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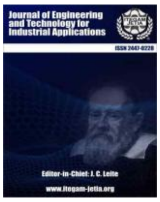

RESEARCH ARTICLE

OPEN ACCESS

POWER QUALITY IMPROVEMENT THROUGH HARMONIC FILTERS USING TASMANIAN DEVIL OPTIMIZATION ALGORITHM

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ABSTRACT

To enhance power quality (PQ) through active power filters (APF) in radial distribution systems (RDS), this study investigates the application of the Tasmanian Devil Optimization (TDO) and Osprey Optimization Algorithm (OOA). Despite their benefits, the growing use of solar photovoltaic (PV) systems presents challenges with PQ, including harmonic distortion because of their nonlinear features. Harmonics are the leading cause of low PQ in such systems. Here, the PV injects harmonics into the RDS and is categorized as a nonlinear distribution generator (NLDG). This study examines the effect of the nonlinear loads (NLs) of two end nodes and the incorporation of the NLDG into the RDS on the entire RDS. APFs are positioned carefully to reduce the harmonics and improve the PQ. The suggested method minimizes the APF current while abiding by inequality limitations by utilizing an optimization algorithm. The TDO was used to determine the appropriate APF size. It is inspired by natural processes such as photosynthesis. It has a good balance between exploration and exploitation for effective search. The efficacy of the TDO was demonstrated through simulations on the IEEE-69 bus RDS and was compared with that of the OOA. The outcomes validate that the TDO is stable and efficient in resolving this optimization issue for PQ enhancement in RDS.

I. INTRODUCTION

Electrical engineering is changing owing to artificial intelligence (AI) and modern soft computing techniques. AI systems can predict and enhance power grid behavior, thereby reducing energy losses and increasing stability. Machine learning is applied to analyze massive amounts of sensor data to identify equipment flaws and prevent outages. Control systems with AI capabilities can manage intricate energy distribution networks and effectively integrate renewable energy sources into the grid. Computational technologies, such as finite element analysis, which simulates electrical systems and components, assist in performance prediction and design optimization. Owing to these developments, electrical engineering is evolving to become more intelligent, effective, and sustainable [1-3].

The modern environment has made electronic devices increasingly necessary, leading to an increased reliance on them. These devices include PCs, cell phones, dimmers, inverters, variable-speed drives, continuous power supplies, and light-emitting diodes. They cause the distribution system to acquire harmonics, resulting in low power quality (PQ) [4]. Furthermore, distributed generation (DG) sources, such as solar photovoltaic and wind farms, are the main forces behind the growth of smart grids. Its many advantages have drawn considerable attention. Integrating DG with a radial distribution system (RDS) is a crucial responsibility in the industry [5]. However, owing to the harmonics of the converter, inadequate integration can result in PQ issues [6].

A converter-based DG system, called nonlinear DG (NLDG), adds harmonics to the RDS [7]. However, these devices produce more harmonic pollution owing to their nonlinear properties. As a result, suppliers and consumers are becoming increasingly concerned about harmonics in PQ systems. The performance of distribution systems is negatively impacted by these harmonics, underscoring the urgency of finding solutions [8]. Several harmonic mitigation techniques are discussed in the literature [9]. An active power filter (APF) reduces the harmonics.

At the same node, it provides a nonlinear current through the RDS, similar to the NL load but in the opposite direction. Consequently, the harmonics were reduced or mitigated as required. Their ratings significantly influence the success of APFs. To ensure cost-effectiveness, they must be precisely proportioned and positioned [10]. Additionally, to achieve optimal performance, it is necessary to comply with IEEE regulations regarding individual and total harmonic distortion in voltage (IHDv and THDv, respectively) [11]. However, an analysis of the precise location and rating of APFs in RDS is required to determine whether modern power distribution networks are still stable, trustworthy, and efficient. The more NL and renewable energy sources are added to the RDS, the more crucial it is to lower the harmonics and improve the PQ.

The positioning and rating of APFs can enhance power efficiency, lower harmonic distortion, and strengthen RDS voltage stability, all of which improve the general functionality of the device. Recent studies have underscored the significance of optimizing the location and size of APFs to improve grid reliability and PQ, while also emphasizing the need for further research [12-14]. APF's current should be as low as feasible to minimize expenses. An optimization strategy is required for this. Consequently, several optimization methods have been proposed. Both PSO and its variants have been applied in [15], whereas a genetic method was employed in [16]. This problem has also been approached using other techniques, such as the harmony search [17], firefly algorithm [18], grey wolf optimizer [19], and, most recently, the JAYA algorithm [20].

