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# Power Quality Enhancement through Active Power Filters in Radial Distribution System using Pelican Optimizer

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**ABSTRACT-** In this paper, an application of pelican optimization algorithms (POA) for the enhancement of power quality (PQ) using active power filters (APFs) in radial distribution systems (RDS) is addressed. The harmonics is the main concern of the PQ. Nonlinear loads (NLs) inject the harmonics into the RDS. Here, nonlinear distributed generation (NLDG) is also considered along with NL at two end nodes. By using APFs, the harmonics are minimized to standard limits. Here, APFs are placed with proper size to minimize the harmonics and to improve the PQ. The POA is utilized to optimize the size of APF at proper placement. Inspired by natural processes, the POA has balanced exploration and exploitation characteristics. Subject to inequality constraints, the optimization's goal is to minimize the APF current. The simulation is done on the IEEE-69 bus RDS to assess the POA's performance. A comparison study is carried out using the artificial bee colony (ABC) optimization algorithm. The simulation results validate the POA algorithm's stability and efficacy in solving the optimization problem.

**Keywords:** Active power filter, Harmonics, Pelican optimization algorithm, Power quality, Radial distribution system.

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## 1. INTRODUCTION

As power electronic devices are so essential to modern life, there is a growing dependence on them. These devices include light-emitting diodes, compact fluorescent lamps, inverters, dimmers, variable speed drives, constant power supplies, mobile phones, and personal computers.

Moreover, one of the main factors advancing the growth of smart grid is distributed generation (DG). It is attracting considerable focus because of its many advantages. Incorporating DG into the radial distribution system (RDS) is one of the field's significant tasks [1, 2]. However, improper integration can lead to power quality (PQ) issues stemming from the harmonics generated by the converter [3]. The term nonlinear DG (NLDG) refers to a converter-based DG system that adds harmonics to the RDS [4, 5].

However, harmonic pollution rises due to these gadgets' nonlinear features and NLDG. As such, users' and suppliers' concerns about harmonics in PQ are growing more widespread. These harmonics have a negative impact on distribution systems' performance, which emphasizing how crucial it is to address these problems [6]. Several methods for harmonics mitigation are covered in [7]. In order to prevent harmonics, an active power filter (APF) is used. It injects nonlinear current into the radial distribution system (RDS) at the same node of NL load but in the opposite direction. Therefore, the harmonics are cancelled. Because an APF's efficacy is directly related to its rating it is essential to size and place them correctly to save the cost [8]. Furthermore, achieving maximum performance requires satisfying standard limitations such as individual and total harmonic distortion in voltage (IHDv) and (THDv) as per IEEE standards [9].

To maintain the stability, dependability, and effectiveness of contemporary power distribution networks, research on the proper positioning and rating of APFs in RDS is crucial. Enhancing PQ and reducing harmonics are critical as renewable energy sources and non-linear loads are increasingly integrated into RDS. APF placement and sizing can minimize harmonic distortions, reduce power losses, and improve voltage stability in RDS, all of which improve the distribution network's overall performance. The importance of APF placement and sizing optimization in improving PQ and grid dependability has been underlined in recent studies [10-12] by highlighting the necessity and requirement of further research in this field.

To decrease the price of APF, its rating should be as low as possible. For this, an optimization technique is required. As a result, numerous optimization strategies have been put forth. PSO and its variants [13] have been utilized. A genetic algorithm is also used [14]. A harmony search [15], firefly algorithm [16, 17], and recently grey wolf optimizer [18] are also utilized for this problem.

According to the No Free Lunch theorem (NFL) [19], no technique can provide the best answers for every optimization issue. Researchers employ new algorithms since the performance of any algorithm can differ depending on the kind of challenge. A newly introduced pelican optimization algorithm (POA) is utilized here. It is proposed by Pavel Trojovsky and Mohammad Dehghani in 2022. It is a newly developed optimization algorithm based on inspiration from nature. Pelicans are search agents in POA; they look for food sources. It takes its cues from how pelicans hunt: individual pelicans, acting as potential solutions, dive for prey, spit out extra water to focus their search, and eventually catch their meal. The cognitive process of pelican behavior and hunting strategy has made these birds proficient hunters. The modeling of the previously indicated method served as the primary source of inspiration for the design of the suggested POA. This technique aids in the algorithm's convergence toward the best answer for a given problem by striking a balance between exploring uncharted territory and exploiting promising solutions. The POA mathematical model is offered for application in resolving optimization problems [20].

