

PAPER • OPEN ACCESS

## The Balancing of Secondary Distribution Feeders by Two Techniques GWO and PSO Applied in Baghdad, Comparative Study

To cite this article: Ibrahim H Al-Kharsan *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **745** 012011

View the [article online](#) for updates and enhancements.

# The Balancing of Secondary Distribution Feeders by Two Techniques GWO and PSO Applied in Baghdad, Comparative Study

Ibrahim H Al-Kharsan<sup>1\*</sup>, Ali F Marhoon<sup>2</sup> and Jawad R Mahmood<sup>3</sup>

<sup>1-3</sup>Electrical Eng. Department, University of Basrah, Basrah, Iraq.

\* Computer Technical Eng. Department, College of Technical Eng., The Islamic University, Najaf, Iraq.

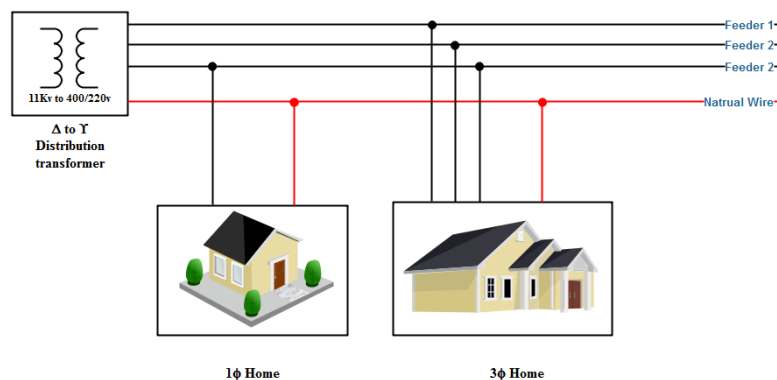
**Abstract.** The distribution network considered the more complex portion of the electrical power system as there is much machinery, and many loads are fed. The load diversity and variety that connected to the distribution networks caused severe problems like load unbalancing, sag, and voltage swell that can violate the system stability. The load balancing in the secondary low voltage distribution networks was regarded as one of the ongoing and stubborn issues studied in this article. In this article, a GWO meta-heuristic algorithm, which used for the first time to solve the imbalance on the secondary transformers, and the outcomes of the GWO compared to the PSO algorithm. The results proved it could resolve the balancing problem based on real data collected from the smart meters installed in two regions in Baghdad. Load balancing accomplished when the same current flows through the three-phase conductors that supplied a particular region in the distribution network. Current equality has a strong effect on the distribution network, ranging from reducing the losses to transformer safety. The phase swapping appeared as a direct and straightforward way of achieving load balance. The results showed that in obtaining balance with a lower number of swaps, the GWO algorithm was better. If solar renewable energy sources penetrated the distribution network, the algorithms could achieve an accepted balancing without requiring any swaps in the home phases.

## 1. Introduction

The unbalancing in the feeders of the secondary distribution networks can be regarded as a stubborn problem besides all the problems mentioned earlier. In Iraq, the secondary network is four wires represent three phases that come after the distribution transformers [1]. The unbalancing in the feeders of the secondary distribution networks can be regarded as a stubborn problem besides all the problems mentioned earlier. In Iraq, the secondary network is four wires represent three phases that come after the distribution transformers. In this paper, the unbalancing studied in the four wires that come after the 11Kv to 400v/220v step-down transformers that called (feeders), as shown in Figure1. The loads connected to the secondary network may be a residential, commercial, or industrial load. From another viewpoint, the loads can be divided according to the number of wires connected to the secondary feeders as a single or three-phase load [2] (refer to Figure 1). Single-phase loads in the LV network have non-constant nature because of a large number of single-phase loads plugged in or out in the homes of consumers. The inequality of the loading on the feeders causes unbalancing in the three wires. The balancing satisfied when identical currents are flowing in the feeders, or the phase angle between each two of them equals  $120^\circ$ , or both of them met [3]. The first mentally thinking to solve



this problem pointing to make the loads in each of the feeders equal in magnitude, and that makes the current of them approximately have near the average value. The load balancing satisfied by redistributing the loads connected to the feeders and transferring some of them from the heavy loaded feeder to the lighter one in a smart way, and this technique called by the phase swapping for load balancing. That means every load movement to a new position represents a new scheme that may let the feeder in balance case. The optimal transferring may be any one among thousands or millions of possibilities in the domain of the problem. The manual searching for the optimal scheme is not intellectual and time-consuming. There is a chance the network back to the balancing state due to switching off some loads in the consumer's homes, and that led to a worse situation. A fast mechanism to handle this problem and give the optimally balanced movement in a short time must be available.



**Figure 1.** The secondary LV distribution networks.

The unbalancing issue has terrible consequences on the network if the suitable solution not achieved in time like:

1. The current of neutral line not equal to zero, and that lead to random tripping of protective relays [4] and [5].
2. The losses will increase, and the equipment of the distribution network will be overloaded [6].
3. The sensitive loads in the system will be affected and may damage or not operated well and reduced the security of the feeders according to the maintenance teams [7].

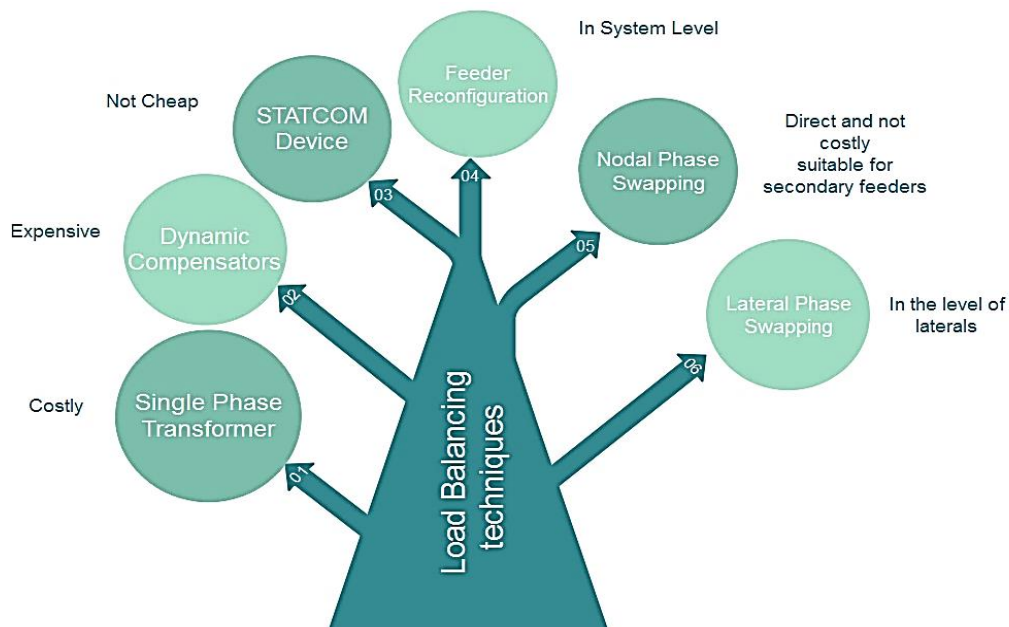
Besides the swapping technique, there are many solutions to achieve the load balancing like using a single-phase transformers [8], using the dynamic compensators [9], or using the power electronic devices like the STATCOM [10]. The options can participate in the balancing of the LV distribution network, but the problem here is costly tools. The feeder reconfiguration and phase swapping regarded as alternative and equivalent solutions with low cost [11]. Reconfiguration approach creates a changing in network topology depending on the open/close switches that lie in the system-level of the network. The reconfiguration used to mitigate the overload in the main transformers and feeders by using the tie and sectionalizing switches available in the network. It may fail to reach balancing because there are few numbers of those switches [12]. For this reason, it is not used in secondary distribution networks because there are no such switches, and for this purpose, relaying in this paper on the phase swapping technique to maintain the balance in the secondary LV distribution system. The **phase swapping** means swapping a part or all the home's phases and reconnect it again to specific feeders according to the decision of the intelligent algorithm chooses the optimal arrangement that ensures equal load distribution among the three feeders [13]. The algorithm needs the advanced metering infrastructure (AMI) for balance realization because it is a smart meter installed in the consumer's homes to read voltage, current, active power, reactive power, and the power factor. The AMI has two ways communication [14] so it can send the data measured and recorded to any analysis and control center (ACC) through the wire or the wireless facilities and receiving the signals from the ACC like the electricity prices or the control signal that command the contactors to take the specific swapping model for balancing. In Baghdad, Al-Rasikh company for trading and commercial agencies, LTD started installing the AMI in two sectors. It set up 50 meters in AL-Qahera and 35 meters in Zaiyna, as shown in Figure 2. In this paper, we assume this smart meter has a swap mechanism with

12 contactors to swap the three-phase of the home and the online photovoltaics (PVs) installed in consumer property on the three feeders.



**Figure 2.** The smart meter installed in two sectors in Baghdad.

The method of phase swapping was seen as a straightforward and low-cost solution to the load balance [15]. There are two kinds of phase swapping: lateral and nodal phase swapping, as illustrated in Figure 3. In this paper, the nodal phase swapping technique used by considering the phases of all the homes as nodes. The algorithm is looking for the optimal arrangement of all these nodes that balanced the feeders.



