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A Novel Approach for Residential Neighborhoods' Electricity Demand in Iraq Distribution Power Grids

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ABSTRACT In Baghdad City's distribution power grid, a massive number of 630 kV distribution transformers (DTs) are used in residential neighborhoods. Each DT is joined to nine low-voltage 0.415 kV distribution feeders. Each feeder has a designated size of 1×240 mm^2 and is joined to a specified number of residential dwellings ($N = 30$) fixed in the initial design stage. The size and number of low-voltage 0.415 kV distribution feeders are set with no change. In this investigation, we use a new approach for modeling electricity demand in residential neighborhoods in Baghdad City and overcome this constraint by finding the optimum number of residential dwellings joined to the same low-voltage 0.415 kV distribution feeder. Two sets of the experimental equations are created to compute the number of residential dwellings that are required to be joined to the low-voltage 0.415 kV distribution feeder. The multi-gradient particle swarm optimization algorithm is used as an optimization tool to handle these experimental equations. Results show that each low-voltage 0.415 kV distribution feeder can be loaded with 50 dwellings instead of 30 due to the diversity among residential dwellings. Several facts about the load profile characteristics of residential dwellings in Iraq are established. This study's outcomes provide useful technical references for Iraq electrical design engineers to update the connection grids of low-voltage 0.415 kV distribution feeders in Baghdad City to achieve economic benefits.

INDEX TERMS Iraqi distribution power grid, low-voltage 0.415 kV distribution feeder, diversity factor, residential dwellings' load profile, electricity modeling.

NOMENCLATURE

SYMBOL	DESCRIPTION
c_1, c_2	Acceleration coefficients are set 2.0
r_1, r_2	Random numbers are within a range of [0, 1]
w	Inertia weight
$N_{iter,explore}$	Number of iterations in the exploration stage
$N_{iter,exploit}$	Number of iterations in the exploitation stage
N_{iter}	Number of iterations
$grad$	Negative gradients
m	Number of particles inside a swarm
V	Velocity factor
X	Position vector
G_{pers}	Personal experience of the particle
G_{best}	Best particle experience in a swarm
I_{ph}	Phase current
$P_{calculated,feeder}$	Calculated maximum kW demand

ABBREVIATION	DESCRIPTION
A	Ampere
BIM	Building information modeling
DPG	distribution power grid
DT	Distribution transformer
DF	Diversity factor
Hz	Hertz
IMERs	Iraq ministry electricity regulations
kV	Kilovolt

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kVA	Kilovolt ampere
kW	Kilowatt
MG-PSO	Multi-gradient particle swarm optimization
N	Number of residential dwellings

I. INTRODUCTION

Electrical loads can be classified into three categories: are residential, commercial, and industrial. Electrical design engineers of distribution power grids (DPGs) in Iraq have progressively focused their attention on residential dwellings load. An extensive effort has been exerted to manage and reduce this sector's electricity consumption given that residential dwellings account for the most extensive electricity consumption share. In addition, residential dwellings contribute considerably to the maximum kW demand. For example, 78000 distribution transformers (DTs) with a massive number of low-voltage 0.415 kV distribution feeders have been installed; the residential dwellings consume more than 3000 MW in the residential neighborhoods of Baghdad City [1].

Electrical design engineers of Iraq DPGs aim to meet two objectives [2]–[4]: studying the current residential dwelling load profile characteristics [5]–[11] and model the electricity kW demand [12]–[18]. The common factor among residential dwellings, called the diversity factor (DF), is the backbone of electricity demand modeling. In general, residential dwellings joined to the same low-voltage 0.415 kV distribution feeder consume different maximum kW demands given their different lifestyles, use of various electrical appliances, and contrasting natural DF. Thus, diversity in electricity kW demands increases. Owing to this diverse nature of electricity kW demands, simultaneous and full-load electricity supply to all residential dwellings is unnecessary.

The DF is computed as the quantitative relation of the sum of individual consumers' maximum demands to the whole system maximum demand [19]–[21]. The DF determines the entire system maximum kW demand for electricity, providing a current landscape perspective of the residential dwelling behavior and characteristics during the maximum kW demand period. In addition, DPGs have become smarter than before, and given the novel technologies utilized in this sector, numerous smart recorders and monitors have been installed to improve the operation of DPGs.

Numerous researchers have conducted studies on electricity usage on residential, commercial, and industrial loads. However, this investigation focuses on residential loads only because they account for the largest share of electricity consumption. The recent studies by other authors are classified into three categories based on their followed analysis approach.

The first category of researchers used survey and probability to provide flexible control on electricity consumption to study and improve residential dwelling load profile characteristics. In [22], the authors used a time-use survey throughout the combination of electrical appliance uses and household activities to determine the Danish residential dwellings' load profile for 24 h.The authors in [23] used a probabilistic model to compare electricity- demand simulated data and actual recorded data in United Kingdom households. They observed a large difference in electricity consumption among residential dwellings due to the geographical distribution of consumers.

The second category used a frequency domain and building information modeling (BIM) to study the residential dwelling load profile. In [24], the authors drew the load patterns of residential dwellings in Japan using BIM software, to control the hot-water operation for 24 h. Linear relationship characteristics have been obtained between the supply and demand for electricity. In [25], the authors used the frequency domain analysis of phase current signals of non-intrusive monitoring systems to study the behaviour of residential dwelling for a day. In [26], the authors used frequency analysis to recognize a household's lifestyle through the electricity bill. The authors suggested a household follow-up a routine in using electrical appliances to reduce electricity bills.

The third category of researchers used technology penetration rates to provide flexible control on electricity consumption to study and improve residential dwellings' load profile characteristics. The authors in [27] used smart appliances, e.g., washing machines and dishwashers, as a potential solution to the study load profile characteristics under smart and non-smart electrical appliances. This procedure was applied to twelve countries in Europe.

In [28], the authors studied the supplied electricity barriers to residential loads in Netherland, such as environment circumstances, renewable power resources, and shift in electricity demand, to provide useful details about the household electricity demand behavior. The investigation in [29] was used to discover possible changes in residential dwelling load profile under current technological development. The authors concluded that the load profile will dramatically change in the future due to an extensive penetration of electric vehicles to the world market, particular types of heating pumps, and air-conditioning systems. Thus, the annual maximum kW demand will increase significantly. However, the growth in solar panels industry development and advanced energy management systems reduce the yearly peak kW demand [30].

In [31], the flexibility of individual technologies, such as electric vehicles and photovoltaic battery systems, were used in residential dwellings' to study the behavior of residential dwellings' load profile in Germany. The authors in [32] proposed the shuffled frog leaping algorithm to handle the daily load curve of residential dwellings to optimize the electricity consumption and determine the long-term operating modes of household electrical appliances. However, monitoring of residential dwellings remains a significant limitation in the study of residential dwelling load characteristics. In [33], orthogonal particle swarm optimization (PSO) algorithm was used to compute the number of residential dwellings joined to the same DT. The authors in [34] utilized a smart meter joined inside a household to record the real power. This procedure provides a means to collect data from dwellings and use the collected data to determine the DT load burden. In [35], the load profile of residential dwellings' load profile was estimated using real-time kW and kVAR meter readings recorded inside a DT.

