

APPLICATION OF WHALE OPTIMIZATION ALGORITHM (WOA) FOR DISTRIBUTION NETWORK RECONFIGURATION SCHEME FOR POWER QUALITY IMPROVEMENTA Bukar¹, G. A. Olarinoye¹, Y. Jibril¹¹Department of Electrical Engineering, Ahmadu Bello University, Zaria-Nigeria.**Keywords:** –

Distribution Network
Reconfiguration (DNR);
Whale optimization
Algorithm (WOA);
Distribution Network (DN);
Power Loss (PL);
Voltage Deviation (VD).

ABSTRACT

Electrical power distribution networks (DN) are usually designed and operated in a radial configuration, but their topology, especially when highly loaded, is often meshed in order to improve system reliability and quality of the supply. This makes it feasible to alter the network topology after an outage to restore the service to affected areas. In addition, various power quality indicators can be improved by modifying the topology of the DNs, achieved by changing the close/open status of sectionalizing and ties switches on the feeders. However, Distribution Network reconfiguration (DNR) is a non-linear, multi-objective, constrained and combinatorial optimization problem hence, Whale Optimization Algorithm (WOA) technique is employed for optimal Distribution Network Reconfiguration of primary Distribution Network with the aim of minimizing the real power loss (PL) and voltage deviation (VD), as well as improving feeder load balancing (FLB). The developed method is applied on IEEE 33 and 69 test systems. To ascertain its applicability to real-life system, the developed DNR technique is also applied on 11kV RIGASA feeder in Kaduna State, Nigeria. The problems this research is trying to address are power losses and voltage deviation and feeder load balancing experienced in Kaduna electricity distribution network subject to some operational constraints. From the simulation results, substantial reduction in power loss was achieved, the voltage profile has improved and the feeder load balancing was achieved when compared with the original network before reconfiguration as well as when compared to using Runner Root Algorithm based DNR.

Article History: –**Received:** Sept. 7, 2023**Reviewed:** Oct 23, 2023**Accepted:** Nov. 24, 2023**Published:** Dec. 28, 2023**1. INTRODUCTION**

Distribution Network (DN) is that part of power system which connects the distribution substations to the customers' service-entrance equipment (Abdelaziz, 2017; Jafar-Nowdeh, *et al.*, 2020). It is therefore, the last stage in delivery of electric power. DNs are designed as overhead and underground cable (Saadat, 1999), and characterized majorly by two voltage levels; primary or feeder voltage level mostly in the range of tens of kV like typical 13.2kV systems and secondary or customer voltage level in the range of hundreds of volts. Typical example of secondary DN serves customers at levels of 415/240V, single-phase, three-wire system. DS at this level is always radial in nature. It is the final stage of conveying power to customers. Being the last stage of the of power delivery, DN contributes at least 40% of the total power loss occurring in the entire system (Abdelaziz, 2017). DNs are generally designed in loop configuration however; they are operated in

radial configuration, for effective coordination of their protection systems. To change the topology of the network from mesh to radial configuration or vice versa, DN reconfiguration technique is applied (Salau, *et al.*, 2016).

Distribution Network Reconfiguration (DNR) is the technique of changing the topological structure of DN by changing the open/close status of the network sectionalizing and tie switches. Sectionalizing switches are Normally Closed (NC) switches placed within each feeder of the DN while tie switches are Normally Open (NO) switches that connect sections of different feeders (Ghasemi, 2016). DNR is one of the complex activities in electric power systems planning as poor configuration leads to increased power losses, poor voltage profile, and low power factor. As such, optimal DNR is an effective way of improving the performance of power DNs such as reducing power losses (Raju & Bijwe, 2008; Thanh & Viet, 2015), voltage

profile improvement (Moshtagh & Ghasemi, 2013; Abdelaziz, 2017), balancing load demand (Thanh & Viet, 2015; Zhai, *et al.*, 2018), increasing distributed generation (DG) penetration (kianmehr, *et al.*, 2018; Capitanescu, *et al.*, 2015), mitigating operational constraint violations (Zhai, *et al.*, 2018), service restoration (P, *et al.*, 2009; D & Lliuwhe, 1997), improving system security (Zu, *et al.*, 2018) and relieving primary feeders either due to overload or allow maintenance activities on that feeder (Nguyen, *et al.*, 2017). There are other services applied to DNs to improve its conditions such as optimal placement of distributed generation (DG) and use of Flexible AC Transmission System (FACTS), however, DNR is the most cost effective (Salau, *et al.*, 2016). The change of the configuration alters the power flow path in the network resulting in altered line currents, node voltages, and degree of unbalances and also level of distortion of the node voltages in presence of harmonics. Since the impedance of the power flow path also changes due to reconfiguration, the voltage available at a node during a voltage sag condition is also liable to be changed. DNR is carried out either offline better known static DNR or online called dynamic DNR. In static DNR, all the system load demands, generations (both from conventional and DG sources) are assumed constant throughout the reconfiguration process. However, in practice, the load demand and DG output change continuously. In some cases, varying load demand and DG output may cause the system condition outside of permitted operating conditions (Zhai, *et al.*, 2018), hence necessitating the dynamic reconfiguration. In dynamic DNR, the distribution system operators can change the topological structure of DNs in real time by changing the status of remotely controlled switches (Zu, *et al.*, 2018). For instance, (Capitanescu, *et al.*, 2015) applied the dynamic reconfiguration method to improve the DG hosting capacity of active DNs by efficiently countering the effects of time-varying demand and DG output. Due to the quite large number of sectionalizing switches (tie switches are not as that many) in typical DN, choosing the right switch to be turned ON or OFF in order to find the optimal configuration is a challenging problem (Kunya, *et al.*, 2019). This is as a result

