Load Balancing in Distribution Networks based on SSA Optimized Algorithm

IBRAHIM A. I. ALTAWIL, MOHAMMAD AWAD MOMANI*
Department of Electrical Power Engineering, Hajjawi Faculty for Engineering Technology,
Yarmouk University, 21163, Irbid,
JORDAN

*Corresponding Author

Abstract: - The low voltage power distribution networks are three-phase networks where most of the clients are supplied from a different single phase with different load behavior. This way of supply causes several problems that imply the unbalance in the voltage percentage (UV %) in the three phases, and unbalanced increase in the neutral currents and power loss limits. One of the mitigation techniques for such problems is through swamping customers between phases and applying much simpler and more reliable smart systems to resolve the balancing problems. The introduction of an automated method based on a re-phasing technique for swamping customers between phases solves the balancing problem directly and effectively. The Salp Swarm Algorithm (SSA) with a set of constraints and limitations in the objective function to ensure the lower number of switching processes was proposed in this paper. It is found that phase balancing using SSA is considered an effective and direct method to decrease power losses, minimizing the problem of voltage or current unbalance, and enhance the system stability and efficiency of the power system. This technique was examined on 19 different low-voltage customers. A comparison between the neutral current before and after the treatments shows that it has been reduced from about 24 A to 1.15 A. The power loss was also reduced from 1.8 to 1.2 kW respectively and finally, UV % was reduced from 11-15% to about 1.2%.

Key-Words: - Salp Swarm Algorithm, Load Unbalance, Unbalance Voltage, Neutral Current, Losses, Rearrangement, Re-phasing, Low Voltage, Distribution System.

Received: April 26, 2023. Revised: May 4, 2024. Accepted: June 14, 2024. Published: July 30, 2024.

1 Introduction

Most of the low voltage distribution (LV) networks in Jordan are radial networks where many customers are supplied from the same feeder or primary electrical substation. A single phase and a neutral wire are used to connect most residential loads to the feeder. It is possible to select any phase to connect a load to three-phase transformers to power four wire systems in LV networks, [1].

Single-phase clients are the customers whose load profiles differ from one another. The variations in load behavior are expected to cause power imbalances between phases, which decrease the system's hosting capacity and increase power losses as well as imbalanced current and voltage. A comparison between medium voltage (MV) or high voltage (H.V.) networks with the low voltage (LV) distribution networks. The highest losses and the voltage regulation in LV networks are more challenging, [2]. A common cause of unbalanced systems includes imbalanced loads, faults in the system, unequal distribution of power, and poorly designed distribution networks, [1], [3], [4]. The unbalance problem sometimes can limit the amount of power transferred through feeders when one of the phases may reach the maximum carrying capacity measured in amperes while the other two phases are unable to carry the full amount of current. This case may result in unnecessary feeder expansion and upgrades.

In modern power distribution systems, the efficient management of loads is of top importance to ensure a stable and reliable supply of electricity. In this context, the three-phase low-voltage distribution networks play a crucial role in delivering power to end-users. With a considerable portion of loads being single-phase in nature and having specific references, the challenge lies in achieving optimal load balancing to enhance system performance and minimize losses, [5].

Load balancing in three-phase low-voltage distribution networks is a complex task, primarily due to the varying characteristics and demands of individual loads. Traditional methods of load balancing often fall short in addressing the specific requirements of single-phase loads, leading to suboptimal distribution and potential overloading of certain phases. Recognizing the need for a more sophisticated approach, researchers and engineers have turned to nature-inspired algorithms for optimization, among which the Salp Swarm Algorithm (SSA) stands out as a promising candidate.

The radial distribution system examined in this paper as it is the simplest network configuration standpoint, easy to ride through faults, has the cheapest construction cost, and requires fewer security measures. However, it is fed by a single power supply, and in the event of an outage, there is no alternate source of power to serve the demand, as seen in Figure 1. Through a comprehensive analysis of the SSA application in load balancing, this study tries to find valuable contribution insights to the field of power distribution engineering. The goal of this research is to provide a robust and adaptive solution that caters to the difficulties of three-phase low-voltage networks, paving the way for more resilient and optimized electricity supply systems in the face of evolving energy demands. Phase balancing is considered effective and direct method to decrease power losses [6] and minimize voltage or current unbalance index [7] and leads to increased system stability and efficiency of power system, [8].