A set of differential equations was used in [36] to determine residential dwelling load characteristics. The authors in [37] utilized kWh meters joined to a power transformer to compute the annual kWh consumption and kW demand. In [38], the load profile data were collected from monthly load curve readings, and electricity consumption was recorded for a month. Subsequently, the artificial neural network was applied to determine the load profile characteristics. In [39], the authors used a genetic algorithm to analyze the data recorded for each DT; the load profile for dwellings joined to a DT was also determined. This procedure was applied to optimize and manage the rating of each DT joined to DPG. In [40], linear programming was applied to formulate the electrical load demand records obtained from smart power meters to determine the electricity consumption during daytime.

The contribution and novelty of this investigation have been organized as follows.

1) The different practical approaches used in previous investigations emphasize the importance of studying residential dwellings load characteristics and electricity modeling. However, they do not address the *DF* among residential dwellings.
2) The *DF* is not addressed by theIraq Ministry of Electricity Regulations (IMERs) for such a practical problem. Thus, this research study can become a technical reference in addition to IMERs.
3) Three residential neighborhoods in Baghdad City, namely, Al-Hurriya City, Al-Mustansiriya, and Al-Jadriya, are selected.
4) A sample of 500 dwellings from each residential neighborhood is obtained. Thus, the total number of residential dwellings is 1500.
5) Smart electricity meters are joined to several low-voltage 0.415 kV distribution feeders to record the maximum kW demand and the number of dwellings joined to each low-voltage 0.415 kV distribution feeder.
6) The real-time kW demand readings are recorded for 24 h.
7) The current design of low-voltage DPG in Iraq includes nine low-voltage 0.415 kV distribution feeders (size: 1×240 mm^2) joined to a DT. Each distribution feeder is joined to a fixed number of 30 residential dwellings in the initial design stage. In the current research study, we determine the *DF* among residential dwellings connected to the same low-voltage 0.415 kV distribution feeder to find the optimum number of residential dwellings required for this distribution feeder.
8) The size and number of the low-voltage 0.415 kV distribution feeder are fixed in the initial design stage with no change. This study overcomes this constraint by finding the optimum number of residential dwellings joined to the same low-voltage 0.415 kV distribution feeder.
9) The load demand profile characteristics and electricity modeling of residential dwellings of each residential neighborhood are determined through finding the experimental relationship between *DF*, maximum kW demand and the number of residential dwellings.
10) The approach used in the current investigation is different from that adopted in our previous study [33]. In [33], we used the coincidence factor of residential consumers to compute the maximum kW demand, and the number of dwellings joined to the same DT. However, in the current investigation, we use the *DF* among residential dwellings to compute the maximum kW demand and find the number of residential dwellings joined to the same low-voltage 0.415 kV distribution feeder.
11) The current investigation satisfies enormous economic benefits in planning and designing DPGs in Iraq by determining the number of residential dwellings connected to the same low-voltage 0.415 kV distribution feeder, savings in kW power demands, and savings in operating cost.
12) This research is more accurate than the previous work describing the load profile characteristics of residential dwellings and electricity modeling in Baghdad City. The kW load demands and the number of residential dwellings connected to the same distribution feeder during the day are determined.

The rest of this investigation is organized as follows. Section II depicts the methodology used in this investigation. Section III provides the outcomes and discussion of this investigation, and Section IV provides the conclusion.

II. METHODOLOGY

This section explains the behavior and characteristics of Baghdad residential dwellings and electricity kW demand modeling. The multi-gradient PSO (MG-PSO) algorithm is applied as an optimization tool for such a practical problem.

A. RESIDENTIAL DWELLING LOAD PROFILE

The residential dwellings in three neighborhoods, namely, Al-Hurriya City, Al-Mustansiriya, and Al-Jadriya, are supplied with electricity from a massive 630 kVA kiosk-type (11/0.415 kV). The low-voltage side of 630 kVA is joined to nine low-voltage 0.415 kV distribution feeders, and each 0.415 kV distribution feeder is joined to a fixed number of residential dwellings (30) in the design stage [41].

The three residential neighborhoods are selected based on the IMERs [41] and briefly described as follows.

1) *Al-Hurriya City:* Ancient dwellings with an area of 150 - 250 m^2; each dwelling has a high-density of people, and most of them have limited incomes.

2) *Al-Mustansiriya:* Old dwellings with an area of 400 - 600 m^2; each dwelling has a medium-density of people, and most of them have medium incomes.
3) *Al-Jadriya:* New dwellings with 400 - 800 m^2; each dwelling has a low- to medium-density population, and most of them have high incomes.

B. MEASUREMENT INSTRUMENTS USED FOR THE LOAD DEMAND OF RESIDENTIAL DWELLINGS

The apparatus equipment used in this investigation are classified as follows.

1) A three-phase (3-ph) kW smart meter (real power measurement) produced by Siemens Company with four wires, 415 V, 160 A, and 50 Hz, is used to measure the kW load demands of residential dwellings joined to the low-voltage 0.415 kV distribution feeder.
2) A Hioki 8701 chart recorder with a Z-fold chart paper is utilized for real-time recording of the load demand changes within 24 h [42].
3) A kWh meter placed in each dwelling is used to measure the kW load demand.

We select 630 kVA kiosk-type DT with 11/0.415 kV, 3-ph, and 50 Hz in this research investigation. Each phase of the low-voltage side is equipped with three low-voltage 0.415 kV distribution feeders. The reasons for selecting this type of DT are as follows:

1) Siemens Company manufactures the 630 kVA kiosk-type DT in the studied residential neighborhoods.
2) Comfortable and safe to measure underground low-voltage distribution cables are used.
3) Electrician staff are available 24 h with high security.
4) The connections of our kW smart meters are established by the electrician staff of the Ministry of Electricity.

C. ANALYSIS OF THE MEASURED RESIDENTIAL DWELLING LOAD DEMAND DATA

Twenty-five 3-ph kW smart meters are used to study the residential dwellings' load profile in Baghdad City by recording the kW load demand in the three residential neighborhoods. Each kW smart meter is connected to a low-voltage 0.415 kV distribution feeder for three days in July or August to cover a possibly large residential area of the test sample, i.e., 1500 residential dwellings. Measurements are performed in summer (July and August) when the ambient temperature is between 48 °C and 53 °C. This procedure provides a landscape perspective of the load demand profile of residential dwellings.

APPENDIX A presents the daily load curves of the residential dwellings in the three neighborhoods. The real-time kW demands measured for several dwellings for 24 h, and the maximum kW load demands are also recorded. Two load demand crests merge each day during the summer season, with one occurring from midnight to morning and the other from afternoon to evening. Both crests are due to the operation of air-conditioning systems in each residential dwelling. Thus, the load profile of residential dwellings during summer is promptly influenced by the number of dwellings joined to the same low-voltage 0.415 kV distribution feeder. The limitations of this research investigation are as follows:

1) The continuous recordings of the 3-ph kW smart meter do not cover all conceivable numbers of dwellings joined to the same low-voltage 0.415 kV feeder.
2) The number of dwellings allocated to each 0.415 kV feeder is nine and executed accordingly in the initial design stage.
3) The electricity supplied to several dwellings is interrupted for at least 2-3 h per day during summer due to the direct electricity interruption program of the Ministry of Electricity. This interruption results in intermittent load recordings for 24 h.
4) Electricity interruption occasionally occurs at the maximum kW load demand period. This procedure becomes difficult, especially when the number of dwellings is large. In several cases, the maximum kW load demand cannot be recorded when the family is unavailable in their residence during the maximum demand period. These difficulties cause the impossibility of covering all residential dwellings and to obtaining a continuous domain of readings.