of many candidate-switching combinations in the system. For this reason coupled with nonlinear characteristics of the DN constraints, DNR is a complex, nonlinear, combinatorial and non-differentiable constrained mixed-integer optimization problem. The complex nature of the DNR problem makes it prohibitive to adopt most of the exact optimization methods to solve it. On the other hand, heuristic techniques have been shown to be particularly suitable to handle the complex optimization problem of DNR. Merlin and Back (Merlin & Back, 1959) were the first to propose the network reconfiguration technique for loss minimization of the system. Later on many researches have been reported in the literature among which are hybrid evolutionary algorithm (EA) (Niknam, 2009), non-dominated sorting genetic algorithm-II (NSGAI) (Moshtagh & Ghasemi, 2013), plant growth simulation algorithm (PGSA) (PV, *et al.*, 2010), ant colony algorithm (Saffar, *et al.*, 2011), multi objective honey bee mating optimization (MHBMO) (Niknam, 2011) and binary particle swarm optimization (B-PSO) (Kunya, *et al.*, 2019). Moreover, due to the impact of network reconfiguration for reduction of network power losses, in most of research works reviewed, this objective is considered along with other objectives formulated multi-objective optimization problem using different evolutionary, heuristic and meta heuristic techniques. In (Ahuja, *et al.*, 2017), a nature-inspired algorithm is adopted to solve the expanded multi-objective DNR model. The hybrid artificial immune systems-ant colony optimization approach is selected in the work due to its ability to handle the multi-objective formulations and to provide restoration solution during contingencies.

2.0 METHODS

2.1 Model of the Network Reconfiguration

The developed optimal DNR of primary DN is aimed at minimizing the real power loss (PL) and voltage deviation (VD), as well as improving feeder load balancing (FLB). These power quality indicators are chosen to improve the system efficiency and equipment (for both customer and utility) reliability.

2.2 Aggregate Objective Function

The objectives of the proposed technique are to minimize the active PL, improve VP and enhance feeder LB. Thus, the objective function has three terms as formulated in (1).

Where;

$$F = \psi f_1 + \beta f_2 + \xi f_3 \quad (1)$$

The first part of the objective function depicts the power loss component obtained by normalizing the PL with its original value as expressed in (2),

$$f_1 = \frac{P_{loss}}{P_{loss}^{initial}} \quad (2)$$

where P_{loss} is the power loss experienced in the optimized DN, while $P_{loss}^{initial}$ is its inherent power loss calculated as;

$$P_{loss}^{initial} = \sum_{i=1}^{n_l} R_i \left\{ \frac{P_i^2 + Q_i^2}{V_i^2} \right\} \text{ for } i = 1, 2, \dots, n_l \quad (3)$$

The second part of the objective function, f_2 is reflects the component of the total voltage deviation, which when minimized, the VP improves. It is similarly obtained by normalizing its minimized value, V_{dev} with its initial value, $V_{dev}^{initial}$.

$$f_2 = \frac{V_{dev}}{V_{dev}^{initial}} \quad (4)$$

The total inherent voltage deviation is computed as;

$$\Delta V_{total}^{initial} = \sum_{j=1}^{n_b} |V_{ref,j} - V_j| \text{ for } j = 1, 2, \dots, n_b \quad (5)$$

$V_{ref,j}$ is the nominal voltage magnitude of load bus j .

The third term of the objective function denotes for the LB component of the lines in the feeders, which is shown in (6) (Georgilakis & Hatziargyriou, 2013).

$$LB = \sum_{j=1}^{n_f} \sum_{i=1}^{n_l} \left(\frac{n_f I_i}{\sum_{i=1}^{n_f} I_i} \right)^2 \quad (6)$$

Where n_l and n_f are the total number of lines (branches) and feeders in the DN respectively. ψ , β and ξ are the weighing coefficients of the power loss, voltage deviation and LB components of the objective function respectively. Since there are different objectives to be satisfied simultaneously, after normalizing

all the terms of the objectives, the weighing coefficients are chosen thoughtfully to avoid convergence problem.

3.0 POWER FLOW ANALYSIS

The DNR technique requires the bus voltages, line currents, active and reactive power demands at each bus and inherent power loss of the system while determining the optimal reconfiguration. These information of the network are primarily obtained using load flow analysis (LFA). However, due to the low R/X ratio of typical DNs and their tri-diagonal admittance matrices, the commonly used Newton Raphson and fast decoupled load flow methods are ineffective in analyzing such networks as they present lot of convergence problem. Hence, in this study, backward-forward sweeping technique for solving PF recursively, proposed in (Das, 1995) is employed.

Load flow is one of the three major problems encountered in symmetrical steady state of power system (PS) operation. The other two are *optimal load scheduling* and *systems control* problems. Load Flow Analysis (LFA) in PS is the steady state solution of the system network.

3.1 APPLICATION OF WHALE OPTIMIZATION ALGORITHM FOR DISTRIBUTION NETWORK RECONFIGURATION

Whale Optimization Algorithm (WOA) is one of the biologically inspired optimization techniques mimicking the hunting behavior of humpback whales. It is the simulated hunting behavior with random or the best search agent to chase the prey and the use of a spiral to simulate bubble-net attacking mechanism of humpback whales. The efficiency of the WOA algorithm developed in this research is evaluated by solving 29 mathematical optimization problems and six structural optimization problems. Optimization results demonstrate that WOA is very competitive compared to the state-of-the-art optimization methods (Mirjalili & Lewis, 2016).

The distribution systems can be described as a matrix with dimensions $M \times L$. Where M is number of branches and L is number of buses. It

can be assumed that whales move between branches and select which one is to be open. The following steps are used to implement the WOA algorithm on distribution network reconfiguration.

Step (1): Initializing the position of search agents Initial random positions for each search agent are set and selecting random switches to be opened (tie switches). Then the initial configuration is checked whether it is a radial system or not. If the system is radial, we can run a power flow analysis on it to calculate total power loss in the system and minimum bus voltage. Now, we can assume that the best configuration is the initial configuration and then start the next step to change the reconfiguration of the system.

