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An Application of Chef-Based Optimization Algorithm for Harmonic Reduction in RDS Using Active Power Filters

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ABSTRACT
The application of APFs to reduce harmonics in radial distribution system (RDS) is examined in the present article. To ensure maximize APF performance, it investigates soft computing techniques, including chef-based optimization algorithm (CBOA) and coati optimization algorithm (COA). Due to its advantages for the environment, distributed generation (DG), especially solar photovoltaic (SPV), has grown in popularity. However, power quality (PQ) problems including harmonic distortion may arise when SPV is integrated into RDS. Nonlinear loads (NLs) that are present in the RDS are usually the source of these harmonics. This paper examines a case where two RDS terminal nodes are connected to both nonlinear distributed generation (NLDG) and NLs. APFs are positioned carefully to reduce harmonics and raise PQ.
The optimization task seeks to minimize the APF's necessary current rating while making sure all operating requirements are satisfied. APF sizing is optimized using CBOA, a bio-inspired algorithm renowned for its balanced exploration and exploitation capabilities. Simulations are performed using IEEE-69 bus RDS to assess CBOA's efficacy. The efficacy of CBOA is juxtaposed with COA, a newly presented soft computing technique. The simulation's results confirm that CBOA is stable and efficient in addressing this specific optimization problem.

Keywords – chef-based optimization algorithm, harmonics, radial distribution system, power system optimization, power quality

Introduction

Power electrical device proliferation, including variable speed drives, dimmers, and LEDs, has drawbacks. Although they are efficient and convenient, the growing number of them in our homes and businesses introduces harmonic disturbances into the electrical grid, which lowers power quality (PQ) [1, 2].
The expansion of the smart grid is driven largely by the increasing adoption of distributed generation (DG) sources like solar and wind power. While these offer numerous benefits, integrating them with existing radial distribution systems (RDS) presents a critical challenge: power quality (PQ) issues [3].
Poor integration, particularly with converter-based DG systems (NLDG), can introduce harmonic distortions into the RDS due to the converters' non-linear characteristics [4, 5]. This "harmonic pollution" raises concerns for both electricity providers and consumers, as it negatively impacts the performance of distribution systems [6, 7].
APFs (Active Power Filters) are a promising solution to mitigate harmonics. They work by injecting a precisely controlled counteracting current into the RDS at the same point as the nonlinear load. This effectively cancels out the harmonic distortions, improving overall PQ. APFs must be carefully sized and placed for optimal performance and cost-effectiveness [8-10]. Meeting industry standards like IEEE's limits for individual and total harmonic distortion in voltage (IHDv and THDv) is also necessary to achieve optimal performance [11].
Careful examination of the exact placement and rating of APFs in RDS is necessary to ascertain whether contemporary power distribution networks continue to be dependable, efficient, and stable. Lowering harmonics and raising PQ become more and more important as NL and more renewable energy sources are added to RDS. The positioning and dimensions of APFs can improve voltage stability, decrease power outages, and reduce harmonic distortions all that enhance the RDS's total efficacy. As evidenced by recent