Furthermore, many research topics employ a range of optimization methodologies, including PQ enhancement using APF [21]. Moreover, numerous research topics use a variety of optimization techniques, such as solar irradiance forecasting [22], PV wind-based microgrid implementation [23], UPQC using PSO-based PI tuning [24], fault detection in AC motors [25], and harmonic mitigation of solar PV [26]. No optimization algorithm can offer optimal solutions to every optimization problem; based on the No Free Lunch Theorem (NFL) [27], researchers use custom algorithms because the nature of the problem can affect how well an algorithm performs. Tasmanian Devil Optimization (TDO), a recently proposed bio-inspired metaheuristic algorithm inspired by the behavior of Tasmanian devils in the wild, was used in this study. TDO mimics the diet of the Tasmanian devil, which consists of attacking live prey and scavenging on carrion.

The algorithm's mathematical modeling and comprehensive design are presented in this publication. The optimization results demonstrate how effectively TDO can investigate and use data, finding a helpful compromise between the two to address the optimization problems. Moreover, the implementation outcomes demonstrate that TDO performs admirably in real-world settings. This was recently proposed by [28]. It has shown promising results in various optimization areas, and this metaheuristic algorithm is an invaluable resource for scholars and practitioners across a wide range of sectors. It is widely used in engineering fields, such as the parameter identification of transformers [29], economic load dispatch [30], tuning of PID controllers [31], and global optimization [32].

The Osprey Optimization Algorithm (OOA), a novel metaheuristic algorithm presented in this study, is modeled after the instinctive hunting behavior of ospreys. The ospreys' method of spotting fish in the water, catching them, and transporting them to a good spot to eat is the basis of the OOA. The algorithm's approach is mathematically modeled to simulate the natural behavior of ospreys during hunting, encompassing two key phases: exploration and exploitation. Proposed it [33]. Numerous technical fields have made extensive use of it, including economic load dispatch [34], reactive power optimization [35], and DC microgrid [36] control. Several important contributions were made to this study, including the use of APFs to handle harmonic reduction when NL and NLDG were present. The following are the primary contributions of this study:

TDO and harmonic load flow (HLF) integration: This study uses a combination of TDO and HLF analyses to obtain a suitable filter rating. This method considers the response of the system to the harmonic production of NL + NLDG.

Comparison of two algorithms: In this study, two algorithms, TDO and OOA, are compared and analyzed for four distinct scenarios: NLs + NLDGs (without APF), a single APF on 27 and 67, and double APFs on 27 and 67. The aim of this assessment was to evaluate their efficiency in ascertaining a suitable APF grade. TDO advantage over OOA: In all scenarios and data evaluated, the computational trials showed that the TDO worked better than the OOA by producing the least amount of APF current.

To the best of our knowledge, this is the first instance of a TDO being used to solve a problem. Computational testing was used to assess the performance of the TDO, and the value of the optimal fitness function was compared with that of the OOA. In this study, the NL + NLDG buses under consideration were simulated using the IEEE-69 RDS system to ascertain the most suitable value of the APF current employing TDO and OOA.

II. METHODOLOGY

APF, RDS modeling, HLF, and TDO are used to develop an objective function that increases PQ while reducing harmonics are all covered in this part.

II.1 MODELING OF RDS, HLF, AND APF

The three RDS parameters, impedance, resistance, and inductance, are represented in a harmonic environment in line with [37]. As stated in [37], a harmonic generator was used to represent the APF. Harmonic analysis was performed using the network topology-based HLF approach [38]. The two correlation matrices that form the basis of this method are the BCBV and BIBC.

II.2 OBJECTIVE FUNCTION

The objective function (OF) is an important aspect of the optimization process. Constrained nonlinear problem: Identification of the proper APF rating to reduce harmonics. In this instance, the decision component is the APF current.