Step (2): Updating positions of search agents In each iteration (i), a new configuration is produced using (WOA) by selecting some switches to be open. The configuration must be evaluated by 3 important actions:

1. Check system radiality:

By forming incidence matrix (A), the system is checked if it is radial or not if the system is not radial, the configuration is discarded and the fitness function (power loss) is set to equal infinity.

2. Run power flow analysis:

“Forward Sweep Backward Sweep” is the method used for load flow of the system and check the bus voltage limit. $V_{min} > 0.91$ and $V_{max} < 1$. If the system does not satisfy voltage limit condition, the configuration is discarded also, and the fitness function is set to equal infinity.

3. Evaluate fitness function (P_{loss})

Step (3): Determination of best configuration to get minimum power loss. The process continues until reaching the maximum number of iterations. At each iteration, if fitness function is less than initial fitness function, then the current configuration is set to be the best configuration.

4.0 RESULTS AND DISCUSSION

4.1 Validation Using IEEE 33-bus System

The first DN used in this work is 33-bus, single feeder radial DN with a total active and reactive load demand of 3.72MW and 2.30MVar on 12.66kV respectively (Mahboubi-Moghaddam, et al., 2016). It has 37 branches, 32 sectionalizing switches and 5 tie switches as shown in Figure 1.

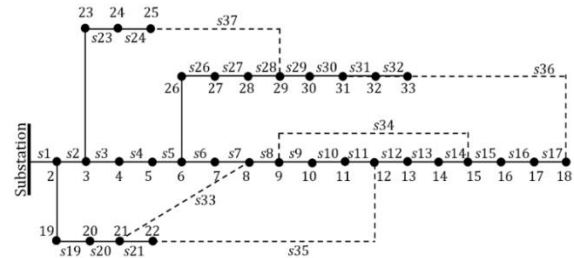


FIG 1. SINGLE LINE DIAGRAM OF IEE 33-BUS SYSTEM

The comparison of results obtained using base case (before reconfiguration) as well as runner root algorithm (RRA) optimization presented (Nguyen *et al.*, 2017) is summarized in table1, fig 2 discusses the voltage profile improvement obtained using WOA when compared to the original case (before reconfiguration) and when using Runner Root Algorithm (RRA). Also, fig 3 and fig 4 describes the reduction in active and reactive power losses when compared to the case before optimization and after optimization.

Table 1: Summary of WOA performance on IEEE 33-bus system

Scenario	Tie-switches	Voltage Deviation (pu)	Power Loss (kW)	Feeder Load Balancing (%)
Base case (original)	s33, s34, s35, s36, s37	1.772	210.98	67.71
RRA-optimized	s7, s9, s14, s32, s37	1.342	188.43	52.88
WOA-optimized	s7, s11, s14, s28, s32	1.124	175.94	46.72
% reduction of WOA over base case		57.65%	44.56 %	48.09%
% reduction of WOA over RRA		19.39%	22.26 %	15.66%

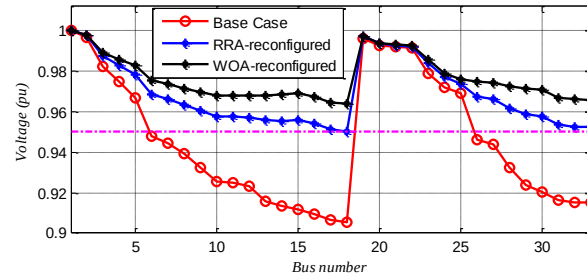


Fig 2. Voltage Profile of Original, RRA-reconfigured and WOA-reconfigured IEEE 33-bus System

