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Harmonics Reduction in Radial Distribution System by Harmonics Filters Utilizing Ant Lion Optimizer

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Abstract

In this study, the main goal is to improve power quality (PQ) in radial distribution systems (RDS) by carefully integrating active filters (AFs). Nonlinear loads (NLs) can produce harmonics that negatively affect PQ. The effective mitigation of NL harmonics by introducing AFs lowers the total harmonic distortion in voltage (THDv). Simulations using the IEEE-69 bus system validate the effectiveness of this method by showing a notable improvement in PQ together with minimum AF sizing. In this work, two optimization techniques are compared to get the lowest AF current: ant lion optimizer (ALO), and improved particle swarm optimization (IPSO). The simulation results show a notable improvement in PQ and validate the efficacy of the suggested AF placement and sizing technique. The optimization procedure shows that ALO minimizes AF current more effectively than IPSO. Finding the best approach to improve the location and size of AFs is made easier with the help of this comparative analysis of optimization techniques.

Keywords: ALO; Harmonics; IPSO; Power Quality; RDS.

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1. Introduction

Radial distribution systems' (RDS) power quality (PQ) has declined due to the widespread use of power electronics devices in daily life. PQ problems show up as variations in the RDS's voltage or current. One prominent factor leading to harmonic generation is the inherent nonlinear nature of power electronics equipment. The accompanying nonlinear loads (NL) allow harmonics to enter the system when these nonlinear devices are coupled to the RDS. Although linear loads can also be problematic, NL-induced harmonics broadly affect the entire RDS.

These harmonics have a negative impact on the quality of the voltage and current, which interferes with the operation of sensitive loads and causes money losses, electricity

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waste, mal-operation of protective systems, and overheated equipment [1]. Incorporating NLs makes PQ issues worse in RDS.

Harmonic filters, which can be divided into passive and active categories, are a suitable solution to the harmonic problems in RDS. Passive filters are less expensive but could cause resonance effects in the RDS. Using active filters (AFs) as a dependable alternative is advised. AFs generate harmonics that are either the same or different from those NLs introduced. At the common coupling point, AF effectively cancels and balances the harmonics generated by NLs. The cost of AFs is directly proportional to their current. For this reason, AFs are thought to be a more dependable option than passive filters when it comes to reducing harmonics in RDS and avoiding resonance problems [2]. IEEE standards indicate that the threshold for total harmonic voltage distortion (THDv) is 5 % [3].

Rather than focusing on any particular harmonic, the goal is to make sure that the THDv at every RDS bus stays below this predetermined threshold. Because costs are directly impacted by the current flowing through AFs, optimizing this current is essential to meeting the specified limit in the RDS. This guarantees a cost-effective strategy for preserving high PQ in RDS.

Optimization techniques are used to calculate the APF current. The optimization algorithms are used in various fields of engineering, such as efficient control of windmill induction generators [4], deep learning approach for wheat leaf diseases and cricket highlight video summarization [5,6], and evolution algorithms in task scheduling [7]. Which one of the various algorithms is suitable for the problem? The No Free Lunch theorem emphasizes that various algorithms are created for particular circumstances. Therefore, it permits the use of different algorithms for different problems [8]. Here, the ant lion optimizer (ALO) is used in this research to calculate the minimal current needed for AFs coupled with harmonic load flow (HLF). Finding the lowest AF current necessary to maintain the RDS's total THDv below the specified 5 % standard limit at all the buses.

This paper is organized as follows: in Section 2, the problem formulation is explained; in Section 3, results and discussion are presented; and in Section 4, a conclusion is provided.

2. Problem Formulation

As previously indicated, a number of optimization techniques were used to ascertain the minimal current necessary for the AF to abide by accepted limitations [9]. The algorithms that were specifically employed were the genetic, particle swarm optimization (PSO), firefly, music-inspired, and grey wolf optimizer [10-14].

Inspired by ant lions' foraging habits, the ALO is an optimization system that takes its cues from nature. ALO, which was created to tackle intricate optimization issues, strikes a balance between discovery and exploitation, emulating the cooperative communication and adaptive searching seen in ant lions. Several optimization disciplines have shown this approach's adaptability and effectiveness [15].

This study expands on the traditional PSO framework by adding an improved PSO (IPSO) to the ALO approach [16]. The two optimization algorithms are combined with the HLF to determine the minimum current needed for the AF.

