, Validation, Methodology, Investigation, Conceptualization. **Ahmed M. Zobaa:** Writing – review & editing, Validation, Methodology, Investigation, Conceptualization.

Declaration of competing 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.

References

[1] Kalaira NAA, Kalairc AR, Saleemd Z, Khana N. Review of harmonic analysis, modeling and mitigation techniques. *Renew Sustain Energy Rev* 2017:1152–87.
[2] a. W. F. W. X. Alexandre B. Nassif, "An Investigation on the Selection of Filter Topologies for Passive Filter Applications," *IEEE TRANSACTIONS ON POWER DELIVERY,* vol. 24, pp. 1710-1718, 2009.
[3] Badrzadeh KSSB, Wilson RC. Designing passive harmonic filters for an aluminum smelting plant. *IEEE Trans Ind Appl* 2011;47(2):973–83.
[4] Chang HLWGW, Chu SY. A probabilistic approach for optimal passive harmonic filter planning. IEEE Transactions on Power Delivery", Jul 2007;22(3):1790–8.
[5] C. H. C. Su, "Design of passive harmonic filters to enhance power quality and energy efficiency in ship power systems," *IEEE Industrial Communication and Power System Technology Conference*, pp. 1-8, Apr. 2013.
[6] Ding WXT. A filtering scheme to reduce the penetration of harmonics into transmission systems. *IEEE Trans Power Delivery* Feb. 2016;31(1):59–66.
[7] X. R. D. Pan, X. Wang, H. Yu, Z. Xing, "Analysis and design of current control schemes for LCL-Type grid-connected inverter based on a general mathematical model", IEEE Transactions on Power Electronics," pp. 4395-4410, Aug. 2017.
[8] Zobaa AM, Abdel Aleem SHE, Youssef HKM. Bi-Level damped double-tuned harmonic passive filters design: Multi-criteria decision-making analysis. *Ain Shams Eng J* 2023/9//, 2023.;14(9):102082.
[9] N. Hidayah Abdul Kahar, A. F. Zobaa, R. A. Turky, A. M. Zobaa, S. H. E. Abdel Aleem, and B. Ismail, "Comparative analysis of optimal damped and undamped passive filters using MIDACO-solver," *Ain Shams Engineering Journal,* vol. 14, no. 8, pp. 102056-102056, 2023/8//, 2023.
[10] Alhaider MM, Abdel Aleem SHE, Ali ZM, Zobaa AM. Harmonics management and hosting capacity enhancement: Optimal double-resistor damped double-tuned power filter with artificial hummingbird optimization. *PLoS One* 2024;19(5):e0303207.
[11] Khattab NM, Abdel Aleem SHE, El'Gharably AF, Boghdady TA, Turky RA, Ali ZM, et al. A novel design of fourth-order harmonic passive filters for total demand distortion minimization using crow spiral-based search algorithm. *Ain Shams Eng J* 2022/5//, 2022.;13(3):101632.
[12] Mohamed IF, Abdel Aleem SHE, Ibrahim AM, Zobaa AF. Optimal Sizing of C-Type Passive Filters under Non-Sinusoidal Conditions. *Energy Technol Policy* 2014/01/01, 2014.;1(1):35–44.