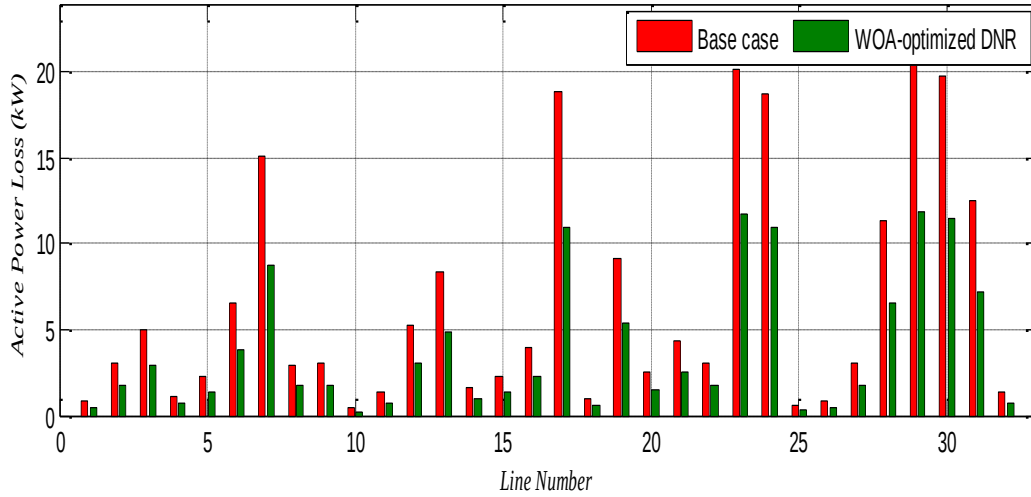


Fig 3. Active power loss of IEEE 33-bus system with and without WOA-based DNR

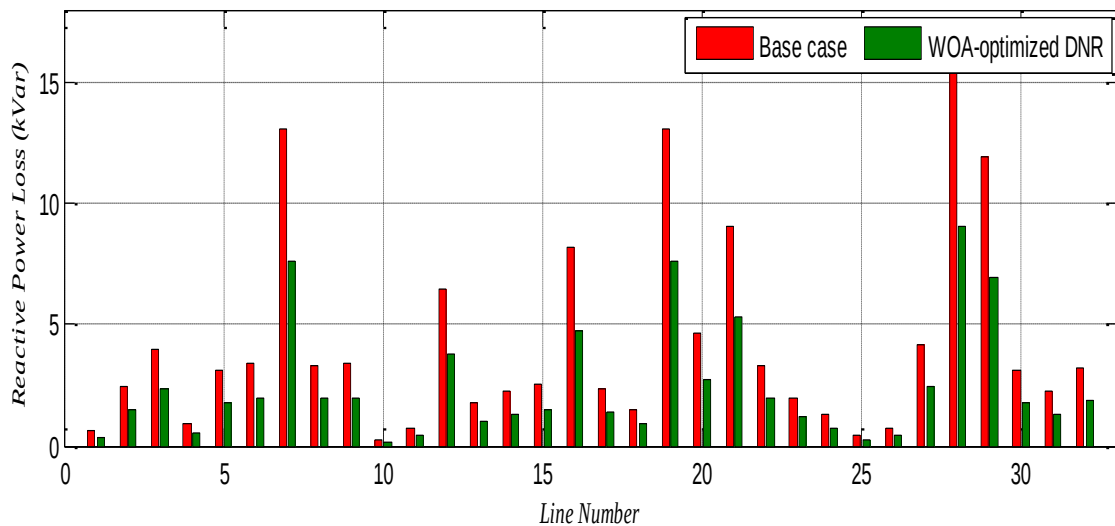


Fig 4. Reactive power loss of IEEE 33-bus system with and without WOA-based DNR

4.2 Validation Using IEEE 69-Bus System

The 69-bus system is also one of the standard test systems. The developed reconfiguration model is validated using the standard 69-Bus distribution network. This system consists of 69 buses, 1 main feeder, 7 laterals, 73 branches of

68 sectionalizing switches and 5 tie switches. The substation voltage is 12.66kV and the base power is 10MVA (Savner & Das, 2007). This is represented by the single line diagram as shown in Figure 5 (Fathy *et al.*, 2017).

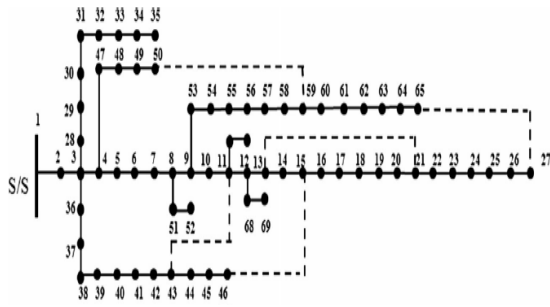


Fig 5. single line diagram of IEEE 69-bus test feeder system

the performances of WOA on the IEEE 69-bus system is elaborated in table 2 where the comparison was made with results obtained before and after reconfiguration as well as those obtained using Runner Root algorithm (RRA).

Table 2. Summary of WOA performance on IEEE 69-bus system

Scenario	Tie-switches	Voltage Deviation (pu)	Power Loss (kW)	Feeder Load Balancing (%)
Base case	s69, s70, s71, s72, s73	0.2140	224.98	82.25
RRA-optimized	s14, s58, s61, s68, s69	0.1982	192.62	74.48
WOA-optimized	s15, s58,	0.1744	167.22	61.33

s62, s69, s70			
% reduction of WOA over base case	22.70%	34.54 %	34.11%
% reduction of WOA over RRA	13.64%	15.18 %	21.44%

Figures 6 below describes the voltage profile improvement before and after reconfiguration as well as the comparison made using Runner Root Algorithm (RRA). The voltage profile has Improved by 22.7% after using WOA while 13.64% voltage profile improvement was achieved when compared with the result obtained using Runner Root Algorithm.

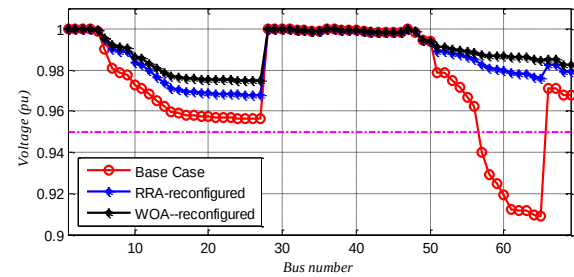


Fig 6. Voltage profile of original, RRA-reconfigured and WOA-reconfigured IEEE 69-bus System

The reduction in active and reactive power losses are elaborated in figure 7 and 8. 34.54% reduction in power loss was achieved after optimization using WOA and 15.18% reduction in power loss was achieved when compared with the optimization using Runner Root algorithm (RRA).

