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RESEARCH ARTICLE

Enhancing Electrical Distribution System Efficiency: A Software Tool Design for Conductor Cross-Section Optimization With TLBO Algorithm

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HIGHLIGHTS

- *TLBO algorithm used for the first time in cross-section optimization*
- *For the first time, a cross-section optimization tool was designed with the combination of MATLAB and Excel software*
- *A new dimension has been introduced to conductor cross-section optimization with the combination of metaheuristic algorithms and different softwares.*

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ABSTRACT

In radial distribution networks with many separate branches and sections, it is very difficult to calculate the optimum conductor cross-section. This work introduces a new tool for optimizing conductor cross-sectional area in electrical distribution systems by utilizing the Teaching-Learning-Based Optimization (TLBO) algorithm. The tool can optimize the conductor crossection of the multisection, branching distribution systems. The maximum current carrying capacity constraint is taken into consideration when formulating the objective function to choose the ideal conductor size for each network segment. The optimal conductor sizes are determined by both desired percent voltage drop and current carrying capacity of the conductor. By calculating the currents drawn from the line segments in advance, the search space of the optimization algorithm is narrowed. MATLAB and Excel were used to determine the ideal conductor size. The conductor, which is chosen using the suggested method, will preserve appropriate voltage levels in radial distribution systems while optimizing the overall savings in conducting material and energy loss costs. The outcomes show that the optimal selection of conductor problem can be solved by the TLBO algorithm in a practical and effective manner. Results of testing the suggested tool on a radial distribution system are noteworthy.

Keywords: *Distribution Networks, TLBO, Metaheuristics, Conductor Optimization*

I. INTRODUCTION

The best choice of conductor sizes is critical to the effective design and operation of radial distribution systems. To address this important factor, researchers have developed a variety of methodologies and algorithms over time. The purpose of this review of the literature is to give a broad overview of the developments in conductor size selection for radial distribution systems, emphasizing significant contributions and techniques used.

Early studies, such as those by Wang et al. in 2000 [1] and Sivanagaraju et al. in 2002 [2], laid the groundwork for conductor size selection methodologies. These studies concentrated on useful methods and optimization strategies for figuring out the ideal conductor sizes for radial distribution systems while taking load characteristics and system limitations into account.

In a study conducted in 2023 by Gallego Pareja et al. Mixed Integer Linear Programming (MILP) model is suggested for primary distribution systems that simultaneously optimizes the placement of capacitor banks and conductor selection, highlighting the significance of taking reactive power management into account in addition to conductor sizing [3]. Voltage regulation and system efficiency are improved by this integration.

Numerous research works have showcased case studies and practical implementations of ideal conductor selection techniques. In 2017, The benefits and usefulness of choosing the best conductor for distribution system planning were demonstrated by Joshi et al. [4]. A case study conducted in 2010 on the best conductor selection for agricultural distribution systems was presented by Raju et al., emphasizing the value of customized solutions for particular applications [5]. Ranjan et al. in 2006 [6] and Kumari et al. in 2018 [7] examined the application of evolutionary programming methods for the best conductor selection, placing a focus on the accuracy of the solutions and computational efficiency. In addition to addressing financial considerations, Waseem et al. provided an affordable technique for optimal cable sizing to reduce power loss and save energy in 2018 [8]. Methodologies for selecting conductor size have come a long way, but issues with scalability, computational complexity, and integration with new technologies still need to be resolved. Prospective avenues for research could encompass the advancement of hybrid optimization methodologies, integration of renewable energy sources, and contemplation of dynamic operating conditions to augment system resilience. Within the field of electrical engineering, distribution system design optimization is still a vital undertaking to guarantee effectiveness, dependability, and economy. The careful selection of conductor cross-sections, which directly affects system performance and operational integrity, is essential to this optimization. This paper presents a novel approach to conductor cross-section sizing by integrating MATLAB and Excel, utilizing MATLAB's computational power and Excel's intuitive interface to expedite the design process. The software tool uses a metaheuristic optimizer to help engineers make well-informed decisions about the size of conductors, which will ultimately improve the dependability and efficiency of electrical distribution systems. This introduction lays out the purpose, goals, and structure of the suggested software tool and prepares the reader for a thorough examination of its design principles and real-world uses.

For efficiency and dependability, it is essential to optimize electrical distribution systems, which are vital in transporting electricity from generation sources to end users. Utilizing sophisticated computational techniques and tools to tackle intricate problems related to system design and operation characterizes the state of the art in conductor cross-section optimization.

Conductor cross-section optimization has been transformed by recent developments in computational techniques, such as numerical simulation and optimization algorithms. Advanced simulation capabilities are available for analyzing distribution system performance under different operating conditions through software tools such as PSCAD/EMTDC and DIgSILENT. However, not all engineers may have access to these tools and they usually require specific knowledge.

For the optimization of conductor cross-section, the combination of MATLAB and Excel offers a strong substitute. Excel offers a recognizable interface for data input, manipulation, and visualization, while MATLAB offers a robust platform for numerical analysis, optimization, and modeling. By utilizing the advantages of both platforms, this combined method enables engineers to carry out complex analyses quickly and easily.

The suggested software tool offers a thorough approach to conductor cross-section optimization in the MATLAB and Excel environments, improving upon current techniques. Through the integration of sophisticated computational methods with intuitive user interfaces, the approach seeks to enable engineers to more easily access conductor sizing tools and make well-informed decisions about the design and operation of distribution systems.

In conductor cross-section optimization, the application of metaheuristic optimization algorithms has gained popularity, enabling engineers to methodically look for the best solution within a predetermined design space. Specifically, metaheuristic algorithms have demonstrated potential in handling intricate optimization issues involving numerous goals and limitations.