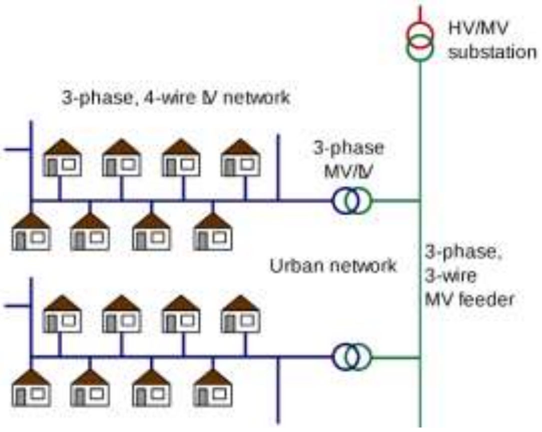

Fig. 1: Typical radial distribution system, [9]

This paper proposes the SSA algorithm to mitigate and solve the problem of load balancing in three-phase LV distribution networks. The algorithm is selected as it offers an intelligent and adaptive approach to redistributing loads efficiently, [1].

In [1], the consumer load arrangement on three-phase systems was made based on switching techniques for feeders and unit levels. In [2] the heuristic algorithm was used to study the effect of different numbers of contactors in each house and all the cases showed high performance in load balancing and reduced the imbalance index. In [3] a balancing approach that uses a Genetic Algorithm was applied with the aim of minimizing the active power losses over an interval of 24 hours in Romania. The method is tested in a real Romanian low-voltage distribution network with Smart Metering load data. based on the literature, most of the previous work was made on the feeder level or based on smart meters using a heuristic algorithm, but in this paper, we focus on load phase switching based on rephrasing techniques. The paper is organized as follows, Section 1 is the introduction of the paper, Section 2 is an unbalancing problem, mitigation techniques, and re-phasing technique in distribution system. Section 3 presents the system under study. Section 4 is the SSA followed by Results discussion and conclusion in Sections 5 and 6 respectively.

2 The Unbalance Problem in LV the Distribution System

The unbalanced loads arise when the power consumption on one or more phases differs significantly from the others, leading to potential issues such as voltage deviations, increased losses, and reduced system efficiency. Understanding and mitigating the effects of unbalanced loads are essential for ensuring the reliability and optimal performance of three-phase low-voltage distribution networks. The unbalanced voltage (UV) distribution in electrical systems can result from various factors, including uneven loads, unequal distribution of power, or faults in the system, [10]. This imbalance can lead to several problems, such as voltage fluctuations, decreased system efficiency, and potential damage to equipment. A common cause of unbalanced systems includes inadequate design of the distribution network can lead to voltage imbalances, for example, asymmetrical transmission impedances; this may include issues with transformer connections, conductor sizes, or improper planning, [4].

It is important for utilities and operators to have effective monitoring and control systems in place to detect and address the UV in the distribution network promptly. Therefore, to solve UV voltage distribution, utilities and system operators typically employ strategies such as load balancing, regular maintenance, and monitoring, implementing voltage regulation devices, and the re-phasing technique, [4], [11]. The re-phasing technique is employed in this paper to reduce the problem of imbalanced load on specific feeders.

National Electrical Manufacturers Association (NEMA) defined the UV problem and current unbalance equations as follows, [12]:

$$UV\% = \frac{V_{max}-V_{avg}}{V_{avg}}\% \quad (1)$$

Where V_{max} is the maximum voltage and V_{avg} is the average voltage magnitude of the three-phase voltages given by:

$$V_{avg} = \frac{|V_a|+|V_b|+|V_c|}{3} \quad (2)$$

Where the acceptable voltage unbalance ratio is about ±2% in Jordan. The unbalanced occurrence has a negative impact on the power system, which lowers system stability and security, [1], [11]. The low voltage distribution feeder's overall losses can be expressed as follows, [7]:

$$\mathrm{P_{loss}} = \sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{r_i} \frac{\mathrm{P_i}^2+\mathrm{Q_i}^2}{|\mathrm{V_i}|^2} \quad (3)$$

Where: n is the number of load buses, P is the active power in Watt, Q is the reactive power in VAR, r is the resistance in ohm and V is the bus voltage. The losses in electrical systems are often represented by the term I_i^2r, where I is the current and. In the case of unbalanced loads, the higher currents in certain phases lead to increased I_i^2r losses in those phases. The power dissipated as heat in the conductors is proportional to the square of the current.

2.1 Load Balancing Problem and Mitigation Techniques

Low voltage distribution network may have a balanced three-phase system if [5]: the three phases have approximately the same power, voltages, and current. Moreover, the load flow variation although 24 hours is the same in the three phases. Different load balancing mitigation strategies employed in power system areas such as:

a) Load Balancing Algorithms that employ advanced load balancing algorithms are crucial for mitigating the impact of unbalanced loads. Algorithms such as the SSA offer an intelligent and adaptive approach to redistributing loads efficiently, [1].

b) Smart Grid Technologies that integrate smart grid technologies enable real-time monitoring and control of distribution networks. Smart grid solutions, such as advanced metering infrastructure (AMI) and intelligent load controllers, contribute to dynamic load management, [2].

c) Distributed Energy Resources (DERs) that introduce DERs, such as solar photovoltaic systems and energy storage, provide a decentralized approach to load balancing. These resources can help mitigate the effects of unbalanced loads and contribute to overall network stability, [3]. Phase switching is the most efficient and best way to balance low-voltage networks. As a result, it lowers the imbalance index. Phase swapping needs to have a minimum number of executions to ensure system security while lowering system load.