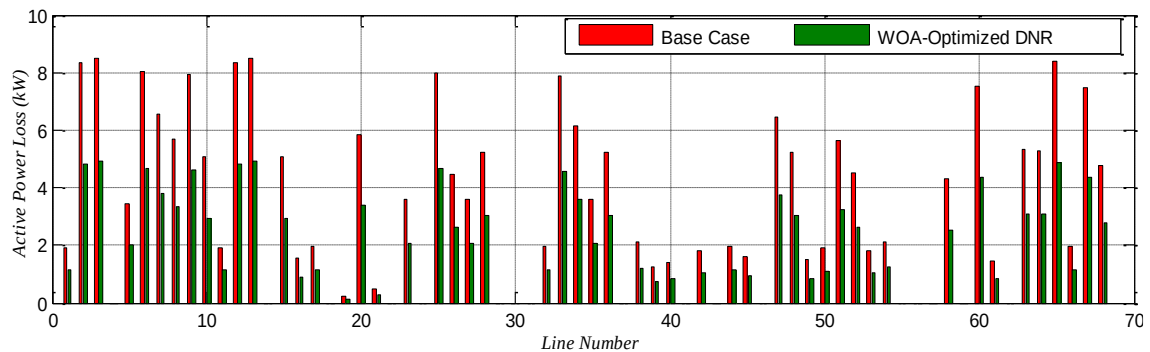


Fig 7. Active power of IEEE 69-bus system with and without WOA-based DNR

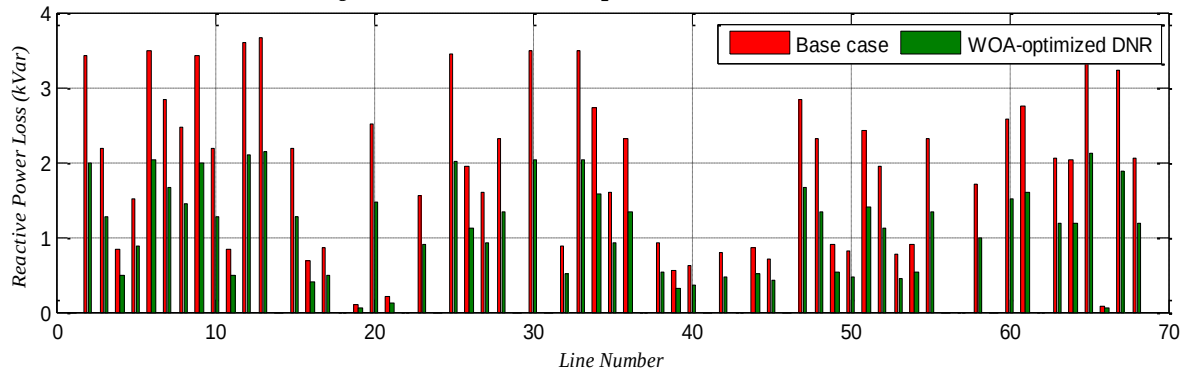


Fig 8. Reactive power of IEEE 69-bus system with and without WOA-based DNR

4.3 11kV RIGASA FEEDERS

Rigasa injection substation is a 4-feeder, radial DN supplied through twin 15MVA, 33/11kV transformers. The network is owned and operated by Kaduna Electric Distribution Company (KAEDCO). For the purpose of this study, two feeders of the network are considered. The first feeder has 46 substations (buses) interconnected with 42 distribution lines (branches). The feeder has a radial topology as

shown in its single line diagram in Figure 9. The second feeder has 31 buses and 30 branches. Each of the branches has a sectionalizing switch as shown in figure 10, while between buses 35 – 50 (s72), 44 – 56 (s73), 33 – 58 (s74) and 41 – 65 (s75), there are normally-open tie switches, though not indicated on the line diagrams for brevity's sake.