Although there have been significant advances in the literature in conductor cross-section optimization recently, tools that combine computational power and user-friendly interfaces that are both accessible and versatile are still needed. The software tool that was created fills this need by providing a workable and effective way to increase the effectiveness of electrical distribution systems.

Additionally, although previous research has shed light on a variety of approaches and instruments for conductor cross-section optimization, there is a noticeable lack of studies that particularly address the incorporation of metaheuristic algorithms like TLBO into the MATLAB and Excel environments for this purpose. This study aims to close this gap by presenting a brand-new software tool design that optimizes conductor cross-sections using the TLBO metaheuristic algorithm by combining the computational power of MATLAB with the intuitive interface of Excel.

In radial distribution systems, choosing the right conductors is essential to reliable power delivery, reduced losses, and improved system performance. To solve this challenging engineering problem, researchers have investigated a number of metaheuristic optimization strategies over time. This review of the literature attempts to give a thorough overview of how these methods have evolved, with a particular emphasis on how they are used in radial distribution systems to choose the best conductors.

Because metaheuristic optimization algorithms are effective at solving complicated optimization problems, they have attracted a lot of attention. For the best conductor selection in radial distribution systems, these algorithms—which include Evolutionary Strategies (ES), Particle Swarm Optimization (PSO), Genetic Algorithm (GA), Differential Evolution (DE), Imperialism Competitive Algorithm (ICA), Harmony Search Algorithm (HSA), Whale Optimization Algorithm (WOA), and Crow Search Algorithm (CSA) have been used extensively.

Mendoza et al. in the year of 2006 established the use of evolutionary strategies for conductor size selection, which served as the basis for further studies in this field [9]. In 2009 a discrete PSO approach was proposed by Sivanagaraju and Rao, who also showed that it works well for conductor selection [10]. In order to minimize loss, Rao looked into the use of Differential Evolution in radial distribution systems in a study conducted in 2010 [11].

The integration of conductor selection and capacitor placement has been the subject of numerous studies aimed at improving system performance. In 2014 Mozaffari Legha combined PSO with capacitor placement[12], while Samal et al. utilized DE for simultaneous allocation of capacitors and conductor sizing [13].

Some studies have performed comparative analyses in order to assess how well various optimization algorithms perform. Samet and Mozaffari Legha compared the Imperialism Competitive Algorithm with PSO [14], highlighting its competitive edge. The usefulness of Selective PSO for loss reduction in radial distribution systems was evaluated by Khalil and Gorpinich in 2012 [15].

Novel metaheuristic approaches have been investigated recently for the best conductor selection. Abdelaziz and Fathy introduced the Crow Search Algorithm, demonstrating its efficacy in conductor size optimization [16]. A discrete version of the Vortex Search Algorithm for three-phase distribution networks was proposed by Martinez-Gil et al. in 2021 [17].

From the first uses of ES to more recent developments like CSA and the Vortex Search Algorithm, researchers are still looking for novel ways to solve the problems related to conductor size optimization. These initiatives aid in the creation of more dependable and efficient distribution networks, which eventually helps both consumers and the electricity sector.

The literature review concludes by emphasizing the role that conductor cross-section optimization plays in improving the effectiveness of electrical distribution systems and by pointing out the need for tools that are both accessible and adaptable, capable of fusing sophisticated optimization algorithms with user-friendly interfaces. By utilizing the TLBO metaheuristic algorithm in the MATLAB and Excel environments, the suggested software tool seeks to meet this need by providing engineers with a workable and effective way to optimize conductor sizing in distribution system design.

II. MATERIAL AND METHODS

A. Conductor Cross-secction Sizing Proceure

Sizing electrical conductor cross sections involves determining the appropriate size of wires or cables to carry electrical current safely and efficiently while minimizing losses due to resistance. The cross-sectional calculation of a distribution network given as an example in Figure 1 will be calculated step by step. First, the longest and most loaded side of the network is determined. The longest and most loaded part of our network is the TR-2-15-24 side, which is only indicated by important poles.

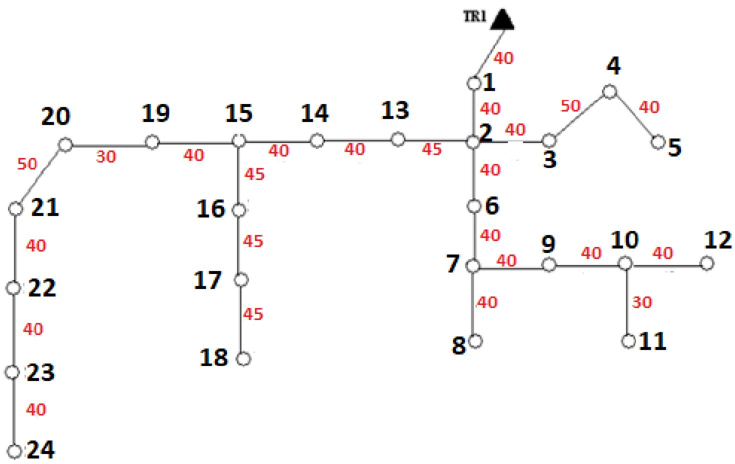

Figure. 1. Radial distribution network[18]

In the radiated power method, it is assumed that a certain power is drawn from each unit length of the line. Since the length of the line is certain, the total load between two poles is determined. Since the subscribers are connected to the line through poles, the calculated line loads are reduced to the poles and the pole powers are found. Accordingly, the power drawn from a pole:

$$P_{a-b} = \frac{J*l}{2} \tag{1}$$

Here P_{a-b}:power of the pole (W), l:distance between a-b poles (m), J:Radiated power (W/m) (120 W/m in this study). As seen in Figure 2, the loads drawn from each pole are added up to form the loads that fall on each section of the line following the determination of the pole loads.

