

# GREY WOLF OPTIMIZER FOR OPTIMAL ALLOCATION AND SIZING OF DISTRIBUTED GENERATION FOR LOSS REDUCTION AND VOLTAGE IMPROVEMENT IN DISTRIBUTION SYSTEM

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## Abstract

In recent years, distributed generation (DG) is becoming an interesting topic for researchers and engineers for improving the distribution system performance by reducing power loss and enhancing the voltage profile. Meanwhile, DG integration in the system requires a technical solution to get maximum benefits and avoid any negative impacts in terms of location and size of DG presence. In this paper, a meta-heuristic optimization method called Grey Wolf Optimizer (GWO) which is a novel optimization algorithm is applied to find the optimal location and size of DG in radial distribution systems. Moreover, the real power loss minimization and voltage profile improvement are the objective functions in this paper considering DG which injects only real power. The proposed algorithm is compared with other three well-known optimization methods including the genetic algorithm (GA), Artificial Bee Colony (ABC), and Particle Swarm Optimization (PSO). Also, the algorithm performance is evaluated with 33 and 69 bus radial distribution systems. The obtained results show the proposed method provided better performance with less computation time when compared with the other three algorithms.

**Keywords:** Distributed generation, Grey wolf optimizer, Distribution System, Loss reduction, Voltage improvement

## Introduction

Electrical power plays a very important role in human daily life and development, and it is transferred from generation units through high voltage transmission lines before stepping down to a usable level in the distribution system. Distribution systems deliver the electrical power to the customers; hence, it has been considered as the

most important among the three divisions of generation, transmission, and distribution. Power reliability mainly depends on an efficient distribution system. Distribution systems contribute about 70% of power loss while only about 30% of loss occurred in transmission and generation (Ang *et al.*, 2018). Therefore, distribution is the

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main concern to consider nowadays for power quality improvement and cost-saving. With the continuous increase of demands and system expansion, it has been caused challenges for the utilities to maintain the system reliability and quality, and when the heavy loads are connected to the system, the voltage magnitude is dropped and the power loss is also increased (Mehta *et al.*, 2018). Hence, the utilities have been looking for a smarter way to meet customer requirements. One smart solution to solve these problems is to change the topology of the distribution system by installing external power sources rather than reconfiguring the whole system (Vidyasagar *et al.*, 2016).

DG has been defined by many scholars and institutions. DG was defined as the generation of electricity by facilities that are sufficiently smaller than the central power plant and it is designed to interconnect or connect to any point in a power system, according to IEEE. DG is the on-site small power producer which injects the power directly to the distribution system for power loss reduction and power quality enhancement. Some researchers defined DG as a dispersed generation or embedded generation developed in this century due to huge technological advancement in the area of the smart grid. Moreover, (Ioan Dulau *et al.*, 2016) defined as electrical power production near to customer location integrating with renewable and non-renewable energy resources. DG has been considered as the backbone in the distribution network in power loss reduction and power quality improvement because the integration of DG in the system can reduce system loss and improve voltage profile economically and effectively (Georgilakis and Hatziargyriou, 2013). Due to the concern about fossil fuel depletion and environmental pollution, renewable energy is becoming more incentive. Many countries made a consensus to reduce greenhouse gas emissions and enhance the penetration of clean energy during KYOTO protocol commitment. Hereby, renewable DG was considered and raised as an effective way to achieve commitment. DG owners can also get more benefits from the utilities by providing a high selling energy price due to the advantages of DG presence in the systems (Omran *et al.*, 2011). Furthermore, DG is more suitable in a competitive market to provide ancillary services such as spinning reserve, voltage regulation, reactive power control, and frequency control (Rueda-Medina and Padilha-Feltrin, 2012). Aman *et al.* (2012) claimed that the integration of DG changes the system from one power source to multiple power source supply, and it changes from passive to active networks. There are several issues to be considered when DG is installed in the existing distribution network because it affects the reliability

and operation of the networks. Non-optimal placement and sizing of DG can result to increase system losses, voltage fluctuation, protection failure, system instability, and ineffective investment cost. Therefore, DG should be placed and size optimally in the system to get high benefits and avoid various negative problems.