Because the cost of the APF increases with its current rating, it is imperative to lower the current. The following three restrictions were considered to raise the PQ in RDS with APF: The three variables are THDv, IHDv, and Iapfmax. Whereas the third standard limit depends on the NL current, the first two are required by IEEE Standard 519. The objective function is expressed as

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

The highest-order harmonic in this formula is denoted by H. The dynamic penalty is denoted by DP. The total number of buses is n, and the representation of the bus number is m. The objective function is subject to the following restrictions.

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

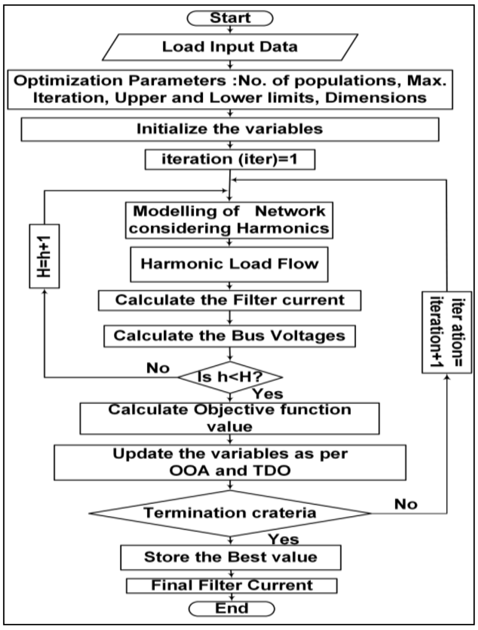


Figure 1: Flowchart.
Source: Authors, (2026).

Figure 1 shows a flowchart of the application of the TDO to reduce harmonics and enhance PQ in RDS. As shown in Figure 2a, this study uses a modified IEEE-69 bus RDS [39], where the buses in the system with NLs are linked to the NLDGs. The 5th to 49th harmonics in the NLs' harmonic spectrum match the features of a six-pulse converter [4]. The NLs are carefully placed at the end nodes of RDS buses 27 and 67, as shown in Figure 2a. Matlab code simulating the presented optimization can be seen form Figure 2b.

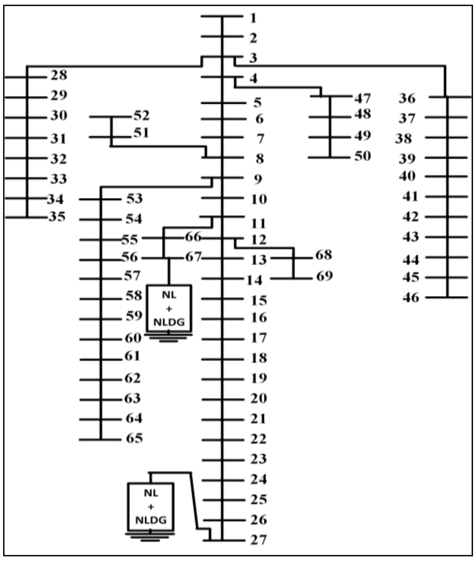
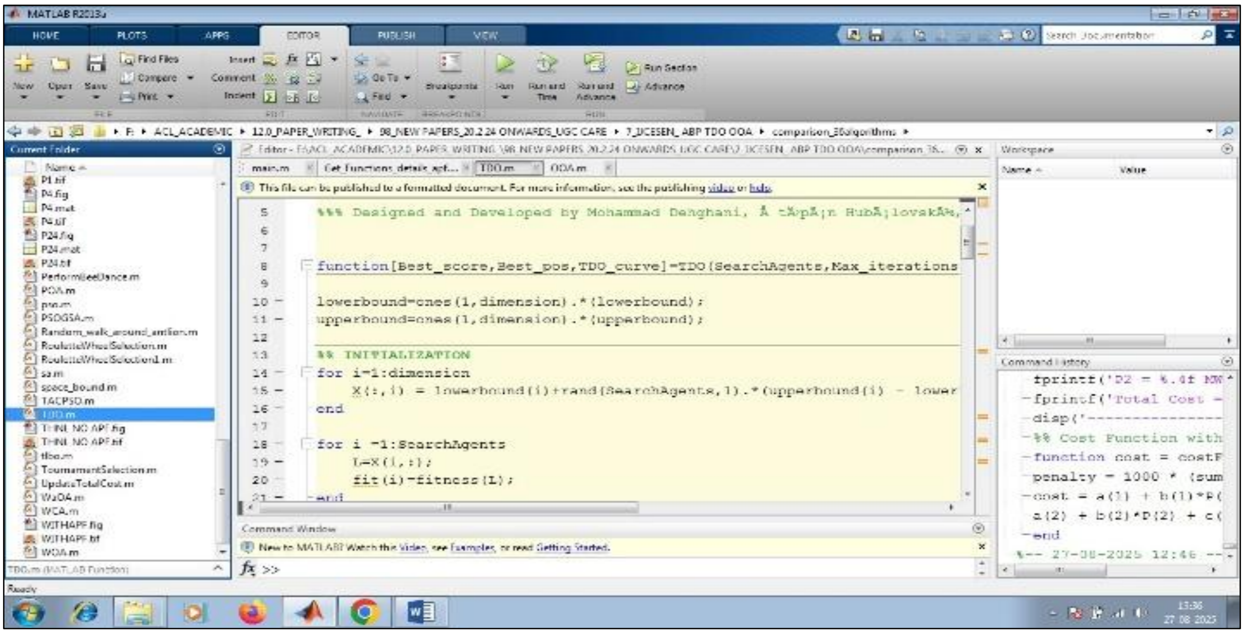