[13] Zobaa AF, Abdel Aziz MM, Abdel Aleem SHE. Comparison of Shunt-passive and Series-passive Filters for DC Drive Loads. *Electr Power Compon Syst* 2010/1//, 2010.;38(3):275–91.
[14] Rahat O, Saniei M, Seifossadat SG. Modeling and new tuning of the distribution transformer-integrated passive power filter and its effects on the transformer performance and network power quality. *Electr Pow Syst Res* 2023/01/01/, 2023.; 214:108844.
[15] Kritsanasuwan K, Leeton U, Kulworawanichpong T. Harmonic mitigation of AC electric railway power feeding system by using single-tuned passive filters. *Energy Rep* 2022/11/01/, 2022.;8:1116–24.
[16] Bajaj M, Singh AK. Optimal design of passive power filter for enhancing the harmonic-constrained hosting capacity of renewable DG systems. *Comput Electr Eng* 2022/01/01/, 2022.;97:107646.
[17] Melo ID, Pereira JLR, Variz AM, Ribeiro PF. Allocation and sizing of single tuned passive filters in three-phase distribution systems for power quality improvement. *Electr Pow Syst Res* 2020/03/01/, 2020.;180:106128.
[18] M. A. Fahmy, A. M. Ibrahim, M. E. Baici, and S. H. E. Abdel Aleem, "Multi-objective optimization of double-tuned filters in distribution power systems using Non-Dominated Sorting Genetic Algorithm-II." pp. 195-200.
[19] S. H. E. A. Aleem, A. F. Zobaa, and A. C. M. Sung, "On the economical design of multiple-arm passive harmonic filters." pp. 1-6.
[20] M. T. Elmathana, A. F. Zobaa, and S. H. E. A. Aleem, "Economical design of multiple-arm passive harmonic filters for an industrial firm - Case study." pp. 438-444.
[21] A. Lamlom, A. Ibrahim, M. E. Balci, A. Karadeniz, and S. H. E. Abdel Aleem, "Optimal design and analysis of anti-resonance C-type high-pass filters." pp. 1-6.
[22] Abdel Aleem SHE, Zobaa AF, Balci ME. Optimal resonance-free third-order high-pass filters based on minimization of the total cost of the filters using Crow Search Algorithm. *Electr Pow Syst Res* 2017/10//, 2017.;151:381–94.
[23] Abdel Aleem SHE, Zobaa AF. Optimal C-type filter for harmonics mitigation and resonance damping in industrial distribution systems. *Electr Eng* 2017/3//, 2017.; 99(1):107–18.
[24] Y. K. H. Akagi, A. Nabae, "Instantaneous reactive power compensators comprising switching devices without energy storage components," *IEEE Transactions on Industrial Application,* vol. IA-20, no. 3, pp. 625-630, May 1984.
[25] A. N. H. Akagi, S. Atoh, "Control strategy of active power filters using multiple voltage-source PWM converters," *IEEE Transactions on Industrial Application,* vol. IA-22, no. 3, pp. 460-465, Jun. 1986.
[26] Singh K-A-H-B, Chandra A. A review of active filters for power quality improvement. *IEEE Trans Ind Electron* 1999;46(5):960–71.
[27] Lenwari NOW. A novel heuristic optimization algorithm for automated design of resonant compensators for shunt active filters. *Power Electronics IET* Nov. 2013;6 (9):1842–50.
[28] Badoni ASM, Singh B. Adaptive recursive inverse-based control algorithm for shunt active power filter. *Power Electronics IET* Apr. 2016;9(5):1053–64.
[29] Bekakra Y, Zellouma L, Malik O. Improved predictive direct power control of shunt active power filter using GWO and ALO – Simulation and experimental study. *Ain Shams Eng J* 2021/12//, 2021.;12(4):3859–77.
[30] Fujita HAH. A practical approach to harmonic compensation in power systems-series connection of passive and active filters. *IEEE Transactions on Industrial Application* 1991;27(6):1020–5.
[31] Salmon JC. Reliable 3-phase PWM boost rectifiers employing a stacked dual boost converter subtopology. *IEEE Trans Ind Appl* 1996;32(3):542–51.
[32] Bhattacharya CCA, Bhattacharya S. Parallel-connected shunt hybrid active power filters operating at different switching frequencies for improved performance. *IEEE Trans Ind Electron* Nov. 2012;59(11):4007–19.
[33] X. W. Haofeng Bai, Frede Blaabjerg, " "A grid-voltage-sensorless resistive-active power filter with series LC-Filter," *IEEE Transactions on Power Electronics,* vol. 33, no. 5, pp. 4429-4440, May 2018.
[34] Ghasem Ahrabian FS, Haque MT. Hybrid Filter Applications for Power Quality Improvement of Power Distribution Networks Utilizing Renewable Energies. *IEEE ISIE* 2006, 2006..
[35] X. Li, "An Investigation on Harmonic Filtering Techniques in Power Systems," A thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Energy Systems, Department of Electrical and Computer Engineering, University of Alberta, 2019.
[36] L. M. Julian C. Giacomini , Humberto Pinheiro, Cassiano Rech, "Design methodology of a passive damped modified LCL filter for leakage current reduction in grid-connected transformerless three-phase PV inverters," *IET Renewable Power Generation,* vol. 11, no. 14, pp. 1769-1777, 2017.
[37] J. L. B. Park, H. Yoo, and G. J. E. Jang, "Harmonic mitigation using passive harmonic filters: Case study in a steel mill power system," vol. 14, no. 8, 2021.