Many methods have been proposed and addressed to solve the optimization of DG application in the distribution system. The analytical method was proposed to find the optimal location and capacity of DG in radial distribution (Prakash and Khatod, 2016). Alinezhad *et al.* (2015) applied the multi-objective of cost function to reach all the objectives including optimal placement and size of DG. The comparison between voltage-sensitive based and optimization-based approaches to solving optimal DG location and sizing was presented (Uniyal and Kumar, 2016). Moradi and Abedinie (2012) proposed a new approach which is the combination of GA and PSO is developed for determining optimal location and size of DG in radial distribution networks. Abu-Mouti and El-Hawary (2013) applied modified ABC algorithm for optimal location and size of DG by considering the power factor of DG at unity and lagging. Dinakara *et al.* (2017) studied the optimal location and size of DG units considering the various type of DG. PSO was used to find the location and capacity of DG units (Rama Prabha *et al.*, 2012). The determination of the optimal location of DG based on voltage sensitivity index (VSI) and voltage deviation index was proposed (Vidyasagar *et al.*, 2016). Doung Quoc and Nadarajah (2013) considered the multiple DG unit using the improved analytical method and loss sensitivity factor (LSF). Harmony search was introduced for determining optimal DG placement and size (Rao *et al.*, 2013). Zahra and Amir (2013) applied cuckoo search used for solving the problem of DG optimization in the distribution system. Giri and Bera (2018) used GWO to optimize the scaling factors of fuzzy-PI controllers for Hybrid Distributed Generation System. Moreover, GWO was applied for solving optimization of battery energy storage in the aims of cost mitigation in a micro-grid (Sharma *et al.*, 2015). Improved Grey Wolf Optimizer (IGWO) was used to find the sizing of the optimal reactive power source for power system operation enhancement (Ibrahim *et al.*, 2018). Hassan *et al.* (2020) proposed a new hybrid cuckoo search algorithm and grey wolf optimizer (CSA-GWO) for the optimal control strategy for performance enhancement of HVDC-based offshore wind farms. Meanwhile, Yahiaoui *et al.* (2017) applied for optimal design of hybrid renewable energy system PV-Diesel Generator-Battery. In optimization literature surveys, GWO

which is a novel nature inspired meta-heuristic optimization algorithm was proved to be usable for all optimization problems. To the best knowledge of authors, GWO has not been used in literature for the optimal location and sizing of DG in radial distribution considering real power loss and voltage improvement.

This paper is organized into four main sections. The problem formulation of the objective function involving active power loss minimization, the system constraints of the controlled variables, and the overview of GWO including the working procedure of the proposed algorithm are presented in materials and methods section. Simulation results and discussions are placed in next section. Finally, the conclusion of this work is placed in conclusion section.

## Materials and Methods

### Objective Function

Power loss formulation in this paper is obtained by computing power flow between two buses as illustrated in Figure 1.

The power flow between buses  $i$  and  $k$  at bus  $i$  is given as,

$$S'_{ik} = V_i (V_i^* - V_k^*)^* Y_{ik} + V_i V_i^* Y_{ik0} \quad (1)$$

Meanwhile, the power flow from buses  $k$  and  $i$  at bus  $k$  is calculated as,

$$S'_{ki} = V_k (V_k^* - V_i^*)^* Y_{ki} + V_k V_k^* Y_{ki0} \quad (2)$$

As a result, the power loss of the two is the sum of the power flow in the equation (1) and equation (2).

$$S'_{Total\ loss} = S'_{ik} + S'_{ki} \quad (3)$$

The total power loss in the system is obtained by summing all the power loss in each node. Besides, the power loss in the slack bus can be obtained by combining the power flow at the

terminated bus (Ang and Leeton, 2019). Throughout this study, reactive power loss is neglected, so the objective function is formulated as,

$$F_{Loss} = \text{real} \left( \sum_{i=1}^n S'_{i\ Total\ loss} \right) \quad (4)$$

Where  $n$  is the total number of lines and  $S'_{Total\ loss}$  is the system complex power loss.

