Introducing newly developed Nomadic People Optimizer (NPO) algorithm to find optimal sizing of a hybrid renewable energy

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Abstract

In this work, the main objective the provision of electric supply to a residential complex located in a remote area in Iraq (Thi-Qar) that has no access to electricity grid. This study relied on the Nomadic People Optimizer (NPO) for the Multi-objective design of a grid independent PV/Wind/Battery hybrid energy system. The hybrid systems considered in this study consist of a photovoltaic array, wind turbine, and battery storage. The hybrid system optimized the electricity supply of a residential complex with 30 houses in Thi-Qar which is located in southern Iraq on latitude 31.06° and longitude 46.26°. The major purpose of this optimization is to find optimal sizing of renewable energy with battery storage to minimizing Total Life Cycle Cost (TLCC), this is an economic aspect, which in turn reduces the cost of energy. Second objective is minimizing Total Dump Energy (TDE) with continuous provide the load by electricity (Reliability as constrained) through life cycle of project for a 25 years. The data used in this study, such as solar radiation, wind speed, and temperature was collected from weather forecast in Thi-Qar for every hour over the course of a full year; the electrical demand was collected from Thi-Qar Electricity Distribution Directorate for the same housing complex and the same number of houses in an area equipped with electricity. Also, the prices of the system components, cost of maintenance, and cost of fuel were collected from Thi-Qar Iraq market.

Keywords: Renewable Energy, Solar Energy, Wind Energy, Nomadic People Optimizer, Optimization.

1. Introduction

Population increase, industrial and suburban developments are contributing to daily increase in energy demand beyond the level that can be effectively compensated by the available energy sources, thereby leading to energy shortage in some areas [1], [2]. Conventional energy sources are used in the large-centralized power generation systems and these sources are not just limited, they are also scarcely available on earth's crust. Furthermore, these conventional energy sources, such as fossil fuels are associated with negative environmental impact due to the high level of CO2 emission which contributes to global warming [3]. Consequently, many countries have over the years began the exploration of renewable energy sources as a source of clean energy that is inexhaustible and environmentally-friendly. These clean energy sources also help to minimize global warming, reduce over dependence on the fossil fuels, and minimize air pollution [4]. Conventional generators are used in the remote areas for electricity generation and these generators depend on fossil fuels to operate and are most times relatively more
expensive; they also release an appreciable amount of CO₂. Other sources of challenges are the storage and transportation of such fuels to the rural areas where they are used to generate electricity. Hybrid renewable energy (HRE) systems are emission-less energy systems that consist of wind and solar which serves as new solutions to electricity-related problems in the remote areas that are not connected to the power grid [5], [6]. The Earth daily receives much energy from the sun [7], [8]; the amount of energy emitted by the sun per minute is enough to address global energy needs for one year, meaning that in one day, the amount of energy released by the sun can serve the current global population for 27 years. In fact, "the amount of solar energy released by the sun in 3 days is equivalent to the energy stored in all fossil energy sources.” Considering this huge amount of energy from the sun, scientists have been devising ways of trapping this energy since the 18th century by building several forms of solar thermal collectors. Horace de Saussure, a Swiss scientist, invented the first ever solar thermal collector [9]. This was followed by the work of Alexander Edmond Becquerel, a French physicist who in the year 1839 invented the technology for direct energy production from solar energy. This marked the beginning of the present-day solar cell technology [10], [11]. One of the renewable energy projects that is attracting global attention is wind energy projects as they are currently attracting more interest globally compared to other renewable and conventional energy sources [12]. The increase in the number of wind energy projects is attributed to its low production cost and technology advancement when compared to the conventional and other renewable energy sources. Iraq is currently facing energy crisis which has driven the search for alternative and successful energy sources. As the country strives towards harnessing alternative energy sources, wind energy potential is seriously being considered; however, appropriate environmental assessments are necessary to ensure appropriate selection of the sites for wind turbines installation. The wind energy potential of any specific site is normally assessed using wind statistical models [5]. Over the past few years, wind energy projects have increased tremendously; Since 1995, the global installed wind energy capacity has increased from 1.29 GW in 1995 to about 370 GW by 2015 [13], [14]. According to the U.S. Energy Information Administration’s statistics of the U.S. renewable energy supply, the total energy generated by renewable energy resources are in the trend of increasing. Meanwhile, wind and solar energy are rapidly providing a greater percent of the total renewable energy supply each year [15]. This study employs a novel swarm-based metaheuristic called “Nomadic People Optimizer (NPO)” which relies on the pattern of life of nomads. The NPO simulates the life pattern of the nomads during their search for sources of life (such as grass and water for their animals); the algorithm also captures how the nomads have lived for several years and how they have been continuously migrating from place to place in search of comfort. This algorithm has a peculiar ability of achieving the right balance between exploration and exploitation and does not rely on any control parameters to control the search process. [16].