Figure 2a: IEEE-69 bus RDS.
Source: Authors, (2026).



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```
%%% Designed and Developed by Mohammad Dehghani, Å tÄ›pÃ¡n HubÃ¡lovskÃ½,


function[Best_score,Best_pos,TDO_curve]=TDO(SearchAgents,Max_iterations

lowerbound=ones(1,dimension).*(lowerbound);
upperbound=ones(1,dimension).*(upperbound);

%% INITIALIZATION
for i=1:dimension
    X(:,i) = lowerbound(i)+rand(SearchAgents,1).*(upperbound(i) - lower
end

for i =1:SearchAgents
    L=X(i,:);
    fit(i)=fitness(L);
end
```

New to MATLAB? Watch this Video, see Examples, or read Getting Started.

```
fx >>
```

```
 fprintf('P2 = %.4f MW
-fprintf('Total Cost =
-disp('----------------
-%% Cost Function with
-function cost = costF
-penalty = 1000 * (sum
-cost = a(1) + b(1)*P(
 a(2) + b(2)*P(2) + c(
-end
%-- 27-08-2025 12:46 --
```

Figure 2b: Simulation setup.
Source: Authors, (2026).

II.3 THE PROCEDURE FOR SIMULATION

First, the pertinent data from the test system, including the harmonic spectrum, were loaded. The optimization parameters were specified in the next step. Step 3 is a simulation of the harmonic context created using the inputs. HLF analysis should be performed in Step 4. In step 5, the THDv should be computed using the NLs and NLDGs. Incorporate the APF into the system prior to step 6. The APF is included in the HLF in step 7. In Step 8, the minimum practical APF current is determined using the TDO. Step 9: Define the termination standards for the approach. Similarly, identical actions are performed for the OOA.

III. RESULTS AND DISCUSSIONS

As shown in Figure 2a, the IEEE-69 bus system has two NLs + NLDGs at buses 27 and 67. This example has only two nodes with NLs + NLDGs, but the harmonic influence is amplified and affects all 68 buses in the system. Without the APF, the HLF determines the THDv% of each bus, as shown in Figure 3. The THDv values of 40 of the 68 buses (excluding the first bus, which is a source bus) show that harmonics have a considerable effect on the RDS; these readings are larger than 5%. Remarkably, only two buses have NLs + NLDGs, and all buses have THDv. A bus cannot fulfill the IEEE standard limit if its THDv is greater than 5%. It displays the low PQ of the RDS. NLs + NLDGs were present on buses 27 and 67.