[38] X. W. Remus Narcis Beres, Marco Liserre, Frede Blaabjerg, and Claus Leth Bak, "A Review of Passive Power Filters for Three-Phase Grid-Connected Voltage-Source Converters," *IEEE JOURNAL OF EMERGING AND SELECTED TOPICS IN POWER ELECTRONICS*, 2016.
[39] L. M. a. N. Faundes, "Active/passive harmonic filters: Applications, challenges & trends," *in 2016 17th International Conference on Harmonics and Quality of Power (ICHQP)*, pp. 657-662, 2016.
[40] N. G. P. Sanjan, M.S. Bhaskar, U. Subramaniam, D.J. Almakhles, S. Padmanab, N.G. Yamini, "Enhancement of power quality in domestic loads using harmonic filters," *IEEE ACCESS,* vol. 8, 2020.
[41] Ieee, "IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems," *IEEE Std 519-2014 (Revision of IEEE Std 519-1992)*, pp. 1-29, 2014.
[42] R. a. S. Adjie Bagaskara "Environmental Effects on Parameters of Leakage Current Equivalent Circuits of Outdoor Insulators," *Emerging Science Journal,* vol. 8, no. 1, 2024.
[43] S. K. a. A. R. A. R. Abdul Rahman, "Design and Study the Performance of a CMOS-Based Ring Oscillator Architecture for 5G Mobile Communication," *Emerging Science Journal,* vol. 8, no. 1, 2024.
[44] J. S. R.-A. Noelia Cruz-Pérez , Vasiliki L. P. Koronaiou , Anja Jančula , Jesica Rodríguez-Martín , Alejandro García-Gil , José C. Fontes and Juan C. Santamarta, "SWOT Analysis of the Benefits of Hydropower Energy in Four Archipelagos," *Civil Engineering Journal,* vol. 10, no. 07, 2024.
[45] Aljarrah J-A-H-R, Al-Omary M, Salem Q. Research on The Impact of 100% PV Penetration in Power Distribution Systems. In: *International Engineering Conference on Electrical, Energy, and Artificial Intelligence (EICEEAI)*; 2022. p. 1–5.
[46] S. P. C. O. A. Ajeigbe, T. O. Olwal, and A. M. Abu-Mahfouz, "Harmonic control strategies of utility-scale photovoltaic inverters," 2018.
[47] M. A. Rafat Aljarrah , Qusay Salem , Murad Al-Omary , Ibrahim Abuishmais, Wasseem Al-Rousan, "Application of Passive Harmonic Filters in Power Distribution System with High Share of PV Systems and Non-Linear Loads," *INTERNATIONAL JOURNAL OF RENEWABLE ENERGY RESEARCH,* vol. 13, no. 1, 2023.
[48] Liqaa Alhafadhi JT. Advances in reduction of total harmonic distortion in solar photovoltaic systems: A literature review. *International Journal of Energy Eesearch Wiley* 2019.
[49] M. A. E.-H. Mahmoud M. Elkholy, A.A. El-Fergany, "Harmonic analysis of hybrid renewable microgrids comprising optimal design of passive filters and uncertainties " *Electric Power Systems Research*, pp. 491-501, 2018.
[50] B. H. Ravinder K, "Investigations on shunt active power filter in a PV-wind-FC based hybrid renewable energy system to improve power quality using hardware-in-the-loop testing platform," *Electr Power Syst Res* 2019.
[51] S. H. Pouresmaeil E, Mehrasa M, Shokridehaki MA, Rodrigues EMG,Catalao JPS, "Integration of renewable energy for the harmonic current and reactive power compensation," *2015 IEEE 5th International Conference on Power Engineering, Energy and Electrical Drives (POWERENG)*, 2015.
[52] K. S. A. Bajaj M, "Hosting capacity enhancement of renewable-based distributed generation in harmonically polluted distribution systems using passive harmonic filtering.," *Sustainable Energy Technol Assess*, 2021.
[53] P. G. Patowary M, Deka BC, "An adaptive current control-detuned harmonics elimination schemes for enhancement of power quality in RES interfaced AC-grid network.," *Sustain Energy Technol Assess*, pp. 11-23, 2018.
[54] L. x,. Emerging Power Quality Challenges Due to Integration of Renewable Energy Sources. *IEEE Transaction Industrial Applications* 2017.
[55] O. R. A. Meshack Magaji Ishaya , Ephraim Bonah Agyekum , Mohamed F. Elnaggar, Mohammed M. Alrashed and Salah Kamel, "Single-tuned passive filter (STPF) for mitigating harmonics in a 3-phase power system," *Scientific Reports*, 2023.
[56] S. s. a. Aashish Jaiswal a, b, and Sanchari Deb, "A novel technique to detect and mitigate harmonic during islanding in grid connected PV system," *Energy Reports*, pp. 3940-3956, 2024.
[57] A. A. a. F. I. J. Bonolata Biswas Taya, "Total harmonic distortion mitigation and voltage control using distribution static synchronous compensator and hybrid active power filter," *International Journal of Advanced Technology and Engineering Exploration,* vol. 11, 2024.
[58] D. Z. Xiuhui Tang, Hua Chai, "Synthetical Optimal Design for Passive-Damped LCL Filters in Islanded AC Microgrid," *Journal of Energy and Power Technology,* vol. 3, no. 3, 2021.
[59] Zobaa AF, Aleem SHEA. A New Approach for harmonic distortion minimization in power systems supplying nonlinear loads. *IEEE Trans Ind Inf* 2014;10(2):1401–12.
[60] P. Kumar. "Autism-Based Optimization (ABO) algorithm," October 2024, 2024; https://www.mathworks.com/matlabcentral/fileexchange/173675-autism-based-optimization-abo-algorithm.