The process of swamping customers between phases, usually occurs at a load which causes disturbances in the electrical system therefore, reducing the number of switches is an essential goal in this research. To guarantee the lower number of switching processes and avoid or reduce the effect of electrical system disturbances the following constraints and limitation in the objective function in the SSA algorithm have been proposed. The range of the objective function in SSA to be V_m was set to be ±2% V_m. Set the objective function in the SSA to be the average current of three-phase current measurements. These special SSA objective functions are used to expand the range of switching periods of the load between phases to reduce the cost of the switching process and reduce disturbance in the system. Moreover, it decreases the running time consumed for the SSA algorithm.

2.2 Re-phasing Technique

Phase swapping is a direct and effective way to balance a feeder in terms of phases, and this method based on load-balancing algorithms will be implemented in this work. Re-phasing of the single-phase customers can lead to more reduction of unbalanced indexes and losses on feeders. Nevertheless, increasing the number of re-phased customers is impractical due to practical difficulties and increasing costs, [13]. Applying a limitation on the number of customers to experience phase changes in SSA is vital. The number of swapping, time to do swapping, and determining the customer that must be swapping between phases is essential. By changing the phases of a few customers, the performance of the network power quality and power losses can be improved, [14].

In this work, the SSA algorithm is employed to find the best distribution for single-phase customers on three-phase networks by moving heavy single-phase loads to lightly loaded phases through a switching system connected to 19 different customers. Various hardware phase switch selector devices are used to switch customers between phases; all these devices have the same layout, as seen in Figure 2, which combines a single-phase output with a three-phase input.

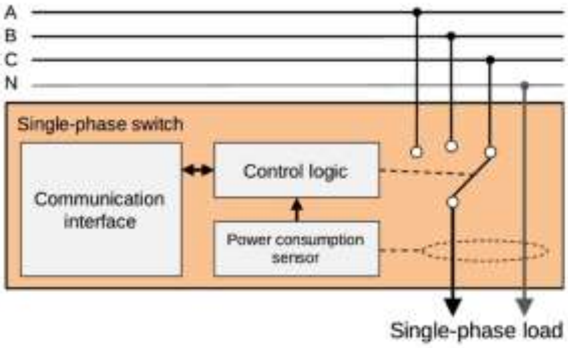

Fig. 2: Re-phasing Technique, [9]

3 System under Study

The three-phase distribution feeder under testing as seen in Figure 3, served 19 single-phase clients (customers).

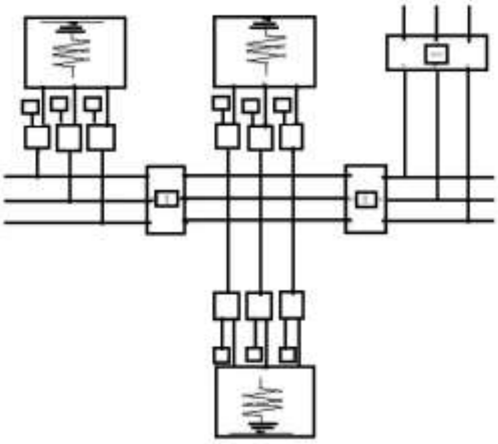

Fig. 3: Part of the feeder under study

The feeder parameters, Aluminium 95 mm^2 cross-section, 700-meter length, supplied from a three-phase transformer rated 250 kVA. Table 1 illustrates the distribution of the 19 customers (loads) among the three phases system.

Table 1. Distribution of loads among three-phase feeder

Phase	Number of Customers connected to the phase	Customers
A	9	2, 3, 7, 10, 13, 15, 17, 18, 19
B	5	1, 4, 5, 9, 14
C	5	6, 8, 11, 12, 16

Before load balance treatment, a measurement of a six-day time window (6 cases) has been taken and recorded in med of July 2021. A 19 smart meters have been installed in the houses of each customer, also, three smart meters installed on the sending end of the selected feeder. After balancing, the recorded data needs to be compared with the recorded data again. The comparison includes the sending end (three-phase currents) and the neutral current shown in Figure 4.