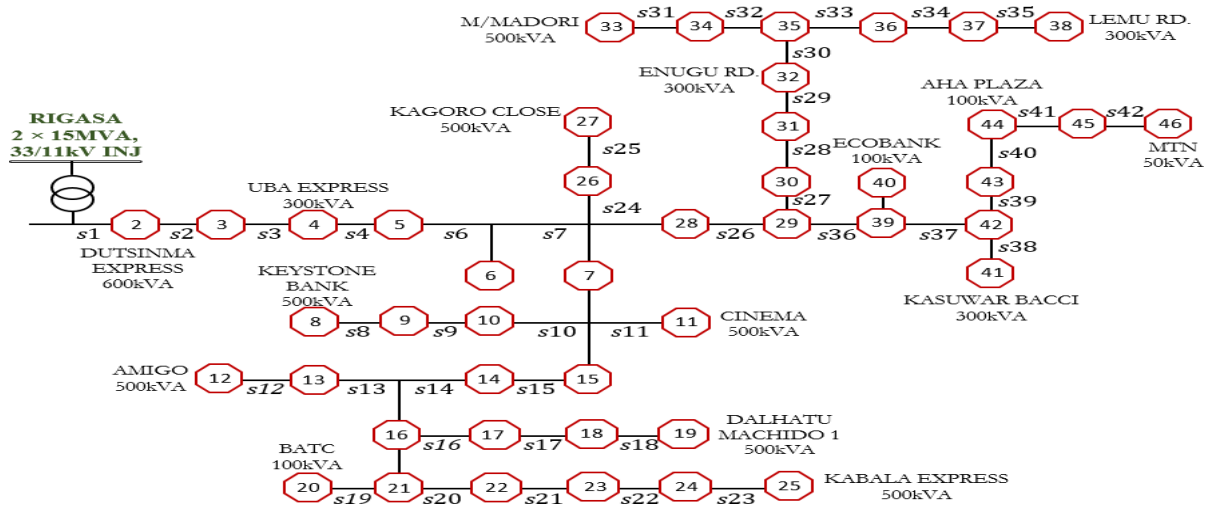


FIG 9. Feeder 1 of RIGASA 2x15MVA, 33/11kV Injection Substation

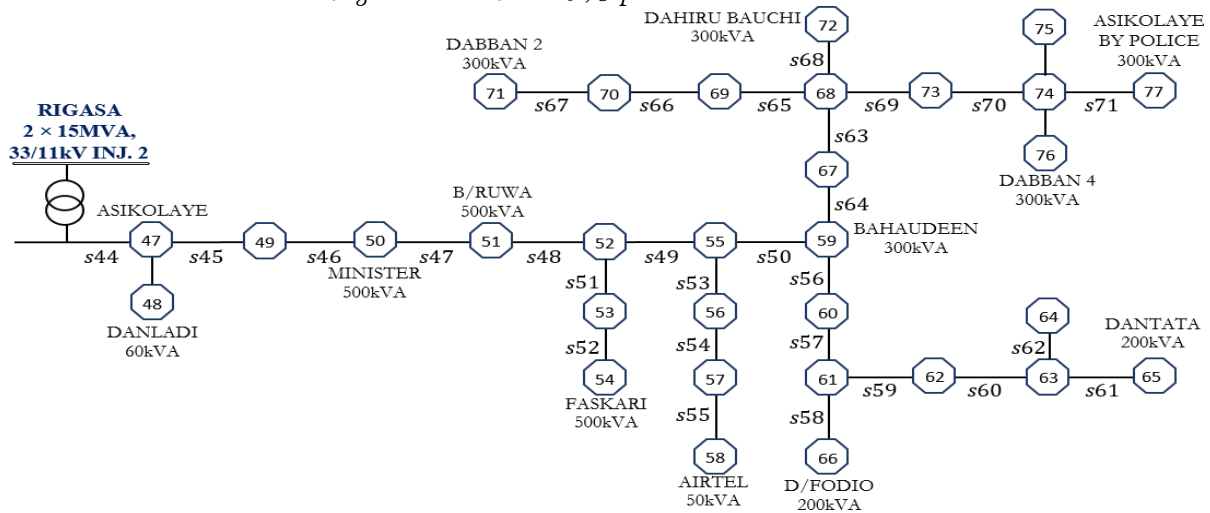


FIG 10. Feeder 2 of RIGASA 2x15MVA, 33/11kV Injection Substation

The network is analyzed with a total active and reactive load demands of 5.6MW and 4.3MVar.

By optimally reconfiguring the network using the WOA algorithm, the topology of the network changes. The normally-closed sectionalizing switch s30 is opened there by separating buses 32 and 35. The normally - opened tie switch between buses 35 – 50 is closed. This transferred the loads on buses 33, 34, 35, 36, 37 and 38 from Feeder 1 to Feeder 2. Similarly, the loads on buses 44, 45 and 46 are also transferred to Feeder 2 by opening s40 and closing s73.

The voltage profiles of the reconfigured are shown in Figure 11. It can be observed that the voltages of buses on Feeder 1 have

significantly improved, even though it is at the detriment of those on Feeder 2.

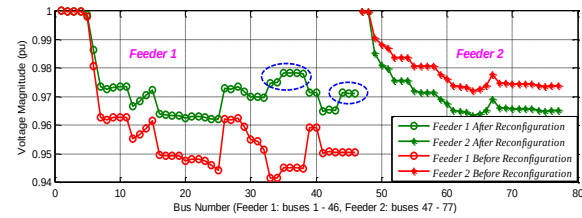


Fig 11. Voltage profile of Rigasa Feeder system before and after the WOA-based DNR

It not only the voltage profiles that improve, but also the remaining components of the objective function; power loss and feeder load balancing. Table 3. summarizes the improvement observed on the voltage profile and the reduction in the power loss.

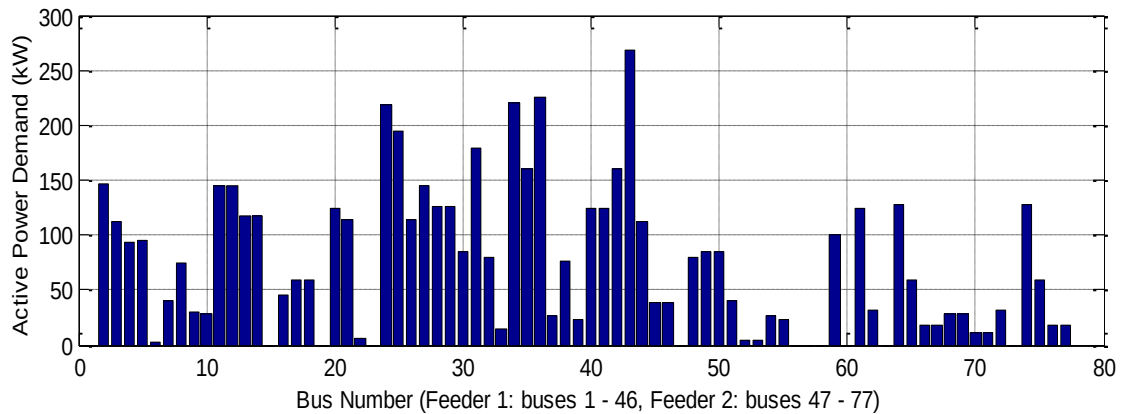


Fig 12. Active power of Rigasa Feeder system before and after the WOA-based DNR

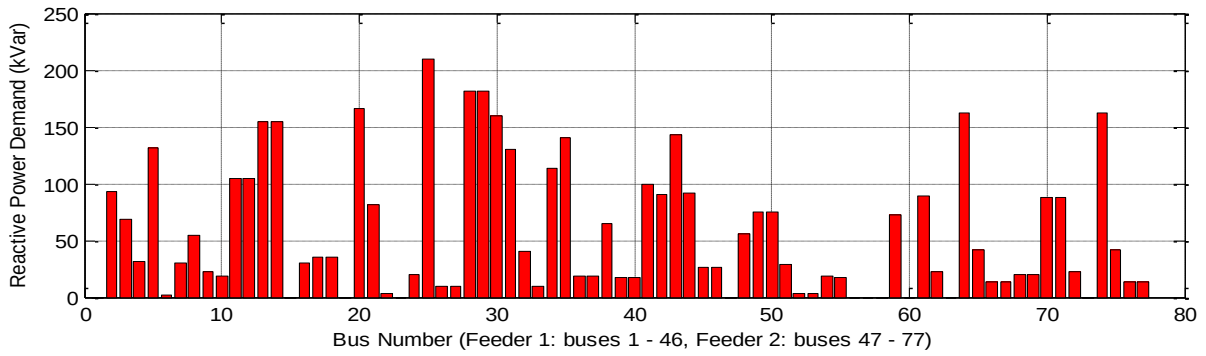


Fig 13. Reactive power of Rigasa Feeder system before and after the WOA-based DNR

Table 3. Summary of WOA performance on Rigasa feeder

Parameters	Before Reconfiguration	After Reconfiguration	%Improvement /Reduction
Tie switches	s72, s73, s74, s75	s30, s40, s74, s75	-----
Voltage Deviation (pu)	2.5484	2.1153	20.47%
Power Loss (kW)	427.28	294.67	44.90%
Feeder Load Balancing (%)	43.72%	58.01%	32.68%
Min voltage magnitude (pu)	0.9415	0.9622	-----

It is observed that through the optimal reconfiguration of the network, the voltage deviation (VD) has been reduced by 20.47%, implying that the voltage profile has been improved by that percentage. Similarly, the power loss has been reduced by 44.90%, while the feeder load balancing (FLB) index is found to have improved from 43.72% to 58.01%.