APPENDIX B provides the summary of residential dwelling loads recorded during summer for the residential neighborhoods of Al-Hurriya City, Al-Mustansiriya, and Al-Jadriya.

To model the measured data in APPENDIX B for each residential area, we consider the following assumptions.

1) The number of residential dwellings is denoted by N.
2) The sum of individual residential dwelling maximum kW demand measured is represented by $P_{measured,consumers}$ in (kW).
3) The maximum kW demand measured for the whole residential dwellings joined to the same 0.415 kV distribution feeder is indicated by $P_{measured,feeder}$ in (kW).

Figure 1 shows the load profile characteristics and behavior of residential dwellings in the three neighborhoods during a maximum load demand period in summer season (i.e., July and August, 3:00 PM to 5:00 PM; the range of temperature reaches between 48 °C and 53 °C. The measured results in APPENDICES A and B demonstrate the relationship between the sum of individual dwellings' maximum kW load demand and the maximum kW load demand of residential dwellings joined to the same 0.415 kV distribution feeder. For a particular number of dwellings, this relationship is linear for all three residential neighborhoods. When the N number of dwellings is more than 50 (Fig. 1), a distinct gap exists between $P_{measured,consumers}$ and $P_{measured,feeder}$. This condition confirms that the DF is available among residential dwellings and gives us a view of the load profile characteristics of residential dwellings.

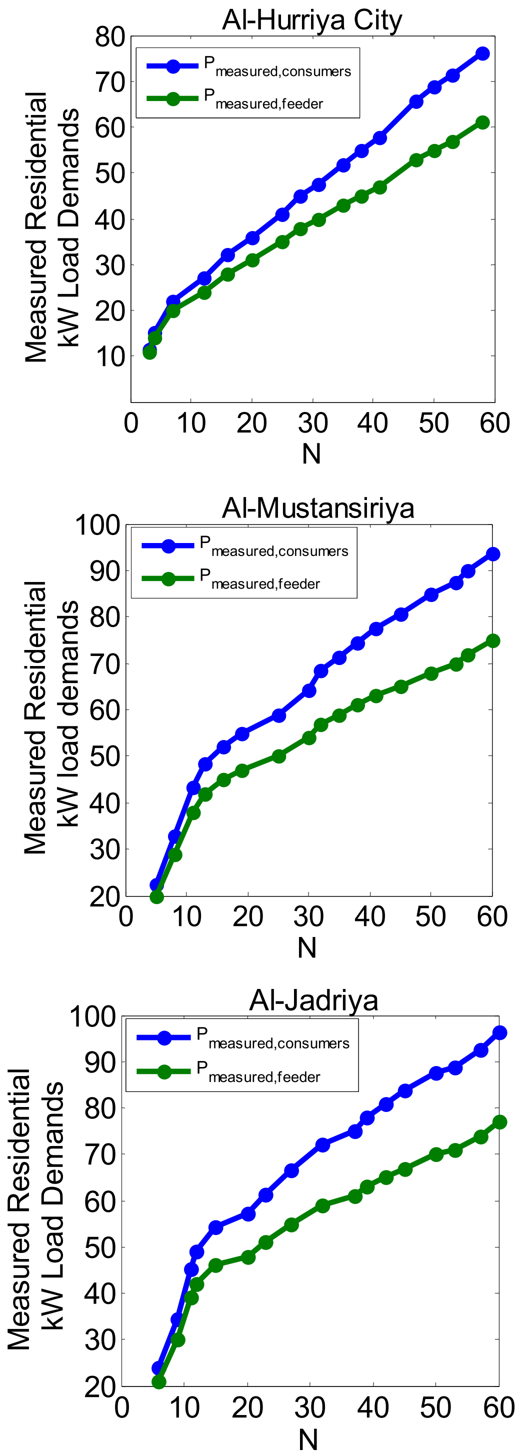

FIGURE 1. Measured kW load demands of residential dwellings in the maximum demand period in Al-Hurriya City, Al-Mustansiriya, and Al-Jadriya neighborhoods.

D. MG-PSO ALGORITHM

The MG-PSO algorithm is applied as an optimization tool for handling the research problem. Recent studies have validated this algorithm's capability in solving real-world problems in science and engineering [43]–[46].

This algorithm uses several distinct negative gradients through inspections and research on the target population for an optimum solution. The best particle inside a swarm population is prevented from the fall in the local minima arising from different negative gradients to obtain a possible solution.

Two stages of exploration and exploitation processes are constructed in this algorithm. The first stage is the exploration stage, in which a particle is an explorer, and m explorers utilize distinct episodes. In every episode, a new neighborhood is discovered by m explorers through a distinct negative gradient. The m explorers in the first stage are used to boost the algorithm's global search capability. At the end of the early stage, the m explorers supply a search space boundary that will use a new search space in the next stage.

The second stage is the exploitation stage, in which a particle is an exploiter, and m exploiters use one negative gradient that is less than that used in the first stage to exploit the best neighborhood in the search space. A small imperceptible change in velocity and position vectors during the updating processes is achieved using a slightly negative gradient. Thus, the m particles move steadily toward the candidate solution, that is, global optimum. Subsequently, the m exploiters boost the algorithm's local research capability.

The integration of the two stages provides the equilibrium between their processes in a search space area, and they are successfully used to overcome the disadvantages of gradient optimization methods. Negative gradient variations prevent the best particle inside a swarm population from dropping to the local minimum and ensuring its escape.

E. LEARNING STRATEGY

The following assumptions demonstrate the MG-PSO algorithm learning strategy. The m particles inside a swarm population seeking a solution in a d-dimensional space, and each ith particle $(i = 1, 2, \ldots, m)$ adjusting its moving path on the basis of two guides are *its personal experience* $\boldsymbol{G_{pers,i}}$ and *its neighborhood's best experience* G_{best}, respectively. When seeking for a possible solution, the ith particle gains information from its $G_{pers,i}$ and G_{best}. In this manner, a particle utilizes the best experience of m particles while selecting G_{best} as the best neighbor experience.

In the first stage, an explorer follows distinct episodes, and the m explorers in every episode apply a distinct negative gradient to discover a new search space area, i.e., new neighborhood. The m explorers aim to obtain a new neighborhood in a d-dimensional search space, and they achieve the best neighborhood among the used distinct episodes. The m explorers in every episode gain the best position vector following their neighborhood by applying a distinct negative gradient.

The neighborhood is achieved by considering the ceiling and floor of every element of the best position vector. These procedures yield a new search space, the best neighborhood throughout the d-dimensional search space that will be utilized in the next stage.

In the second stage, an exploiter is utilized, and the m exploiters utilize one negative gradient that is less than that used in the first stage. This stage aims to obtain an optimum solution, i.e., the best position used by the best particle in a swarm, by exploiting m exploiters in the best neighborhood achieved from the exploration stage.

F. STRUCTURE

In this section, we discuss the structure of the MG-PSO algorithm and parameters used. Assume that N_{grad} is the number of negative gradients utilized, and the population of m particles inside a swarm searches for a possible solution of an objective function in a d-dimensional search space area.

The $N_{grad}-1$ negative gradients are utilized in the exploration stage, and one negative gradient is utilized in the exploitation stage.

Different negative gradients are used to boost the local and global search capabilities of the swarm in a d-dimensional search space. In addition, the inertia weight w follows one negative gradient in each episode. The negative gradient of w controls the tendency to converge of m particles during the search processes in the two stages to obtain a solution.