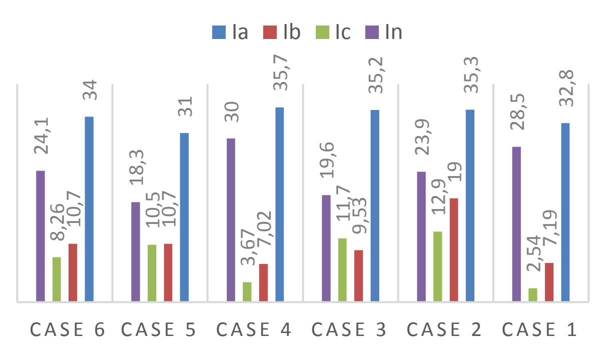

Fig. 4: The three-phase currents and neutral current for the feeder under study

4 Salp Swarm Algorithm

The SSA is a new swarm intelligence algorithm that is used to simulate the foraging behavior of the sea swarm slap. The SSA has advantages that imply fewer parameter requirements and effectiveness for both continuous and discrete problems, [8], [15]. When moving and feeding in the water, SSA mimics the actions of salps, a kind of marine animal. Inspired by common methods found in nature, such as salps, which can prevent the optimum local, flexibility, simplicity, and behavior to identify a feasible solution to a real-world problem, [15], [16], this algorithm was created. The SSA Algorithm suggests that the load will be spread across the feeder as efficiently as possible to reduce feeder losses, balance voltage, and current, eliminate current imbalance (neutral current), and keep it close to zero. The multi-objective function incorporates both the voltage balance equation and the current balance equation, as seen below [15]:

$$obj\ fun\ 1 = \left(\frac{I_a}{I_m} - \frac{I_b}{I_m}\right)^2 + \left(\frac{I_c}{I_m} - \frac{I_b}{I_m}\right)^2 + \left(\frac{I_a}{I_m} - \frac{I_c}{I_m}\right)^2 \quad (4)$$

$$obj\ fun\ 2 = \left(\frac{V_a}{V_m} - \frac{V_b}{V_m}\right)^2 + \left(\frac{V_c}{V_m} - \frac{V_b}{V_m}\right)^2 + \left(\frac{V_a}{V_m} - \frac{V_c}{V_m}\right)^2 \quad (5)$$

$$obj\ fun = obj\ fun\ 1 + obj\ fun\ 2 \quad (6)$$

where: I_a, I_b and I_c are the phases currents a, b, c.
I_m: nominal rating value of current.
V_a, V_b and V_c : voltages per phase a,b ,c

V_m: is nominal value for secondary voltages of the transformer.

The outcome is zero without balancing when the square in Equations (4) – (6) used to eliminate the negative value in the goal functions. Some limitations must be considered while using the SSA technique to lower the switch status numbers. Therefore, it is best to transfer loads as seldom as possible to reduce the feeder's current load and enhance system security. Similar to earlier approaches based on swarm techniques, the Salps' position in the n-dimensional search space, where n is the variable number for the task, is precisely determined. The locations of each Salps are then stored in a two-dimensional matrix called x. It is also believed that the swarm's intended goal is to find a food supply with the name *f* that is present in the search area. It is recommended [8] to use the following equation to update the position of the leader:

$$x_d^1 = \begin{cases} f_d + c_1\left((\mathrm{u}b_d - lb_d) \times c_2 + lb_d\right), & c_3 \geq 0 \\ f_d - c_1\left((\mathrm{u}b_d - lb_d) \times c_2 + lb_d\right), & c_3 < 0 \end{cases} \tag{7}$$

Where: x_d^1 defines the position of the food supply in the *dth* dimension, the upper bound of the *dth* dimension, and the lower bound of the *dth* dimension.
f_d is the position of the first salp (leader) in the dth dimension.

According to Equation (7), the leading salps adjust their positions in order to track the food supply. The coefficient C_1, which is time-varying or dependent on the number of iterations, is the most important parameter in the SSA because it is the only one that regulates the balance between exploration and exploitation. It has the following definition, [15], [16], [17], [18]:

$$c_1 = 2 \times e^{-\left(\frac{4t}{T}\right)^2} \tag{8}$$

Where: T is the maximum iteration numbers and t is the current iteration.
Random values between 0 and 1 are uniformly generated for the parameters c_2 and c_3. Indeed, they indicate the step size and whether or not the next location in the dth-dimensional should point in the direction of +∞ or -∞. The following equation, [15], [16], [17], [18] is used to update the followers' position:

$$\mathrm{x}_\mathrm{d}^\mathrm{i} = \frac{1}{2}\left(\mathrm{x}_\mathrm{d}^\mathrm{i} - \mathrm{x}_\mathrm{d}^{\mathrm{i}-1}\right) \tag{9}$$

Figure 5 provides a summary of the application of SSA for voltage and current balance in the distribution system.

5 Results and Discussion

This section presents the main paper results as follows:

5.1 Voltage Assessment

The end user's voltage is regulated by the government Energy and Minerals Commission to be approximately ±2% of the nominal voltage. UV, overvoltages, or undervoltages may cause home appliance failure on the user's end. Moreover, the modern smart kWh meters are designed to be sensitive to UV. Once balanced loads are obtained by utilizing SSA with the lowest number of load swaps, all voltage magnitudes fall within the multi-objective function constraints.