studies, APF location and size matter, optimization in boosting grid reliability and PQ by highlighting the necessity for more study [12-14].
To cut costs, APF's rating needs to be minimal as practical. Regarding it, optimization approach is vital. Consequently, many optimization techniques were suggested. There has been use of PSO and its variations [15]. Additionally, a genetic approach is used [16] and grey wolf optimizer [17]. Other methods, such as the harmony search [18], firefly algorithm [19, 20], and most newly, the JAYA algorithm [21] are applied to this problem.
For instance, the best placement and size for distributed generation [22], the best location for an electrical vehicle charging station [23], optimal embedding of capacitor [24], optimal operation of microgrid [25], ideal battery power storage framework planning [26]. Furthermore, a number of research topics employ a range of optimization methodologies, including PQ enhancement using APF [12], reactive power dispatch [27], PV-wind based microgrid implementation [28], and harmonic mitigation of solar PV [29].
In accordance with No Free Lunch Theorem (NFL) [30], no single technique can offer the most effective solutions for all optimization problems. Since the nature of the issue may have an impact on an algorithm's performance, researchers employ unique algorithms.
Scientists are working with algorithms that are inspired by cookery. The Chef-based optimization algorithm (CBOA) is a novel metaheuristic method, is formed in published work. Learning is the main motivation origin used in CBOA plan. Training programs that teach cooking skills. The mathematical modeling of the cookery training process's phases aims to improve both the local and global search capacities for exploration and exploitation.
This metaheuristic approach was recently introduced by Trojovska et al. [31]. Due to its promising performance in several optimization domains, it is a helpful tool for researchers and professionals in a multitude of fields. It is extensively utilized in the medical field for the diagnosis of breast cancer as well as worldwide optimization and engineering problems [32, 33]. Here, it is used to the PQ enhancement problem.
A cooperative technique that emulates the foraging habits of the South American mammal coatis, the coati optimization algorithm (COA) was recently suggested by Dehghani et al. [34]. The algorithm is widely used in various engineering sectors, such as big data optimization [35], emotion recognition [36], optimal power flow [37], and PV cell parameter estimation [38]. COA effectively searches for optimal solutions in complex environments, proving adaptable to various coati behaviors and producing excellent results.
The improvement of PQ via APFs when NL and NLDG are present is the subject of numerous significant contributions presented in this work. The following are the primary contributions:
• Integration of CBOA with harmonic load flow (HLF): for the purpose of determine appropriate filter rating, the article combines the CBOA with HLF analysis. This method takes into account the system's reaction to harmonics brought about by the NL + NLDG.
• Two algorithms are compared: Two algorithms, CBOA and COA, are compared and examined in this study for four different scenarios: NLs + NLDGs (without APF), APF at 27, APF at 52, and APFs at 27 and 52. Evaluating their efficacy in identifying the proper APF rating is the goal.
• Superiority of CBOA over COA: Computational tests show that, for all situations and data examined, the CBOA performs better than the COA by producing a least APF current.
As far as the authors are aware, main problem is the first to use the CBOA. Computational tests are used to assess CBOA's performance, and COA and the ideal value of the performance function are contrasted. In this section, IEEE-69 RDS system is utilized to simulate and find the optimal APF rating for the NL + NLDG buses under consideration utilizing CBOA and COA.
The format of presented document consists of the following: The problem formulation is given in the following section, followed by written analysis and discussion of the findings, and a conclusion to the article in the final portion.

1. Problem Formulation

The following part discusses APF, RDS modeling, load flow that has harmonics and the development of an objective function using CBOA to lower harmonics and increase PQ.

1.1. Modeling of RDS, HLF, and APF

Resistance, inductance, and impedance the three RDS parameters are modeled in a harmonic environment in accordance with [39]. As stated in [39], modeling the APF as a harmonic source. The HLF technique, which is based on network topology, is used for harmonic analysis [40].

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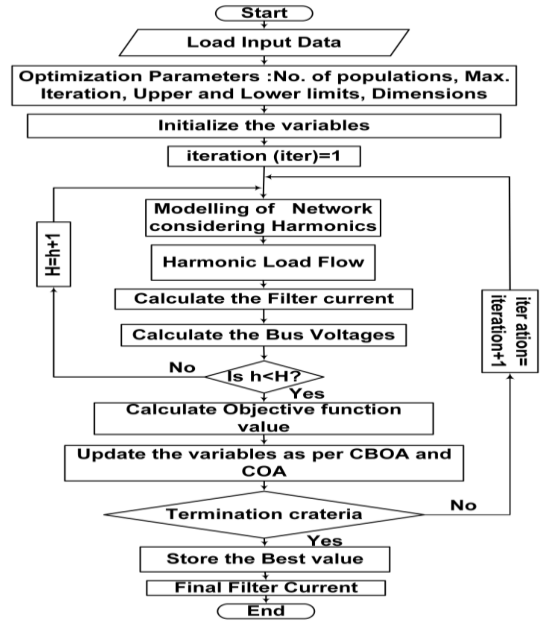