Consider N_{iter} as the total number of iterations during the search processes by m particles. The number of iteration achieved by m explorers in the exploration stage is $N_{iter,xplore}$ and given by Eq. (1).

$$N_{iter,xplore} = \gamma \times N_{iter}, \tag{1}$$

where γ is a positive and real number in the range of [0, 1]. The number of iterations achieved by m exploiters in the exploitation stage is $N_{iter,exploit}$ and given by Eq. (2).

$$N_{iter,exploit} = (1-\gamma) \times N_{iter}, \tag{2}$$

For the kth negative gradient, $k = 1, 2, \ldots, N_{grad}$, the initial and final values of w are denoted as $w_{ini,k}$ and $w_{ini,k}$, respectively. Both values are positive and real numbers in the range of [0, 1], in which the following is obtained:

$$w_{ini,k} > w_{fin,k}, \tag{3}$$

The kth negative gradient, $grad_k$, $k = 1, 2, \ldots, N_{grad}-1$ in the exploration stage is given by the following:

$$grad_k = \frac{w_{fin,k} - w_{ini,k}}{N_{iter,xplore}}, \tag{4}$$

Meanwhile, the negative gradient $grad_{N_{grad}}$ in the exploration phase is given by Eq. (5).

$$grad_{N_{grad}} = \frac{w_{fin,N_{grad}} - w_{ini,N_{grad}}}{N_{iter,xploit}}, \tag{5}$$

The N_{grad} gradients are designated such that Eq. (6) is satisfied.

$$\left|grad_1\right| > \left|grad_2\right| > \left|grad_3\right| \cdots > \left|grad_{N_{grad}}\right|, \tag{6}$$

For the kth negative gradient, $k = 1, 2, \ldots, N_{grad}$, the $w_k(t)$ at iteration, t, is given by Eq. (7).

$$w_k(t) = grad_k \times t + w_{ini,k}, \tag{7}$$

Figure 2 provides the pseudocode of the MG-PSO algorithm. In the exploration and exploitation stages, using different negative gradients in each episode satisfies the following steps.

Step #1: The m explorers can discover a new neighborhood within a d-dimensional search area.

Step #2: The best exploiter can prevent the m exploiters from falling into a local minimum.

Step #3: The diversity in negative gradients boosts the capability of the local search of m exploiters to obtain an optimum solution.

Step #4: The guides $G_{pers,i}$ and G_{best} are used to update the velocity vector $V_i(t)$ (Figure 2). The conflict between the two guides leads to a loss of balance between the global and local search processes. However, in the MG-PSO algorithm, the conflict is eliminated using the two stages with different negative gradients.

Step #5: The combination of the m explorers and m exploiters balances the global and local search processes.

Step #6: The variables c_1 and c_2 [47]–[49] are acceleration coefficients for the m particles with positive and real numbers with a range of [1, 2] (Fig. 2). The variables $r_1(t)$ and $r_2(t)$ [47]–[49] are created randomly within the range of [0, 1] with uniform distribution (Fig. 2).

G. DETERMINING THE DFs OF RESIDENTIAL DWELLINGS JOINED TO THE LOW-VOLTAGE 0.415 kV DISTRIBUTION FEEDER

The DF of residential dwellings is an essential part of the plan, design, and future expansion of DPGs [7], [20], [50], [51]. Electrical design engineers use the DF to estimate the maximum kW demand for selecting the main distribution feeder size. The 24 h maximum kW demands by residential dwellings do not coincide and show diversity. This diversity reduces the maximum kW demand of the residential dwellings joined to the same low-voltage 0.415 kV distribution feeder.

To achieve the objective of this investigation, we assume that the maximum kW demand of each residential dwelling is P. The P for N number of residential dwellings is, $P_i = P_1, P_2, \ldots, P_N, (i = 1, 2, \ldots, N)$.

The sum of individual residential dwelling maximum kW demands is calculated by using Eq. (25).

$$P_{measured,consumers} = \sum_{i=1}^{N} P_i \tag{25}$$

The maximum kW demand measured from residential dwellings that are joined to the same low-voltage 0.415 kV distribution feeder is indicated by $P_{measured,feeder}$. Thus, the DF for N number of residential dwellings can be calculated using Eq. (2) [20], [52]:

$$DF = \frac{P_{measured,consumers}}{P_{measured,feeder}} \tag{26}$$

Begin MG-PSO algorithm

Let $f(x)$ be the objective function to be minimized

Select $N_{iter}, N_{grad}, w_{ini,k}, w_{fin,k}, k = 1, 2, \ldots, N_{grad}$

Determine $N_{iter,xplore}$ and $N_{iter,xploit}$ using Eqs. (1) and (2), respectively

Initialization: Iteration, t = 0

The velocity and position vectors of the ith particle ($i = 1, 2, \ldots, m$) in d-dimensional space are

$V_i = [v_{i1}, v_{i2}, \ldots, v_{id}]$ (8)

$X_i = [x_{i1}, x_{i2}, \ldots, x_{id}]$ (9)

For $i = 1, 2, \ldots, m$

Initialize $V_i(0)$ and $X_i(0)$

Initialiaze $G_{pers,i}(0) = X_i(0)$ (10)

Evaluate $f(x)$ using $X_i(0)$

End i loop

$f(G_{best}(0)) = min\{fG_{pers,i}(0)\}$

Obtain $G_{best}(0)$ corresponding to minimum $fG_{pers,i}(0)$ (11)

Begin the stage of exploration

for $k = 1, 2, \cdots, N_{grad} - 1$ **(begin of episode** k**)**

Determine $grad_k$ using Eq. (4)

for $t = 1, 2, \ldots, N_{iter,xplore}$

Determine $w_k(t)$ using Eq. (7)

for $i = 1, 2, \ldots, M$

Update the particle's velocity and position vectors as follows:

$V_i^k(t) = w_k(t)V_i^k(t-1) + c_1r_1(t)[G_{pers,i}^k(t-1) - X_i^k(t-1)] + c_{12}r_2(t)[G_{best}^k(t-1) - X_i^k(t-1)]$ (12)

$X_i^k(t) = X_i^k(t-1) + V_i^k(t)$ (13)

Evaluate the particle's performance by substituting Eq. (13) in $f(x)$

Update $G_{pers,i}$ as follows:

$G_{pers,i}^k(t) = \begin{cases} X_i^k & if \quad f(X_i^k(t) \le f(G_{pers,i}^k(t-1) \\ G_{pers,i}^k(t-1) & Otherwise \end{cases}$ (14)

Obtain $f(G_{pers,i}^k(t))$

end i loop

Obtain $f(G_{best}^k(t))$ as follows:

$f\left(G_{best}^k(t)\right) = min\{fG_{pers,i}^k(t))\}$ (15)

Obtain $G_{best}^k(t)$ corresponding to $f(G_{best}^k(t))$

end t loop

Obtain $G_{best}^k(N_{iter,xplore})$ and $f(G_{best}^k(N_{iter,xplore})$

end k loop (end of episode k)

for $k = 1, 2, \ldots, N_{grad} - 1$

Obtain $f(G_{best}^k(N_{iter,xplore}))$

end k loop

$f(G_{best,xplore}) = min\{f(G_{best}^k(N_{iter,xplore}))\}$ (16)