As explained [17], the issue formulation in this study takes place in a harmonic framework, wherein factors like line resistances and inductances are purposefully designed with harmonics. In this case, the AF is considered a nonlinear load generator, and the HLF is organized according to the procedure given in literature [18]. The thorough combination of ALO, IPSO, and HLF skillfully tackles the harmonic-related problems, offering a more sophisticated and efficient method of determining the lowest current necessary for AF performance within particular given bounds.

Finding the lowest active AF current that successfully reduces harmonics is the key goal in order to keep each bus's THDv below the 5 % threshold. This objective function (OF) can be stated mathematically as:

$$OF = (Iaf)_{Min} \quad (1)$$

The detailed process for determining the minimum AF current is shown in Fig. 1. The systematic procedure outlines the steps required to lower the AF current for each bus in the RDS while preserving harmonic suppression within the designated THDv limit.

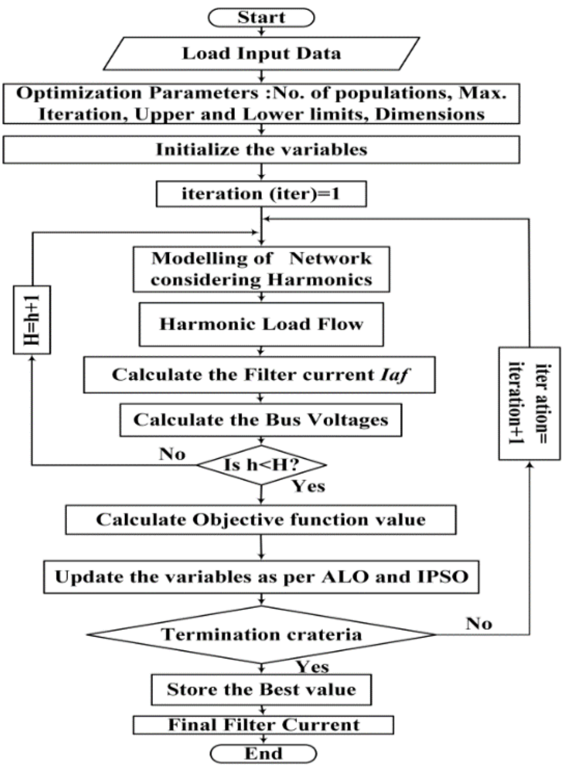

Fig. 1. Flowchart for determining the minimum AF current.

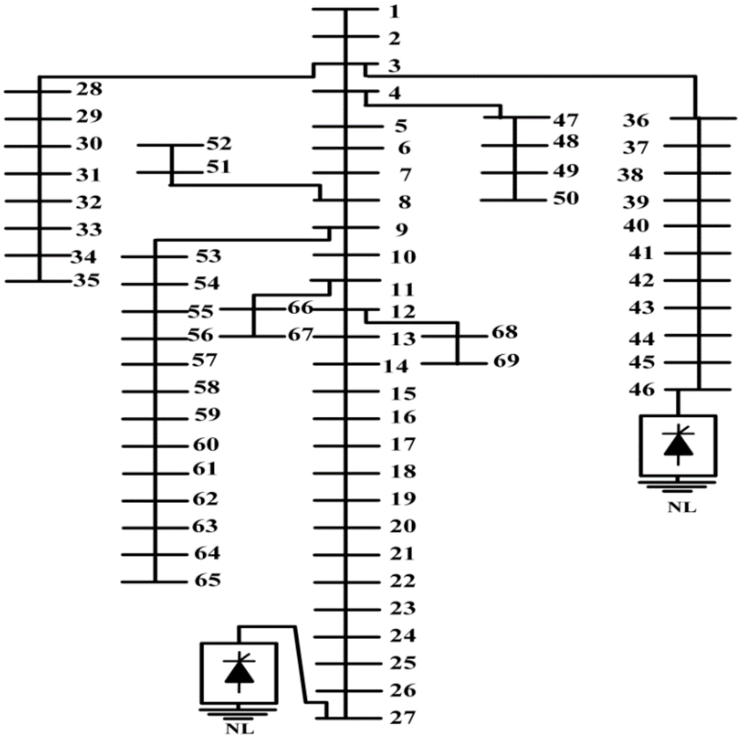

Fig. 2. IEEE 69 RDS with NLs at 27 and 46.