### System Constraints

It must make sure that all constraints are within the allowable limits. Bus voltage, power from DG, current are the inequality constraints.

$$V_{i\ min} \leq V_i \leq V_{i\ max} \quad (5)$$

$$V_{min,DG} \leq V_{DG} \leq V_{max,DG} \quad (6)$$

$$P_{min,DG} \leq P_{DG} \leq P_{total\ demand} \quad (7)$$

Where,  $V$  is the voltage magnitude,  $P_{DG}$  is the real power injected by DG and assume the minimum of DG is 1kW in this paper, and  $P_{total\ demand}$  is the total real power demand.

### Power Balance Constraints

Power balance is the equality constraints and DG is considered to inject only real power to the system. The common power flow and power balance without including DG can be written as,

$$P_{Slack} = \sum_{i=1}^{N_L} P_{D,i} + \sum_{i=1}^{N_{br}} P_{Loss,i} \quad (8)$$

$$Q_{Slack} = \sum_{i=1}^{N_L} Q_{D,i} + \sum_{i=1}^{N_{br}} Q_{Loss,i} \quad (9)$$

Consequently, power flow and power balance equations of real power considering the presence of DG unit can be written as,

$$P_{Slack} + \sum_{i=1}^{N_{DG}} P_{DG} = \sum_{i=1}^{N_L} P_{D,i} + \sum_{i=1}^{N_{br}} P_{Loss,i} \quad (10)$$

Where  $P_{slack}, Q_{slack}$  are the active and reactive power at the slack bus, respectively,  $P_{D,i}, Q_{D,i}$  are the active and reactive power demands at bus  $i$ , respectively,  $P_{loss,i}, Q_{loss,i}$  are the active and reactive power loss at bus  $i$  respectively and,  $P_{DG,i}$  is the active power produced from DG unit at bus  $i$ .

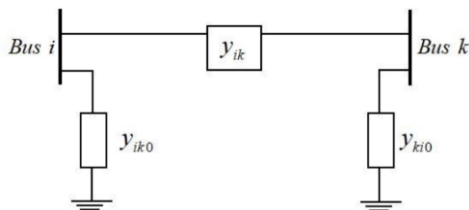


Figure 5. Diagram of power flow between two buses.

### Grey Wolf Optimizer

Many optimization methods have been developing in the last decade. Meanwhile, most of the popular techniques are nature-inspired methods that mimic the natural behavior of animals, physical phenomenon, as well as evolutionary concepts. Moreover, GWO is a novel meta-heuristic optimization technique that inspired the natural group hunting behavior of the leadership hierarchy of wolves (Mirjalili *et al.*, 2014). Grey Wolf naturally prefers to live in a group that consists of 5 to 12 on average. Furthermore, they have a strict social dominant hierarchy that consists of a leader and following subordinate wolves as illustrated in Figure 2. Alphas ( $\alpha$ ) are considered as a leader of pack. Also, they take responsibility to make any decision including where to sleep, time to hunt, time to wake up, and so on. They are not required to be strongest but they are the best in managing various tasks in the pack of wolves.

The second level of the hierarchy of the grey wolf called Betas ( $\beta$ ). They help alphas to make decision in any task. Besides, they advise and take the command from alpha to lower level wolves. Betas can also be substituted for alphas when one of alphas is absent due to oldness or death. The lowest class of the grey wolf is called omegas ( $\omega$ ). They must submit to all dominant wolves in the pack. Moreover, if the other wolves are not alphas, betas, or omegas called deltas ( $\delta$ ). They are the third level of the wolf pack and they submit to alphas and betas. But they dominate to omegas. Due to their interesting natural hunting behavior and social hierarchy, the mathematical formulation is modeled to form as GWO and perform an optimization method. The designed mathematical formulation of their hunting behavior by encircling the prey first and it can be illustrated by the mathematical expression as,