Asmaa Elhussiny received the B.Sc., and M.Sc. degrees in Electrical Power and Machines from Menoufia University, Shibin El-Kom, Egypt, in 2008 and 2018, respectively. Following graduation, she worked as an Electrical Engineer at Egypt's National Organisation for Potable Water and Sanitary Drainage (NOPWASD). She has been working as the general manager at NOPWASD since 2020. Additionally, she received a diploma from Erasmus University in Rotterdam, Netherlands in 2022 for her work on urban heritage strategies. In 2023, she participated in a fellowship program at the International Training Centre of the International Labour Organisation in Turin, Italy. She is pursuing her Ph.D. in Electrical Engineering at Menoufia University, Faculty of Engineering. Her research interests include power electronics applications in renewable energy resources, Multilevel Inverters, and HVDC systems. Her current main research interests are power quality and Harmonic mitigation solutions. She has also been a registered member of the Egyptian Syndicate of Engineers since 2008.

Shady H. E. Abdel Aleem received B.Sc., M.Sc., and Ph.D. degrees in Electrical Power and Machines from the Faculty of Engineering, Helwan University, Egypt, in 2002, and the Faculty of Engineering, Cairo University, Egypt, in 2010 and 2013 respectively. Currently, he is an Associate Professor at the Department of Electrical Engineering, Institute of Aviation Engineering and Technology, Giza, Egypt. He is the Vice Dean for Education and Student Affairs. Also, he is a consultant of power quality studies in ETA Electric Company, Egypt. His research interests include harmonic problems in power systems, power quality, renewable energy, smart grid, energy efficiency, optimization, green energy, and economics. Dr. Shady is the author or co-author of many refereed journals and conference papers. He has published 200 plus journal and conference papers, 25 plus book chapters, and 12 edited books with the Institution of Engineering and Technology (IET), Elsevier, Springer, CRC Press, and InTech. He was awarded the State Encouragement Award in Engineering Sciences in 2017 from Egypt. He was also awarded the medal of distinction from the first class of the Egyptian State Award in 2020 from Egypt. Dr. Shady is a senior member of the Institute of Electrical and Electronics Engineers (IEEE). Dr. Shady is also a member of the Institution of Engineering and Technology (IET). He is an Editor/Guest Editor/Associate Editor for the International Journal of Renewable Energy Technology, Vehicle Dynamics, IET Journal of Engineering, Energies, Sustainability, Technology and Economics of Smart Grids and Sustainable Energy, and Others.