The artificial bee colony (ABC) algorithm is a metaheuristic optimization method motivated by honey bee foraging behavior. It imitates how bees search for and utilize food sources in a colony. ABC uses scout, spectator, and employed bees to iteratively find the best answers to optimization problems. Since its introduction by D. Karaboga and B. Basturk in 2005, ABC has become well-liked due to its ease of use and efficiency in resolving a various numerical optimization problem [21]. Applications for it can be found in machine learning, engineering, and other fields looking for effective optimization techniques [22-25].

Various optimization techniques are utilized for various fields of research like optimal placement and sizing of DG [26], PQ enhancement in microgrids [27], MPPT [28], electric vehicles and PQ enhancement using APF [10].

Recent literature has thoroughly documented the effectiveness of POA and its variants in solving complex optimization problems. For example, POA has been effectively used in the field of power systems for energy management in microgrids [29], optimal sizing of microgrid [30], reconfiguration [31], and wind turbine fault classification [32]. These newer uses highlight the POA algorithm's adaptability and stability in handling various optimization challenges.

The paper presents several key contributions related to the PQ enhancement through APFs in the presence of NL and NLDG. The main contributions are as follows:

Integration of pelican optimization algorithm (POA) with harmonic load flow (HLF): The paper couples the POA with HLF analysis to find the proper rating of the filter. This approach considers the consequence of harmonics caused by the NL + NLDG on the system.

Comparison of two algorithms: The paper compares and analyzes two algorithms, namely POA and ABC, for four cases: NLs + NLDGs (without APF), APF at 27, APF at 69 and APFs at 27 and 69. The goal is to evaluate their performance in terms of finding the proper rating of the APF.

Superiority of POA over ABC: The computational tests demonstrate that the POA outperforms the ABC by yielding a least APF current in all scenarios for considered data.

The POA is used first time for this problem, as per the knowledge of authors. POA's performance is evaluated using computational tests, and the fitness function's best value is compared with ABC. Here, the IEEE-69 RDS system is employed and simulated to find the most suitable value of APF current for considered NL + NLDG buses using POA and ABC. This paper is structured as follows: In the next section, formulation of the problem is presented; then, analysis and discussion of results are written; and the paper is concluded in the last section.

## 2. PROBLEM FORMULATION

This section covers load flow with harmonics (HLF), APF, and RDS modeling. Using POA, an objective function with constraints is developed to enhance PQ by reducing harmonics, *i.e.*, THDv, within standard limits.

### 2.1. Modleing of RDS, APF and HLF

The parameters of RDS, *i.e.*, resistance, inductance, and impedance, are modeled in a harmonic environment as per [33]. The APF is modeled as a harmonic generator, as explained in [33]. For the analysis of harmonics, the HLF approach based on network topology is employed [34]. The BIBC matrix and the BCBV matrix are the two relationship matrices that constitute the foundation of this technique.

### 2.2. Objective function

An integral component of the optimization procedure is the objective function (OF). Finding the proper rating of APF to improve PQ is a constrained nonlinear problem. The APF current is the decision variable in this case. Because the cost of APF increases as its current rating increases, it is crucial to decrease APF's current.

In order to enhance the PQ in RDS using APF, three constraints have been taken into account: *(i)* THDv, *(ii)* IHDv, and *(iii)* Iapf max. The first two standard limitations are mandated by IEEE Standard 519, and the third constraint depends on the NL current [9]. An objective function is illustrated as,

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

In this equation, H represents the highest-order harmonic. DP denotes the dynamic penalty factor. m stands for the bus number, while n indicates the total buses.