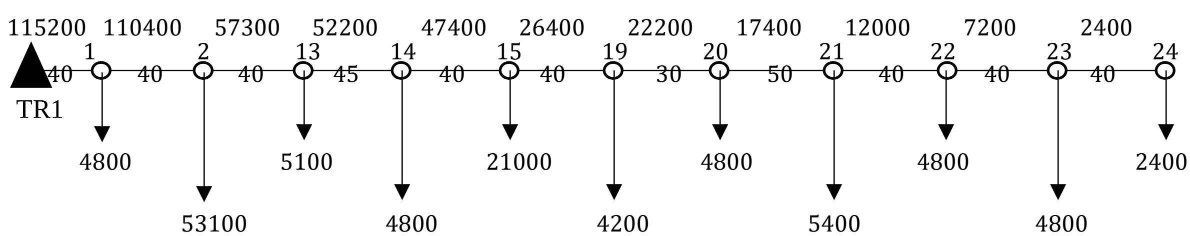

Figure. 2. Pole loads and moment diagram

The moment diagram of the power drawn from the system together with the pole powers is shown in Figure 2. The cross-section calculation is done with equation 3. (Voltage drop is chosen 5%)

$$q = \frac{100*L*P}{3*k*e\%*V_{PN}^{2}} \tag{2}$$

Here L*P is the moment (M) and is calculated by multiplying the line length by the power drawn from the line. k is the conductivity constant of aluminum and has a value of 35. e% is the requested percentage voltage drop. V_{PN} is the phase neutral voltage.

$$M_1 = 40 * 115200 + 40 * 110400 + 40 * 57300 + 45 * 52200 + 40 * 47400 + 40 * 26400 + 30 * 22200 + 50 * 17400 + 40 * 1200 + 40 * 7200 + 40 * 2400 = 19032562$$

According to the drawn load and the desired voltage drop, the cross-section of the aluminum conductor is 74.9 mm^2.

$$74.9 = \frac{100 * 19032562}{3 * 35 * 5 * 220^2}$$

As it is known, the cross sections of aluminum conductors are standard and the calculated value is selected as the closest larger value. Since the cross-section is always selected larger than the calculated cross-section, the cross-section calculation is made again for the parts of the line where relatively less power is drawn. In addition, the cross-sectional calculation here is an end-to-end cross-sectional calculation for the longest and most loaded side of the network. Therefore, it is suitable for the most loaded part of the line, between TR1 and pole number 2, and it must be recalculated for less loaded parts, taking into account the current carrying capacity, without exceeding the percentage voltage drop. Otherwise, a large cross-section network will be designed. Less loaded sections are the sections after the branch poles. In this example, 15-19 carries less load than 2-15 and 2-15 carries less load than TR1-2. This means that between 15-19 should have the thinnest cross-section and between TR1-2 should have the thickest cross-section. However, in the calculation made, the cross-section of the whole line was found to be 74.9 mm2 and the conductor named Philox with a cross-section of 84.99 mm2, which is an upper cross-section, will be used. Recalculation is made for thin sections. For this reason, the cross-sectional calculation in radial networks cannot be done in one attempt and calculations are performed repeatedly from the thickest part to the thinnest part according to the complexity of the network. Aluminum conductors used in energy distribution and their properties are given in Table 1.

Table I. Aluminum conductors used in energy distribution networks and their properties.

Name	Cross-section ($\boldsymbol{mm^2}$)	Current capacity (A)	K value
Rose	21.14	138	9.308
Lily	26.66	149	7.380
Pansy	42.37	214	4.644
Poppy	53.49	247	3.678
Aster	67.45	286	2.917
Philox	84.99	331	2.315
Oxlip	107.3	393	1.833
Daisy	135.2	443	1.455
Peony	152.1	478	1.293
Tulip	170.6	513	1.153

The K value of the conductor is a parameter used for convenience in voltage drop calculation and is calculated as given in equation 3.

$$K = \frac{100}{3*k*e\%*V_{PN}^2} \tag{3}$$

Percentage voltage drop using the K value is calculated by Equation 4.

$$e\% = 10^{-7} * K * M \tag{4}$$

Since the cross-section calculation cannot be done in one attempt and requires repetitive operations, a metaheuristic optimization algorithm is proposed to make these tasks easier and in a shorter time.

B. Excel Part of the Study

As mentioned before, the Excel program acts as an interface in this study. The user enters the information about the network into the designed excel program. The Excel sheet has features that can be expanded as much as desired. For complex networks, it allows more information to be entered thanks to the creep feature. The Excel interface design is seen in Figure 3.