For the two buses, the THDv values were 27.34% and 11.68%, respectively. In total, 40 buses exceeded the THDv 5% threshold. The information above suggests that the RDS is somewhat contaminated with harmonics. Harmonic filters must be used to adhere to the IEEE standard limitations. Buses 27 and 67 were allocated the APF concurrently with the NLs + NLDGs. The scenario consisted of one APF on bus 27, one APF on bus 67, and two APFs on each bus. The APF rating is a crucial factor to consider because it directly affects the system cost. The TDO optimization process determines the required APF current. There is a maximum population of 30 and an allowable number of iterations of 60. The steps in the applicable flowchart for the selected test system (Figure 1) were used to emulate this approach.

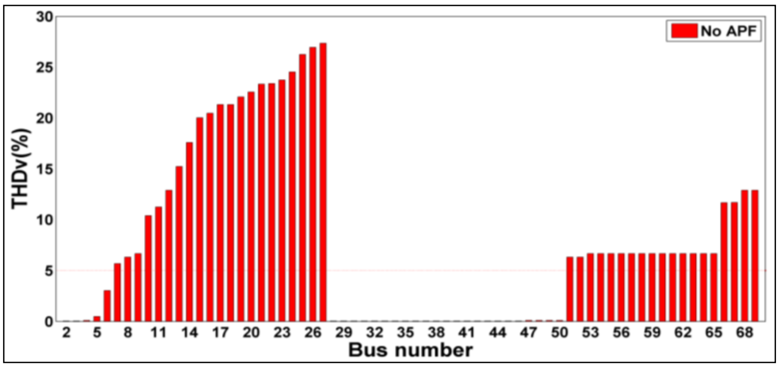

Figure 3: THDv at all buses when APF is absent.
Source: Authors, (2026).

III.1 CASE 1

Buses 27 and 67 connect the NLs and NLDGs, as shown in Figure 2a. The system was substantially harmonically distorted by these two nodes. Bus 27 (27.34%) had the maximum THDv in the absence of APF, whereas bus 67 had 11.68%.

III.2 CASE 2

To reduce the THDv as much as possible, the APF was positioned near bus 27. Figure 4 illustrates how OOA converged to a value higher than TDO (46.7726 p.u.), whereas TDO decreased to 0.0995 p.u. It has been observed that the APF should be placed on bus 27. It is the correct placement. TDO performed better than OOA under the given conditions.

III.3 CASE 3

In this case, no algorithm converged and satisfied the constraints. Because of the penalty, the OOA and TDO values are higher (72.7829 p.u.). No single algorithm can meet all requirements. This implies that bus 67 was not positioned correctly for the APF to increase PQ.

III.4 CASE 4

Buses 27 and 67 were equipped with APFs. Figure 5 shows the results of the HLF with the optimization methods. The convergence curve for each algorithm is displayed in Figure 5 under the required conditions. The TDO approach for determining the minimum APF current is shown in figure. The OOA did not converge to find the lowest APF current. However, as shown in Figure 5, the TDO method provides the minimum APF current that converges within the specified limits efficiently with a value of 0.0983 p.u. When the APFs are installed at buses 27 and 67, the TDO approach converges well; in these circumstances, the OOA calculates the APF current to be 34.2303 p.u.

This is deemed improper. Table 1 shows the comparative values of the considered algorithms.Figure 6 illustrates that the THDv values of all the system's buses are now less than 5% following the installation of APFs at buses 27 and 67. It is noteworthy that busses 27 and 67 now have THDv of 4.94 % and 5 %, respectively, as opposed to their previous THDv of 27.34% and 11.68%, respectively, without the APF and with the APFs implemented. As can be shown in Figure 6, every bus satisfies the THDv constraints of below or equivalent to 5%. As a result, improving PQ in the RDS depends critically on the bus number and sizing of the APFs.