5.0 CONCLUSION

An optimal network reconfiguration scheme for the 33kV RIGASA FEEDER was established using Whale Optimization Algorithm (WOA) for the purpose of minimizing the real power loss (PL) and voltage deviation (VD), as well as for improving feeder load balancing (FLB).

- It is observed that through the optimal reconfiguration of the network, the voltage deviation (VD) has been reduced by 20.47%, implying that the voltage profile has been improved by that percentage.
- Similarly, the power loss has been reduced by 44.90%.

- The feeder load balancing (FLB) index is found to have improved from 43.72% to 58.01%.

REFERENCES

- Abdelaziz, M. (2017). Distribution network reconfiguration using a genetic algorithm with varying population size. *Electric Power Systems Research*, 142, 9-11.
- Abubakar, A. S. (2014). *Development of an Optimal Reconfiguration Algorithm for Radial Distribution Electrical Power Networks (A Case Study of Zaria Distribution Network)*, 1-101.
- Ahmadi, H., & Martí, J. R. (2015). Minimum-loss network reconfiguration: A minimum spanning tree problem. *Sustainable Energy, Grids and Networks*, 1, 1-9.
- Alhaddad, F. M., & El-Hawary, M. (2014). *Optimal Filter Placement and Sizing Using Ant Colony Optimization in Electrical Distribution System*. Paper presented at the Electrical Power and Energy Conference (EPEC), 2014 IEEE, 128-133.
- Allan, R. (2013). *Reliability evaluation of power systems*: Springer Science & Business Media.
- Amanulla, B., Chakrabarti, S., & Singh, S. (2012). Reconfiguration of power distribution systems considering reliability and power loss. *IEEE Transactions on Power Delivery*, 27(2), 918-926.

- Capitanescu, F., Ochoa, F. L., Margossian, H. & Hatziaargyriou, D. N. (2015). Assessing the potential of network reconfiguration to improve distributed generation hosting capacity in active distribution systems. *IEEE Transaction Power System*, 30(1), p. 346–56.
- C, Y., Goswami, S. & Chatterjee, D., (2016). Effect of network reconfiguration on power quality of distribution system. *Electrical Power and Energy Systems*. Volume 83, p. 87–95.
- Das, D., (1995). A simple and efficient method for load flow solution of radial distribution networks. *Electrical Power System*, pp. 17(5), 335–346.
- Dahalan, W. M., & Mokhlis, H. (2012). *Network reconfiguration for loss reduction with distributed generations using PSO*. Paper presented at the Power and Energy (PECon), 2012 IEEE International Conference on, 823-828.
- Daniel, L. C., Khan, I. H., & Ravichandran, S. (2005). *Distribution network reconfiguration for loss reduction using ant colony system algorithm*. Paper presented at the INDICON, 2005 Annual IEEE, 619-622.
- Djavid, H. P., & Jalilian, A. (2010). Developing a new distribution test system to estimate customer outage costs using accurate and approximate procedures. *Energy*, 35(3), 1300-1311.
- Duan, D.-L., Ling, X.-D., Wu, X.-Y., & Zhong, B. (2015). Reconfiguration of distribution network for loss reduction and reliability improvement based on an enhanced genetic algorithm. *International Journal of Electrical Power & Energy Systems*, 64, 88-95.
- Esmailian, H. R., Fadaeinedjad, R., & Attari, S. M. (2013). Distribution network reconfiguration to reduce losses and enhance reliability using binary gravitational search algorithm, 385.
- Etemadi, A., & Fotuhi-Firuzabad, M. (2008). Distribution system reliability enhancement using optimal capacitor placement. *IET Generation, Transmission & Distribution*, 2(5), 621-631.
- Fathy, A., El-Arini, M., & El-Baksawy, O. (2017). An efficient methodology for optimal reconfiguration of electric distribution network considering reliability indices via binary particle swarm gravity search algorithm. *Neural Computing and Applications*, 1-16.
- Georgilakis, P. S. & Hatziaargyriou, N. D. (2013). Optimal Distributed Generation Placement in Power Distribution Networks: Models, Methods, and Future Research. *IEEE Transaction on Power System*, 28(3), pp. 3420-3428.
- Ghasemi, S., (2016). Balanced and unbalanced distribution networks reconfiguration considering reliability indices. *Ain Shams Engineering Journal* xxx (2016), Volume xx, p. xxx–xxx.
- Gupta, N., Swarnkar, A., & Niazi, K. (2014). Distribution network reconfiguration for power quality and reliability improvement using Genetic Algorithms. *International Journal of Electrical Power & Energy Systems*, 54, 664-671.
- Imran, A. M., Kowsalya, M. & Kothari, D. (2018). A novel integration technique for optimal network reconfiguration and distributed generation placement in power distribution networks. *Electrical Power and Energy Systems*, Volume 63, p. 461–472.
- Jafar-Nowdeh, A. (2020). Meta-heuristic matrix moth–flame algorithm for optimal reconfiguration of distribution networks and placement of solar and wind renewable sources considering reliability. *Environmental Technology & Innovation*, Volume 20, pp. 1-12.
- Jahani, M. T. G., Nazarian, P., Safari, A. & Haghifam, M. (2019). Multi-objective optimization model for optimal reconfiguration of distribution networks with demand response services. *Sustainable Cities and Society*, Volume 47, pp. 1-11.
- kianmehr, E., Nikkhah, S. & Rabiee, A. (2018). Multi-Objective Stochastic Model for Joint Optimal Allocation of DG Units and Network Reconfiguration from DG Owner’s and Disco’s Perspectives. *Renewable Energy*, pp. 1-13.