<table>
<tr><th>B</th><th>C</th><th>D</th><th>E</th><th>F</th><th>G</th><th>H</th><th>I</th><th>J</th><th>K</th></tr>
<tr><td colspan="2"></td><td></td><td>Source</td><td>Line|---|</td><td>Branch<:::</td><td>Line|---|</td><td>Branch<:::</td><td>Line|---|</td><td>Branch<:::</td></tr>
<tr><td colspan="2">Pole numbers</td><td></td><td>Transforme</td><td>|--------|</td><td>0</td><td>|---------|</td><td>0</td><td>|---------|</td><td>0</td></tr>
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<tr><td colspan="2">N.of intermediate poles</td><td></td><td></td><td>0</td><td></td><td>0</td><td></td><td>0</td><td></td></tr>
<tr><td colspan="2">Branch Lengths</td><td></td><td></td><td></td><td>0</td><td></td><td>0</td><td></td><td>0</td></tr>
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<tr><td colspan="2">Line power d.(w/m)</td><td></td><td></td><td>0</td><td></td><td>0</td><td></td><td>0</td><td></td></tr>
<tr><td colspan="2">Branch power d.(w/m)</td><td></td><td></td><td></td><td>0</td><td></td><td>0</td><td></td><td>0</td></tr>
<tr><td colspan="2">Total line loads(P)</td><td></td><td></td><td>0</td><td></td><td>0</td><td></td><td>0</td><td></td></tr>
<tr><td colspan="2">Line currents</td><td></td><td></td><td>0</td><td></td><td>0</td><td></td><td>0</td><td></td></tr>
<tr><td colspan="2">K values</td><td></td><td></td><td>0</td><td></td><td>0</td><td></td><td>0</td><td></td></tr>
<tr><td colspan="2">Moments</td><td></td><td></td><td>0</td><td></td><td>0</td><td></td><td>0</td><td></td></tr>
<tr><td colspan="2">$\%e_s=10^{-7}.K.L.P$</td><td>0</td><td></td><td>0</td><td></td><td>0</td><td></td><td>0</td><td></td></tr>
<tr><td colspan="2">delta V=</td><td>0</td><td></td><td>0</td><td></td><td>0</td><td></td><td>0</td><td></td></tr>
</table>

Figure. 3. Designed Excel Sheet

In the excel sheet displayed in Figure 3, the green cells are filled with the characteristics of the radial network to be designed by the user. This information includes line segment lengths, branch lengths, power densities of the line and branches and the number of poles between the important poles to be used in the moment calculation. The blue cells, i.e. the loads and line currents falling on the line segments, are automatically calculated by excel after the green cells are entered. Line loads are the sums of the loads on the line segments themselves and the loads on the segments after them.

$$P_i = L_{Li} * J_{Li} + L_{Bi} * J_{Bi} + L_{L(i+1)} * J_{L(i+1)} + L_{B(i+1)} * J_{B(i+1)} + \cdots + \cdots L_{L(i+n)} * J_{L(i+n)} + L_{B(i+n)} * J_{B(i+n)} \quad (5)$$

Where P_i is the sum of the loads on the i th line segment, L_L is the line segment lengths, J_L is the line segment power densities, L_B is the branch lengths and J_B is the branch power densities. After the loads falling on different line segments are found, the currents drawn from the line segments are found with the help of equation 6. Because the conductors must be suitable in terms of current carrying capacity. The currents found here are used to determine the minima of the search space of the metaheuristic algorithm. In other words, the minimum cross sections are determined by the current carrying capacity. The actual cross sections are found by calculating both current carrying capacity and voltage drop. Both the current carrying capacity and a voltage drop below the desired voltage drop ratio must be ensured.

$$I_i = \frac{P_i}{\sqrt{3} * V_i * \cos(\emptyset)} \quad (6)$$

The blue cells calculated by Excel, i.e. line loads and currents, are read by the MATLAB software with the "xlsread" function. Then, moment calculation is made with the number of intermediate poles and average spans between poles as in Figure 2. After the transfer process from Excel and moment calculation, conductor optimization is performed by the TLBO algorithm running in MATLAB for each segment of the line. The TLBO algorithm determines the minimum cross-sections by selecting various combinations of K values for the conductors. The TLBO algorithm is only allowed to select K values from the K values of standard conductors. After the optimum conductors are found, MATLAB software sends the K values of these conductors and the moments of the relevant line segments to Excel with the help of the "xlswrite" function. These values are written in yellow cells in the Excel document. The aim is to enable the user to see the voltage drop in terms of voltage and percentage and to validate the suitability of the determined cross-sections. The red cells of the excel file are where the user can see the results and validate the effectiveness of the results. Figure 4 lists every procedure that has been described.

