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Research Article

Power Quality Enhancement through Active Power Filters in RDS using One to One based Optimizer

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ABSTRACT
This paper presents the application of a one-to-one based optimizer to improve power quality in radial distribution system using active power filters. Harmonics are a major issue affecting PQ, mainly caused by nonlinear loads that introduce distortions into the RDS. In this study, nonlinear distributed generation is also considered along with NLs at two end nodes. Harmonics reduction at acceptable standard and filters sizing techniques are for enhanced the PQ. The OOBO algorithm is used to determine the optimal placement and size of APFs. It is a population-based optimization technique with a good balance between exploration and exploitation capabilities. The objective of the optimization is to minimize the APF current while satisfying inequality constraints. The performance of the OOBO is evaluated through simulations on the IEEE 69-bus RDS. A comparative analysis is also performed using the artificial bee colony optimization algorithm. The simulation results demonstrate that the OOBO algorithm is stable and effective in solving the optimization problem.

Keywords: active power filter (APF)**;** harmonics; one to one based optimizer; radial distribution system (RDS); total harmonic distortion in voltage (THDv); individual harmonic distortion in voltage (IHDv); nonlinear distributed generation (NLDG); artificial bee colony (ABC)

1. Introduction

There is an increasing reliance on electronic devices like Light-emitting diodes, small fluorescent lights, inverters, dimmers, variable speed drives, constant power supply, cell phones, and PCs are some of these gadgets. Distributed generation is one of the key elements driving the development of smart grids. Due to its numerous benefits, it is receiving a lot of attention. One of the major tasks in the sector is integrating DG into the radial distribution system (RDS) [1,2]. However, because of the harmonics produced by the converter, poor integration may result in problems with power quality (PQ) [3]. A converter-based DG system that adds harmonics to the RDS is referred to as nonlinear DG (NLDG) [4,5]. However, the nonlinear characteristics and NLDG of these devices increase harmonic pollution. As a result, worries regarding harmonics in PQ are becoming more common among suppliers and users. The performance of distribution systems is negatively impacted by these harmonics, underscoring the importance of resolving these issues [6].

A number of harmonic mitigation techniques are discussed. An is used to prevent harmonics [7]. At the same NL load node but in the opposite direction, it introduces nonlinear current into the RDS. The harmonics are therefore eliminated. The effectiveness of an APF is closely correlated with its rating, therefore proper sizing and placement are crucial for cost savings [8]. Additionally, according to IEEE standards, meeting standard constraints such IHDv and THDv is necessary to achieve optimal performance [9].

As non-linear loads and renewable energy sources are increasingly, improving PQ and lowering harmonics are crucial. The distribution network's overall performance can be enhanced by APF location and sizing, which can decrease harmonic distortions, lower power losses, and increase voltage stability in RDS. Recent studies [10] have emphasized the significance of APF placement and sizing optimization in enhancing PQ and grid dependability, emphasizing the need for additional research in this area.

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APF's rating should be as low as feasible in order to lower its cost. An optimization method is needed and many strategies have been proposed as a result. PSO and its variant [11] have been applied. Additionally, a genetic algorithm is employed [12]. For this problem, the firefly algorithm [14, 15], harmony search [13], and more recently, the grey wolf optimizer [16] are also used.

The No Free Lunch theorem [17] states that no method can offer the optimum solutions for every optimization problem. A recently developed one-to-one based optimizer (OOBO) is used. It is a recently developed optimization method for resolving optimization issues in a number of scientific fields. The main concept behind the design of the proposed OOBO is to avoid the algorithm depending on particular members of the population while efficiently utilizing the knowledge of all members in the process of updating the algorithm population [18]. A metaheuristic optimization technique inspired by the foraging habits of honey bees is the artificial bee colony (ABC) algorithm. ABC algorithm determines the optimal solutions to optimization problems using scout, spectator, and employed bees [19]. Applications for it can be found in engineering, machine learning, and other domains seeking efficient optimization methods [20–21].

Various optimization techniques are utilized for various fields of research like PQ enhancement in microgrids [22], MPPT [23], electric vehicles.

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 OOBO with harmonic load flow (HLF): The paper couples the OOBO 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 OOBO and ABC, for four cases: NLs + NLDGs (without APF), APF at 35, APF at 46 and APFs at 35 and 46. The goal is to evaluate their performance in terms of finding the proper rating of the APF.