3. Results and Discussion

3.1. *System data*

Fig. 2 illustrates the use of the modified IEEE-69 bus test setup in this study, as described in literature [19]. In this configuration, the harmonic spectrum includes an adjustable six-pulse converter covering harmonics from 5 to 49, while buses 27 and 46 have NLs. The harmonic impact is enhanced by NLs placed purposefully at the end nodes. Even though there are 69 nodes in the system, only two of them contain NLs; yet, the effects of these harmonics are distributed throughout all buses. Without the use of an AF, Table 1 shows the THDv for each bus in this harmonically contaminated system.

THDv values greater than 5 % for all twenty buses (except the first one) show that harmonics are widely distributed across the RDS. Every bus collects THDv data, even though there are only two nodes with NLs. Bus 27 has the highest THDv, at 13.04 %. Harmonic filter(s) must be used to reduce these excessive THDv values and bring them within allowable bounds. The AFs are located exactly where the NLs are connected to buses 27 and 46.

Table 1. THDv at all buses in the absence of AF.

Bus No.	THDv (%)	Bus No.	THDv (%)	Bus No.	THDv (%)	Bus No.	THDv (%)
2	0.01	19	**9.88**	36	0.06	53	2.01
3	0.02	20	**10.17**	37	0.70	54	2.01
4	0.03	21	**10.64**	38	1.20	55	2.01
5	0.15	22	**10.66**	39	1.34	56	2.01
6	0.92	23	**10.87**	40	1.35	57	2.01
7	1.71	24	**11.35**	41	4.80	58	2.01
8	1.90	25	**12.38**	42	**6.27**	59	2.01
9	2.01	26	**12.80**	43	**6.46**	60	2.01
10	3.13	27	**13.04**	44	**6.51**	61	2.01
11	3.38	28	0.02	45	**7.07**	62	2.01
12	4.36	29	0.02	46	**7.07**	63	2.01
13	**5.77**	30	0.02	47	0.03	64	2.01
14	**7.19**	31	0.02	48	0.03	65	2.01
15	**8.64**	32	0.02	49	0.03	66	3.38
16	**8.91**	33	0.02	50	0.03	67	3.38
17	**9.42**	34	0.02	51	1.90	68	4.36
18	**9.43**	35	0.02	52	1.90	69	4.36

Both IPSO and the ALO are used in the optimization procedure to find the necessary AF current. Common optimization parameter settings are applied to refine the results, with a maximum of 30 populations and 50 iterations.

The flowchart parts provide a methodical way to apply the ALO algorithm in the tested system under consideration.

3.2. *Steps*

The following actions are part of the investigation:

(i) Integrate the test system with the harmonic spectrum and any pertinent data.
(ii) Establish and set up the ALO algorithm's optimization settings.
(iii) Put essential inputs into a harmonic framework context.
(iv) Carry out the simulation of the HLF.
(v) Using only the NLs, compute the THDv.
(vi) Calculate THDv with NL only.
(vii) Add the AF to the simulation of the HLF.
(viii) To determine the least amount of AF current needed, apply the ALO optimization technique.
(ix) Take note of and hold onto the optimum value.
(x) To repeat the optimization process, use the IPSO technique.
(xi) Print the minimum AF current that was eventually found through the optimization process.

3.3. *Without AF, NLs at buses 27 and 46*

The coupling of NLs at buses 27 and 46 results in a severely harmonic-distorted system in the absence of an AF, as seen in Fig. 3. With a THDv of 13.04 %, bus 27 has the highest THDv, followed by bus 46 with 7.07 %. Interestingly, twenty buses exceed the THDv standard limit.

3.4. *AF implementation at bus 27*

An AF is installed at bus 27 in an attempt to resolve this problem and lower THDv to levels that are reasonable. Still, using only one AF is not enough to get THDv values around 5% for each bus. There is a need for additional refining because none of the optimization strategies converge to the minimal AF value needed.

3.5. *AF implementation at bus 46*

The AF is then moved to bus 46. None of the algorithms converges to the lowest value of the AF current, as was already mentioned. This demonstrates that THDv cannot be brought down to within the standard limit on all buses by a single AF. The next part discusses how effective it is to deploy two AFs.