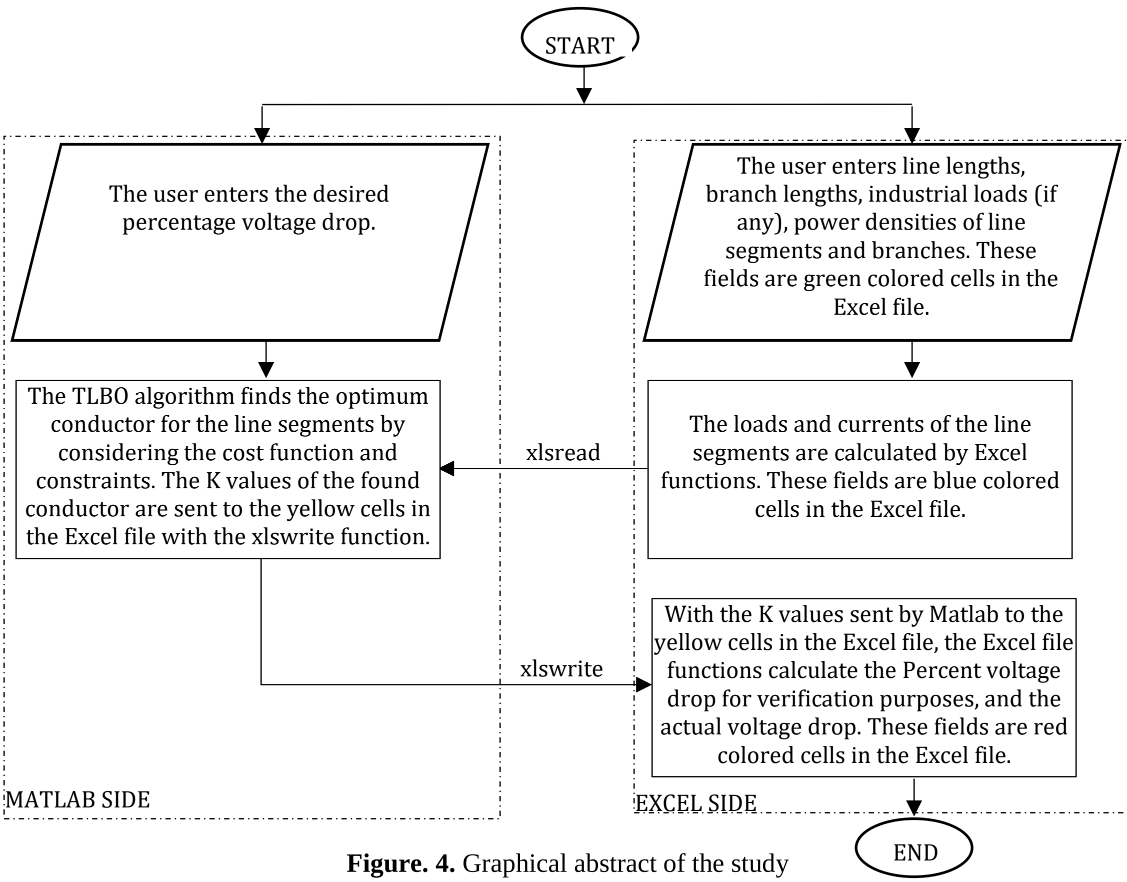

Figure. 4. Graphical abstract of the study

C. Teaching Learning Based Optimization (TLBO)

Apopulation-based optimization algorithm known as Teaching-Learning-Based Optimization (TLBO) was developed with inspiration from the teaching-learning process seen in a classroom. In 2011, Rao et al. presented it [19]. TLBO imitates the way that knowledge is imparted to students by teachers and how students pick up knowledge from one another. This is a basic explanation of how TLBO functions:

1. Initialization: TLBO begins with a population of possible solutions that is initially generated, usually at random.
2. Teacher Phase: In this stage, the population's best solution the teacher is determined. The instructor then disseminates its expertise (optimal resolution) to every member of the populace.
3. Student Phase: During this stage, every member of the population gains knowledge from both their teachers and other people. As part of the learning process, students update their solutions in light of the information that their peers and teacher have shared.
4. Population Updating: Based on the newly discovered solutions, the population is updated following the learning phase. In this step, the newly learned solutions are usually substituted for the worst ones.
5. Termination: When a stopping condition is satisfied, such as reaching a predetermined number of iterations or

arriving at a workable solution, the algorithm comes to an end.

TLBO has been used to solve a variety of optimization issues, such as machine learning, scheduling, and engineering design. Its effectiveness and simplicity make it a desirable option for resolving optimization issues, particularly when the search space is vast or complicated. The secret to TLBO's success is its capacity to strike a balance between exploitation and exploration by promoting knowledge exchange among members of the populace. Using a collaborative learning approach, high-quality solutions are frequently found in a reasonable amount of time. Figure 5 displays the TLBO algorithm's flowchart.

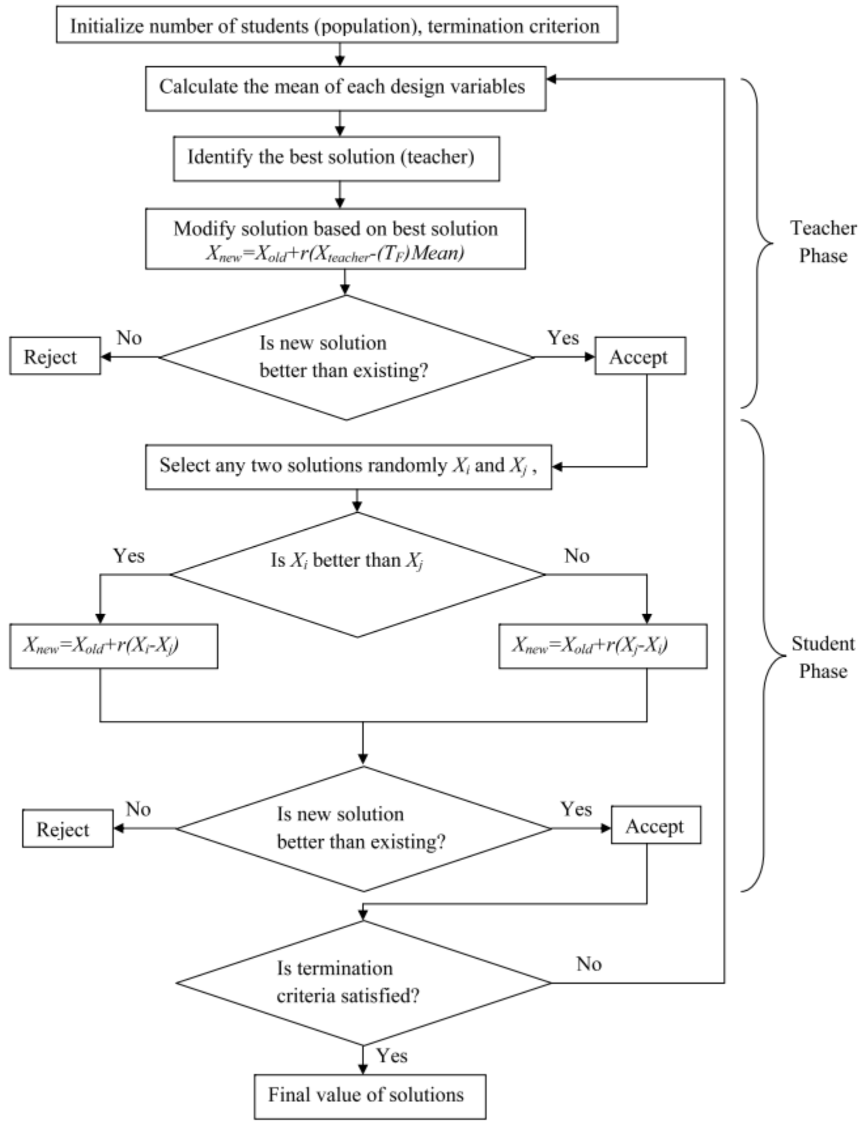

Figure. 5. Flowchart of the TLBO algorithm[19]

Metaheuristic algorithms such as TLBO are often used to minimize objective functions associated with the problem. The objective function used in this study is obtained by subtracting the calculated voltage drop from the desired voltage drop and is given in Equation 7.

$$OF = \min(abs(\%e_{demanded} - \%e_{calculated})) \quad (7)$$

The reason for subtracting the calculated voltage drop from the desired voltage drop is to force the objective function of the TLBO algorithm to converge to zero, in other words, to force the calculated voltage drop to be equal to the desired voltage drop.