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

The OOBO is used first time for this problem, as per the knowledge of authors'. OOBO'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 OOBO 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, APF, and RDS modeling. Using OOBO, 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 [24]. The APF is modeled as a harmonic generator, as explained in [24]. For the analysis of harmonics, the HLF approach based on network topology is employed [25]. 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,

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

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:

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$$THD_V - 0.05 \le 0$$
$$IHD_V - 0.03 \le 0 \quad \text{.....(2)}$$
$$I_{apf} \le I_{apf,MAX}$$

Figure 1, shows the flowchart that explains how to use OOBO to improve PQ in RDS.

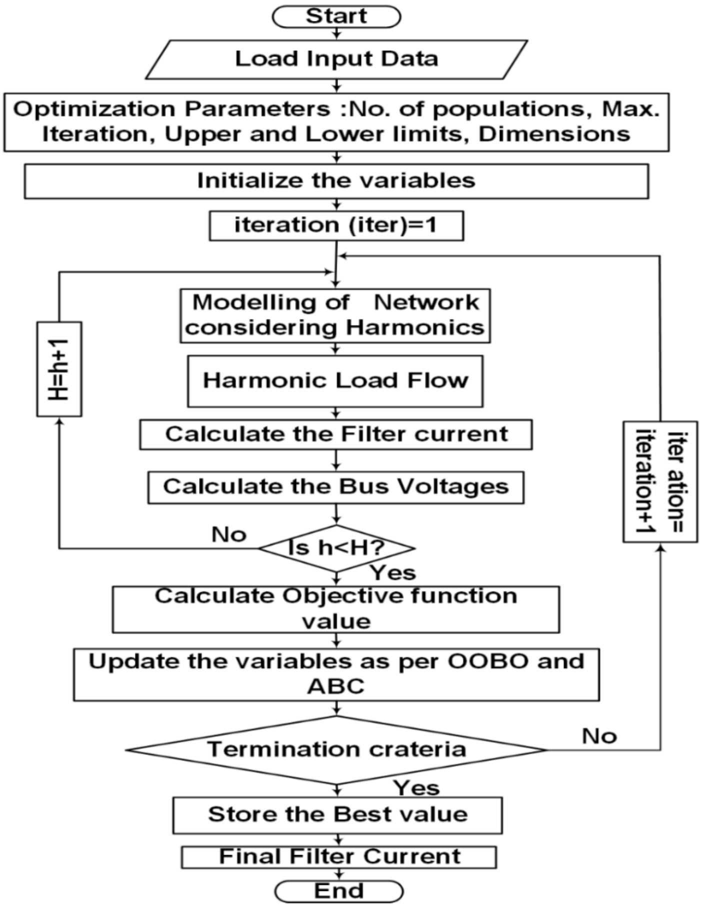

Figure 1: Flowchart

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 OOBO. Step 9: Set terminating criteria of an algorithm. Repeat these procedures for ABC also.

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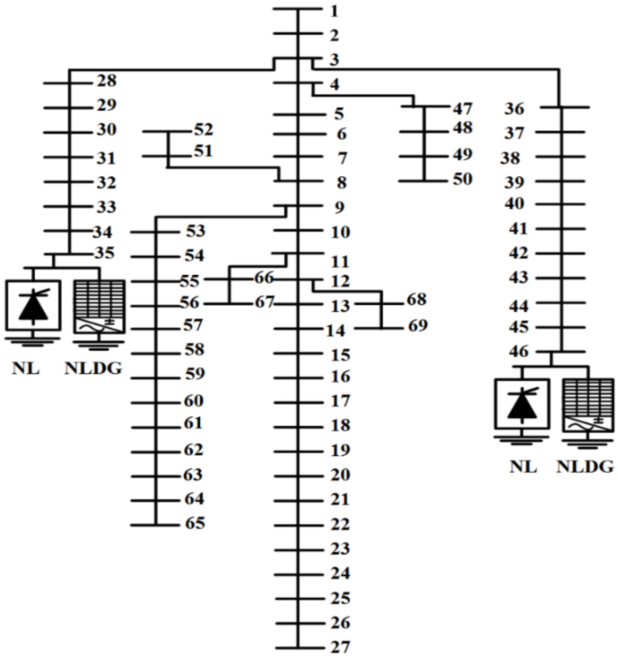