The objective function is subjected to following constraints:

$$\begin{aligned} &THD_V - 0.05 \le 0 \\ &IHD_V - 0.03 \le 0 \\ &I_{apf} \le I_{apf,MAX} \end{aligned} \quad (2)$$

*Figure 1*, shows the flowchart that explains how to use POA to improve PQ in RDS. The dynamic penalty is indicated by the term DP. In this case, DP is added to the objective function to eliminate the impractical solutions and is utilized to handle constraints. The optimization process modifies the penalty amount. If the limitations are met, there is no penalty; if not, there is a significant one. The punishment rises as the limits for violations rise.

Implementation of any algorithm for the optimization problem is a challenging task. Here, the POA is implemented and coupled with the harmonic load flow to find the best size of the active power filter. All the optimization algorithms have two general parameters: the number of search agents or populations and the maximum number of iterations. Moreover, most of the algorithms have algorithm-specific parameters. These algorithm-specific parameters make a difference from the other algorithms. The POA has an algorithm-specific parameter, "R," which is a constant. It is used in the equation to mathematically simulate the behavior of pelicans during hunting. Tuning of R is required to get optimal results. The range of R is 0 to 1. By trial and error, the value of R is tuned, and R=0.2 is used here.

## 2.3. Steps for simulation

Load the relevant data, including the harmonic spectrum, from the test system first. In the following step, define the optimization settings.
Proceed to *Step 3*, where the inputs are created into a model of the harmonic environment.
*Step 4* should involve the HLF analysis.
*Step 5* should involve computing the THDv utilizing NLs + NLDGs. Before moving on to
*Step 6*, integrate the APF into the system.
In *Step 7*, incorporate the APF into the load flow harmonics. *Step 8* involves figuring out the lowest feasible APF current using the POA.
*Step 9*, Set terminating criteria of an algorithm. Repeat these procedures for ABC also.