There is a constraint when minimizing the objective function. As mentioned before, when determining the conductor cross-section in distribution networks, the current carrying capacity of the conductor must be suitable for the network while ensuring the percentage voltage drop. The minimum objective function is valid if the cross-section of the conductor can meet the current drawn from that part of the line. The optimization constraint is given in equation 8.

$$I_{Line\_Part(i)} \leq I_{Conductor\_Line\_part(i)} \; i = 1, \dots \dots N \tag{8}$$

III. RESULTS

The tool's accuracy and dependability in optimizing conductor cross-sections were evaluated by validating it against established analytical models and empirical data. The outcomes showed good agreement between the software's outputs and those acquired using conventional techniques, demonstrating the TLBO algorithm's efficacy in conductor sizing optimization. The test of the tool designed in this study was performed by optimizing the conductor cross-sections of the sample distribution network in Figure 1. The cross-sections of the distribution network in Figure 1 are designed in such a way that the voltage drop does not exceed 5% at the end users fed from poles 24, 18, 5, 8, 11 and 12. It should be noted that the user should perform the optimization process for the longest and most loaded parts of the line from largest to smallest during optimization. Therefore, the longest and most loaded side, TR-24, was optimized first. Then TR-15, which is fed from the same segment and is relatively shorter and less loaded, was optimized. The other segments were optimized with the same logic. On the Excel screen, the optimization results between TR-24 are displayed in Figure 6.

<table>
<tr><th>B</th><th>C</th><th>D</th><th>E</th><th>F</th><th>G</th><th>H</th><th>I</th><th>J</th><th>K</th></tr>
<tr><td></td><td></td><td></td><td>Source</td><td>Line|---|</td><td>Branch<:::</td><td>Line|---|</td><td>Branch<:::</td><td>Line|---|</td><td>Branch<:::</td></tr>
<tr><td>Pole numbers</td><td></td><td></td><td>Transforme</td><td>|--------|</td><td>2</td><td>|---------|</td><td>15</td><td>|---------|</td><td>24</td></tr>
<tr><td>Line lengths(L)</td><td></td><td></td><td></td><td>80</td><td></td><td>125</td><td></td><td>240</td><td></td></tr>
<tr><td>N.of intermediate poles</td><td></td><td></td><td></td><td>1</td><td></td><td>2</td><td></td><td>5</td><td></td></tr>
<tr><td>Branch Lengths</td><td></td><td></td><td></td><td></td><td>400</td><td></td><td>135</td><td></td><td>0</td></tr>
<tr><td>Industrial Load</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Line power d.(w/m)</td><td></td><td></td><td></td><td>120</td><td></td><td>120</td><td></td><td>120</td><td></td></tr>
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<tr><td>Total line loads(P)</td><td></td><td></td><td></td><td>117600</td><td></td><td>60000</td><td></td><td>28800</td><td></td></tr>
<tr><td>Line currents</td><td></td><td></td><td></td><td>178,6748</td><td></td><td>91,16061</td><td></td><td>43,75709</td><td></td></tr>
<tr><td>K values</td><td></td><td></td><td></td><td>2,315</td><td></td><td>2,315</td><td></td><td>3,678</td><td></td></tr>
<tr><td>Moments</td><td></td><td></td><td></td><td>9024000</td><td></td><td>6562500</td><td></td><td>3456000</td><td></td></tr>
<tr><td>$\%e_s=10^{-7}.K.L.P$</td><td></td><td>4,879392</td><td></td><td>2,089056</td><td></td><td>1,519219</td><td></td><td>1,271117</td><td></td></tr>
<tr><td>delta V=</td><td></td><td>10,73466</td><td></td><td>4,595923</td><td></td><td>3,342281</td><td></td><td>2,796457</td><td></td></tr>
</table>

Figure. 6. TR – Pole 24 conductor cross section optimization results

Upon closer inspection of Figure 6, it is understood from the K values TR-2(2.315), 2-15(2.315), 15-24(3.678) and help of Table 1 that the conductors optimized by the TLBO algorithm are TR-2(Philox), 2-15(Philox) and 15-24(Poppy). With these conductors, it is seen that the voltage drop is 4.879 %, below 5% and they can easily carry the currents drawn from the relevant line segments when the current carrying capacities are considered in Table 1.