Fig. 1 Flowchart for harmonic reduction in RDS

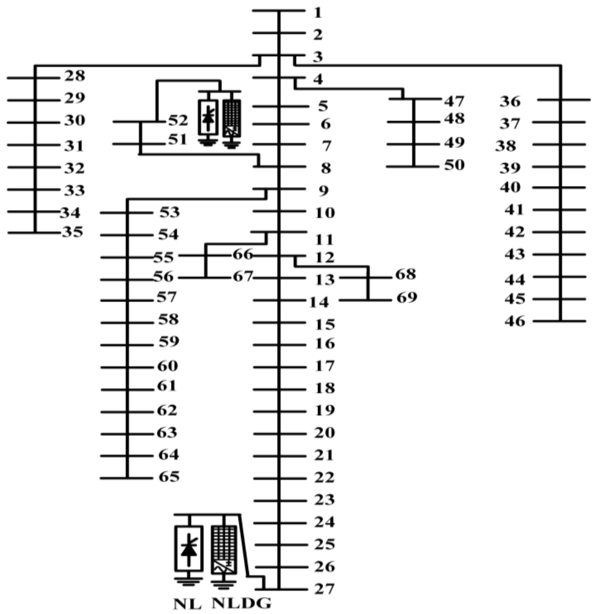

Fig. 2 IEEE-69 bus RDS using NL and NLDG

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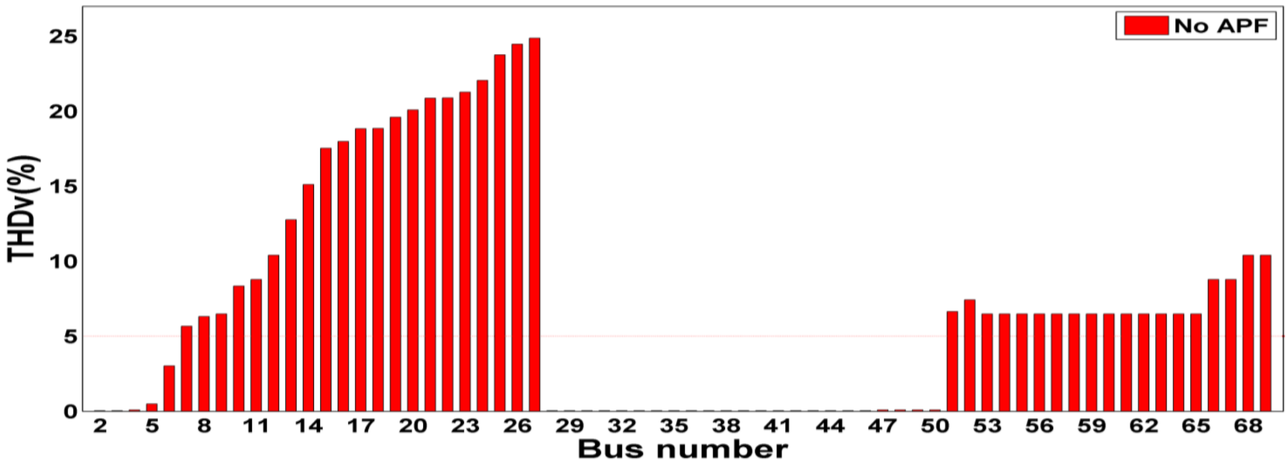

Fig. 3 THDv at all buses in absence of APF

The two relationship matrices that form the basis of this method are the BIBC matrix and the BCBV matrix.

1.2. Objective function

An essential component of the optimization technique is the objective function (OF). Determining appropriate APF rating to enhance PQ is a limited nonlinear problem. In this instance, the variable of decision is the APF current. It is essential to lower APF's current because its cost rises with its current rating. The following three restrictions were taken into consideration for the improvement of PQ in RDS using APF: THDv, IHDv, and Iapf max are the three variables. The primary two standard limitations are required by IEEE Standard 519, whereas third constraint is contingent on the NL current. As an example, objective function is displayed as

$$OF_{apf} = \min \sum_{m=1}^{n} \sqrt{\sum_{h=2}^{H} \left| I_{apf,m}^{h} \right|^{2}} + DP \tag{1}$$

H is the highest-order harmonic in this equation. The dynamic punishment factor is indicated by DP. Bus number m is symbolized by n, which is the total number of buses.
The following limitations apply to the objective function:

$$THD_V - 0.05 \le 0$$
$$IHD_V - 0.03 \le 0$$
$$I_{apf} \le I_{apf,MAX} \tag{2}$$

The flowchart in Figure 1 illustrates how to utilize CBOA to lower harmonics and increase PQ in RDS.