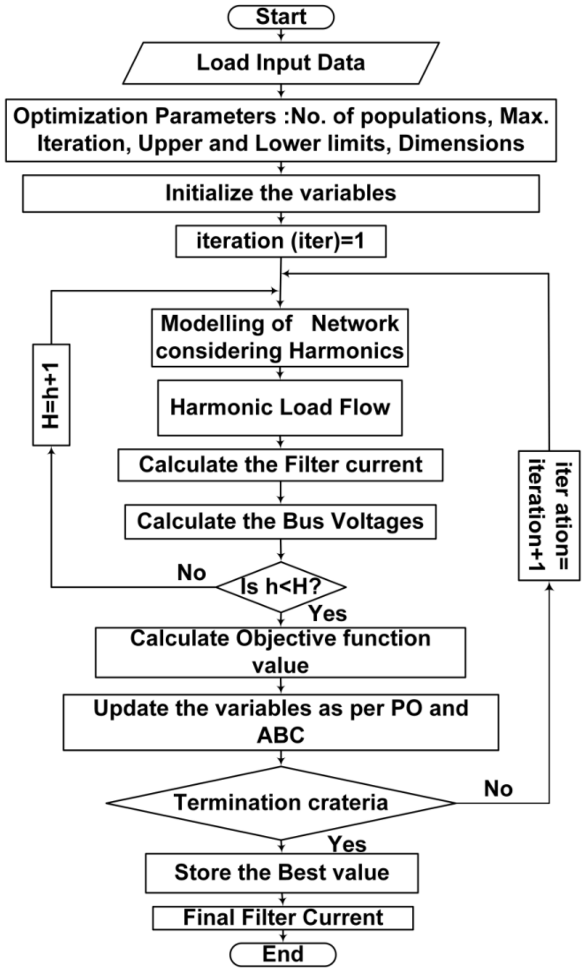


**Figure 1.** Flowchart

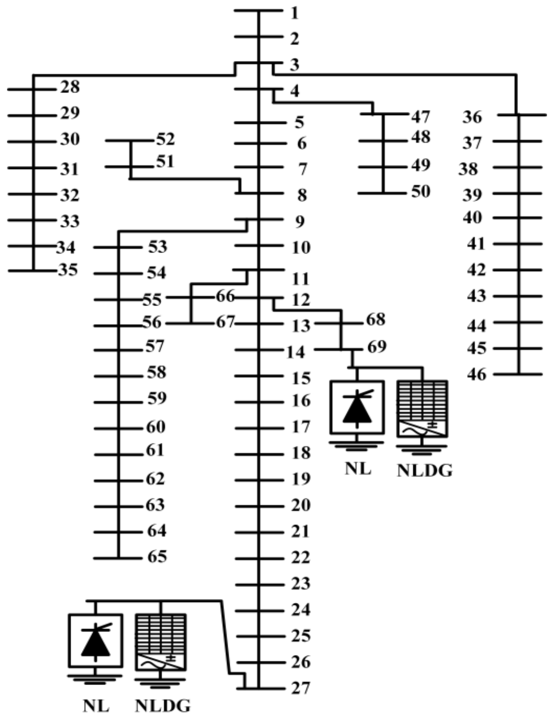


**Figure 2.** IEEE-69-bus RDS

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# 3. RESULTS AND DISCUSSION

This section deals with the result analysis and discussion.

The IEEE-69 bus system has two NLs + NLDGs at buses 27 and 69 as, shown in *fig. 2*. Here, only two nodes have NLs + NLDGs; the harmonic influence is magnified and affects all 69 buses in the system.

In the absence of an APF, HLF computes the THDv% for each bus, and *figure 3* shows the findings.

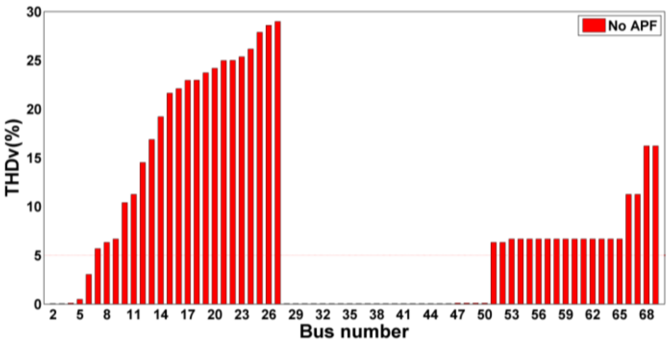


**Figure 3.** THDv at all buses without APF

The widespread influence of harmonics over the RDS is evident in the THDv readings of forty out of the total sixty-eight buses (excluding the first bus acts as a source bus) which is more than 5%. Surprisingly, only two buses have NLs + NLDGs, whereas all buses display THDv. Forty buses with THDv greater than 5% cannot meet the IEEE standard limit. It shows the poor PQ in RDS. The buses 27 and 69 have NLs + NLDGs. Both have THDv values of 28.96% and 16.20%, respectively. A total of 40 buses crosses the 5% limits of THDv.

The above stats indicate that RDS is a highly polluted harmonic system. Harmonic filter/s is/are required to achieve IEEE standard limits. The APF is simultaneously assigned to the same bus as the NLs + NLDGs, i.e., buses 27 and 69. The scenario is (i) single APF at bus 27, (ii) single APF at bus 69, and (iii) APFs at both buses. Now the size of APF is also an important criterion as it is directly proportional to its cost. In this instance, the POA optimization procedure determines the necessary APF current. The general optimization parameters, maximum number of populations, and iterations are 30 and 70, respectively.

This procedure is thoroughly reproduced for the selected test system by following the steps in the corresponding flowchart *(figure 1)*.

## 3.1 NLs + NLDGs (without APF) at 27 and 69

The NLs + NLDGs are connected at bus 27 and 69, as seen in *fig. 2*. These two nodes cause a significant harmonic distortion in the system. The highest THDv without APF is at bus 27 (28.96 %). The THDv of bus 69 is 16.20 %.