Obtain $BEST(G_{best,xplore})$

Obtain new search space (neighborhood) by taking $CELL$ and $FLOOR$ of each element of $BEST(G_{best,xplore})$

End exploration stage

Begin the stage of exploitation

Use the new search space

Initialization: Iteration, t = 1

for $i = 1, 2, \ldots, M$

$V_i(1) = V_1(N_{iter,xplore})$ corresponding to $BEST(G_{best,xplore})$ (17)

$X_i(1) = X_1(N_{iter,xplore})$ corresponding to $BEST(G_{best,xplore})$ (18)

$G_{pers,i}(1) = G_{pers,i}(N_{iter,xplore})$ corresponding to $BEST(G_{best,xplore})$ (19)

end i loop

$G_{best,xploit} = BEST(G_{best,xplore})$ (20)

Determine $grad_{N_{grad}}$ using Eq. (5)

Update

for $t = 2, 3, \ldots, N_{iter,xploit}$

Determine $w_k(t)$ using Eq.(7)

for $i = 1, 2, \ldots, M$

Update the particle's velocity and position vectors as follows: $V_i(t) = w_{N_{grad}}(t)V_i(t-1) + c_1r_1(t)[G_{pers,i}(t-1) - X_i(t-1)] + c_1r_1(t)[G_{best,xploit}(t-1) - X_i(t-1)]$ (21)

$X_i(t) = X_i(t-1) + V_i(t)$ (22)

Evaluate the particle's performance by substituting Eq. (22) in $f(x)$

Update $G_{pers,i}(t)$ as follows:

$G_{pers,i}(t) = \begin{cases} X_i(t) \; if \; f(X_i(t) \le f(G_{pers,i}(t-1) \\ G_{pers,i}(t-1) \quad Otherwise \end{cases}$ (23)

Obtain $f(G_{pers,i}(t))$

end i loop

Obtain $f(G_{best,xploit}(t))$ as follows:

$f(G_{best,xploit}(t)) = min\{f(G_{pers,i}(t))\}$ (24)

Obtain $G_{best,xploit}(t))$ corresponding to $f(G_{pers,i}(t))$

end t loop

Optimum solution = $G_{best,xploit}(N_{iter,xploit})$

Optimum value = $f(G_{best,xploit}(N_{iter,xploit}))$

End exploitation stage

End MG-PSO algorithm

FIGURE 2. Pseudocode of the natural learning mechanism of the MG-PSO algorithm.

The DF is usually greater than or equal to one. When the $DF = 1$, that is, a low DF, poor diversity exists among residential dwellings. Thus, the sum of individual maximum kW demands equals the maximum kW demand of the whole system. Subsequently, the cable size increases to meet the total maximum kW demand. However, when the $DF > 1$, the sum of individual maximum kW demands becomes greater than the maximum kW demand for the whole system. Subsequently, the cable size decreases to meet the total maximum kW demand.

In this approach, we use the MG-PSO algorithm as an optimization tool to model two objective functions, i.e., the *DFs* of N number of residential dwellings and the maximum kW demand of N number of residential dwellings, for three residential neighborhoods.

The first objective function is the *DFs* of N number of residential dwellings (Eq. (27)).

$$DF = a_1 \times e^{-\left(\frac{N-b_1}{c_1}\right)^2} + a_2 \times e^{-\left(\frac{N-b_2}{c_2}\right)^2} \quad (27)$$

where a_1, b_1, c_1, a_2, b_2, and c_2 are unknown and constant parameters. N is the number of residential dwellings. Eq. (27) is a second-order equation, and the MG-PSO algorithm is used to find the constant and unknown parameters a_1, b_1, c_1, a_2, b_2, and c_2 imposed on the first objective function from the obtained data shown in Figure 1.

The MG-PSO algorithm is applied to the three residential neighborhoods, (i.e., Al-Hurriya City, Al-Mustansiriya and Al-Jadriya) to obtain the DF for N number of dwellings as shown in Eqs. (28) – (30).

Al-Hurriya City:

$$DF = 1.252 \times e^{-\left(\frac{N-54.14}{92.29}\right)^2} + 0.1328 \times e^{-\left(\frac{N-5.246}{17.33}\right)^2} \quad (28)$$

Al-Mustansiriya:

$$DF = 1.25 \times e^{-\left(\frac{N-56.71}{91.35}\right)^2} + 0.243 \times e^{-\left(\frac{N+5.479}{27.78}\right)^2} \quad (29)$$

Al-Jadriya:

$$DF = 1.252 \times e^{-\left(\frac{N-53.68}{92.29}\right)^2} + 0.044 \times e^{-\left(\frac{N+4.945}{17.69}\right)^2} \quad (30)$$

H. DETERMINING THE MAXIMUM kW LOAD DEMAND OF RESIDENTIAL DWELLINGS JOINED TO THE LOW-VOLTAGE 0.415 kV DISTRIBUTION FEEDER

As mentioned previously, the residential dwellings joined to the same 0.415 kV distribution feeder consume different maximum kW demands at the same time due to DF. In this section, a quantitative relationship is established between the maximum kW demand and N number of dwellings.

Equation (31) shows the second objective function and is also applied to determine the maximum kW demand $P_{calculated,feeder}$ of the existing N number of residential dwellings:

$$P_{calculated,feeder} = g_1 \times e^{-\left(\frac{N-h_1}{n_1}\right)^2} + g_2 \times e^{-\left(\frac{N-h_2}{n_2}\right)^2} \quad (31)$$

where g_1, h_1, n_1, g_2, h_2, and n_2 are unknown and constant parameters, and N is the number of residential dwellings. Eq. (31) is a second-order equation, and the MG-PSO algorithm is used to find the constant and unknown parameters g_1, h_1, n_1, g_2, h_2, and n_2 imposed on the second objective function from the obtained data shown in Figure 1.

The MG-PSO algorithm is applied to obtain a set of experimental equations to describe the maximum kW demand $P_{calculated,feeder}$, of the residential dwellings in all three residential areas for N number of dwellings, as shown in Eqs. (32 – 34).

Al-Hurriya City:

$$P_{calculated,feeder} = 61.86 \times e^{-\left(\frac{N-64.17}{39.08}\right)^2} + 14.66 \times e^{-\left(\frac{N-18.41}{19.40}\right)^2} \quad (32)$$

Al-Mustansiriya:

$$P_{calculated,feeder} = 72.58 \times e^{-\left(\frac{N-58.45}{43.26}\right)^2} + 17.22 \times e^{-\left(\frac{N-17.24}{13.58}\right)^2} \quad (33)$$

Al-Jadriya:

$$P_{calculated,feeder} = 74.69 \times e^{-\left(\frac{N-58.91}{41.13}\right)^2} + 20.83 \times e^{-\left(\frac{N-17.77}{14.89}\right)^2} \quad (34)$$

The two sets of Equations (28)–(30) and (32)–(34) can help design engineers in Iraq in planning, designing, and determining kW power demand through selecting the optimum number of residential dwellings that can be joined to the low-voltage 0.415 kV distribution feeder.

III. SIMULATION AND DISCUSSION

This section discusses the research study simulation results and provides a case study of Al-Hurriya City to clarify this investigation.

A. RELATIONSHIP BETWEEN DF AND N NUMBER OF DWELLINGS

The measured results from the 3-ph kW smart meters are handled using the Matlab software package 2015-A on a personal computer, which has an Intel (R) Core (TM), CPU running with a RAM of 4 GB, and 2.1 GHz processor speed. The operating system is 64-bit with Windows 7 Pro.