<table>
<tr><th>B</th><th>C</th><th>D</th><th>E</th><th>F</th><th>G</th><th>H</th><th>I</th><th>J</th><th>K</th></tr>
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<tr><td colspan="2">Line lengths(L)</td><td></td><td></td><td>135</td><td></td><td>0</td><td></td><td>0</td><td></td></tr>
<tr><td colspan="2">N.of intermediate poles</td><td></td><td></td><td>2</td><td></td><td>0</td><td></td><td>0</td><td></td></tr>
<tr><td colspan="2">Branch Lengths</td><td></td><td></td><td></td><td>0</td><td></td><td>0</td><td></td><td>0</td></tr>
<tr><td colspan="2">Industrial Load</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Line power d.(w/m)</td><td></td><td></td><td>120</td><td></td><td>0</td><td></td><td>0</td><td></td></tr>
<tr><td colspan="2">Branch power d.(w/m)</td><td></td><td></td><td></td><td>0</td><td></td><td>0</td><td></td><td>0</td></tr>
<tr><td colspan="2">Total line loads(P)</td><td></td><td></td><td>16200</td><td></td><td>0</td><td></td><td>0</td><td></td></tr>
<tr><td colspan="2">Line currents</td><td></td><td></td><td>24.61337</td><td></td><td>0</td><td></td><td>0</td><td></td></tr>
<tr><td colspan="2">K values</td><td></td><td></td><td>9.308</td><td></td><td>0</td><td></td><td>0</td><td></td></tr>
<tr><td colspan="2">Moments</td><td></td><td></td><td>1093500</td><td></td><td>0</td><td></td><td>0</td><td></td></tr>
<tr><td colspan="2">$\%e_s=10^{-7}.K.L.P$</td><td>1.01783</td><td></td><td>1.01783</td><td></td><td>0</td><td></td><td>0</td><td></td></tr>
<tr><td colspan="2">delta V=</td><td>2.239226</td><td></td><td>2.239226</td><td></td><td>0</td><td></td><td>0</td><td></td></tr>
</table>

Figure. 7. TR – Pole 18 conductor cross section optimization results

For the section of the line between TR and the last pole numbered 18, the cross-sectional calculation was made only between 15-18. Because TR-15 was determined in the previous step. Therefore, in this step, the voltage drop is taken as (5-voltage drop in the previous section), not 5 %. There is a total voltage drop of 3.608 % between TR-15, 2.089 % between TR-2 and 1.519 % between 2-15. Therefore, there should be a maximum voltage drop of 5-3.608=1.392 % between 15-18. When Figure 7 is analyzed, Rose conductor with a K value of 9.308 was selected by TLBO for the 15-18 range. When Rose conductor is used in this section, both the voltage drop does not exceed 1.392 % and the current drawn from this section of the line can be easily carried.

<table>
<tr><th>B</th><th>C</th><th>D</th><th>E</th><th>F</th><th>G</th><th>H</th><th>I</th><th>J</th><th>K</th></tr>
<tr><td></td><td></td><td></td><td>Source</td><td>Line|---|</td><td>Branch<:::</td><td>Line|---|</td><td>Branch<:::</td><td>Line|---|</td><td>Branch<:::</td></tr>
<tr><td colspan="2">Pole numbers</td><td></td><td>2</td><td>|--------|</td><td>5</td><td>|---------|</td><td></td><td>|---------|</td><td></td></tr>
<tr><td colspan="2">Line lengths(L)</td><td></td><td></td><td>130</td><td></td><td>0</td><td></td><td>0</td><td></td></tr>
<tr><td colspan="2">N.of intermediate poles</td><td></td><td></td><td>1</td><td></td><td>0</td><td></td><td>0</td><td></td></tr>
<tr><td colspan="2">Branch Lengths</td><td></td><td></td><td></td><td>0</td><td></td><td>0</td><td></td><td>0</td></tr>
<tr><td colspan="2">Industrial Load</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Line power d.(w/m)</td><td></td><td></td><td>120</td><td></td><td>0</td><td></td><td>0</td><td></td></tr>
<tr><td colspan="2">Branch power d.(w/m)</td><td></td><td></td><td></td><td>0</td><td></td><td>0</td><td></td><td>0</td></tr>
<tr><td colspan="2">Total line loads(P)</td><td></td><td></td><td>15600</td><td></td><td>0</td><td></td><td>0</td><td></td></tr>
<tr><td colspan="2">Line currents</td><td></td><td></td><td>23.70176</td><td></td><td>0</td><td></td><td>0</td><td></td></tr>
<tr><td colspan="2">K values</td><td></td><td></td><td>9.308</td><td></td><td>0</td><td></td><td>0</td><td></td></tr>
<tr><td colspan="2">Moments</td><td></td><td></td><td>1014000</td><td></td><td>0</td><td></td><td>0</td><td></td></tr>
<tr><td colspan="2">$\%e_s=10^{-7}.K.L.P$</td><td>0.943831</td><td></td><td>0.943831</td><td></td><td>0</td><td></td><td>0</td><td></td></tr>
<tr><td colspan="2">delta V=</td><td>2.076429</td><td></td><td>2.076429</td><td></td><td>0</td><td></td><td>0</td><td></td></tr>
</table>

Figure. 8. TR – Pole 5 conductor cross section optimization results

For the section of the line between TR and the last pole numbered 5, the cross-sectional calculation was made only between 2-5. Because TR-2 was determined in the first step. Therefore, in this step, the voltage drop is taken as (5-voltage drop in the previous section), not 5 %. There is a total voltage drop of 2.089 % between TR-2. Therefore, there should be a maximum voltage drop of 5-2.089=2.911 % between 2-5. When Figure 8 is analyzed, Rose conductor with a K value of 9.308 was selected by TLBO for the 2-5 range. When Rose conductor is used in this section, both the voltage drop does not exceed 2.911 % and the current drawn from this section of the line can be easily carried.