**Figure 3.** The load balancing methods and their specifications

The load balancing problem does not have an optimal solution, but many reasonable sub-optimal solutions can be adequate to let the feeders in a sharp balancing situation. The searching for those solutions is the role of the artificial intelligent (AI) algorithms. The algorithm chooses the perfect solution that the new arrangement for the home phases and translated to a signal sent to all the smart

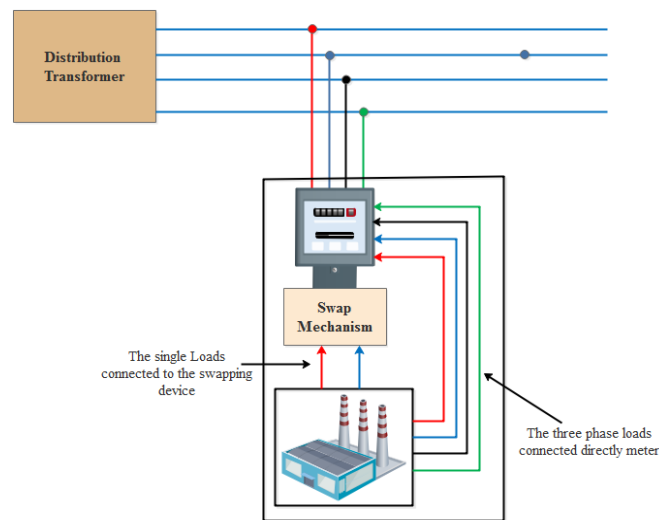
meters in homes to swap their phases positions according to the received signal, and the resultant is balanced feeders. All the algorithms may succeed in solving the balancing problems, but each one competed with others by the speed to find the solution, the code complexity, the number of swapped phases to reach balancing, and the optimality of the solution. In [13], the balancing problem solved by using the Tabu search (TS) algorithm in four phases swapped only. In [16], the authors proposed that an algorithm can decrease the unbalancing by 5.26% compared with the balancing of the LINDO program. In [17], the simulated annealing (SA) algorithm is used for balancing purposes. The SA achieved a good sub-optimal result, and they are an opportunity to miss the optimal solution and consume more time, but at the same time, SA can avoid any local minimum, and the results are better than the result of Greedy or the Quenching algorithms. Jinxiang et al. not considered the voltage drops, and that converted the nonlinear balancing to a linear issue, and that allowed him to apply the used mixed-integer programming and solve the balancing problem [18]. In [19], the genetic algorithm (GA) used to achieve the load balancing in a secondary distribution network. Gandomkar also used the GA to make a distribution network with 135 laterals - Laterals are segments branching off the primary feeder, representing the final primary voltage portion of the power travel from the substation to the customer- in balancing case. From an optimization view, this is a difficult problem because of the vast searching space for this problem [20]. The fuzzy logic technique used in the article [21] for phase balancing of the distribution feeders, and it succeeds in solving the problem to a large extent. In this article, the balancing matter will solve first by two AI algorithms i.e., grey wolf optimization (GWO) and particle swarm optimization with Matlab 2018b simulation and random data generated to test their performance. The PSO already is there, and there are many papers used it to solve a similar problem [7], [22], [23], [24] and [25]. The GWO algorithm [26] is new in this field, and it proves itself by satisfying very competitive results with a fewer number of swaps. The models of algorithms modified to be a multi-objective function MOGWO and MOPSO to take the number of exchanges in the consideration during the balancing process. The proposed models of the algorithms modified for the second time so it can distribute all the PVs installed in homes on the feeders without causing any balancing problem.

## 2. The Problem Description

The problem of load balancing is one of the more complicated issues due to a large number of solutions available in the search space. The search space of the balancing problem can compute as  $(3^L)$  where L is the number of phases of all the homes that balancing must be done for. The phases of homes and the PV can be regarded as nodes, and the duty of the algorithms is finding the optimal connection to the three feeders in a way that guarantees the current in all of it have a symmetrical magnitude. The balancing issue regarded as one of the *NP-complete* (non-deterministic polynomial time complete) that have a nonlinear nature [27]. These problems may have an excellent suboptimal solution, and there is no optimal solution. The solution domain can be increased dramatically with the increase in the number of nodes. The GWO and PSO trying to solve the balancing problem (phase unbalance index (PUI%)  $\leq$  the threshold).

The balancing problem solved under the following assumptions:

- All the loads connected to the home phases are a single-phase load.
- The three-phase loads are balanced in nature [28], [29], [30] and [31] so it can connected directly to the feeders before the swap controller as shown in Figure 4.



**Figure 4.** The connection of single and three phases to the electricity meter.

- All the home phases have the same power factor for the mathematical simplification (that allows us to use the algebraic instead of vector addition when need to find the total current consumed from the specific feeder). This assumption is famous specially in the residential areas [32],[18],[27],[33],[34].
- The electro motors of the compressors of the single-phase air conditioners have the inverter technology [35],[36],[37]. The inverter engineering can minimize the harmful effect of switching on and off as a result of the swapping phase that the system suffers.
- The voltage drops are neglected.
- The single-phase loads can connect to one feeder in each swap process.

In brief, the main objective of the study was:

- Comparing between two modified intelligent algorithms GWO and PSO, for satisfying the current balancing in the secondary feeders that comes after the 11Kv to 400/220v distribution transformers in Iraq (refer to Figure 1).

### 2.1 Objective Function

The objective function (OF) represents the importance of each individual in the searching process for finding the optimal individual that satisfied the demanding objective considerably throughout the iterations. The objective function sometimes called by the fitness function [38], cost function [39] and [40]. In this paper, the two algorithms investigating the individuals that satisfied in the first scenario one objective function (PUI%) and the GWO and PSO modified to attain two objective functions (PUI% and SF%) in standard time in a second scenario. Both of the optimization algorithms in this paper solving a problem with minimizations OFs. The feeders will be in a perfect balancing situation if the algorithm reaches the threshold of PUI and that with a minimum number of swaps if the SF% was minimum.

#### 2.1.1 Phase Unbalance Index

The phase unbalance index is a factor that explains the voltage or the current imbalance in the distribution feeders. PUI% define as the ratio of the negative sequence to the positive sequence components of the voltage or the current. The current PUI% is the same as the voltage merely the difference is the using of current's positive and negative components rather than the corresponding components of the voltage in the equation (1). PUI% of the current computed according to the IEEE Std. 936 (1987) that care by the magnitude of the unbalanced current and ignore the phase angle between the current of the feeders (the equations (2) – (4)). The accepted ratio of the unbalancing is

10% because if it increased more than that, the temperature of the windings of the transformers would grow up; therefore, the losses will increase, and in that case, the life span of the transformers will be less [41]. Mathematically:

$$\text{PUI} = \frac{\text{The Negative components of current}}{\text{The Positive component of current}} \times 100\% \quad (1)$$

$$\text{PUI}\% = \frac{\text{maximum deviation from the average currents of feeders}}{\text{average}} \times 100\% \quad (2)$$

$$\text{PUI}\% = \frac{\max(|I_{Feeder1} - I_{mean}|, |I_{Feeder2} - I_{mean}|, |I_{Feeder3} - I_{mean}|)}{I_{mean}} \times 100\% \quad (3)$$

$$I_{mean} = \frac{(I_{Feeder1} + I_{Feeder2} + I_{Feeder3})}{3} \quad (4)$$

Here,  $I_{Feeder1}$ ,  $I_{Feeder2}$  and  $I_{Feeder3}$  is the magnitude of feeder currents.  $I_{mean}$  is the average value of the three feeder currents.

### 2.1.2 Swap Factor Index

The swapping number is a vital matter, and the algorithm must take care of it because it hurts the consumer's devices. Generally, the swapping harms the electrical loads because it switched off and then reconnect it again to another feeder, and that may damage (the lights) or shorting the life span (the motors) loads. The harmful effects as an example on the motor are a direct result for the overcoming on the moment of inertia in the starting operation point. Each time the motor drawing a large amount of current (inrush current), and that may damage the conductors or insulators by the overcurrent happen in the transient period. Besides the possibility of motor damage, the in-rush current imposes increasing in the electrical bills due to the large inrush current. The swaps factor (SF%) define as the ratio between the total number of phases swapped between the initial and final distribution network configuration to the total number of homes phases. Mathematically see the equation (5) and (6),

$$\text{SF}\% = \frac{\text{The total number of phases swapped}}{\text{The total number of phases}} \times 100\% \quad (5)$$

$$\text{SF}\% = \frac{S_{\text{Swithes}}}{T_{\text{Swithes}}} \times 100\% \quad (6)$$

Where the  $S_{\text{Swithes}}$  represent the total phases that swapped from feeder to another feeder.  $T_{\text{Swithes}}$  is the overall number of the home phases.

## 3. Algorithms

The GWO in 2014 [26] and PSO in 1995 [42] regarded as a metaheuristic algorithm that deals with the complex nonlinear problems that have a broad search space area. It is entered all the engineering fields to solve an optimization engineering problem. In this paper, the two algorithms utilized for balancing the secondary feeders. The main reason to choose the GWO algorithm is the novelty because there is no paper solved the phase swapping load balancing by the GWO. To test the performance of GWO, the results has been compared with a famous and rigid algorithm work in the same field and solved the same problem. PSO frequently used in the domain of solving load balancing problems like in [7], [22]–[25] as an example.

Both of them have the following standard features:

- Does not requires derivatives and that make it stable.
- Simpler to understand and implement.
- Fewer parameter to adjust.
- Lower computational complexity.
- Able to run parallel computation
- Useful to solve the problem that not have a mathematical model.

### 3.1 GWO Algorithm

Mirjalili, in 2014, introduced the grey wolf optimization paper that succeeds in the solution of 29 complex mathematical problems in addition to three classical engineering problems with constraints. GWO algorithm finds the fittest solution inspired by the grey wolves when hunting prey (the fittest solution). There are three main steps in GWO algorithm:

1. Pursuit, oncoming and become closer and closer to the prey.
2. Follow up, surrounding, and teasing the prey until it stops.
3. Entrapping the prey.

For more knowledge about the GWO inspiration and the three steps above see the papers [26], [43]. The GWO model in summarized way can be discussed as a separate section included the following:

- The Grey wolves Social Hierarchy.
- Encircling the prey.
- Hunting the prey.
- Attacking the prey.
- Searching the prey.

#### 3.1.1 The Grey wolves Social Hierarchy

The wolves in the GWO algorithm can be divided into four parts from the viewpoint of the leadership. The leader of the pack called alpha ( $\alpha$ ), the leader advisors called Beta ( $\beta$ ) and Delta ( $\delta$ ), and the ordinary wolves named Omega ( $\omega$ ).

#### 3.1.2 Encircling

The wolves surrounded the prey during the hunting, and that can be represented mathematically by the equations (7) and (8).

$$\vec{O} = |\vec{K} \cdot \vec{R}_p(x) - \vec{R}(x)| \quad (7)$$

$$\vec{R}(x+1) = \vec{R}(t) - \vec{B} \vec{O} \quad (8)$$

Where the (x) represents the current iteration,  $\vec{O}$  represent the updated position vector of the wolves,  $\vec{R}$  is a vector indicated to the grey wolf position,  $\vec{B}$  and  $\vec{K}$  are vectors of the coefficients.  $\vec{R}_p$  is a position vector of the prey. The  $\vec{B}$  and  $\vec{K}$  vectors compute from the equations (9) and (10)

$$\vec{B} = 2a \cdot \vec{r}_1 - \vec{a} \quad (9)$$

$$\vec{K} = 2 \cdot \vec{r}_2 \quad (10)$$

Where  $\vec{a}$  decreased linearly from 2 to 0 during the iterations and the  $r_1$  and  $r_2$  are vectors with a random value between 0 and 1.