The measured data shown in APPENDIX B are treated using the MG-PSO algorithm. The MG-PSO algorithm is executed with the following parameters.

1) Number of particles $m = 20$ particles;
2) Number of runs = 25 independent runs;
3) Total number of iteration, $N_{iter} = 500$ iterations;
4) The total number of negative gradients, $N_{grad} = 3$; two negative gradients for the exploration stage and one for the exploitation stage using the trial and error method;
5) Number of dimensions, $d = 2$;
6) Upper and lower boundaries are $[-100, 100]$ and $[-100, 100]$, respectively.

The other specific parameters are shown in Table 1.

In this section, the residential dwellings load profile characteristics are used to determine the relationship between the measured and calculated *DFs* for N number of dwellings

TABLE 1. Parameters Used in the MG-PSO Algorithm.

Parameters	exploration stage		exploitation stage
	$k = 1$	$k = 2$	$k = 3$
m	20	20	20
N_{run}	25	25	25
c_1, c_2	2.05	2.05	2.05
γ	0.3	0.3	0.3
N_{iter}	150	150	350
$w_{ini,k}$	0.80	0.80	0.35
$w_{ini,k}$	0.10	0.20	0.20
$grad_k$	- 4.66×10-3	- 3.99×10-3	- 4.28×10-4

in the three residential neighborhoods (Al-Hurriya City, Al-Mustansiriya and Al-Jadriya). Figure 3 shows these results.

The measured *DFs* of *N* number of dwellings is shown in blue color, whereas the calculated *DF* of *N* number of dwellings is represented in red color (Fig. 3). The MG-PSO algorithm can be used to estimate the *DF* of *N* number of residential dwellings through the congruence between the measured *DF* and calculated *DF* results (Fig. 3).

Residential dwellings' load characteristics in three neighborhoods in Baghdad City exhibit a linear relationship with exponential characteristics (Fig. 3). The start and end of the linear characteristics are when $N = 3$ and $N = 50$, respectively. Subsequently, when the *N* number of dwellings is more than 50, the *DF* becomes approximately constant.

Thus, when *N* increases to 50, the *DF* increases gradually. Then, when *N* exceeds more than 50, the *DF* becomes constant at approximately ∼1.25. Thus, the maximum diversity satisfied by the residential dwellings is 1.25 when the number of dwellings joined to the 0.415 kV distribution feeder is between 50 and 60. This result means that adding residential dwellings to the distribution feeder is not ideal because such action will eliminate the diversity of residential dwellings.

The study's outcomes above provide useful technical references for electrical design engineers in Iraq to update the connection grids of low-voltage 0.415 kV distribution feeders in Baghdad City by setting 50 residential dwellings to each low-voltage 0.415 kV distribution feeder. The maximum permissible *DF* obtained for Baghdad residential dwellings is 1.25.

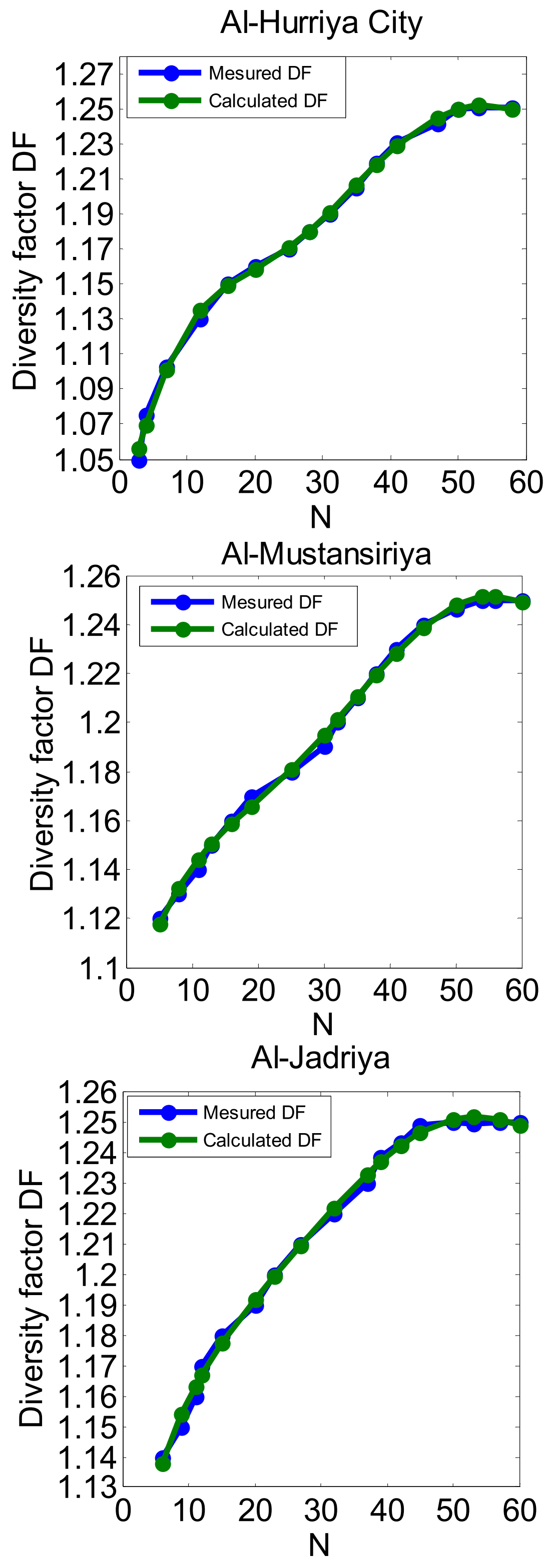

FIGURE 3. Measured and calculated experimental relationships between the *DF* and *N* number of residential dwellings.

B. RELATIONSHIP BETWEEN MAXIMUM KW DEMAND AND N NUMBER OF DWELLINGS

Figure 4 shows the second quantitative relationship between the measured and calculated maximum kW demand for *N* number of residential dwellings in three residential neighborhoods in Baghdad City (Fig. 4).

The measured maximum kW demand $P_{measured,feeder}$ of *N* number of dwellings is shown in blue color, whereas the calculated maximum kW demand $P_{calculated,feeder}$ of *N* number of dwellings is represented in red color (Fig. 4).