- Kabir, A. M. (2015). *Radial Distribution Network Modeling and Analysis Considering Power Flow and Reconfiguration (A Case Study of Azare Distribution Network)*, 1-188.
- Kaur, M., & Ghosh, S. (2016). Network reconfiguration of unbalanced distribution networks using fuzzy-firefly algorithm. *Applied Soft Computing*, 49, 868-886.
- Kavousi-Fard, A., & Niknam, T. (2014). Multi-objective stochastic distribution feeder reconfiguration from the reliability point of view. *Energy*, 64, 342-354.
- Kennedy, J. (2011). Particle swarm optimization *Encyclopedia of machine learning* (pp. 760-766): Springer.
- Kersting, W. H. (2001). *Radial distribution test feeders*. Paper presented at the Power Engineering Society Winter Meeting, 2001. IEEE, 908-912.
- Khalil, T. M., & Gorpinich, A. V. (2012). *Optimal conductor selection and capacitor placement for loss reduction of radial distribution systems by selective particle swarm optimization*. Paper presented at the Computer Engineering & Systems (ICCES), 2012 Seventh International Conference on, 215-220.
- Kunya, A. B., Shehu, G. S., Hassan, U. M. & Lawan, A. U. (2019). Simultaneous Distribution Network Reconfiguration and Optimal Placement of Distributed Generation. *Journal of Applied Materials and Technology*, Volume 1, pp. 46-53.
- Le Roux, P. (2013). *Optimisation of Technical Power Losses in Distribution Networks Using Genetic Algorithm and Load Flow*. Tshwane University of Technology, 1-51.
- Lliuwhe, S. (1997). Distribution feeder reconfiguration for service restoration and load balancing. *IEEE Transaction Power System*, 12(2), p. 724–9.
- López, J. C., Lavorato, M., & Rider, M. J. (2016). Optimal reconfiguration of electrical distribution systems considering reliability indices improvement. *International Journal of Electrical Power & Energy Systems*, 78, 837-845.
- Mazza, A., Chicco, G., & Russo, A. (2014). Optimal multi-objective distribution system reconfiguration with multi criteria decision making-based solution ranking and enhanced genetic operators. *International Journal of Electrical Power & Energy Systems*, 54, 255-267.
- Mendoza, J., Lopez, M., Coello, C. C., & Lopez, E. (2009). Microgenetic multiobjective reconfiguration algorithm considering power losses and reliability indices for medium voltage distribution network. *IET Generation, Transmission & Distribution*, 3(9), 825-840.
- Merlin, A., & Back, H. (1975). *Search for a minimal-loss operating spanning tree configuration in an urban power distribution system*. Paper presented at the Proc. 5th Power System Computation Conf., Cambridge, UK, 1-18.
- Messac, A. (2015). *Optimization in practice with MATLAB®: for engineering students and professionals*: Cambridge University Press, 147-179.
- Nasiraghdam, H., & Jadid, S. (2012). Optimal hybrid PV/WT/FC sizing and distribution system reconfiguration using multi-objective artificial bee colony (MOABC) algorithm. *Solar Energy*, 86(10), 3057-3071.
- Nguyen, T. T., Nguyen, T. T., Truong, A. V., Nguyen, Q. T., & Phung, T. A. (2017). Multi-objective electric distribution network reconfiguration solution using runner-root algorithm. *Applied Soft Computing*, 52, 93-108.
- Nguyen, T. T., & Truong, A. V. (2015). Distribution network reconfiguration for power loss minimization and voltage profile improvement using cuckoo search algorithm. *International Journal of Electrical Power & Energy Systems*, 68, 233-242.
- Niknam, T., Fard, A. K., & Baziar, A. (2012). Multi-objective stochastic distribution feeder reconfiguration problem considering hydrogen and thermal

- energy production by fuel cell power plants. *Energy*, 42(1), 563-573.
- Parasher, R. (2014). Load flow analysis of radial distribution network using linear data structure. *arXiv preprint arXiv:1403.4702*.
- Prasad, K., Ranjan, R., Sahoo, N., & Chaturvedi, A. (2005). Optimal reconfiguration of radial distribution systems using a fuzzy mutated genetic algorithm. *IEEE Transactions on Power Delivery*, 20(2), 1211-1213.
- Raju, G. K. V. & Bijwe, P. R. (2008). Efficient reconfiguration of balanced and unbalanced distribution systems for loss minimization. *IET Generation, Transmission and Distribution*, 2(1), p. 7–12.
- Ramesh, L., Chowdhury, S., Chowdhury, S., Natarajan, A., & Gaunt, C. (2009). Minimization of power loss in distribution networks by different techniques. *International Journal of Electrical Power and Energy Systems Engineering*, 2(1), 1-6.
- Rani, D. S., Subrahmanyam, N., & Sydulu, M. (2015). Multi-objective invasive weed optimization—an application to optimal network reconfiguration in radial distribution systems. *International Journal of Electrical Power & Energy Systems*, 73, 932-942.
- Rupa, J. M., & Ganesh, S. (2014). Power flow analysis for radial distribution system using backward/forward sweep method. *International Journal of Electrical, Computer, Electronics and Communication Engineering*, 8(10), 1540-1544.
- Saadat, H. (1999). Power System Control. In: *power system analysis*. New York: Mc Graw Hill, pp. 527-576.
- Salau, A. O., Gebru, Y. W. & Bitew, D. (2016). Optimal network reconfiguration for power loss minimization and voltage profile enhancement in distribution systems. *Electrical Power and Energy Systems*, Volume 78, p. 801–815.
- Savier, J., & Das, D. (2007). Impact of network reconfiguration on loss allocation of radial distribution systems. *IEEE Transactions on Power Delivery*, 22(4), 2473-2480.