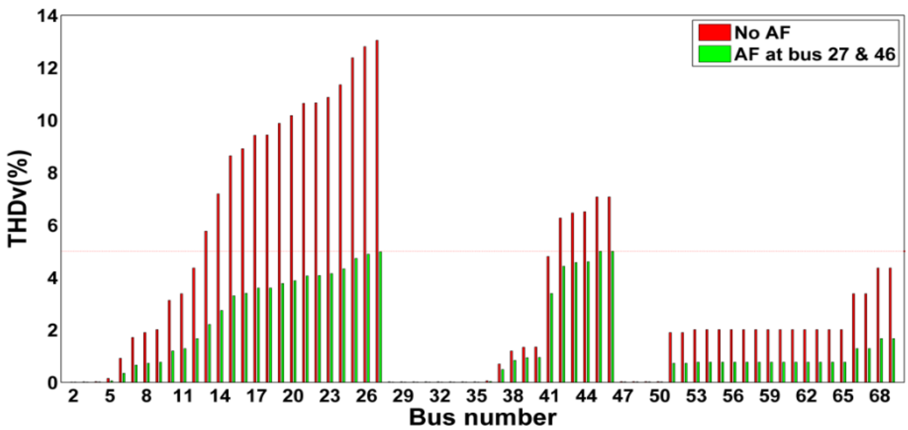

Fig. 3. All bus THDv without AF and AFs at buses 27 and 46.

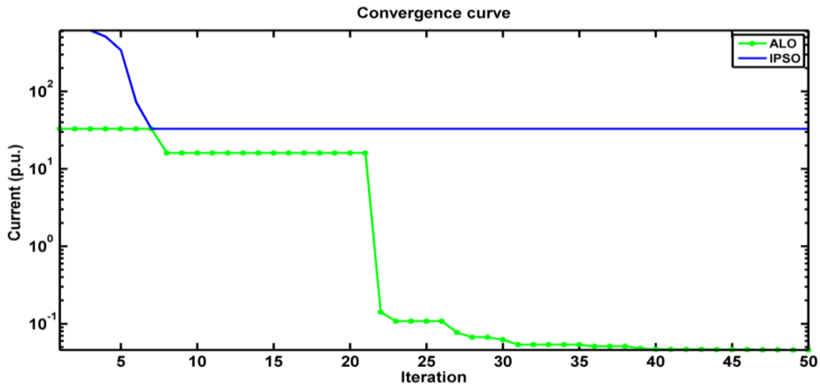

Fig. 4. Convergence curves of ALO and IPSO AFs at buses 27 and 46.

3.6. *Buses 27 and 46 have AFs installed*

An important step forward has been made with the successful deployment of AFs at buses 27 and 46. Fig. 4 presents the results of HLF with optimization techniques and the convergence curves of all algorithms within the given parameters. The ALO successfully ascertains the minimum AF current in this case. ALO performs better than IPSO algorithms, as evidenced by its notable ability to converge and yield the lowest AF current. The AF current of 0.0460 (p.u.) has been determined.

An overview of the system following the installation of AFs at busses 27 and 46 is shown in Fig. 3. Crucially, THDv levels below 5 % are now displayed on every bus. Busses 27 and 46 notably show a notable decrease from their initial THDv values of 13.04 % and 7.07 % without the AF to 4.98 % and 5 %, respectively. This uniform THDv decrease on all buses highlights how important AFs are to improving PQ in the RDS.

4. Conclusion

This research successfully uses the ALO to determine the best places to put AF in the RDS for a given condition. The successful generation of simulation results for the IEEE-69 bus test system is achieved by integrating HLF with ALO. The results show that harmonics considerably affect the RDS even when there are only two linked NLs. As a result, twenty buses have values for THDv of more than 5 %. Interestingly, Bus 27 has the highest THDv at 13.04 %, highlighting the detrimental impact of harmonics on the PQ of the RDS. The necessity of accurate AF positioning is highlighted by the insufficiency of putting the AF just at Bus 27 or 46 to reduce harmonics to acceptable levels. On the other hand, moving the AFs to Buses 27 and 46 guarantees THDv values of less than 5 % for each bus, highlighting the vital part precise AF placement plays in improving PQ. The research shows that two AFs are adequate to satisfy THDv constraints over the whole RDS. Despite the IPSO failing to converge in order to discover the minimum AF current, the ALO successfully calculates a minimum AF current of 0.0460 p.u., meeting the conditions for increased PQ in the RDS. These findings highlight the strategic importance of AF placement and optimization methods in successfully lowering harmonics and enhancing the PQ.

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