Figure 2: IEEE-69-bus RDS

3. Results and discussion

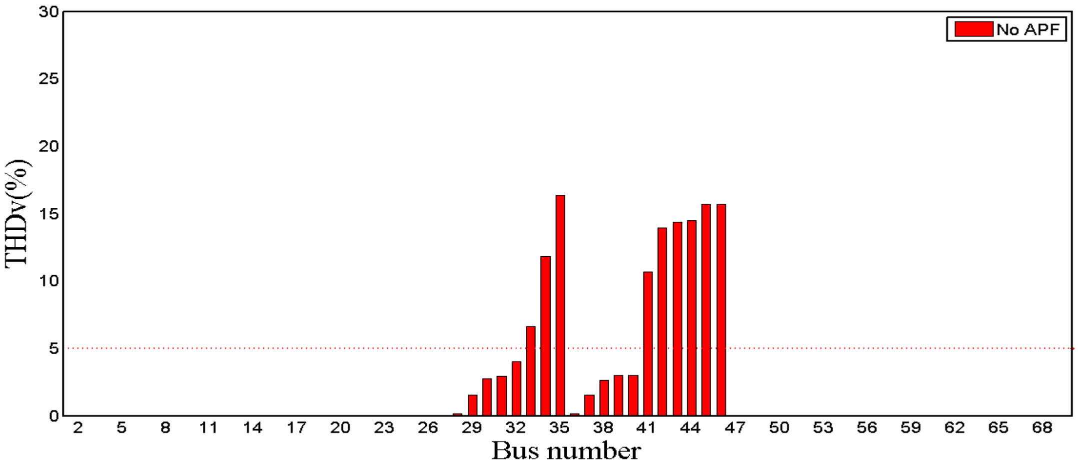

Figure 3: THDv at all buses without APF

This section deals with the result analysis and discussion. The IEEE-69 bus system has two NLs + NLDGs at buses 35 and 46 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 Fig. 3 shows the findings.

The widespread influence of harmonics over the RDS is evident in the THDv readings of nine 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. Nine buses with THDv greater than 5% cannot meet the IEEE standard limit. It shows the poor PQ in RDS. The buses 35 and 46 have NLs + NLDGs. Both have THDv values of 16.34% and 15.71%, respectively. A total of 9 buses cross 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 35 and 46. The scenario is (i) single APF at bus 35, (ii) single APF at bus 46, 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

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OOBO optimization procedure determines the necessary APF current. The general optimization parameters, maximum number of populations, and iterations are 30 and 50, respectively.
This procedure is thoroughly reproduced for the selected test system by following the steps in the corresponding flowchart (Fig. 1).
3.1 NLs + NLDGs (without APF) at 35 and 46:
The NLs + NLDGs are connected at bus 35 and 46, as seen in Fig. 2. These two nodes cause a significant harmonic distortion in the system. The highest THDv without APF is at bus 35 (16.34 %). The THDv of bus 46 is 15.71 %.