#### 3.1.3 Hunting

In the real world, grey wolves can determine the location of prey and surrounded it. In the mathematical domain, we do not know about the prey location. To find the prey, we assume that the site of alpha (the best solution), Beta, and Delta is the nearest to the prey location, so depending on the alpha place in search agents and forced all the other solutions to update their position according to it. The hunting can represent mathematically by equations (11) to (17).



$$\vec{O}_\alpha = |\vec{K}_1 \cdot \vec{R}_\alpha - \vec{R}| \quad (11)$$

$$\vec{O}_\beta = |\vec{K}_2 \cdot \vec{R}_\beta - \vec{R}| \quad (12)$$

$$\vec{O}_\delta = |\vec{K}_3 \cdot \vec{R}_\delta - \vec{R}| \quad (13)$$

$$\vec{R}_1 = \vec{R}_\alpha - \vec{B}_1 \cdot (\vec{O}_\alpha) \quad (14)$$

$$\vec{R}_2 = \vec{R}_\beta - \vec{B}_2 \cdot (\vec{O}_\beta) \quad (15)$$

$$\vec{R}_3 = \vec{R}_\delta - \vec{B}_3 \cdot (\vec{O}_\delta) \quad (16)$$

$$\vec{R}(t+1) = \frac{\vec{R}_1 + \vec{R}_2 + \vec{R}_3}{3} \quad (17)$$

According to these equations, positions of the ordinary wolves will be in random place around the circle of alpha eventually.

#### 3.1.4 Attacking (exploitation)

The last part in the hunting of the prey after encircling it and force it to stop is attacking. The closing toward the prey is represented mathematically by reducing the  $\vec{a}$  value. The decreasing of  $\vec{a}$  will lead to make  $\vec{B}$  have a lower value whereas  $\vec{B}$  initially have a value in  $[-a, a]$  range that shrinkage in the course of iterations. Finally, when  $|\vec{B}| < 1$  the wolves directed toward the prey.

#### 3.1.5 Searching (exploration)

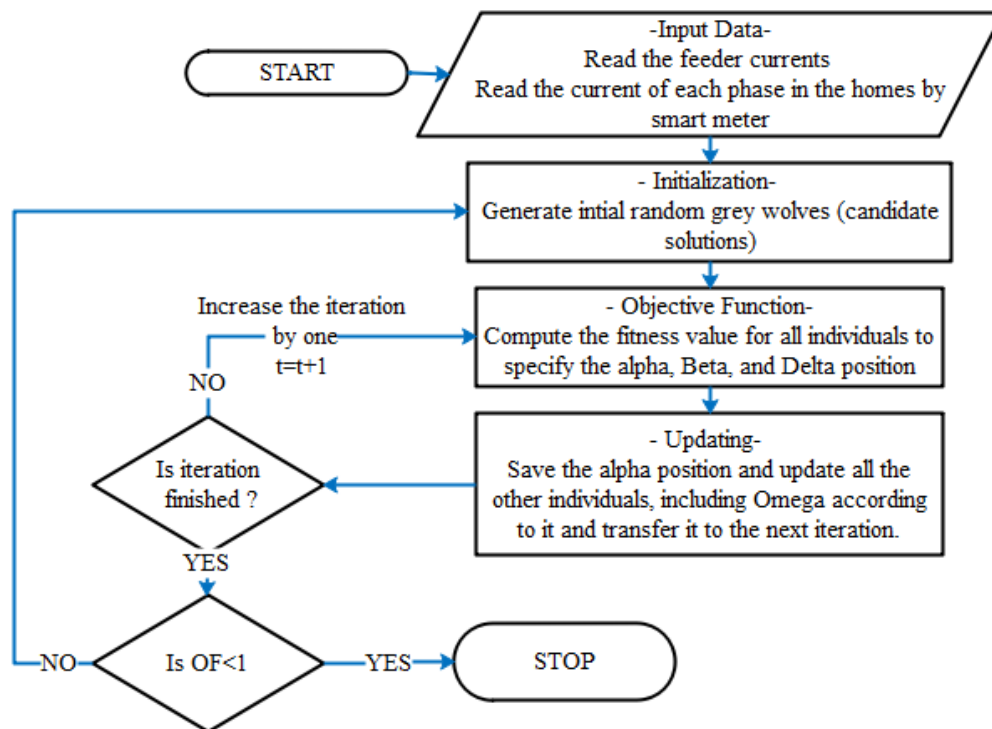
In nature, wolves prevail in the hunting area and accumulate around the target when allocating their location. This behavior can be translate mathematically depending on two parameters  $\vec{B}$  and  $\vec{K}$ . The value of  $\vec{B}$  enables the algorithm to search for the optimum solution depending on the following cases:

- When the values of  $\vec{B}$  less than -1 the algorithm bounded the search agents to converge toward the prey.
- When the values of  $\vec{B}$  greater that 1 the search agent diverge from the prey in the hope of finding better one.

From another side,  $\vec{K}$  vector creates to simulate all that setbacks and obstacles that may confront the wolves and prevent it from hunting in nature. From the optimization view of point, this vector can ensure that the algorithm falls down in the local minima. The  $\vec{K}$  is a random vector that lies in the range  $[2, 0]$ . It changed during the iterations to satisfied the randomness in all the iteration course.

#### 3.1.6 The flow chart

The flowchart of the GWO algorithm explains in outline way the steps to reach the prey (the optimum solution) as shown in Figure 5.



**Figure 5.** The flowchart of GWO algorithm

### 3.2 PSO Algorithm

The particle swarm optimization (PSO) meta-heuristic algorithm is one of many algorithms based on swarm intelligence (SI). SI is a property of the systems that its individuals tend to show an intelligent collective behavior to reach a higher intellectual level more than the smart of any individual in the swarm [44]. The PSO imitate the social or cooperative action of the animals that are living in swarms, fish, or flocks. The search agents in GWO called by the grey wolves, and in PSO, it is called by the particles. As the grey wolves searching the search space to finding the prey, the particles searching to find the food place (the optimal solution). The particles obey three fundamental principles, named as continuity, remembrance, and communicating. The first precept compels the particle to take the same direction that previously travels in. The second precept gives the ability to the particles to return to the best point found during particle moving. The third factor represents the particle ability to information exchange with all the other particles, and that helps the particle to be close to the global best point found by the swarm [15].

#### 3.2.1 The Mathematical Model

In the first iteration, a group of random solutions initialized by the algorithm, and it called by particles. Throughout all the iterations, every particle moves according to three precepts (continuity, remembrance, and communicating) [45]. The particles are exploring the search space to looking for optimal solutions. The position and velocity of each particle toward the possible solution can be denoted as  $K_n^m$  and  $S_n^m$  for the particle ( $m$ ) in the iteration ( $n$ ). The particles keep in its memory the best position it reached until the current iteration that called by  $X_m$ , and by communicating with others, it can know the best location that all the swarm located in the past traveling  $X^g$ . The velocity of particle  $m$  at the next iteration ( $n+1$ ) can be symbolized as  $S_{n+1}^m$  and represented mathematically by equation (18).

$$\overrightarrow{S}_{n+1}^m = o \overrightarrow{S}_n^m + Z_1 \cdot \text{Rand}_1 (\overrightarrow{X}^m - \overrightarrow{P}_n^m) + Z_2 \cdot \text{Rand}_2 (\overrightarrow{X}^g - \overrightarrow{P}_n^m) \quad (18)$$

Where:

- $\text{Rand}_1$  and  $\text{Rand}_2$  are any random function generate numbers in the interval  $[0,1]$
- $o$  is the inertial weight factor.
- $Z_1$  and  $Z_2$  are the learning factors.

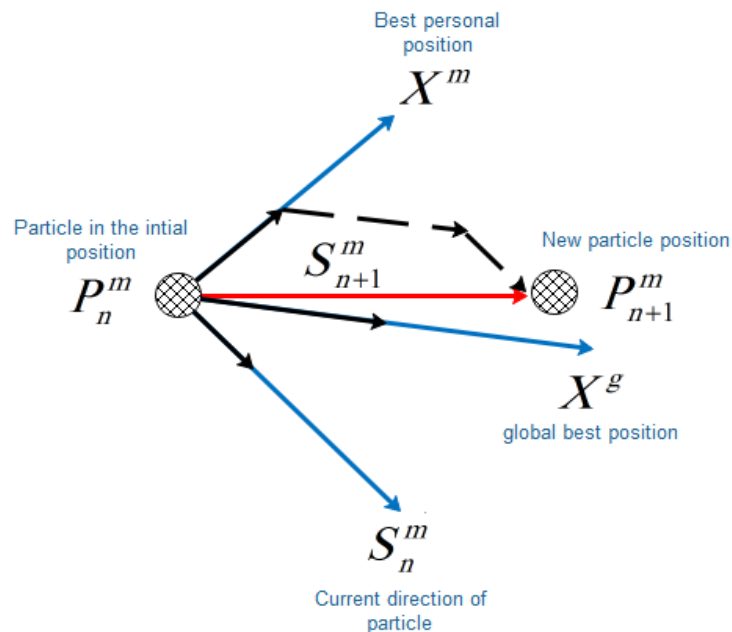
The ( $o$ ) factor decreased linearly in the period  $[0.9 \ 0.4]$  [7] and the  $Z_1$  and  $Z_2 = 2$  [15]. The inertia factor can compute by the equation (19).

$$o = o_{\max} - \frac{o_{\max} - o_{\min}}{n_{\max}} \times n \quad (19)$$

Where  $n_{\max}$  is the number of the maximum iteration, and  $n$  is the iteration under the processing. When the iteration finished, the new particle position computed by adding the new speed to the last position as in equation (20).

$$P_{n+1}^m = P_n^m + S_{n+1}^m \quad (20)$$

The Figure 6 shown the movement of the particle to a new position as the resultant of three-movement toward the best particle position, global best position and current direction that represent the new velocity.



**Figure 6.** The PSO particle movement in 2-dimensions search space.

The flowchart for PSO to achieve load balancing is shown in Figure 7. The flow chart consists of six stages, starting by importing the data from the smart meters till finding the optimal solution that satisfies the load balancing for secondary distribution transformer.

### 3.3 Swapping Model

The swapping process is done by using an automatic electric switch (AES) that can shift the phases from their original connection to different connections according to a control signal from the ACC unit

that installed with the secondary transformer for achieving the balancing in the secondary feeders. There are many types of AES in the markets nowadays; as a sample, an AES with 25A rate produces by IndoAsian Indian company appears in Figure 8.