$$\vec{D} = |\vec{C} \cdot \vec{X}_p(t) - \vec{X}(t)| \quad (11)$$

$$\vec{X}(t+1) = \vec{X}_p(t) - \vec{A} \cdot \vec{D} \quad (12)$$

$$\vec{A} = 2\vec{a} \cdot \vec{r}_1 - \vec{a} \quad (13)$$

$$\vec{C} = 2 \cdot \vec{r}_2 \quad (14)$$

Where,  $t$  indicates the current iteration,  $\vec{A}$  and  $\vec{C}$  are the coefficient vectors,  $\vec{X}_p$  refers to position vector of the prey,  $\vec{X}$  is the position vector of a grey wolf,  $\vec{a}$  is linearly decreased from 2 to 0 over the course of iterations, and  $r_1, r_2$  are random vectors in  $[0,1]$ .

During the hunting period, three best solutions are obtained (alphas) and other search agents including omegas update their position based on their current position. As a result, the following expressions can be formulated as,

$$\vec{D}_\alpha = |\vec{C}_1 \cdot \vec{X}_\alpha(t) - \vec{X}(t)| \quad (15)$$

$$\vec{D}_\beta = |\vec{C}_2 \cdot \vec{X}_\beta(t) - \vec{X}(t)| \quad (16)$$

$$\vec{D}_\delta = |\vec{C}_3 \cdot \vec{X}_\delta(t) - \vec{X}(t)| \quad (17)$$

$$\vec{X}_1 = \vec{X}_\alpha(t) - \vec{A}_1 \cdot \vec{D}_\alpha \quad (18)$$

$$\vec{X}_2 = \vec{X}_\beta(t) - \vec{A}_2 \cdot \vec{D}_\beta \quad (19)$$

$$\vec{X}_3 = \vec{X}_\delta(t) - \vec{A}_3 \cdot \vec{D}_\delta \quad (20)$$

$$\vec{X}(t+1) = \frac{\vec{X}_1 + \vec{X}_2 + \vec{X}_3}{3} \quad (21)$$

Equation (15), (16), and (17) indicate the distance alphas, betas, and deltas with respect to omegas respectively. Consequently, Equation (18), (19), and (20) identify the current position of alphas, betas, and deltas respectively. Finally, Equation (21) updates the position based on the current position of best solution of alphas, betas, and deltas respectively.

### Proposed Algorithm Procedure

The application of GWO in this paper is to determine the optimal location and capacity of DG unit in radial distribution networks. GWO was integrated with Newton-Raphson power flow. The procedures of the proposed algorithm can be depicted as shown in the Figure 3.

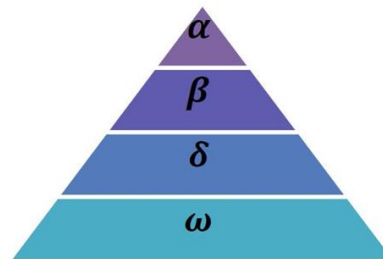


Figure 2. Hierarchy of grey wolf (dominance decreases from top-down).

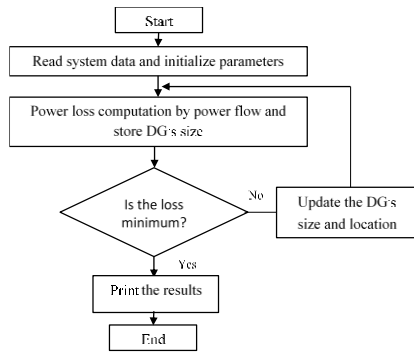


Figure 3. Flow chart of the proposed algorithm.

## Results and Discussion

To achieve the results and performances of the prepared program, all tested cases have been simulated by utilizing the personal computer which was in Intel®, core i5-6200U, 2.8GHz, RAM 8GB. Besides, the proposed algorithm was tested with the 33, and 69 bus of radial distribution systems. The objective function of the total real power loss and it was implemented using GWO, with 50 of the populations and 200 maximum iterations as shown in Table 1.