## 3.2 APF placed on bus 27

The APF is connected at bus 27 to lower the THDv as much as possible. On the other hand, for THDv, less than 5% of all buses have a single APF, which is sufficient if appropriately placed. *Figure 4* illustrates that POA has reached a minimum value of 0.1295 p.u. In contrast, ABC is converged at a very high value compared to POA (8.7460 p.u.). Therefore, in this scenario, POA is converged and capable of finding the minimum value of APF current. It is noted that bus 27 is a proper placement for APF. This placement is optimal because only one APF is capable of reducing the THDv by less than 5%. The nonlinear load is placed at bus 27, an end node. It directly influences the twenty-six buses (2 to 27); therefore, when it reduces the harmonics of nonlinear load at bus 27, the harmonics are effectively reduced at twenty-six buses. In other words, only one APF placed on bus 27 can reduce the THDv on all buses by less than 5%. Here, the performance of POA is better than ABC in terms of the current APF.

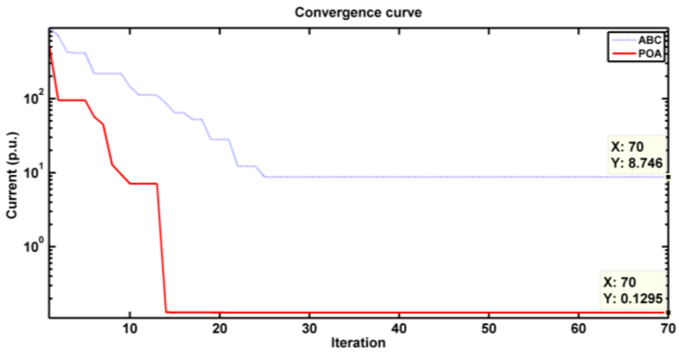


**Figure 4.** Algorithm convergence curves while APF is at bus 27

## 3.3 APF placed on bus 69

In this scenario, no algorithm is capable to fulfill the constraints and convergence. Both are not converged. POA converged at 36.16 p.u. and ABC converged at 36.31 p.u. It is confirmed from *fig. 5*, that no one algorithm is capable to fulfill the constraints. It means that this placement, *i.e.* bus 69 is not a proper placement for APF to improve the PQ.

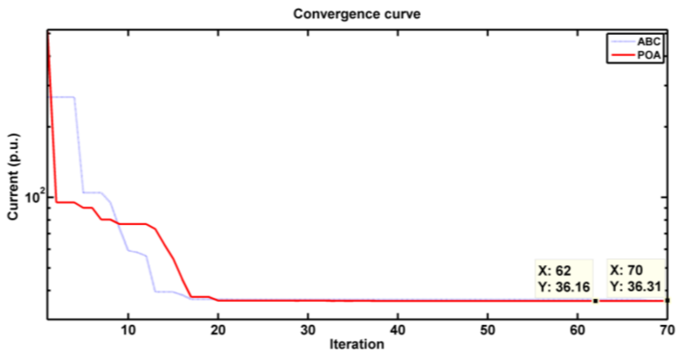


**Figure 5.** Algorithm convergence curves while APF is at bus 69

## 3.4 APFs placed on buses 27 and 69

There are now two buses with APF, 27 and 69. The outcome of HLF using optimization methods is displayed in *figure 6.*

It shows each algorithm's convergence curve for the specified condition. *Figure 6* illustrates how the POA calculates the minimum APF current. The ABC does not converge to obtain the lowest APF current, as demonstrated by this example.

Conversely, the POA algorithm delivers the lowest APF current under the specified parameters and effectively converges, as shown in *figure 6*. The computed APF current reaches 0.1198 (p.u.). Nonetheless, the POA method does converge successfully when the APFs are placed at bus 27 and 69; under these conditions, ABC (80.9600 p.u.) determined the APF current. It is regarded as inappropriate.