Figure 7. AC AES 25A, 48v with 3 poles produced by  Company

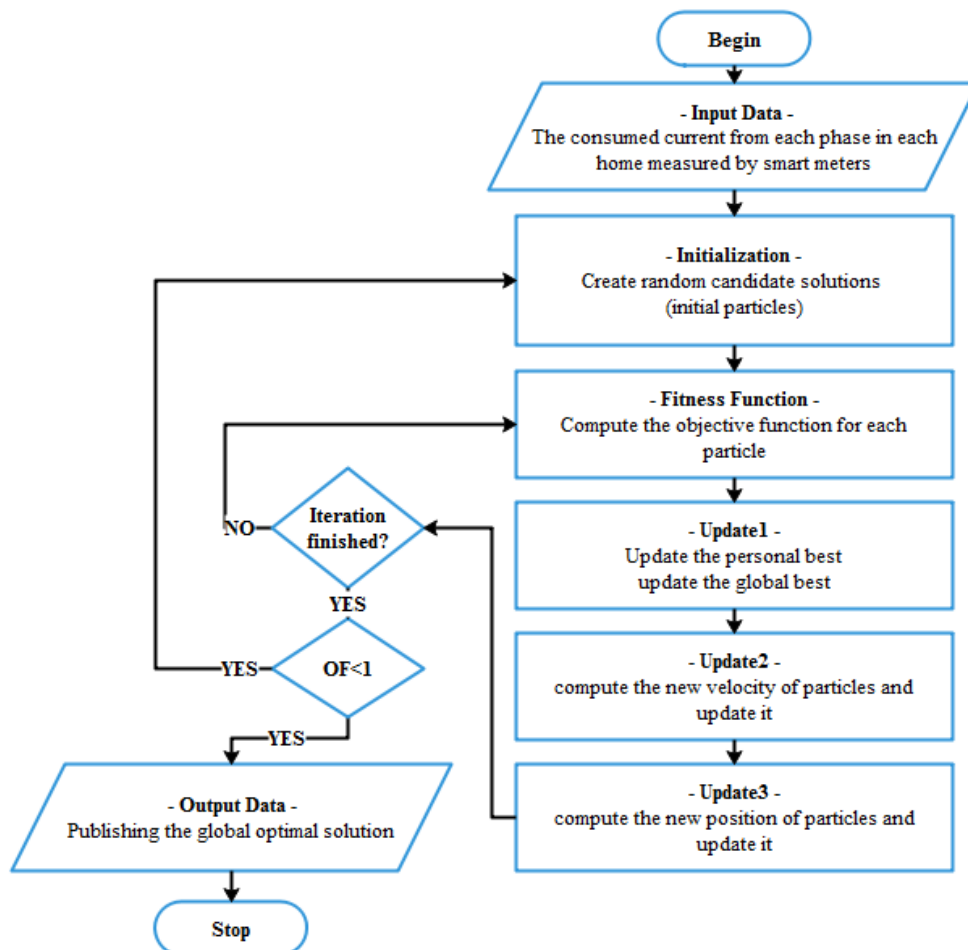
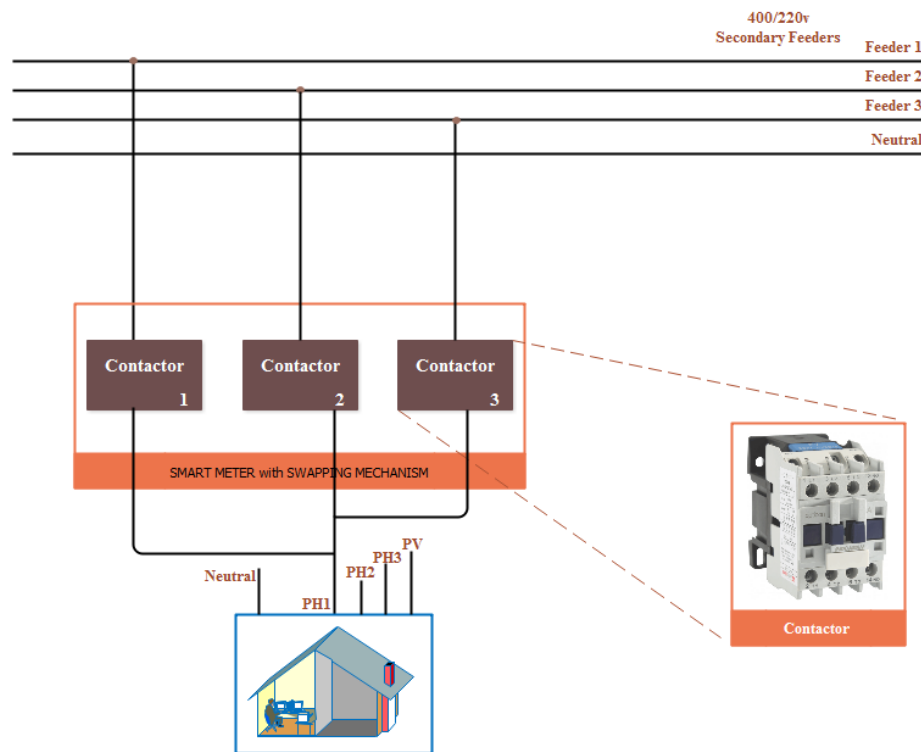


Figure 8. The flowchart of PSO algorithm.

It can be considered as AES carries through it a high current. The real smart meter illustrated in Figure 2 proposed in this paper to perform the phase swapping process by using nine AES that gives the smart meters the ability to disconnect the targeted phases in specific homes based on the signal coming from the algorithm and reconnect it to the appropriate feeder to perform the balancing task. The smart

meter also has three other AES to make the online PV connected to any secondary feeder in case the home has a non-traditional source of energy like the PVs, as shown in Figure 9.



**Figure 9.** A smart home has a smart meter with a swapping mechanism. The other two phases (PH2 and PH3) and PV connected to the feeders correspondingly as PH1 with three contactors for each one.

According to the first assumption in the problem described earlier mentioned, the swapping process will be done for the phases loaded with single-phase loads. The three-phase loads outside the swapping system and connected directly to the electricity meter before the meter. Depending on the assumption number 5, we can write the equation (21):

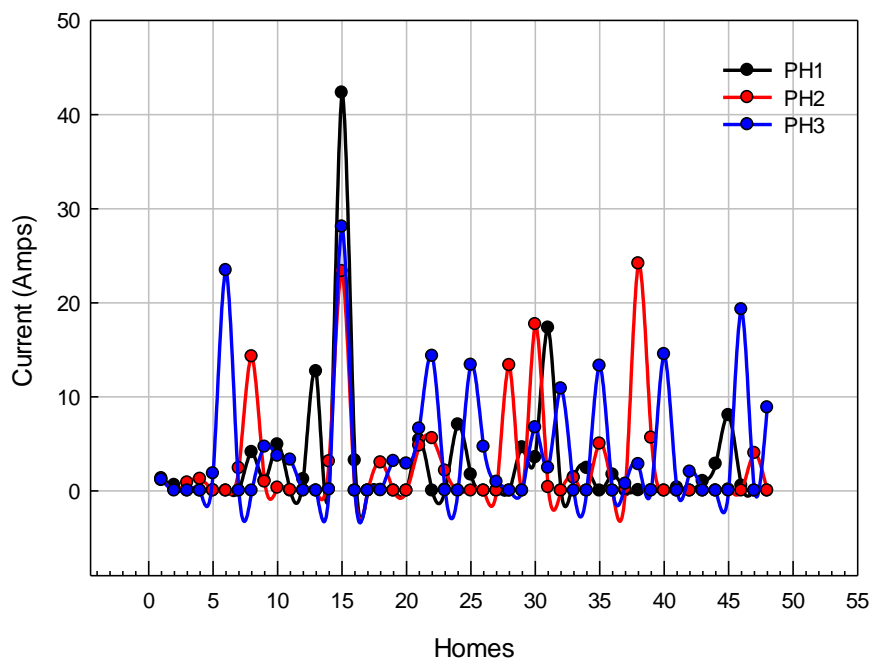
$$\sum_{i=1}^3 C_i = 1 \quad (21)$$

Where C represents the AES that connected one node to a specific feeder in each swapping scheme

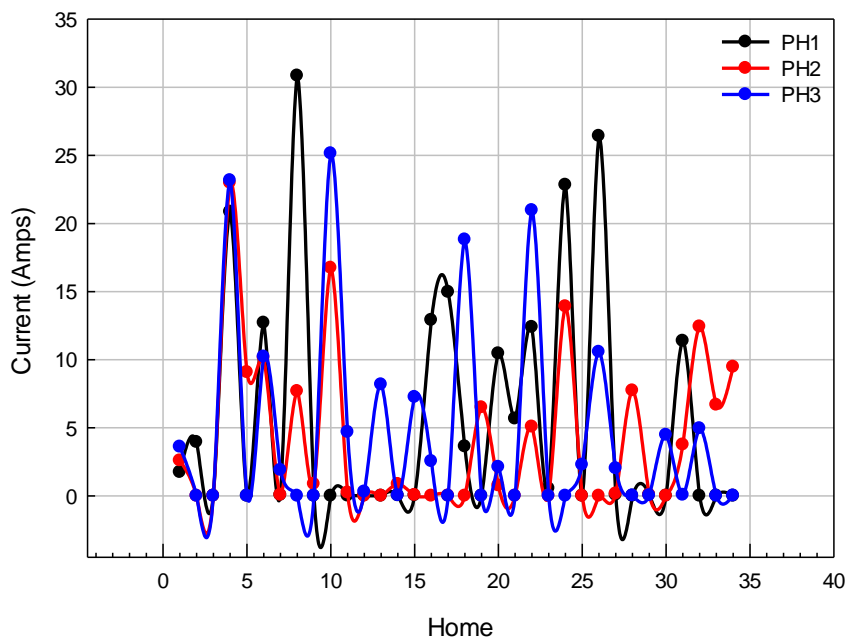
#### 4. Result and Discussion

The real data collected from the meters in AL-Qahera and Al- Zaiyna applied in the algorithms to get balancing in the two sectors. Figures 10 and 11 illustrated real currents data recorded by Al-Rasikh Company based on the smart meters, and it represents a snapshot of the currents consumed by each phase in all the homes in the two sectors on a specific day in summer of 2019. The current consumed in the two sectors not symmetrical, and that causes unbalancing in the secondary feeders. The GWO algorithm used 100 search agents in each one of 50 iterations to satisfy the feeder balancing -case 1- and modified two times to succeed in solving the case 2 and case3. The GWO algorithm solved the following issues efficiently:

- Achieve the balancing only for the three-secondary feeders (Case1)
- Achieve the balancing but with a minimum number of swapping (Case2).
- Achieve the balancing with a minimum number of swapping with even distribution of PVs on the feeders (Case3).