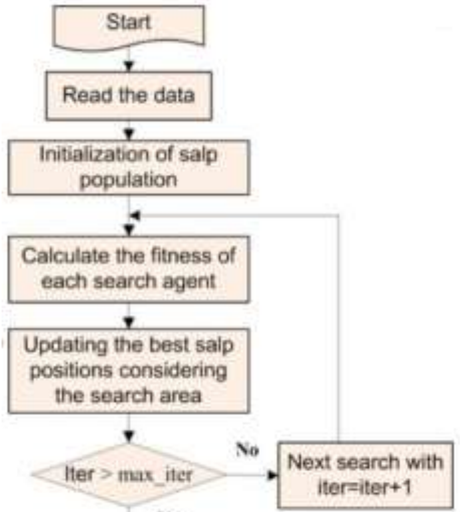

Fig. 5: SSA utilized for the best balance of voltage and current flow chart, [19]

Figure 6, clearly displays the three-phase voltage before and after the SSA application with the lowest number of switching (6 switching) and how the situation improves, case 6 represents the best results obtained. It is necessary to illustrate how the voltage drop in the feeder is causing the customer's end voltages to decrease.

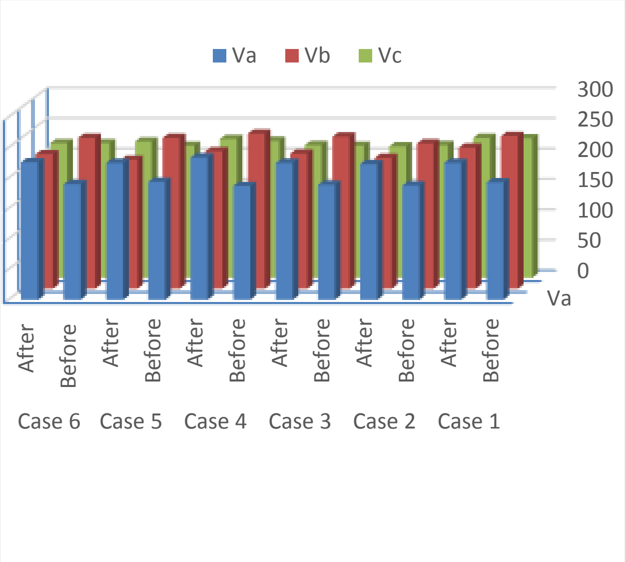

Fig. 6: Three-phase voltage of the feeder before and after the switching

After balancing, all magnitudes fall within allowable ranges. The minimum voltage percentage occurs at Case 6, just six consumers need to switch for the voltage magnitude to fall within an acceptable range. The percentage results of other cases need more than 6 switching to get the voltage within an acceptable range. As feeder end voltage magnitudes increase, the fraction of UV will decrease even further, as indicated in Table 2.

Table 2. Percentage of UV% for all study cases

UV %	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Before	11.9%	11.2%	14.3%	14.7%	11.7%	13.5%
After	1.3%	2.3%	1.5%	2.0%	2.1%	0.9%

5.2 Currents Assessment

A balanced state is one in which there is an equal current in every phase during the loading phase. Figure 7 compares the total currents in each phase of the two situations before and after the load-balancing treatments. The SSA results of a minimum switching number have been consider which indicate that load balancing current is nearly complete because SSA can distribute the current over the subject feeder. The results shown in Figure 7 represent the currents after balancing for the minimum number of swaps. Case 6, which displays the SSA results (best) of measurements as input data, demonstrates excellent current balancing of the three-phase system according to the SSA results.

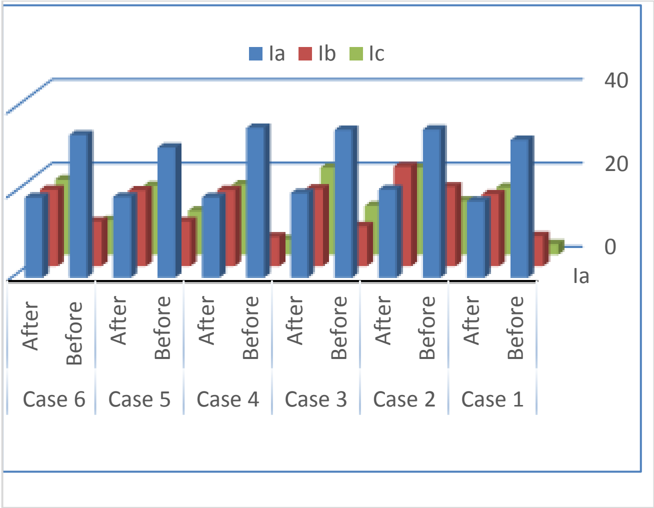

Fig. 7: Three-phase currents of the feeder before and after the switching

Figure 8 shows the neutral current before and after SSA treatments. It is clear from the figure that the neutral current has dropped significantly. The balancing for the lowest swapping numbers can result in a lower neutral current rather than balancing for the highest switching numbers. Thus, employing the maximum swapping numbers may not always be necessary to achieve load balancing. It can be sufficient to swap only the smallest number of end users to get a good result and reduce the load that voltage and current place on the distribution networks. There is no discernible difference in the values of neutral current in all cases because all magnitudes after balancing are within acceptable bounds.