This study makes use of an altered IEEE-69 bus RDS [41], as shown in Fig. 2. The NLDGs are presumably associated with buses that have NLs in the system. The harmonic spectrum of the NLs, spanning from the fifth to the 49^{th}, is consistent with the characteristics of a six-pulse converter [2]. The NLs are specifically positioned at end nodes in a deliberate manner at busses 27 and 52 of RDS.

1.3. The simulation process

First, load the pertinent data from the test system, encompassing the harmonic spectrum. Define optimization settings in next step. Continue to step 3, where the harmonic surroundings model is generated using inputs. In Step 4, the HLF analysis is performed. The THDv should be calculated using NLs + NLDGs in step 5. Integrate the APF into the system prior to proceeding to step six. Include APF in load flow harmonics in next seven. Using CBOA, step 8 entails determining the lowest practical APF current. Step 9: Establish an algorithm's termination conditions. Likewise, repeat these steps for COA.

2. Results and Discussion

The analysis and discussion of the results are covered in this section.

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As seen in Fig. 2, two NLs + NLDGs are located at buses 27 and 52. In this case, the consequence of harmonics is amplified with consequences all 68 buses in RDS even if only two nodes have NLs + NLDGs. When there is no APF, HLF calculates the THDv% for every bus; the results are displayed in Fig. 3.
Harmonics have a significant impact on the RDS, as evidenced by forty of the sixty-eight buses' THDv values (not including the first bus, which acts as a source bus); these readings are greater than 5%. Surprisingly, all buses display THDv, but only two have NLs + NLDGs. If a bus's THDv exceeds 5%, The IEEE standard restriction cannot be met by it. It demonstrates the RDS's weak PQ. NLs + NLDGs are present on busses 27 and 52. The corresponding THDv values for the two are 24.87% and 7.42%. In total, forty buses surpass the THDv 5% threshold.