### 33 Bus Tested System

This system consists of 33 buses which bus 1 is the slack bus and others are load buses (Baran and Wu, 1989) as shown in Figure 4.

Loss saving with a capacity of installed DG when it was placed in each bus as illustrated in Figure 5. From the figure, it was observed that the highest loss saving could be achieved when placed DG at bus 6 with a capacity of 2.626MW with loss saving 102.88kW. It is followed by bus 25 which provides a power loss saving of 101kW with a capacity of 2.485MW. Moreover, it was also investigated that when DG was placed at the non-optimal location, it gave very less loss saving with high capacity of DG size. For instance, when DG was placed at bus 1, bus 2, bus 3, the sizes of DG were high with less loss saving.

Table 1. Algorithm parameter settings.

| Parameters        | Algorithms |     |     |     |
|-------------------|------------|-----|-----|-----|
|                   | GA         | ABC | PSO | GWO |
| Population        | 50         | 50  | 50  | 50  |
| Maximum iteration | 200        | 200 | 200 | 200 |

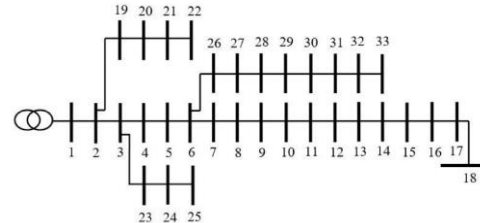


Figure 4. 33 buses radial distribution system.

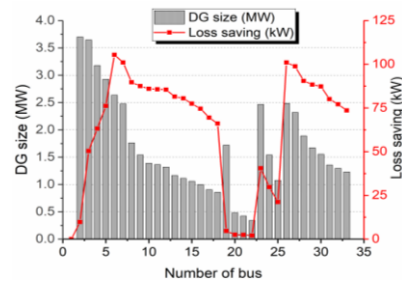


Figure 5. Loss saving and size of DG of 33 bus system.

Table 2 shows the simulation results of the four methods, and the obtained sizes of DG were 2.615MW, 2.625MW, 2.626MW, and 2.626MW of GA, ABC, PSO, and GWO respectively. It was noticed that obtained GA, ABC provided comparable loss with the amount of 103.68kW, 103.65kW respectively and PSO and GWO gave the same amount of 103.62kW. In term of computation (CPU) time, GWO spent less time to reach the solution with 60.20s while GA, ABC, and PSO spent 73.72s, 596.95s, and 829.90s respectively. PSO spent more time followed by ABC, and GA.

Before placing DG, the voltage profile was poor since most of the bus voltage was closed to the lower boundary of the specified range. Nonetheless,

Table 2. Simulation results of 33 bus system.

| Algorithms         | Without DG | With DG |        |        |        |
|--------------------|------------|---------|--------|--------|--------|
|                    |            | GA      | ABC    | PSO    | GWO    |
| Loss (kW)          | 206.50     | 103.68  | 103.65 | 103.62 | 103.62 |
| Location           | -          | 6       | 6      | 6      | 6      |
| Size(kW)           | -          | 2.615   | 2.625  | 2.626  | 2.626  |
| Loss saving (kW)   | -          | 102.82  | 102.85 | 102.88 | 102.88 |
| Loss reduction (%) | -          | 49.83   | 49.83  | 49.83  | 49.83  |
| CPU time(s)        | -          | 73.72   | 596.95 | 829.70 | 60.20  |

it was improved significantly after adjusting DG size to its optimum point as illustrated in Figure 6. Moreover, the convergence characteristic comparison of the four algorithm was illustrated in Figure 7. It proved that GWO could reach the solution with less CPU time.