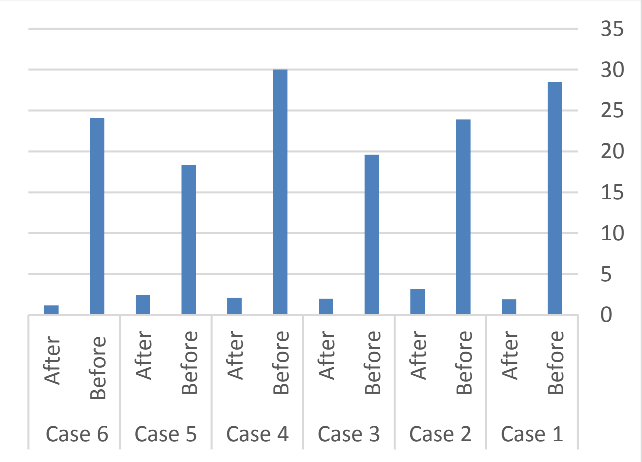

Fig 8: The neutral current before and after the treatments

5.3 Losses Assessment

The number of kWh of power lost in the system is one of the most significant indicators for the financial health of distribution companies. Loss minimization is a difficult practice in the electrical engineering field, load balancing employing the SSA minimizes losses. Load balancing reduces power losses by achieving a current balance among feeders; the net consequence is total power losses reduced. Before and after balancing as shown in Figure 9 shows a decrease in total losses. The balancing had been established and the number of swaps had a critical role in reducing losses.

As shown in Figure 9, the power losses over the feeder under investigation have been greatly reduced by transferring just six customers between phases. Furthermore, when most customers migrate from phase A to phases B and C the biggest loss reduction is achieved when a maximum number of swamps occur.

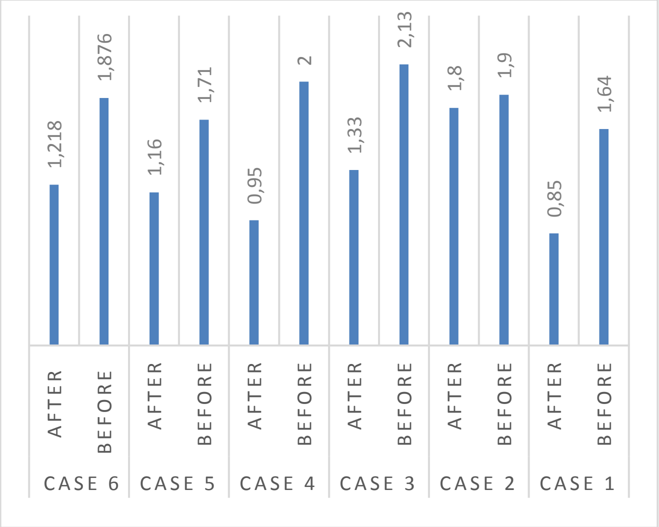

Fig. 9: Total power losses assessments

5.4 Swamping Assessment

Referring to Table 1 displays the number of customers connected to each phase before the treatments. Figure 10 shows how the 19 customers are distributed among the three phases that depend on the load of each customer.

It is obvious that phase A used to have the highest number of connected customers, which may be due to working team consideration. The SSA results showedshow the get the best load balancing therefore less balancing trouble than to have 5 customers connected to phase A, while other customers are distributed between phases B and C (Figure 11). Therefore, to resolve the balancing trouble, six swamping processes must be performed in between load phases to get the best balancing state which provides the lowest neutral current.