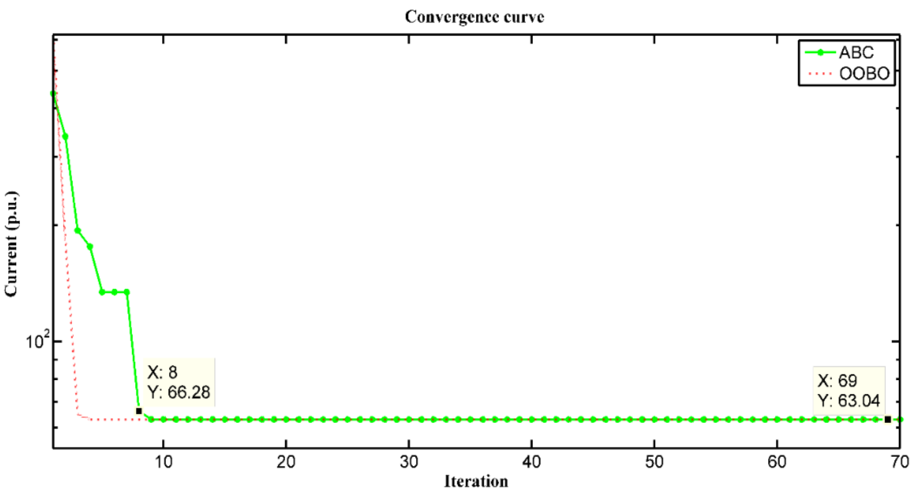

Figure 4 Algorithm convergence curves while APF is at bus 35

3.2 APF on bus 35

The APF is connected at bus 35 to lower the THDv as much as possible. Fig. 4 illustrates that OOBO has reached a minimum value of 63.04 p.u. Similarly, ABC is converged at a same value. In this scenario, no algorithm is capable to fulfill the constraints and convergence. The OOBO has reached minimum value faster compared to ABC. It shows that bus 35 is not a proper placement for this scenario.

3.3 APF on bus 46:

Same way, in this scenario also, no algorithm is capable to fulfill the constraints and convergence. Both are not converged. OOBO converged at 64.87 p.u. and ABC converged at same value, but later. Here, OOBO has reached above value for less iteration compared ABC. It is confirmed from Fig. 5, that no one algorithm is capable to fulfill the constraints. It means that this placement, i.e. bus 46 is not a proper placement for APF to improve the PQ.

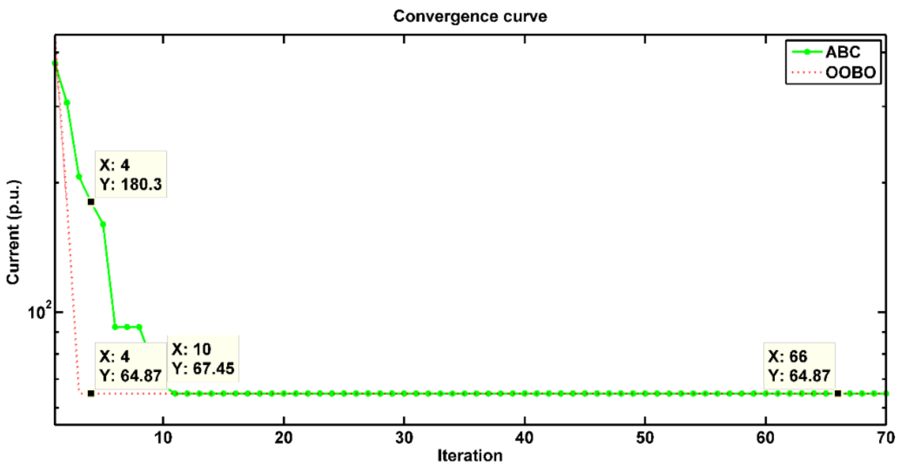

Figure 5 Algorithm convergence curves while APF is at bus 46

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3.4 APFs on buses 35 and 46

There are now two buses with APF, 35 and 46. The outcome of HLF using optimization methods is displayed in Fig. 6.