Elwy El-Kholy is a distinguished electrical engineer with a decorated career spanning over 30 years. He has held leadership roles as President of Delta Technological University, Dean of the Faculty of Engineering at Menoufia University, and Chair of the Department of Electrical Engineering. Professor El-Kholy's expertise lies in power electronics and its applications. He has conducted extensive research and published numerous articles in international journals. He has also supervised several MSc and PhD students. Professor El-Kholy is actively involved in professional organizations and committees, including the Institute of Electrical and Electronics Engineers (IEEE) and the Egyptian Nuclear Security Education Network. He is a dedicated educator and a respected figure in the field of electrical engineering.

AHMED F. ZOBAA received the B.Sc. (Hons), M.Sc., and Ph.D. degrees in electrical power and machines from Cairo University, Egypt, in 1992, 1997 and 2002, respectively, and the Doctoral of Science degree from Brunel University of London, U.K., in 2017. He received his Postgraduate Certificate in Academic Practice from the University of Exeter, U.K., in 2010. He was an Instructor from 1992 to 1997, a Teaching Assistant from 1997 to 2002, and an Assistant Professor from 2002 to 2007 at Cairo University, Egypt. From 2007 to 2010, he was a Senior lecturer in renewable energy at the University of Exeter, U.K. From 2010 to 2019, he was a Senior Lecturer in power systems at Brunel University of London. He is a Reader in electrical and power engineering and a Member of the Brunel Interdisciplinary Power Systems Research Centre at Brunel University of London. His main areas of expertise include power quality, (marine) renewable energy, smart grids, energy efficiency, and lighting applications. He is the Executive Editor-in-Chief of Smart Grids and Sustainable Energy Journal. He is also an Editorial Board member, Editor, Associate Editor, and Editorial Advisory Board member for many international journals. He is a registered Chartered Engineer, Chartered Energy Engineer, European Engineer, and International Professional Engineer. He is also a registered member of the Engineering Council, U.K., the Egypt Syndicate of Engineers, and the Egyptian Society of Engineers. He is a Principal Fellow of the Higher Education Academy, U.K., Fellow of the Institution of Engineering and Technology, Energy Institute, U.K., the Chartered Institution of Building Services Engineers, U.K., the Institution of Mechanical Engineers, U.K., the Royal Society of Arts, U.K., and the African Academy of Sciences.

Ahmed M. Zobaa received the B.Sc. (Hons), M.Sc., and Ph.D. degrees in Electrical Power and Machines from Cairo University, Giza, Egypt, in 2013, 2018, and 2023, respectively. He is currently a full-time Assistant Professor at the Electrical Power Engineering Department, Faculty of Engineering, Cairo University. He is also an Adjunct Assistant Professor at the American University in Cairo, the University of Science and Technology at Zewail City for Science and Technology, and the Institute of Aviation Engineering and Technology. He was an Adjunct Assistant Professor at the British University in Egypt and Ahram Canadian University from January 2024 to July 2024. He was a Teaching Assistant from 2013 to 2018 and an Assistant Lecturer from 2018 to 2023 at Cairo University. He was a part-time Teaching Assistant at the American University in Cairo (AUC) from 2014 to 2023. His research interests include power quality, Photovoltaics, and renewable energy. Dr. Ahmed M. Zobaa is also a Registered Member of the Egyptian Syndicate of Engineers since 2013. He has been an IEEE member since 2010, the IEEE Power and Energy Society (PES) since 2015, and IEEE Young Professionals since 2015.