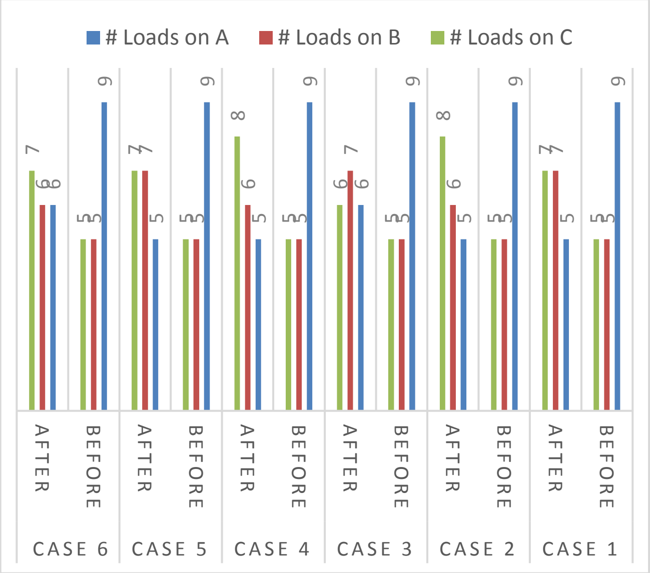

Fig. 10: Number of customers connected to each phase

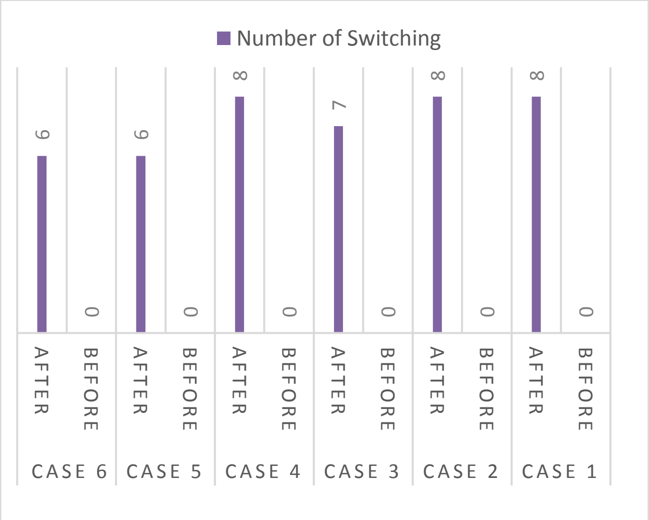

Fig. 11: Number of switching for each SSA treatment

6 Conclusions

This research investigates the use of SSA to mitigate the unbalance problem in the LV radial distribution system. The power losses, the imbalance in voltage and current in phases, and neutral wires on a low-voltage feeder supplying 19 customers are examined. A comparison between the neutral current before and after the treatments shows that the neutral current has been reduced from (For instance; in Case 6 the neutral was reduced significantly from about 24A to 1.15 A; loss reduced from 1.8 to 1.2 kW). The results obtained from the fewest number of customer switching are compared with the SSA-using solutions. The results show that balance is reached for a range of parameters, including voltages, currents, neutral currents, power losses, and voltage imbalance percentage, regardless of the number of swaps. Furthermore, there is currently less burden on the system. Consequently, low-voltage networks experience a reduction in operating expenses. Once the perfect balance is reached, the incidence of electric current disturbances at the consumers reduces, maintaining the security and safety of the system.

Declaration of Generative AI and AI-assisted Technologies in the Writing Process

During the preparation of this work, the authors sometimes used ChatGPT AI tool in order to improve the readability and language of our manuscript especially in the Section 1 and 2 respectively. It is mainly used for sentence rephrasing. Our own software particularly the Matlab2023 produces all the figures in the paper.

References:

[1] Fahim, M., Hassan, M. E., and Najjar, M. B. E. “Single phase load balancing in a three-phase system at distribution and unit level, “In *2018 IEEE International Conference on Industrial Technology* (ICIT), 20-22 February 2018, Lyon, France, doi:10.1109/icit.2018.8352365.

[2] Handhal, F. K., and Rashid, A. T., “Load balancing in distribution system using heuristic search algorithm,” *In 2018 International Conference on Advance of Sustainable Engineering and its Application (ICASEA)*, 14-15 March 2018, Wasit-Kut, Iraq, pp. 48-53. IEEE.

[3] Ivanov, O., Neagu, B.C., Gavrilas, M., Grigoras, G. and Sfintes, C.V., “Phase Load Balancing in Low Voltage Distribution Networks Using Metaheuristic Algorithms,” In *2019 International Conference on Electromechanical and Energy Systems (SIELMEN)*, Craiova, Romania, 9-11 October 2019, doi:10.1109/sielmen.2019.8905900.

[4] Montoya, O. D., Arias-Londoño, A., Grisales-Noreña, L. F., Barrios, J. Á., and Chamorro, H. R.,“Optimal Demand Reconfiguration in Three-Phase Distribution Grids Using an MI-Convex Model.” *Symmetry*, *13* (7), 1124, 2019. https://doi.org/10.3390/sym13071124.

[5] Badran, O., Mekhilef, S., Mokhlis, H., and Dahalan, W., “Optimal reconfiguration of distribution system connected with distributed generations: A review of different methodologies,” *Renewable and Sustainable Energy Reviews*, vol. 73, pp. 854–867, 2017, https://doi.org/10.1016/j.rser.2017.02.010.

[6] Viegas, J. L., Esteves, P. R., Melício, R., Mendes, V. M. F., and Vieira, S. M., “Solutions for detection of non-technical losses in the electricity grid: A review. *Renewable and Sustainable Energy Reviews*, vol. 80, pp. 1256–1268, 2017, doi: 10.1016/j.rser.2017.05.193.