**Figure 10.** The three-phase consumed current for 48 homes in the Baghdad AL-Qahera sector.



**Figure 11.** The three-phase consumed current for 34 homes in Baghdad Al-Zaiyna sector.

There are two essential factors the reader must know it before looking to the results:

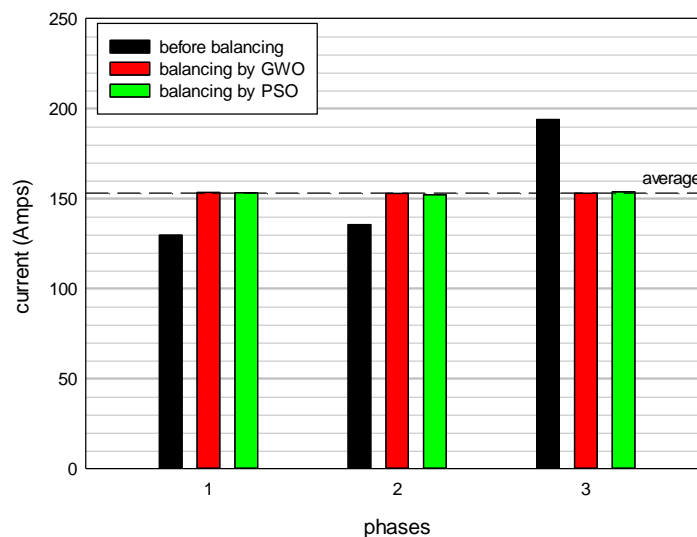
1. The result obtained by MATLAB 2018b simulation environment.
2. The laptop specification is Intel® Mobile Core™ 2 Duo CPU T6400 @ 2.00GHz, and the time consumed was according to these specifications.
3. The balancing case regarded actualized when the value of the objective function is less than 10 percent. The balancing would be better if the number as small as possible below that.

#### 4.1 Achieve the feeder balancing (Case 1)

In this section, the GWO and PSO algorithms adapted to work in the field of electrical power engineering and reach to solving the balancing issue efficiently without caring for the number of swaps. The result for this case can be divided into:

##### 4.1.1 The secondary transformer with 48 homes (AL-Qahera)

In the first case, the two algorithms trying to return the balancing for the imbalance feeders without caring for the swapping number. The current consumption before applying the algorithm is apparent as black vertical bars in Figure 12. After applying the GWO, the current in the secondary feeders reaches to the balancing situation (red vertical bar for GWO and PSO as a green vertical bar). The current consumed in this case was nearly equal to the average, and that mitigates the adverse effects of the unbalancing on the transformer and the secondary lines.



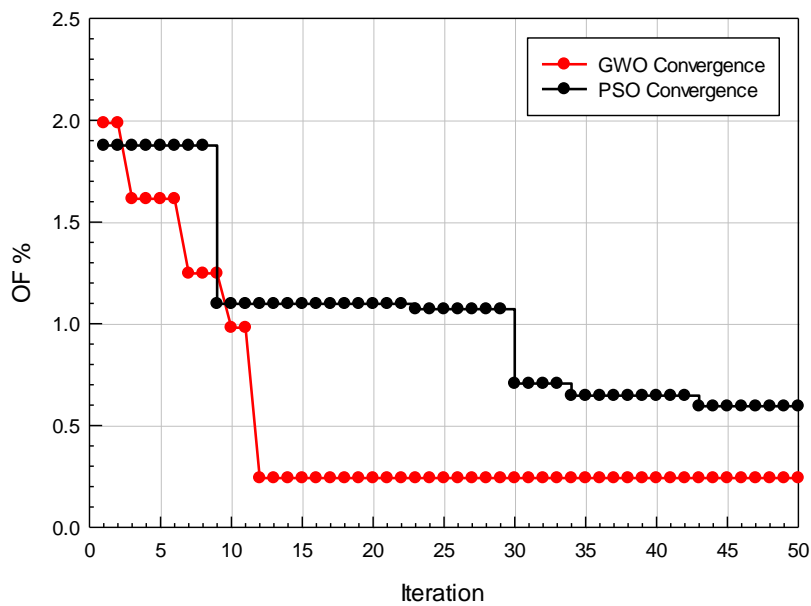
**Figure 12.** The feeder's situation before and after balancing.

The other parameters for the two algorithms are recorded in table 1 like the time consumed, the fitness value, the swapping factor, and the whole number of the shifted phases.

**Table 1:** The results of applying GWO and PSO on 48 homes in AL-Qahera.

Characteristics	GWO Algorithm	PSO Algorithm
<b>Time Consumed in seconds</b>	25.327	16.029
<b>Objective Function</b>	0.2418	0.5947
<b>Swapping factor</b>	68.7500	65.9722
<b>Total number of phases</b>	144	144
<b>Number of swapped phases</b>	99	95

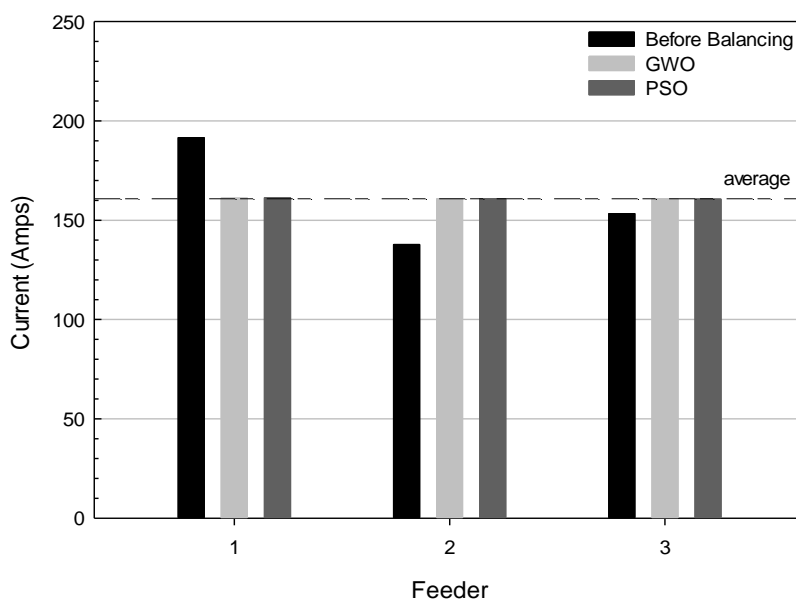
The GWO achieved less objective function compared with the PSO, and that means the balancing in the first case better than that obtained from the PSO algorithm. From another side, the time consumed (see table 1) and the swap factor in PSO better than GWO. The GWO algorithm in the iteration number 12 reaches 0.2418 objective functions but the PSO algorithm until the iteration number 42 not reach the same number and settled down on the 0.5947 to the end. Figure 13 explains clearly that the GWO can reach to the best value faster than the PSO algorithm.



**Figure 13.** The convergence of the two algorithms.

*4.1.2 The secondary transformer with 34 homes (AL- Zaiyna)*

In Zaiyna, the distribution transformer lies in a residential area and feeds 34 houses with three-phase meters. The online data collected from the smart meters in all the houses in a random moment appeared in Figure 11. From the first looking to the figure, the reader can recognize that the currents of the three feeders not in balance case, and that may cause many problems in the distribution network. The data handled by the algorithms to change the phase management to another one better in the balancing side, as illustrated in Figure 14.



**Figure 14.** The algorithms achieved the feeders balancing.

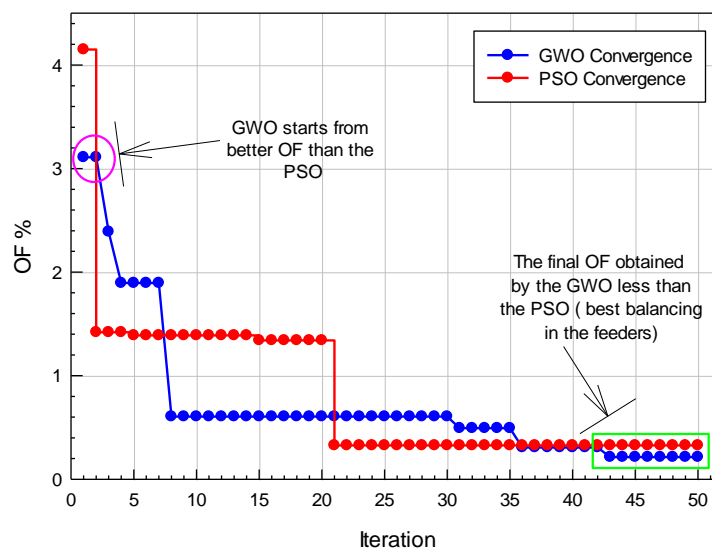
The GWO overcomes the PSO and achieved better results, as Table 2 shown. The time consumed and the number of phases swapped to achieve the balancing by PSO is less than the time consumed by the GWO, but finally, there is a better balancing achieved by the GWO, and that is the goal of this section.



**Table 2.** The results of applying GWO and PSO on 34 homes in AL- Zaiyna

Characteristics	GWO Algorithm	PSO Algorithm
Time Consumed in seconds	23.737	15.209
Objective Function	0.2134	0.3274
Swapping factor	71.5686	69.6078
Total number of phases	102	102
Number of swapped phases	73	71

The convergence of the GWO to reach the balancing case faster and reach a better value beside it starts from the lowest objective function in the first iteration, as is shown in Figure 15.

**Figure 15.** GWO algorithm achieve balancing in AL - Zaiyna sector better than PSO algorithm.

#### 4.2 Feeders Balancing with Minimum Swapping (Case 2)

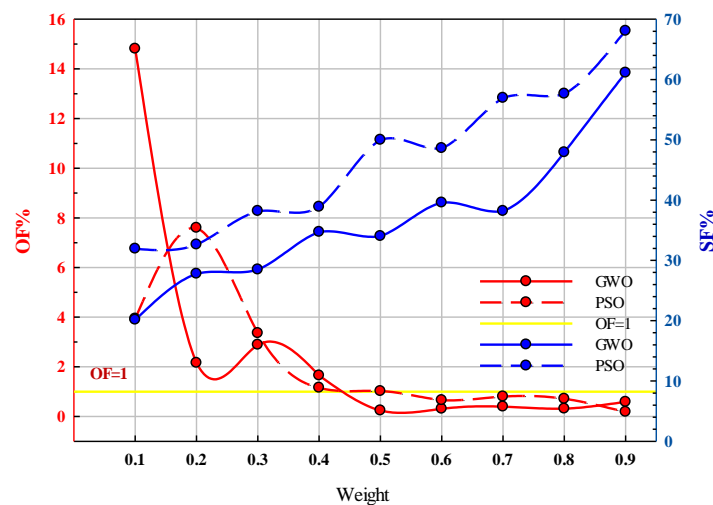
The balancing process is, to some extent, has harmful effects on the consumer apparatuses because the phase-swapping technique evoking disjoint some phases and reconnect it again to another feeder. Loads of the phase have been transferred switched off for a moment and switching on again. This transient behavior can damage some loads if it is sensitive for the suddenly stopping and working. This reason makes us suppose all the loads have the inverter property as the assumption number three above mentioned. Moreover, the two algorithms modified to be a multi-objective (MOGWO and MOPSO), to achieve two objective functions, i.e., the feeders balancing and decreasing the number of swaps as possible. The priori and posteriori regarded approaches for handling the multi-objective problems with more than one fitness function [46],[47],[48]. The first method combined all the objective functions in a single objective function with a group of weights that have different values according to the importance of each objective function. The decision-maker or the designer of the system decided the suitable values of these weights according to specific criteria. In this paper, the multi-objective function takes the form

$$\text{Objective Function} = W * \text{Balancing Value} + (1-W) \text{No. of Swaps} \quad (21)$$