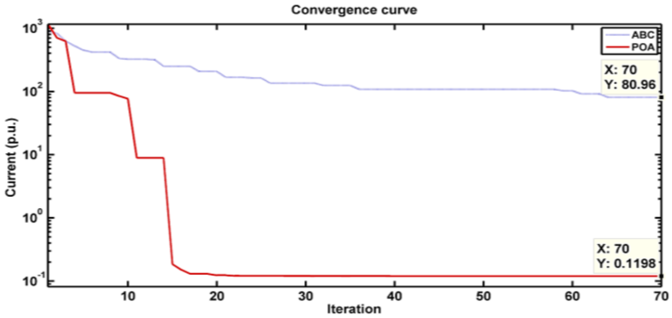


**Figure 6.** Algorithm convergence curves when APFs are present at buses 27 and 69

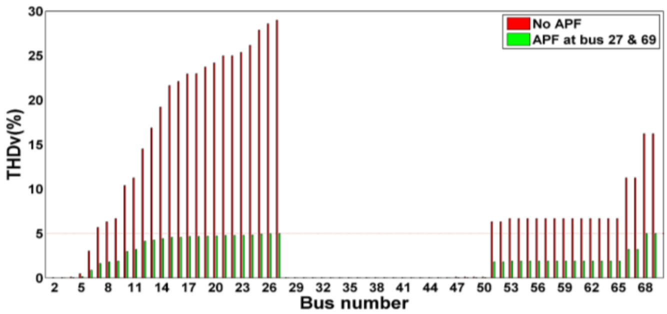


**Figure 7.** THDv at every bus, both with and without APFs after optimization

**Table 1 Comparison of Optimization algorithms**

| Bus | APF | $I_{apf}$ by POA | $I_{apf}$ by ABC | Status |
|---|---|---|---|---|
| 27 | 1 | 0.1295 | 8.7460 | Only POA converged |
| 69 | 1 | 36.16 | 36.31 | Both not converged |
| 27, 69 | 2 | 0.1198 | 80.9600 | Only POA converged |

*Figure 7* demonstrates that all of the system's buses now have THDv values that are less than 5% after the APFs were installed at buses 27 and 69. Notably, buses 27 and 69, which have a THDv of 28.96 % and 16.20 %, respectively, without the APF, now have a THDv of 5.00 % with the APFs in place, as the figure demonstrates. The APF's bus number and rating play a critical role in enhancing PQ in the RDS, as evidenced by *figure 7* that all buses meet the standard limit of THDv is less than or equal to 5%. Table 1 presents the comparison of results obtained by applied two optimization algorithms POA and ABC.

## 4. CONCLUSIONS

In conclusion, this work explores using the POA and ABC to enhance PQ in RDS. Even with two NLS + NLDGs in the RDS, the IEEE-69 bus test system simulation successfully combines POA and ABC with HLF, illustrating the extensive influence of harmonics. The measured THDv, which is more than 5% on forty buses, emphasizes the adverse effects of harmonics on PQ. The bus with the highest THDv, 28.96 %, is 27. The critical role of APF placement is highlighted by the successful reduction of THDv in all buses below 5% achieved by the single APF only when it is placed at bus 27. It is also achieved with two APFs at buses 27 and 69. It is remarkable that with just a single APF or double APFs, THDv may be kept contained by the permitted limit at all RDS buses.

With busses 27 and 69, the POA algorithm meets the requirement and successfully converges, producing a minimum APF current of 0.1198 p.u. On the other hand, ABC cannot converge, demonstrating POA's better performance in this specific case. Compared to the 8.7640 p.u. that ABC obtained, POA converges at 0.1298 p.u. At the same time, a single APF was examined on bus 27. Interestingly, the best location is at both buses, even though the total APF current at busses 27 and 69 (0.1198 p.u.) is lower than at bus 27 alone (0.1298 p.u.). However, bus 27 with a single APF is the best location when installation cost is considered. The total cost is divided into i) fixed cost and ii) incremental cost. Fixed cost depends on the number of APFs. It is a fixed one, while the incremental cost depends on the size of the APF. It is variable according to the size of APF. Here, when APF is placed at bus 27, the size is 0.1295 p.u. The size is greater when APFs are placed on buses 27 and 69 (0.1198 p.u.). Therefore, buses 27 and 69 are the proper placements for APFs at the first site, but if we include the cost analysis, then bus 27 is the optimal placement. The fixed cost on bus 27 is for only one APF, while for two APFs on buses 27 and 69. Therefore, considering the cost analysis, bus 27 is the optimal placement compared to buses 27 and 69.

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**Conflicts of Interest:** Declare conflicts of interest or state "The authors declare no conflict of interest."

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