[7] Qin, S., Li, J., Wang, J., Guo, X., Liu, S., and Qi, L., “A salp swarm algorithm for parallel disassembly line balancing considering workers with government benefits.” *IEEE Transactions on Computational Social Systems*, 11(1), pp. 282-291, 2023, https://doi.org/10.1109/TCSS.2023.3238965

[8] Tatipally, S., Ankeshwarapu, S., and Maheswarapu, S.,“Swarm intelligence methods for optimal network reconfiguration of distribution system,” In *2022 IEEE International Power and Renewable Energy Conference (IPRECON),* pp. 1-6, 16-18 December 2022, Kerala, India, doi: 10.1109/IPRECON55716.2022.10059540.

[9] Souifi, Haifa, and Hsan Hadj Abdallah, "Grey Wolf Optimizer for Optimal Distribution Network Reconfiguration," In *2022 IEEE electrical power and energy conference (EPEC)*. IEEE, 5-7 December 2022, Ottawa, Canada, doi: 10.1109/EPEC56903.2022.10000166.

[10] Tang, Y., Ten, C. W., and Brown, L. E. (2017, September). Switching reconfiguration of fraud detection within an electrical distribution network, *In 2017 Resilience Week (RWS)*, pp. 206-212, IEEE, 18-22 September 2017, Wilmington, United States, doi: 10.1109/RWS40337.2017.

[11] Chandel, P., Thakur, T., Sawle, B. A., & Sharma, R., “Power theft: Major cause of non-technical losses in Indian distribution sector,” *In 2016 IEEE 7th Power India International Conference (PIICON)*, pp. 1-6, IEEE, 25-27 November 2016 , Bikaner, India, doi: 10.1109/POWERI.2016.8077477.

[12] Jahn, R., Holt, M., and Rehtanz, C., “Mitigation of voltage unbalances using a

line voltage regulator," *In 2021 IEEE Madrid PowerTech* (pp. 1-6). IEEE, Jun. 28 - Jul 02, 2021 Madrid, Spain, doi: 10.1109/PowerTech46648.2021.9494930.

[13] Rafi, F. H. M., Hossain, M. J., Rahman, M. S., and Taghizadeh, S., "An overview of unbalance compensation techniques using power electronic converters for active distribution systems with renewable generation," *Renewable and Sustainable Energy Reviews*, *125*, pp. 109812, 2020. https://doi.org/10.1016/j.rser.2020.109812.

[14] Vijay, A. S., Doolla, S., and Chandorkar, M. C., "Unbalance mitigation strategies in microgrids," *IET Power Electronics*, *13*(9), 1687-1710, 2020, https://doi.org/10.1049/iet-pel.2019.1080.

[15] Cheng, X., Zhu, L., Lu, H., Wei, J., and Wu, N., "Robot path planning based on an improved salp swarm algorithm," *Journal of Sensors*,12(1), 2022, doi: 10.1155/2022/2559955.

[16] Esmael, A. A., Da Silva, H. H., Ji, T., and da Silva Torres, R. (2021). Non-technical loss detection in power grid using information retrieval approaches: A comparative study. *IEEE Access*, vol *9*, pp. 40635-40648, 2021, doi: 10.1109/ACCESS.2021.3064858.

[17] Sambaiah, K. S., and Jayabarathi, T., "Optimal allocation of renewable distributed generation and capacitor banks in distribution systems using salp swarm algorithm," *Int. J. Renew. Energy Res.*, *9*(1), pp. 96-107, 2019.

[18] Mirjalili, S., Gandomi, A. H., Mirjalili, S. Z., Saremi, S., Faris, H., and Mirjalili, S. M., "Salp Swarm Algorithm: A bio-inspired optimizer for engineering design problems," *Advances in engineering software*, vol. *114*, pp. 163-191, 2017, https://doi.org/10.1016/j.advengsoft.2017.07.002.

[19] Latif, A., Chandra Das, D., Kumar Barik, A., & Ranjan, S., "Illustration of demand response supported co-ordinated system performance evaluation of YSGA optimized dual stage PIFOD-(1+ PI) controller employed with wind-tidal-biodiesel based independent two-area interconnected microgrid system. *IET Renewable Power Generation*, *14*(6), pp.1074-1086, 2020, DOI: 10.1049/iet-rpg.2019.0940.

Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

- Ibrahim Altawil carried out the simulation and optimization, and he implemented the Algorithm of Section 4.
- M. A. Momani Organized and executed the results of all experiments that are made in Section 5 and he was a responsible for the data manipulation and programming.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

This Research is partially funded by Yarmouk University

Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article. However, this research will be useful for the power utilites such as Irbid District Electricity Company (IDECO).