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

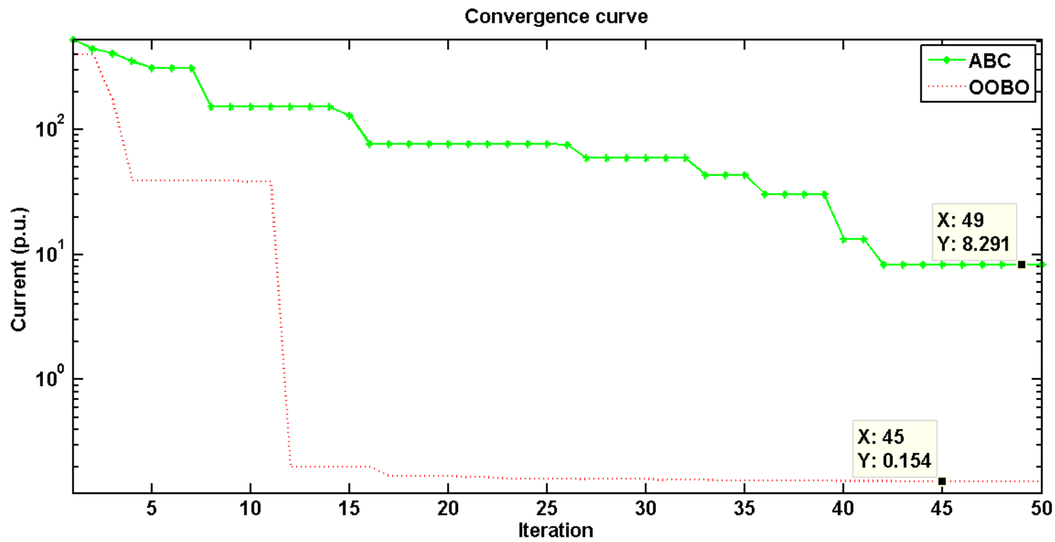

Figure 6 Algorithm convergence curves when APFs are present at buses 35 AND 46

Conversely, the OOBO delivers the lowest APF current under the specified parameters and effectively converges, as shown in Fig. 6. The computed APF current reaches 0.154 p.u.. Nonetheless, the OOBO method does converge successfully when the APFs are placed at bus 35 and 46; under these conditions, ABC (8.291 p.u.) determined the APF current. It is regarded as inappropriate.

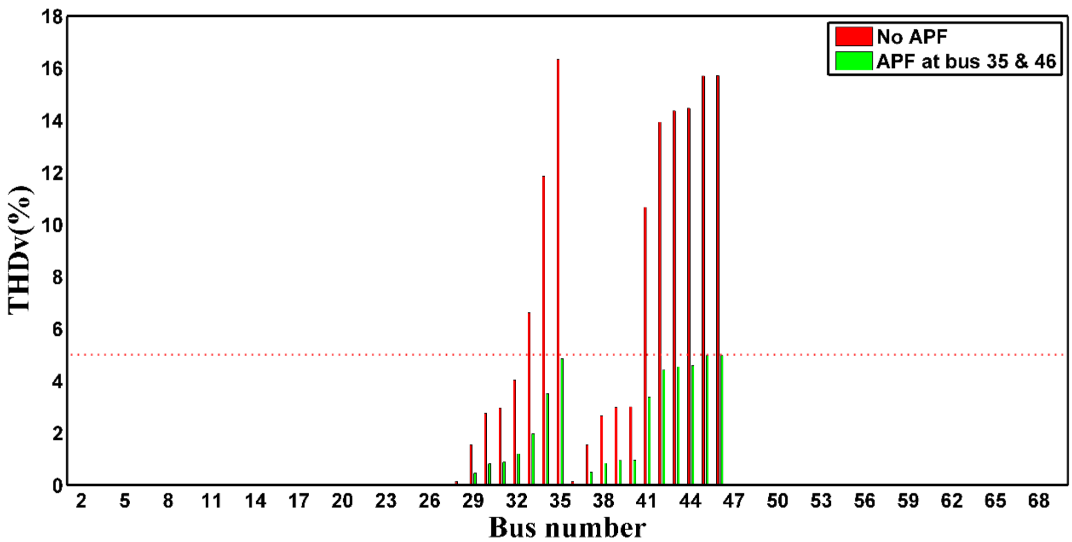

Figure 7 THDv at every bus, both with and without APFs after optimization

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 35 and 46. Notably, buses 35 and 46, which have a THDv of 16.34 % and 15.71 %, 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 Fig. 7 that all buses meet the standard limit of THDv is less than or equal to 5%.

4. Conclusions

In conclusion, this work explores using the OOBO and ABC to enhance PQ in RDS. Even with two NLS + NLDGs in the RDS, the IEEE-69 bus test system simulation successfully combines OOBO 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, 16.34 %, is 35. The critical role of APF placement is highlighted by the successful reduction of THDv in all buses below 5% achieved by the two APFs. Only one APF is not capable to reduce the THDv as per standard limit. It is achieved with two APFs at buses 35 and 46. It is remarkable that with two APFs, THDv may be kept contained by the permitted limit at all RDS buses, i.e. 68 buses.
With busses 35 and 46, the OOBO algorithm meets the requirement and successfully converges, producing a minimum APF current of 0.154 p.u.. On the other hand, ABC cannot converge, demonstrating OOBO's better performance in this specific case. Compared to the 8.291 p.u. that ABC obtained, OOBO converges at 0.154 p.u.. It shows that the performance of OOBO is better compared to ABC optimization algorithm.

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