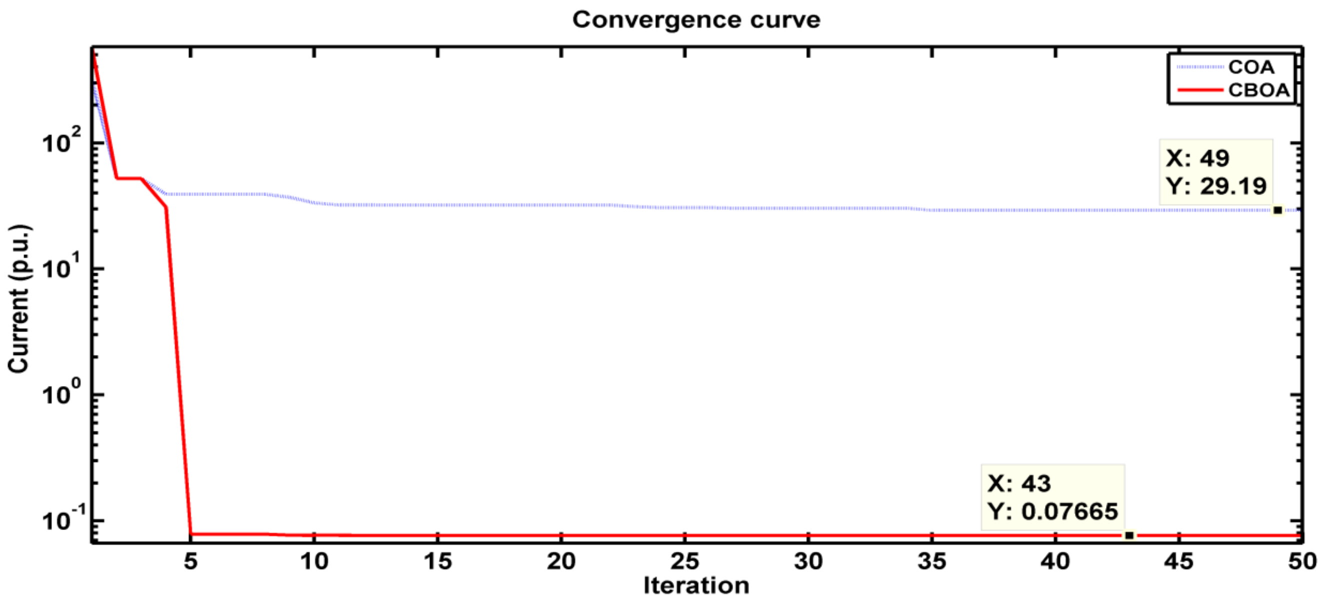

Fig. 4 Convergence curves for techniques when APF is at bus 27

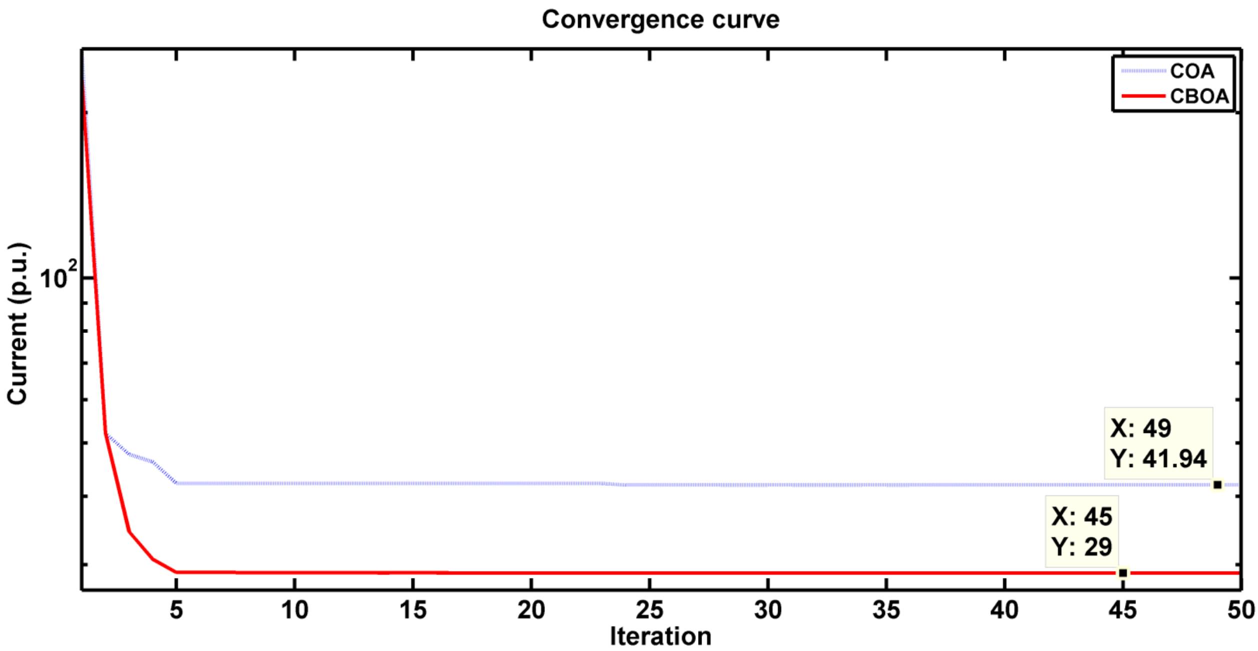

Fig. 5 Convergence curves for techniques when APF is at bus 52

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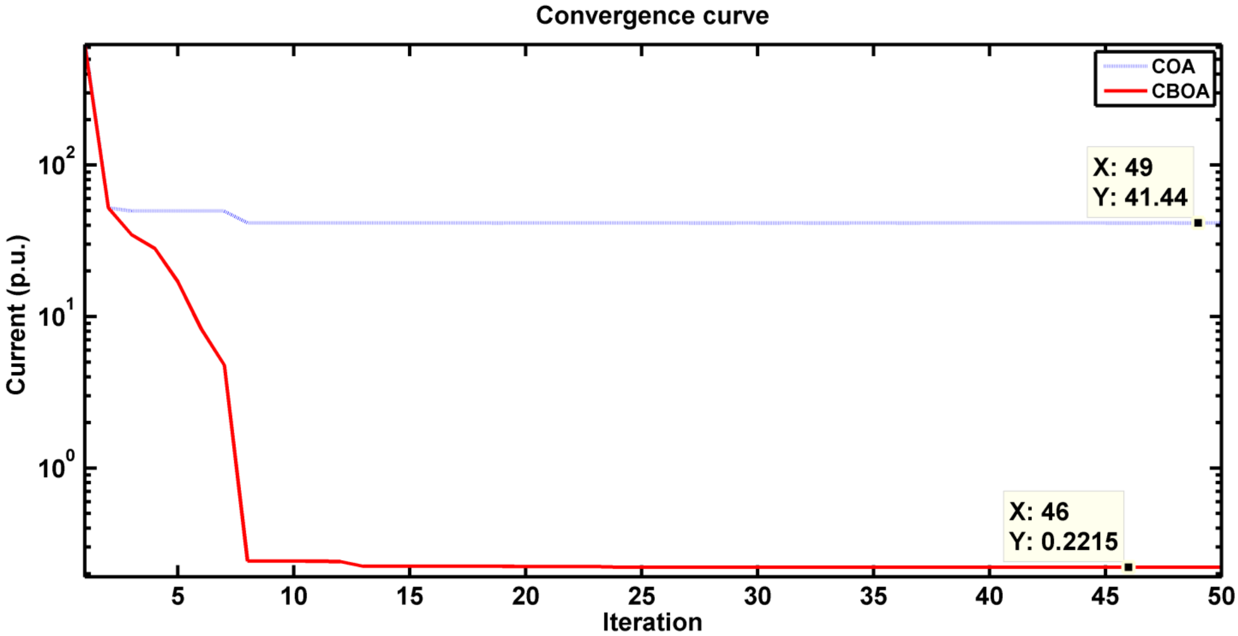

Fig. 6 Convergence curves for techniques when APFs at buses 27 and 52

Based on the aforementioned data, RDS appears to be a relatively contaminated harmonic scheme. To adhere to the IEEE standard, harmonic filter(s) must be utilized. With the NLs + NLDGs, busses 27 and 52 are allotted the APF concurrently. The scenario consists of APFs at both buses, and one at bus 27 and 52. The APF's size is now another important consideration because it directly impacts the cost of the system. In this instance, the CBOA optimization procedure is used to determine the necessary APF current. Thirty and fifty, respectively, are the maximum populations and iterations that are allowed. The actions shown in the relevant flowchart (Fig. 1) are followed in order to fully repeat this method for the selected test system.

2.1. Case 1

As shown in Fig. 2, the NLs + NLDGs are coupled together at bus 27 and 52. The system is significantly harmonically distorted by these two nodes. At bus 52 (7.42%), the THDv without APF is highest. Bus 27 has a THDv of 24.87%.

2.2. Case 2

In order to reduce the THDv as much as feasible, the APF is connected to bus 27. As illustrated in Fig. 4, CBOA has decreased to a value of 0.0766 p.u. and COA has converged at a higher value than CBOA (29.1935 p.u.). It is observed that bus 27 is the appropriate location for APF.

2.3. Case 3