The results of the proposed method were compared with other two methods as shown in Table 3. Murthy (2013) used voltage sensitivity index to determine the placement of DG and varied size of DG. The location of this method was bus 16 while Dinakara *et al.*, found that bus 15 was the most suitable location for DG installation. The sizes of DG of voltage sensitivity index of (Murthy, 2013), (Dinakara *et al.*, 2017) and the proposed method were 1MW, 1.060MW, and 2.626MW with

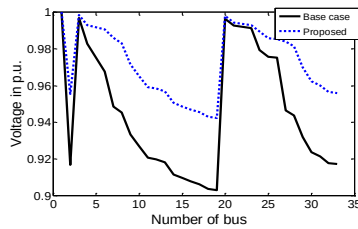


Figure 6. Voltage profile comparison of 33 bus system.

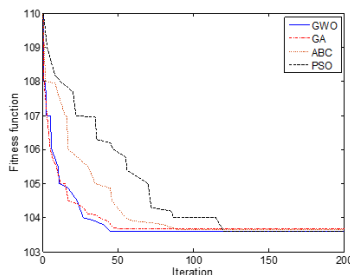


Figure 7. Convergence characteristic comparison of 33 bus system.

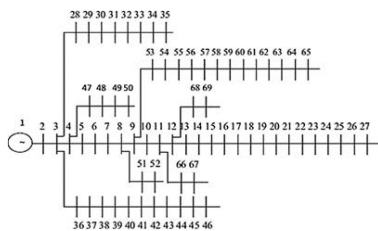


Figure 8. 69 buses radial distribution system.

the losses of 131.9kW, 129kW, and 103.62kW respectively. Hence, the proposed method provided better results when compared with those of the other two methods. From the result, it was shown that GWO gave the better solutions when compared to the two methods in term loss reduction.

### 69 Bus Tested System

This system consists of 69 buses which bus 1 is the slack bus and others are load buses (Baran and Wu, 1989) as shown in Figure 8.

Loss saving with a capacity of DG when it was placed in each bus as illustrated in Figure 9. From the figure, it was observed that the highest loss saving could be achieved when placed DG at bus 60 with a capacity of 1.889MW with loss saving 159.47kW followed by bus 59 which provides loss saving of 152.48kW with a capacity of 1.932MW. Moreover, it was also investigated that when DG was placed at the non-optimal location, it gave very less loss saving with a high capacity of DG size. For instance, when DG was placed at bus 1 to bus 10, the sizes of DG were high with less loss saving due to far distance of generation from the loads.

Table 4 shows the obtained results of the four methods, and the obtained sizes of DG were 1.878MW, 1.888MW, 1.882MW, and 1.889MW of GA, ABC, PSO, and GWO respectively. Also, the power loss obtained from GA, ABC, PSO, and GWO were 86.47kW, 86.43kW, 86.45kW, and 86.41kW. It was noticed that the obtained loss of DG from GWO was lower when compared with those of other three methods. The power losses and DG's sizes obtained from the GA, ABC, and PSO were comparable. Loss saving obtained from GWO was 159.47kW which was higher than those of GA, ABC, and PSO which were 159.41kW, 159.45kW,

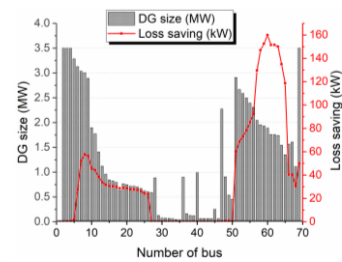


Figure 9. Loss saving and size of DG of 69 bus system.

Table 3. Comparison of the results of 33 bus system.

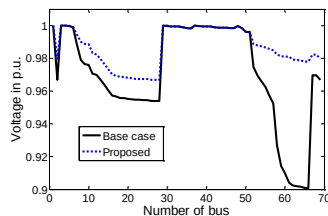
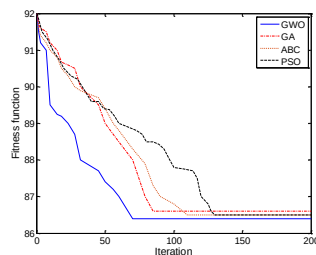
| Parameters  | Voltage sensitivity index (Murthy, 2013) | Dinakara <i>et al.</i> , (2017) | Proposed |
|-------------|------------------------------------------|---------------------------------|----------|
| Location    | 16                                       | 15                              | 6        |
| Size (MW)   | 1                                        | 1.060                           | 2.626    |
| Loss (kW)   | 131.9                                    | 129                             | 103.62   |
| Saving (kW) | 74.6                                     | 77.5                            | 102.88   |