B	C	D	E	F	G	H	I	J	K
			Source	Line|---|	Branch<:::	Line|---|	Branch<:::	Line|---|	Branch<:::
Pole numbers			2	|--------|	7	|---------|	10	|---------|	12
Line lengths(L)				80		80		40	
N.of intermediate poles				1		1		0	
Branch Lengths					40		30		0
Industrial Load									
Line power d.(w/m)				120		120		120	
Branch power d.(w/m)					120		120		0
Total line loads(P)				32400		18000		4800	
Line currents				49.22673		27.34818		7.292849	
K values				7.38		9.308		9.308	
Moments				2208000		1056000		192000	
$\%e_s=10^{-7}.K.L.P$		2.791142		1.629504		0.982925		0.178714	
delta V=		6.140513		3.584909		2.162435		0.39317	

Figure. 9. TR – Pole 12 conductor cross section optimization results

For the section of the line between TR and the last pole numbered 12, the cross-sectional calculation was made only between 2-12. Because TR-2 was determined in the first step. Therefore, in this step, the voltage drop is taken as (5-voltage drop in the previous section), not 5 %. There is a total voltage drop of 2.089 % between TR-2. Therefore, there should be a maximum voltage drop of 5-2.089=2.911 % between 2-12. When Figure 9 is examined, it is understood from the K values 2-7(7.38), 7-10(9.308), 10-12(9.308) and help of Table I that the conductors optimized by the TLBO algorithm are 2-7(Lily), 7-10(Rose) and 10-12(Rose). With these conductors, it is seen that the voltage drop is 2.791 %, below 2.911 % and they can easily carry the currents drawn from the relevant line segments when the current carrying capacities are considered in Table I.

Due to the very short sections, the Excel screens for pole sides 8 and 11 were not included in the study due to repetition. TLBO determined the voltage drop between 7-8 as 0.178 % and the conductor as Rose. TLBO determined the voltage drop between 10-11 as 0.100 % and the conductor as Rose. The results are presented in Table II with all results.

Table II. Overall results of the optimization work

Pole 24 side	Poles →	TR	2	15	24	
	Total %e→		%e=2.089	%e=3.608	**%e=4.879<5**	
Pole 18 side	Poles →	TR	2	15	18	
	Total %e→		%e=2.089	%e=3.608	**%e=4.625<5**	
Pole 5 side	Poles →	TR	2	5		
	Total %e→		%e=2.089	**%e=3.032<5**		
Pole 12 side	Poles →	TR	2	7	10	12
	Total %e→		%e=2.089	%e=3.718	%e=4,700	**%e=4,878<5**
Pole 11 side	Poles →	TR	2	7	10	11
	Total %e→		%e=2.089	%e=3.718	%e=4,700	**%e=4.800<5**
Pole 8 side	Poles →	TR	2	7	8	
	Total %e→		%e=2.089	%e=3.718	**%e=3,896<5**	

Table II shows that the TLBO algorithm has successfully selected conductors for all parts of the sample distribution network without exceeding the desired voltage drop, taking into account the current carrying capacity of the conductors.

Tool's practical utility in optimizing conductor cross-sections for electrical distribution systems show valuable performance in terms of computational efficiency, accuracy, and ease of use. All things considered, the findings in this section show how the software tool can be used to optimize conductor cross-section using the TLBO algorithm, thereby increasing the efficiency of electrical distribution systems.

IV. DISCUSSION

Although conductor cross-section optimization has advanced significantly with the tool, there is still room for improvement and new uses. In distribution networks, the TLBO algorithm has shown to be a reliable technique for conductor size optimization. The capacity of TLBO to manage the complex structure of distribution networks with multiple branches and sections is demonstrated by this study. The findings suggest that by utilizing its teaching and learning phases, which emulate the educational process, TLBO can effectively traverse the vast and intricate search space. This enables the algorithm to efficiently converge to an optimal or nearly optimal solution, even within a problem space with a high dimension. The inclusion of constraints on percent voltage drop and maximum current carrying capacity in the optimization process is a crucial component of this research. These limitations guarantee that the chosen conductor sizes satisfy the network's operational requirements while also optimizing material and energy costs. Through strict adherence to these limitations, the methodology guarantees the electrical distribution system's dependability and safety by preserving voltage levels within reasonable bounds and averting conductor overloading or overheating.

The optimization algorithm's search space is greatly reduced by pre-calculating currents derived from line segments. This preprocessing step is essential because it lowers the computational load on the TLBO algorithm and concentrates the search on workable solutions, which improves algorithm efficiency. This novel method makes evident how crucial domain-specific expertise is to enhancing algorithmic performance and offers a direct route for real-world application. The suggested tool's usefulness and accessibility are demonstrated by the way it manages the optimization process and applies the TLBO algorithm using MATLAB and Excel. The data handling prowess of Excel and the computational capabilities of MATLAB come together to produce a potent tool that practitioners can use with ease. Because of its hybrid design, the tool is guaranteed to be both powerful and easy to use, which makes it appropriate for practical uses in electrical distribution system design and optimization. Future developments might include expanding the software's functionality to handle other aspects of distribution system design and operation, integrating more computational tools and algorithms, and incorporating sophisticated modeling techniques for transient analysis and dynamic simulations.

V. CONCLUSION

This study presents a new tool that maximizes electrical distribution system efficiency by selecting the right conductor cross-section. The tool gives engineers a strong yet intuitive platform for performing cross-section analysis, facilitating educated decision-making and ultimately enhancing system performance and reliability. It does this by combining the strengths of MATLAB and Excel. To sum up, the instrument signifies a noteworthy progression in the domain of electrical distribution system design, providing engineers with an invaluable tool for enhancing conductor cross-sections and augmenting system dependability and efficiency. Collaboration, innovation, and adoption are encouraged by this approach, which has the potential to accelerate the development of a more resilient and sustainable energy infrastructure.

STATEMENT OF CONTRIBUTION RATE

1st author contributed 100%

CONFLICTS OF INTEREST

They reported that there was no conflict of interest between the authors and their respective institutions.

RESEARCH AND PUBLICATION ETHICS

In the studies carried out within the scope of this article, the rules of research and publication ethics were followed.

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