In this instance, no algorithm is able to satisfy the requirements and reach convergence. They don't even slightly converge. The values of CBOA and COA are 28.9967 p.u. and 41.9423 p.u., respectively. Fig. 5 demonstrates that no single algorithm can meet all requirements. This suggests that bus 52's location is unsuitable for the APF to improve PQ.

2.4. Case 4

The buses 27 and 52 have the APFs installed. The outcome of HLF's use of soft computing techniques is displayed in Fig. 6. For every algorithm, the convergence curve is shown in the specified circumstance. Fig. 6 illustrates the CBOA's methodology for calculating the minimal APF current. To determine the lowest APF current, the COA does not converge. However, the CBOA technique, as shown in Fig. 6, converges effectively having the amount of 0.2214 p.u. and offers the lowest APF current within the specified parameters. Whenever the APFs are placed at buses 27 and 52, the CBOA approach performs converge effectively; in such situations, COA has computed the APF current of 41.4381 p.u. It is thought to be inappropriate.
Following the installation of APFs at busses 27, and 52, Figure 7 demonstrates everyone associated THDv amounts the system's buses are now less than 5%. Notably, with the APFs in place, buses 27 and 52, which

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previously had THDv values of 24.87 % and 7.42%, respectively, now have THDv values of 4.98% and 3.16%. Since every bus complies with the THDv requirements threshold, which is below or equivalent to 5%, as shown in Fig. 7, the APF's bus number and rating are crucial in improving PQ in the RDS. The comparison of the outcomes from the application of two soft computing techniques CBOA and COA is shown in Table 1.