**Table 4. Simulation results of 69 bus system.**

| Parameters         | Without DG | With DG |        |        |        |
|--------------------|------------|---------|--------|--------|--------|
|                    |            | GA      | ABC    | PSO    | GWO    |
| Loss(kW)           | 245.88     | 86.47   | 86.43  | 86.45  | 86.41  |
| Location           | -          | 60      | 60     | 60     | 60     |
| Size(kW)           | -          | 1.878   | 1.888  | 1.882  | 1.889  |
| Loss saving(kW)    | -          | 159.41  | 159.45 | 159.43 | 159.47 |
| Loss reduction (%) | -          | 64.86   | 64.86  | 64.86  | 65.04  |
| CPU time(s)        | -          | 485.23  | 2626.4 | 3251.7 | 442.34 |

**Table 5. Comparison of the result of 69 bus system.**

| Parameters  | Voltage sensitivity index (Murthy, 2013) | Dinakara <i>et al.</i> , (2017) | Proposed |
|-------------|------------------------------------------|---------------------------------|----------|
| Location    | 65                                       | 61                              | 60       |
| Size (MW)   | 1.352                                    | 1.760                           | 1.889    |
| Loss (kW)   | 127.2                                    | 94.5                            | 86.4     |
| Saving (kW) | 118.68                                   | 151.38                          | 159.48   |

**Figure 10. Voltage profile comparison of 69 bus system.****Figure 11. Convergence characteristic comparison of 69 bus system.**

and 159.43kW respectively. The better simulation results were achieved with GWO. For CPU time, GWO spent less time to reach the fitness results with 442.34s which is followed by 485.23s, 2626.4s, and 3251.7s of GA, ABC, and PSO respectively.

The voltage profile of before and after installing DG in the system was compared as shown in Figure 10. It was investigated that the voltage profile in the base case was poor because it was closed to the lower boundary of the specified range especially the buses which were located at the end of the system, but it was improved significantly after placing the DG at the optimal bus and size. The voltage of buses at the end of the system was dropped a bit before having DG, and it was improved significantly after installing DG. The convergence characteristic comparison of each

algorithm was shown in Figure 11 and it showed the better convergence curve obtained from GWO followed by GA, ABC, and PSO.

When comparing with the two methods of voltage sensitivity index of (Murthy, 2013) and (Dinakara *et al.*, 2017), it was observed that the proposed method gave the better results as shown in Table 5 because the loss saving obtained from the proposed method was higher than those of the other two methods. Dinakara *et al.*, found that bus 61 was the suitable location while Murthy found that bus 65 was the location for DG installation with capacity of 1.760MW and 1.352MW respectively. From the proposed method, it was found that bus 60 was the optimal location for DG placement with a size of 1.889MW. As a result, the loss obtained from the proposed method was lower.

## Conclusions

GWO which is a recent nature-inspired algorithm was used to determine the optimal location and size of the DG unit in radial distribution networks. A single type of DG that generate only real power was carried out and the proposed method was tested on two well-known systems of 33 and 69 bus systems to show the accuracy and effectiveness. The four algorithms including GA, ABC, PSO, and GWO were applied to solve the assigned problem for comparative purposes. The better results of loss minimization and computation time were achieved with the proposed method when compared with those of GA, ABC, and PSO. It was conveyed that GWO has superior exploration and exploitation characteristics than other swarm intelligence techniques for solving various engineering optimization problems. Furthermore, this research shows the applying a recent meta-heuristic optimization technic for solving the optimal

placement and sizing of DG in 33 and 69 radial distributions. Moreover, this study proved the positive impacts of DG presence in the distribution for power loss reduction and voltage profile improvement, and it conveyed the effectiveness and good performance of the proposed method in solving DG application optimization in radial distribution systems.

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