Where  $W$  represents the importance of the transfer function. The value of  $W$  can be obtained by trying the weights in the period  $[0.1 \ 0.9]$  on the AL-Qahera sector to monitor the effecting of increasing

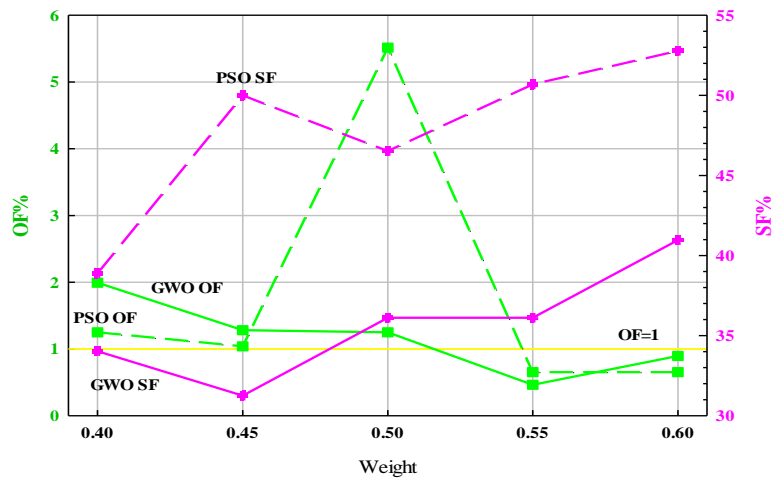
weight on the outputs of the algorithms, and the result was as shown in Figure 16 that refers clearly to the following points:

1. The reasonable weight restricted in the interval [0.4 0.6] because the objective function is approximately reaching the optimal balancing threshold (the yellow straight line), and that gives an excellent balancing in the feeders and in the same time the swapping factor in an acceptable level because there is a trade-off process between the fitness function and the swapping factor.
2. The swap factor curve through all the weights that achieved by GWO has a lower value than that obtained by PSO (the blue curve). This point reflects the truth of the best performance of GWO contrast with the PSO algorithm.
3. The GWO OF curve (the red color) started from the lowest value than PSO and stayed achieving a very competitive result in all the other weights.



**Figure 16.** The weight effect on the performance of GWO and PSO algorithms to reach balancing in AL-Qahera.

For a more focusing look on the best interval in Figure 16, the interval [0.4 0.6] will experiment carefully with 0.05 step in each time to determine the exact weight that can be regarded as the perfect for giving the accepted OF results beside a low swap factor as it is shown in Figure 17. The perfect weight will apply to Al- Zaiyna to solve the balancing problem. The reader can notice clearly that 0.55 weight can regard the best weight according to the balancing if he takes in his account the number of swaps for both algorithms. Speechless, the GWO better than PSO in reducing the swapping number. Henceforth, it will be the weight we dependent on for balancing purpose in this case and the case number 3 that related to PVs penetration.



**Figure 17.** The weight effect on the performance of GWO and PSO algorithms in the interval [0.4 0.6].

The **0.55** weight applied in the two algorithms to solve the balancing problem in:

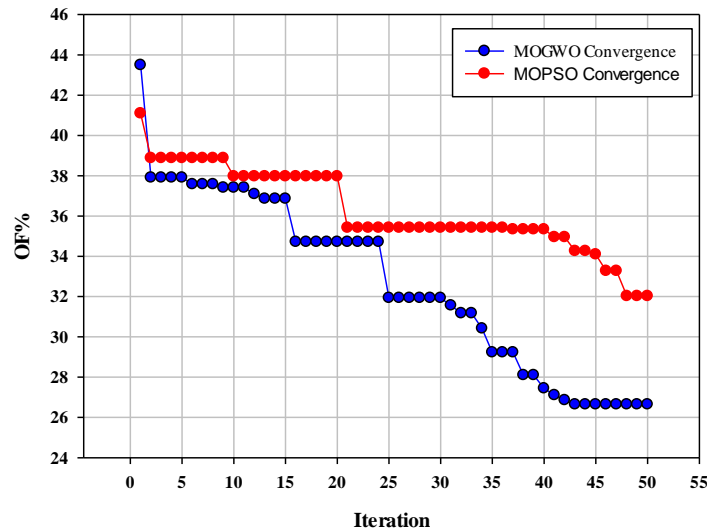
**1. AL-Qahera sector**

The result obtained by applying 0.55 weight on this sector recorded in table3 with the data obtained from the case 1 table 1.

**Table 3.** The results of applying GWO and PSO on 48 homes in AL-Qahera with and without swapping reduction

Characteristics	GWO With	GWO Without	PSO With	PSO Without
Time Consumed in seconds	34.677	25.327	21.225	16.029
Objective Function	0.1699	0.2418	1.0195	0.5947
Swapping factor	41.6667	68.7500	48.6111	65.9722
Number of swapped phases	60	99	70	95
Total number of phases	144	144	144	144

The convergence curve of the two algorithms that applied on AL-Qahera shown in Figure 18.



**Figure 18.** the convergence curve of the MOGWO and MOPSO algorithms. The result has been written in the table 4 can be concluded from the Figure 18.

**Table 4.** The results deduced from the two curves in Figure 18

Characteristics	The result
The OF% in the initial step	Best in MOGWO
The OF% throughout the iterations	Best in MOGWO
The settle down iteration	39 (MOGWO) & 42 (MOPSO)
The final OF%	17.53 (MOGWO) & 22.91 (MOPSO)
The convergence speed	MOGWO faster than MOPSO

## 2. Al-Zaiyna sector

The applying 0.55 weight on AL-Zaiyna produce the results shown in Table 5 that contain the data obtained in the case 1 Table 2.

**Table 5.** The results of applying GWO and PSO on 34 homes in AL- Zaiyna with and without caring for swaps number

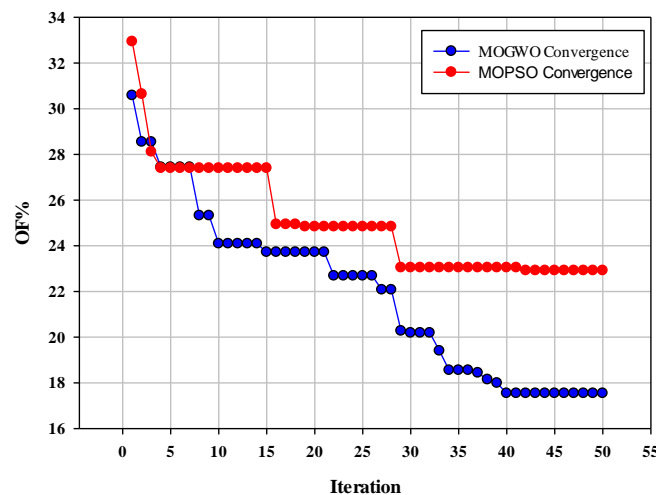
Characteristics	GWO With	GWO Without	PSO With	PSO Without
<b>Time Consumed in seconds</b>	24.698	23.737	15.836	15.209
<b>Objective Function</b>	0.6009	0.2134	1.3469	0.3274
<b>Swapping factor</b>	29.4118	71.5686	50.0000	69.6078
<b>Number of swapped phases</b>	30	73	51	71
<b>Total number of phases</b>	102	102	102	102

In the two sectors as shown from Table 3 and Table 4:

1. In Table 3, GWO gives a difference in the swapping factor by more than 27 percent, and in Table 4 by more than 42 percent, whereas in the PSO, the difference was 17 and 19, respectively.
2. For both of them, the time consumed increased slightly.

3. The two algorithms satisfied  $OF < 1$ . That makes the current in all feeders closely to the average value.
4. No rule tells us determinately that the OF% at the end will increase or decrease, but the essential thing the algorithm can ensure about all the final results will be under the threshold (under 10% in the balancing problem). Indeed, when we look again at the outcome of Tables 3 and 5, we will see that in the cases (with and without), the GWO in both tables reached lower OF level. That gives us evidence that the mechanism of GWO in finding the optimal solution based on initial stochastic solutions is better than that in PSO.

The convergence curve of the two algorithms are shown in Figure 19.



**Figure 19.** The convergence curve of the MOGWO and MOPSO algorithms.

The two curves showed the following:

- The MOPSO, in the beginning, found a better value than the MOGWO, but in the second iteration, the MOGWO compensate that and reach to better OF%.
- The two curves have shown that the MOGWO algorithm can achieve a better OF% throughout the iteration course.
- The MOGWO settle down on the best value (at iteration 43) before the MOPSO (at iteration 48) with a noticeable better OF%.

#### 4.3 Balancing in the case of PVs penetration (Case 3)

Photovoltaics (PVs) have now penetrated the domestic distribution network, and customers have installed it in households to engage in lowering bills for electricity. The PVs used in this document is a single-phase online microFITs (micro feed-in tariff) that are limited renewable generators, below 10 kW [35], and in this paper, the rate not exceed the 10A. The online PVs have a power factor (PF) equal to the PF of the phase that it will connect to it. The weighted sum MOGWO and MOPSO modified to take into consideration the online PVs for load balancing without causing any risks to the system's stability. The weight used in case number 3 is comparable to that used in case number 2. The balance problem is exponential, and the complexity increased with the increase in the number of loads. In another word, in any swapping issue, there are  $3^L$  feasible solutions where L is all the loads connected to the feeders that are included in the swapping operation. The algorithm handled the PVs as a load but with one difference. In contrast to the ordinary loads that consume power from the network, PVs can inject energy into the distribution network, so adding PVs constitutes an extra burden on any searching method.

The MOGWO, MOPSO algorithms must achieve two primary goals:

- Investing online residential solar cells to decrease the consumer's electricity bill while balancing feeders considerably.

- Achieving the load balancing with minimum node.

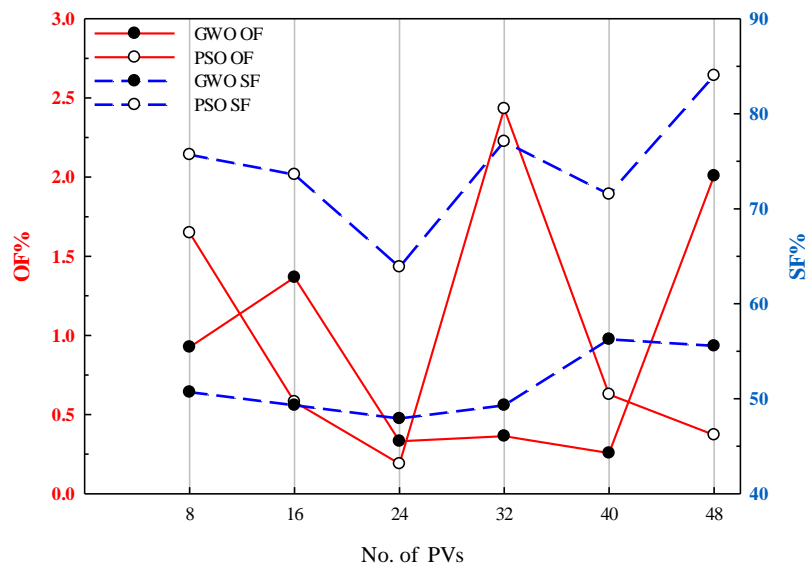
#### 4.3.1 Using all the available nodes to overcome the imbalance case

This part aims to accomplish the load balancing by helping all available PVs installed in the residential area.