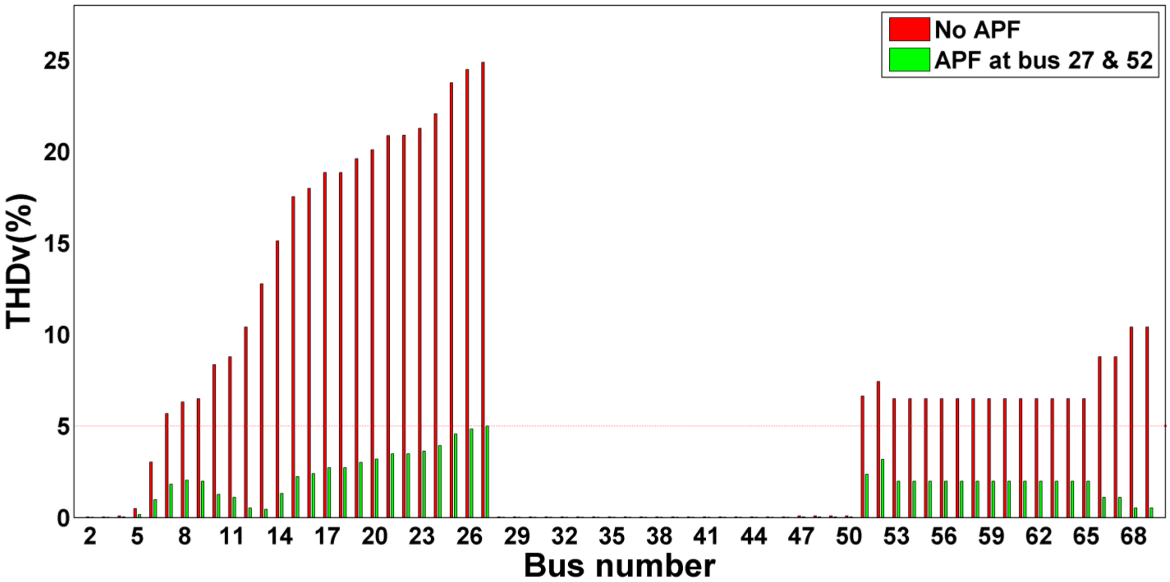

Fig. 7 THDv at each bus following optimization, with and without APFs

Table 1 Comparison of Soft Computing Techniques

Bus	**APF**	I_{apf} **by CBOA (p.u.)**	I_{apf} **by COA (p.u.)**	**Status**
27	1	**0.0766**	29.1935	Only CBOA converged
52	1	28.9967	41.9423	Both not converged
27,52	2	**0.2214**	41.4381	Only CBOA converged

3. Conclusion

This research investigates the application of the CBOA and COA to reduce harmonics through the APFs in RDS in order to improve PQ. The IEEE-69 RDS simulation effectively merges two NLS + NLDGs within the RDS, CBOA and COA with HLF, demonstrating the strong effects of harmonics. The negative impact of harmonics across PQ is highlighted by the calculated THDv that is over 5% on 40 buses. At 24.87 %, bus number 27 has the maximum THDv.

A minimal APF current of 0.0766 p.u. is produced by the CBOA algorithm, which satisfies the criterion and converges satisfactorily with bus 27. But COA is unable to converge, suggesting that CBOA works better in this situation. On the other hand, CBOA converges at 0.0766 p.u., while COA finds 29.1935 p.u.. For every bus, a single APF is enough to lower the THDv by up to 5% and enhanced the PQ of entire RDS.

Moreover, the successful reduction of THDv to 5% across all buses a feat also made achievable by the installation of two APFs at busses 27 and 52 highlights the critical role that APF placement plays. Remarkably, THDv may be maintained below the allowed limit entirely with just two APFs at RDS busses.

Conflicts of Interest

"The authors declare that there is no conflict of interest regarding the publication of this paper."

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