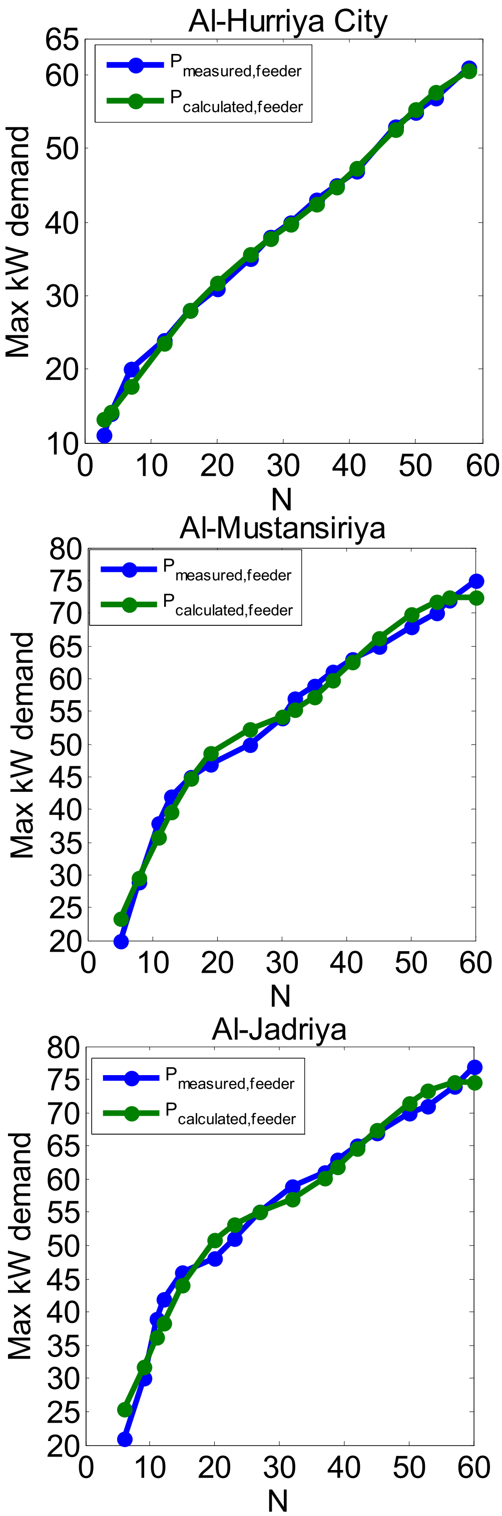

FIGURE 4. Measured and calculated experimental relationships between the maximum kW demand on the low-voltage 0.415 kV distribution feeder and *N* number of residential dwellings.

The MG-PSO algorithm can be used to estimate the $P_{calculated,feeder}$ of N number of dwellings through the congruence between $P_{measured,feeder}$ and $P_{calculated,feeder}$ results.

The relationship between the measured and calculated maximum kW demand exhibits linear characteristics. Thus,

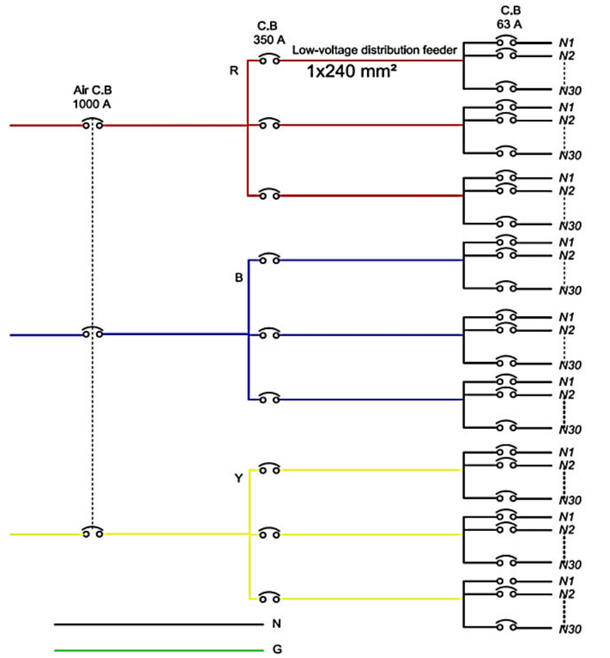

FIGURE 5. Single-Line diagram of the existing Iraq DPG connection of the 0.145 kV low-voltage distribution feeder.

when N number of dwelling increases to the maximum, the kW demand also increases. However, in this study, the maximum allowable N number of residential dwellings is between 50 to 60 residential dwellings.

These quantitative relationships can help electrical design engineers of DPG in Iraq to select the maximum allowable kW demand setting for the low-voltage 0.415 kV distribution feeder based on the maximum N number of dwellings shown in Fig. 4 because the *DF* among residential dwellings is available, and residential dwellings consume different amounts of electricity simultaneously.

C. AL-HURRIYA CITY NEIGHBORHOOD: A CASE STUDY

The experimental Equations (28)–(30) and (32)–(34) used to obtain the *DFs* and maximum kW demands of N number of residential dwellings, respectively, in three residential neighborhoods in Baghdad City are used in Al-Hurriya City as a case study.

Figure 5 shows a single-line diagram of the existing grid connection of the low-voltage 0.145 kV distribution feeder. The low-voltage side of the 630 kVA DT is joined to nine low-voltage 0.415 kV distribution feeders through 1000 A air circuit breaker (CB). The size of each 0.415 kV distribution feeder is 1×240 mm^2 with a maximum phase current $I_{ph} =$ 330 A fixed in the initial design stage. Table 2 provides other technical specifications.

The comparison experiments between the initial design stage and this current study's stage are classified as follows.

1) *In Terms of Planning and Designing:* The current low-voltage DPG in Al-Hurria City has been designed by Siemens Company since 1983. The number of residential dwellings joined to each low-voltage 0.415 kV