##### A. AL-Qahera sector

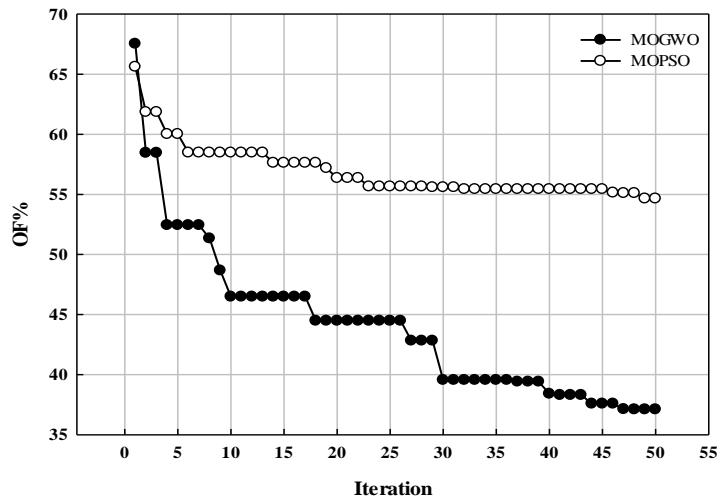
The impact of increasing the amount of photovoltaics in the studied region on the objective function and the swapping factor will be investigated. Figure 20 showed the fitness function and swap factor as photovoltaics increased. The two algorithms are tested six times for testing their performance with the following parameters:

1. The number of homes in all the scenarios are constant equal to 48 homes.
2. The number of PVs in each scenario will be (8,16,24,32,40 and 48).



**Figure 20.** The effect of PVs increasing on the OF and SF.

- The MOGWO accomplished better balance than PSO in nearly all the steps of household growth, despite both below 10%. The MOGWO achieved balancing with less node swapping in all the scenarios of using the PVs gradually compared to the MOPSO algorithm. **If in AL-Qahera, there is one PV in each home, the convergence curve of the first algorithm looks better and reaches less objective function than the PSO, as shown in Figure 21.**



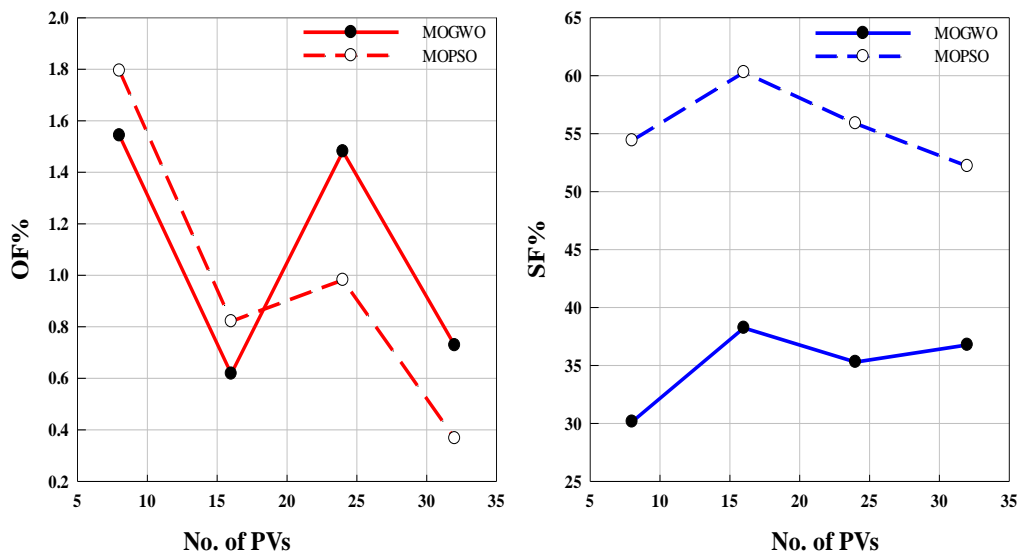
**Figure 21.** The convergence curves of MOGWO and MOPSO along 50 iterations.

**B. Al-Zaiyna sector**

**Thirty-four homes** have smart meters in the Zaiyna region. We assume a portion of these dwellings has a solar energy source and testing the algorithm efficiency in dealing with the following situation:

1. The area has 34 homes and there are just 8 homes have a PVs.
2. The area has 34 homes and there are just 16 homes have a PVs.
3. The area has 34 homes and there are just 24 homes have a PVs.
4. The area has 34 homes and there are just 32 homes have a PVs.

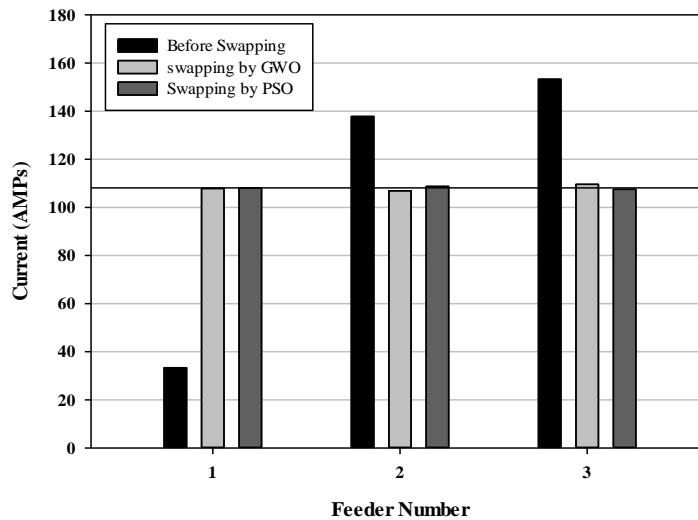
The total result of applying the MOGWO algorithm on the four difference scenarios above shown simultaneously in Figure 22.



**Figure 22.** The impact of household growth on OF and SF

- The balance satisfied by the MOPSO somewhat better than the MOGWO.
- The MOPSO paid a costly price in the form of node swapping. In contrast, by a fewer nodes, the MOGWO achieved balancing, and that represents a vital preference to the MOGWO algorithm.

- Eventually, both of the algorithms strike a balance (refer Figure 23) because the objective function is less than 10%.

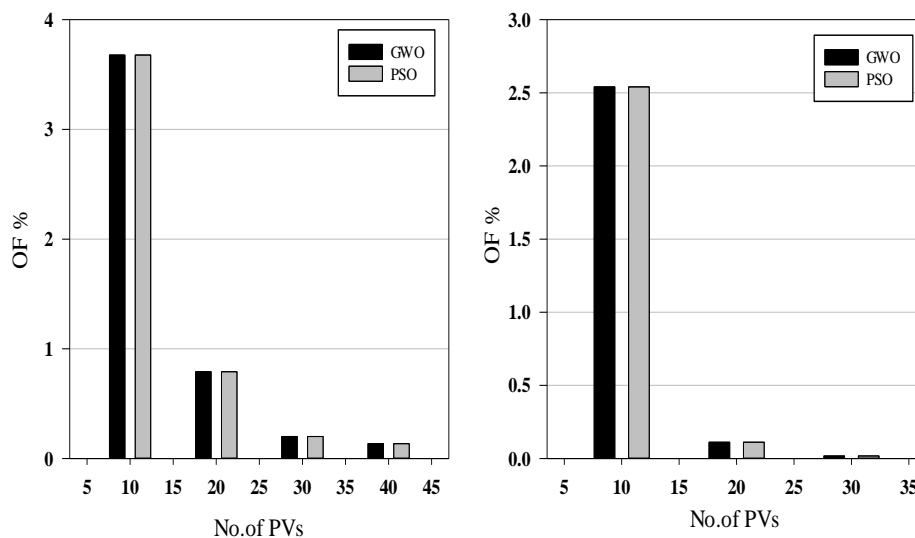


**Figure 23.** The feeder situation before and after the application of balancing algorithms  
 4.3.2 *Impact of swapping the PVs only on the balancing*

In this section, the swapping technique will be applied only to the online PVs in homes in two residential areas (AL-Qahera and Al-Zaiyna). There are four scenarios the algorithms subject to in AL-Qahera and three scenarios the algorithms subject to in Al-Zaiyna because the number of homes is constant and the number of PVs increased by ten each time as following:

- 48 homes.
- (10,20,30 and 40) PVs in AL-Qahera and (10,20 and 30) PVs in Al-Zaiyna.

Figure 24 shows the impact of inserting PVs on the situation of the secondary feeders. The algorithms succeed in the balance accomplishing the for the two regions without having to exchange any phase. It depending on the renewable energy sources that were already intended to be accessible in households.



**Figure 24.** The feeder’s situation in case of PVs increasing



## 5. Conclusion

Because of the continuous development in consumer loads and the penetration of contemporary technologies, which may have a fantastic or unfavourable impact on networks such as photovoltaic cells and electric vehicles, the load balancing in low voltage distribution networks has now been considered as a critical problem. This article used the GWO algorithm to make the phase swapping possible in three different cases to recover the network balance. The result obtained from the cases discussed in this paper can be summarized as following:

1. Compared to the PSO algorithm, the outcomes showed that the suggested algorithm reached to the balancing condition with a lower OF, close swapping factor and better convergence curve in case1.
2. Compared to the PSO algorithm, the outcomes showed that the suggested algorithm reached to the balancing condition with a very close or better OF, better swapping factor and converging curve in case2.
3. With PVs penetration, the MOPSO achieved better balancing but with very high swapping number in contrast with the MOGWO that achieved the balancing with very fewer phase swapping.
4. The both algorithms can achieve equal balancing depending only on the PVs available without swapping any phase in the two regions.

## Acknowledgement

This work was supported by actual information gathered from the smart meters installed by the smart network department at Al-Rasikh company for trading and commercial agencies LTD in AL-Qahera and Al-Zaiyna. This work was partly performed while the researchers visited the company site in Al-Mansoor / Baghdad. Special thanks to Eng. Hussain, who travels with us on a trip to test the smart meters and permit us to check the meter online remotely. Also, thanks to Eng. Mustafa A. Mnati, who was utterly corporate in sending information from time to time.