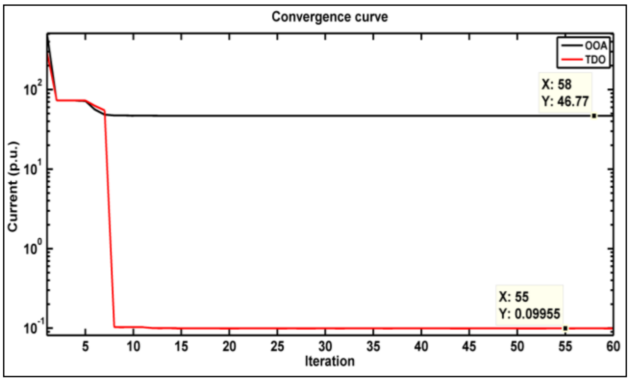

Figure 4: Convergence curves for algorithms when APF is at bus 27.
Source: Authors, (2026).

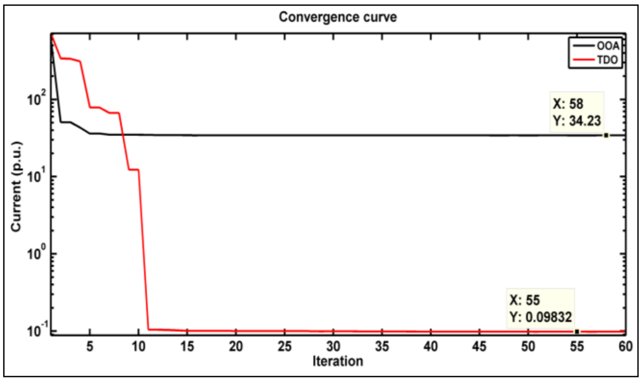

Figure 5: Convergence curves for algorithms when APFs are at buses 27 and 67.
Source: Authors, (2026).

Table 1: Comparison of Optimization Techniques.

Bus	APF	APF current by TDO	APF current by OOA	Convergence of algorithm
27	1	0.0995	46.7727	Only TDO converged
67	1	72.7829	72.7829	Both not converged
27,67	2	0.0983	34.2303	Only TDO converged

Source: Authors, (2026).

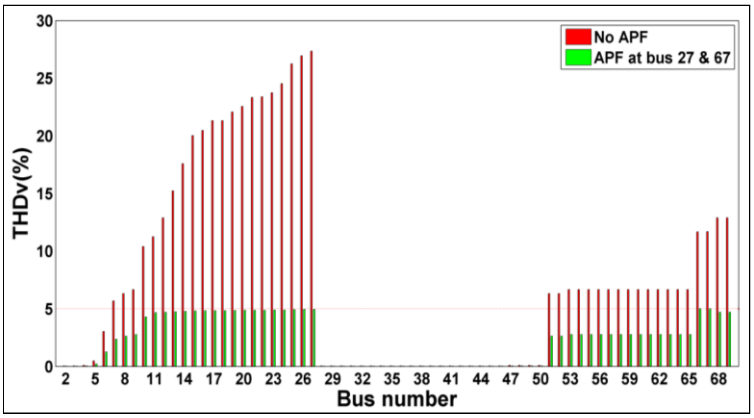

Figure 6: THDv at each bus, following optimization, with and without APFs.
Source: Authors, (2026).

IV. CONCLUSIONS

In order to reduce the harmonics and increase PQ, this article looks into using TDO and OOA in RDS through the APFs. Even though the RDS shows the strong influence of harmonics with two NLS + NLDGs. TDO and OOA with HLF are successfully integrated in the IEEE-69 bus test system simulation. The measured THDv highlights the negative impact of harmonics on PQ, with values greater than 5% on 40 buses. The highest THDv, 27.34%, is found at bus 27. The crucial significance that APF placement plays is highlighted by the fact that THDv was successfully reduced to 5% in all buses a feat that was only possible with one APF at 27 and with two APFs installed at buses 27 and 67. Amazingly, THDv can be contained under the allowed limit on all RDS buses with just one APF and two APFs. The TDO method finds a minimum APF current of 0.0983 p.u., which satisfies the condition and converges with busses 27 and 67 successfully. However, the OOA, is unable to converge, indicating that TDOs perform better in this circumstance. In contrast, OOA converges at 34.2303 p.u., while TDO converges at 0.0983 p.u.

V. AUTHOR’S CONTRIBUTION

Conceptualization: Ashokkumar Parmar, Ashok Lakum, Mehul Dansinh Soalnki.
Methodology: Ashokkumar Parmar, Ashok Lakum, Jaydeepsinh Sarvaiya.
Discussion of results: Ashokkumar Parmar, Ashok Lakum, Divyesh Keraliya, Maqbul Ganchi.
Writing – Original Draft: Ashokkumar Parmar.
Writing – Review and Editing: Ashokkumar Parmar, Ashok Lakum.
Resources: Divyesh Keraliya, Maqbul Ganchi**.**
Supervision: Ashok Lakum, Mehul Dansinh Soalnki
Approval of the final text: Ashokkumar Parmar, Ashok Lakum, Jaydeepsinh Sarvaiya.

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