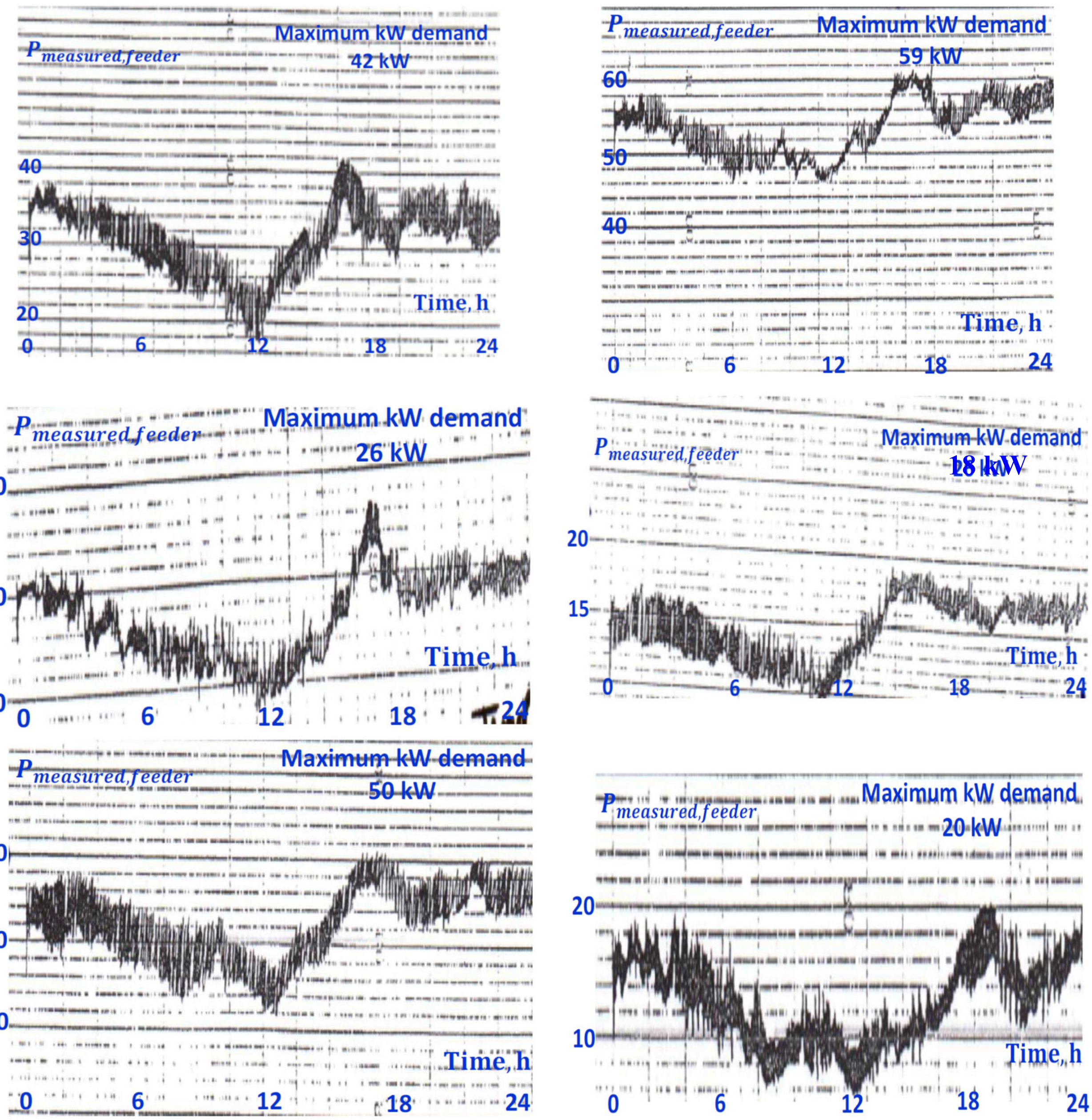

FIGURE 6. Different daily load curves of residential dwellings joined to the 0.415 kV distribution feeders.

distribution feeder is $N = 30$. By applying Eq. (28) or Fig. 3 for Al-Hurriya City when selecting $N = 30$ based on the existing grid connection, the DF is $\sim$1.19. In addition, by applying Eq. (32) or Fig. 4 for Al-Hurriya City, the maximum kW demand, $P_{calculated,feeder} = 38$ kW/phase. Thus, each low-voltage 0.415 kV distribution feeder is loaded by **186.3 A/phase.**

However, in this research, we find that by applying Eq. (28) or Fig. 3 for Al-Hurriya City when selecting $N = 50$, the DF is $\sim$1.25, that is a maximum DF can be reached. In addition, by applying Eq. (32) or Fig. 4 for Al-Hurriya City, the maximum kW demand, $P_{calculated,feeder} = 55$ kW/phase. Then, each low-voltage 0.415 kV distribution feeder is loaded by **270 A/ph**. Thus, each low-voltage 0.415 kV distribution feeder can be loaded with **50** dwellings instead of the previously used number (**30**).

2) *In Terms of Power kW Demand Savings:*
The number of DTs used in Al-Hurriya City is 113 units. The total number of distribution feeders is $113 \times 9 = 1017$. The savings in power due to the difference between the initial design stage and that of the current research study is $((270 - 186.83) \times 240 \times 0.85 \times 1287 =$ **17.25 MW**. This finding means that **17.25 MW** power is unexploited and can be used as a reserve.

TABLE 2. Technical Specifications of the 0.415 kV Low-Voltage Distribution Feeder in Baghdad City.

Type	NAYY
Maximum temperature	160 °C
Ambient temperature	Buried (underground) 20 °C
Maximum current (I_{ph})	330 A
Insulation	PVC
Nominal tension (rated voltage)	1 kV
Power factor	0.85
Nominal frequency	50 HZ
System	Single-core 1×240 mm^2, copper conductor
Nominal voltage in low voltage side	415/240 V, 3-phase, 4-wire with neutral being solidly earthed.

3) *In Terms of Operating Cost Savings:*
The operating cost for 1 MWh in the utilization side is \$40. The power reserve for one hour, as mentioned in point 2, is 17.25 × 40 = **\$690 US**. Subsequently, the savings in operating cost reaches **\$16560** in a day.

In addition, from the above outcomes, several technical facts are established for the residential dwellings' load profile for the electricity modeling in Baghdad City.

1) Change in the load of residential dwelling characteristics. These characteristics include lifestyle, economical operation of air-conditioning and heating systems using smart energy management systems, the number of family members, income, and types of electrical appliances used;
2) Essential household activities are related to electrical appliances usage for 24 h;
3) Environmental changes, such as temperature degree and humidity level;
4) Numerous residential dwellings that use diesel engines as additional sources of electricity, which helps mitigate the burden on DPGs;
5) Using particular types of economical lighting (e.g., LED) and smart sensors that can reduce the maximum kW load demand.

This study's outcomes provide useful technical references for electrical design engineers in Iraq to update the connection grids of low-voltage 0.415 kV distribution feeders in Baghdad City to achieve economic benefits. They can also build DPG systems in Iraq by planning, designing, and estimating kW load demand in the future.

TABLE 3. Recodes of the kW Demands for *N* Number of Residential Dwellings Joined to the 0.415 kV Feeders During the Summer Peak Demand Period.

No.	Neighborhood	*N* residential dwellings	$P_{measured,feeder}$ (kW)	$P_{measured,consumers}$ (kW)
1	Al-Hurriya City	3	11	11.5500
		4	14	15.0600
		7	20	22.0500
		12	24	27.1200
		16	28	32.2080
		20	31	35.9600
		25	35	40.9500
		28	38	44.8280
		31	40	47.5850
		35	43	51.8000
		38	45	54.8720
		41	47	57.8510
		47	53	65.8000
		50	55	68.7500
		53	57	71.2850
		58	61	76.2700
2	Al-Mustansiriya	5	20	22.4000
		8	29	32.7696
		11	38	43.3191
		13	42	48.2989
		16	45	52.2000
		19	47	54.9898
		25	50	59.0000
		30	54	64.2600
		32	57	68.4000
		35	59	71.3895
		38	61	74.4192
		41	63	77.4900
		45	65	80.5995
		50	68	84.7500
		54	70	87.4962
		56	72	89.9976
		60	75	93.7500
3	Al-Jadriya	6	21	23.9400
		9	30	34.4997
		11	39	45.2397
		12	42	49.1400
		15	46	54.2790
		20	48	57.1200
		23	51	61.1984
		27	55	66.5496
		32	59	71.9776
		37	61	75.0286
		39	63	78.0390
		42	65	80.8290
		45	67	83.7000
		50	70	87.5050
		53	71	88.7326
		57	74	92.5053
		60	77	96.2580

D. MG-PSO ALGORITHM WITH SEVERAL FITNESS MEASURES

The MG-PSO algorithm efficiently handles different complex real-world problems in science and engineering, including power systems problems in terms of accuracy, reliability, stability, consistency, convergence rate, and robustness as proved in Section 5 (5.1 – 5.6) [43] and research papers [44]–[46].

IV. CONCLUSION

A new approach for electricity modeling and study of Baghdad City residential dwellings' load profile characteristics was proposed. Three residential neighborhoods in Baghdad City with 1500 residential dwellings have been selected. The MG-PSO algorithm was applied as an optimization tool to establish experimental relationships between the maximum kW demand and *DF* for *N* number of residential dwellings joined to the same low-voltage 0.415 kV distribution feeder. Results demonstrated that each 0.415 kV distribution feeder can be loaded with 50 dwellings instead of 30 due to the diversity among residential dwellings. Although several technical facts about the Baghdad City residential dwellings' load profile characteristics have been established, residential dwellings monitored with a continuous domain of readings remain a significant limitation in the study of residential dwellings. The current research results provide essential details for electrical design engineers in Iraq to build DPGs in the future and help them achieve economic benefits in planning, designing, and saving power kW demand, and operating cost.

APPENDIX A

See Fig. 6.

APPENDIX B

See Table 3.

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