### References

- [1] Fallahzadeh-Abarghouei H, Hasanvand S, Nikoobakht A and Doostizadeh M, 2018 “Decentralized and hierarchical voltage management of renewable energy resources in distribution smart grid,” *Int. J. Electr. Power Energy Syst.*, vol. 100, pp. 117–128.
- [2] Rezkalla M, Zecchino A, Martinenas S, Prostejovsky A M, and Marinelli M, 2018 “Comparison between synthetic inertia and fast frequency containment control based on single phase EVs in a microgrid,” *Appl. Energy*, vol. 210, pp. 764–775.
- [3] Nájera J, Mendonça H, de Castro R M, and Arribas J R, 2019 “Strategies for voltage oscillation mitigation in LV distribution networks with EV smart charging control”.
- [4] Miller G M, Miller W V, and Chen E S, 2018 “Apparatuses and methods for passive fault monitoring of current sensing devices in protective circuit interrupters.” Google Patents.
- [5] Prasad P V, Sivanagaraju S, and Sreenivasulu N, 2008 “Network reconfiguration for load balancing in radial distribution systems using genetic algorithm,” *Electr. Power Components Syst.*, vol. 36, no. 1, pp. 63–72.
- [6] Lin C H, Kang M S, Chuang H J, and Ho C Y, “Phase Balancing of Distribution Systems Using a Heuristic Search Approach.”
- [7] Hooshmand R A and Soltani S, 2012 “Fuzzy optimal phase balancing of radial and meshed distribution networks using BF-PSO algorithm,” *IEEE Trans. Power Syst.*, vol. 27, no. 1, pp. 47–57.
- [8] Rashid M T, 2014 “Design and Implementation of Smart Electrical Power Meter System,” *Iraqi J. Electr. Electron. Eng.*, vol. 10, no. 1, pp. 1–14.
- [9] Pana A, 2011 “Active load balancing in a three-phase network by reactive power compensation,” in *Power Quality Monitoring, Analysis and Enhancement*, IntechOpen.
- [10] Dixon J, Moran L, Rodriguez J, and Domke R, 2005 “Reactive power compensation technologies: State-of-the-art review,” *Proc. IEEE*, vol. 93, no. 12, pp. 2144–2164.
- [11] Gupta N, Swarnkar A, and Niazi K R, 2011 “A novel strategy for phase balancing in three-phase four-wire distribution systems,” *IEEE Power Energy Soc. Gen. Meet.*, pp. 1–7.
- [12] Islam M R, Lu H, Hossain M J, and Li L, 2019 “Mitigating unbalance using distributed network reconfiguration techniques in distributed power generation grids with services for electric vehicles: A review,” *J. Clean. Prod.*, p. 117932.
- [13] Lafortune M, Bouchard D, and Morelli J, 2007 “Phase swapping for distribution system using Tabu search,” in *WSEAS Int. Conf. on Energy Planning, Energy Saving, Environmental Edu.*, pp. 67–71.
- [14] Al-Kharsan I H, Zahid A Z G, Marhoon A F, and Mahmood J R, 2018 “Demand response programs in smart grids—survey,” *Int. J. Eng. Technol.*, vol. 7, no. 4, pp. 5090–5099.
- [15] Schweickardt G, Alvarez J M G, and Casanova C, 2016 “Metaheuristics approaches to solve combinatorial optimization problems in distribution power systems. An application to Phase Balancing in low voltage three-phase networks,” *Int. J. Electr. Power Energy Syst.*, vol. 76, pp.

- 1–10.
- [16] Khodr H M, Zerpa I J, De Oliveira-De Jesús P M, and Matos M A, 2006 “Optimal phase balancing in distribution system using mixed-integer linear programming,” *IEEE PES Transm. Distrib. Conf. Expo. Lat. Am. TDC’06*, vol. 00, pp. 1–5.
- [17] Zhu J, Bilbro G, and Chow M Y, 1999 “Phase balancing using simulated annealing,” *IEEE Trans. Power Syst.*, vol. 14, no. 4, pp. 1508–1513.
- [18] Zhu J, Chow M Y, and Zhang F, 1998 “Phase balancing using mixed-integer programming,” *IEEE Trans. Power Syst.*, vol. 13, no. 4, pp. 1487–1492.
- [19] Knolseisen A B, Coelho J, Mayerle S F, Pimentel F J S, and Guembarovski R H, 2003 “A model for the improvement of load balancing in secondary networks,” *IEEE Bol. PowerTech - Conf. Proc.*, vol. 3, no. Lv, pp. 822–828.
- [20] Gandomkar M, 2004 “Phase balancing using genetic algorithm,” in *39th International Universities Power Engineering Conference: UPEC, University of the West of England (UWE), Bristol, UK Conf. Proc.*, p. 1350.
- [21] Siti M W, Jimoh A A, and Nicolae D V, 2007 “Phase load balancing in the secondary distribution network using fuzzy logic,” *IEEE AFRICON Conf.*, pp. 1–7.
- [22] Hooshmand R and Soltani S H, 2012 “Simultaneous optimization of phase balancing and reconfiguration in distribution networks using BF-NM algorithm,” *Int. J. Electr. Power Energy Syst.*, vol. 41, no. 1, pp. 76–86.
- [23] Tuppadung Y and Kurutach W, 2007 “The modified particle swarm optimization for phase balancing,” *IEEE Reg. 10 Annu. Int. Conf. Proceedings/TENCON*, vol. 00, pp. 1–4.
- [24] Niknam T, 2010 “An efficient hybrid evolutionary algorithm based on PSO and ACO for distribution feeder reconfiguration,” *Eur. Trans. Electr. Power*, vol. 20, no. 5, pp. 575–590.
- [25] Niknam T, 2009 “An efficient hybrid evolutionary algorithm based on PSO and HBMO algorithms for multi-objective distribution feeder reconfiguration,” *Energy Convers. Manag.*, vol. 50, no. 8, pp. 2074–2082.
- [26] Mirjalili S, Mirjalili S, A. L.-A. in engineering Software, and U., 2014 “Grey wolf optimizer,” *Elsevier*, vol. 69, pp. 46–61.
- [27] Wang K, Skiena S, and Robertazzi T G, 2013 “Phase balancing algorithms,” *Electr. Power Syst. Res.*, vol. 96, pp. 218–224.
- [28] Wang Y J and Huang Y S, 2009 “Analysis of a stand-alone three-phase self-excited induction generator with unbalanced loads using a two-port network model,” *IET Electr. power Appl.*, vol. 3, no. 5, pp. 445–452.
- [29] Maheswaran D, Kalyanasundaram A, and Kameshwaran S, 2006 “Power quality issues in a distribution network impact of neutral current due to nonlinear loads,” in *Proc. India Int. Conf. on Power Elect.*, pp. 150–155.
- [30] Jin T and Smedley K M, 2006 “Operation of one-cycle controlled three-phase active power filter with unbalanced source and load,” *IEEE Trans. Power Electron.*, vol. 21, no. 5, pp.

1403–1412.

- [31] Teo C Y and He B G, 2000 “Integrating three-phase load flow and short-circuit current calculation for a low voltage system,” *Electr. Power Syst. Res.*, vol. 53, no. 2, pp. 123–132.
- [32] Raminfard A and Shahrtash S M, 2010 “A Practical Method for Load Balancing in the LV Distribution Networks Case study : Tabriz Electrical Network,” vol. 2, no. 6, pp. 1193–1198.
- [33] Zdraveski V, Todorovski M, and Kocarev L, 2015 “Dynamic intelligent load balancing in power distribution networks,” *Int. J. Electr. Power Energy Syst.*, vol. 73, pp. 157–162.
- [34] Salama M M A, 2013 “Multi-Objective Optimization for the Operation of an Electric Distribution System With a Large Number of Single Phase Solar Generators,” vol. 4, no. 2, pp. 1038–1047.
- [35] “What is the Inverter technology in air conditioners? - Inventor.” [Online]. Available: <https://www.inventorairconditioner.com/blog/faq/what-is-the-inverter-technology-in-air-conditioners>. [Accessed: 01-Nov-2019].
- [36] Rizalman M, 2011 “The Suitability Of Inverter Air-Cornditioning Comparad To Non-Inverter Type For Household Application,”.
- [37] Ushimaru K, 1990 “Japanese power electronics inverter technology and its impact on the American air conditioning industry,” *Pacific Northwest Lab., Richland, WA (USA)*; Energy Int., Inc..
- [38] Mendia I, Gil-López S, Ser J D, Bordagaray A G, Prado J G, and Vélez M, 2017 “Optimal phase swapping in low voltage distribution networks based on smart meter data and optimization heuristics,” in *Adv. in Intelligent Syst. and Comp.*, vol. 514, pp. 283–293.
- [39] An B *et al.*, 2018 “An asymmetrical connection balance transformer-based hybrid railway power conditioning system with cost-function optimization,” *IEEE Trans. Transp. Electrifi.*, vol. 4, no. 2, pp. 577–590.
- [40] Fei C G and Wang R, 2014 “Using phase swapping to solve load phase balancing by ADSCHNN in LV distribution network,” *Int. J. Control Autom.*, vol. 7, no. 7, pp. 1–14.
- [41] Ignatius O K, Saadu A K, and Emmanuel O S, 2015 “Analysis of Copper Losses Due to Unbalanced Load in a Transformer (A Case Study of New Idumagbo 2 x 15-MVA, 33/11-kV Injection Substation),” *Int. J. Res. Rev. Appl. Sci.*, vol. 23, no. 1, p. 46.
- [42] Eberhart R and Kennedy J, 1995 “Particle swarm optimization,” in *Proc. of the IEEE Int. Conf. on Neural Net.*, vol. 4, pp. 1942–1948.
- [43] Mirjalili S, Saremi S, Mirjalili S M, and Coelho L D S, 2016 “Multi-objective grey wolf optimizer: A novel algorithm for multi-criterion optimization,” *Expert Syst. Appl.*, vol. 47, pp. 106–119.
- [44] Hassanien A E and Emary E, 2018 "Swarm intelligence: principles, advances, and applications", *CRC Press*.
- [45] Shi Y and Eberhart R C, 2006 “Parameter selection in particle swarm optimization,” vol. 160, pp. 591–600.

- [46] Branke J, Kaußler T, and Schmeck H, 2001 “Guidance in evolutionary multi-objective optimization,” *Adv. Eng. Softw.*, vol. 32, no. 6, pp. 499–507.
- [47] Marler R T and Arora J S, 2004 “Survey of multi-objective optimization methods for engineering,” *Structural and Multidisciplinary Optimization*, vol. 26, no. 6. Springer-Verlag, pp. 369–395.
- [48] Branke J and Deb K, 2005 “integrating user preferences into evolutionary multi-objective optimization,” *Springer*, Berlin, Heidelberg, pp. 461–477.