2. The problem of optimal sizing

2.1 System construction and modeling

In this research, the proposed HES (Hybrid Energy System) consists of four components, i.e., the PV system, wind turbine system, (Bidirectional inverter & MPPT) (Maximum power Point Tracking) and batteries. The block diagram of the hybrid system considered in this paper is as shown in Fig. 1. The DC bus combines the output/input of the PV panels and the battery bank while the AC bus combines the output/input of the wind turbine and the AC load.
2.2. Preference of energy sources

Hybrid renewable energy sources may feed the load when it is greater or equal to load & the loss in inverter. The excess of energy (if any) may be stored in batteries as charge operation. If the renewable energy sources less than load & loss in inverter and state of charge of battery is greater of minimum, the battery storage will discharge to cover shortage energy that provide load. The load data collected from Thi- Qar Electricity Distribution Directorate for the same housing complex and the same number of houses in an area equipped with electricity for one year for all hours.

To clarify more, the average load for 12 days of year (everyone day represent one month) was taken as shown in fig 2.

![Average load for 12 days of year](image)

**Fig. 2 Average load for 12 days of year (every one day represent one month)**

From fig 2. Note that load increase in summer season and reduce in winter season, where greatest load is in July month and the least load in December month. Where peak power equal 180 kW.

2.3. Mathematical modeling of system components
2.3.1. PV System

The performance of solar panels is highly influenced by weather conditions, panel temperature, and solar radiation. The output power of a PV system at time t can be calculated using [17].

\[ P_{PV}(t) = PR \times RF \times \left( \frac{G}{G_{STC}} \right) \times (1 + B(T_c - T_{STC})) \]  

(1)

Where \( P_{PV}(t) \) is the output power of a solar cell at time (t) [W], \((PR)\) is rated power of solar cell [W], \((G)\) is Solar radiation [W/m²], \((G_{STC})\) is Solar radiation at standard test conditions [W/m²], \((T_c)\) is Cell Temperature[°C], \((T_{STC})\) is Cell temperature of a solar panel at standard test condition [°C], \((B)\) is temperature coefficient of \((P_{Max})\)and \((RF)\) is module derating factor.

cell temperature can determine by following equation[18]:

\[ T_c = T_a + \left[ \left( \frac{NOCT-20}{800} \right) \times G \right] \]  

(2)

\( NOCT \) is the normal operating cell temperature of a solar panel [°C], \( T_a \) is air temperature

The datasheet of solar cell that used in this study shown in Table (1).

| Type                        | Mono Crystalline                  |
|-----------------------------|-----------------------------------|
| Module                      | GSUN-60M                          |
| Maximum Power \((P_{Max})\) | 310 W                             |
| Open Circuit Voltage \((VOC)\) | 40.1V                            |
| Short Circuit Current \((ISC)\) | 9.82A                            |
| maximum Power Current \((IMP)\) | 9.51A                            |
| Module efficiency %        | 19.09 %                           |
| Temperature Coefficient Of \((ISC)\) | +0.039%/°C                     |
| Temperature Coefficient Of \((VOC)\) | -(0.307)%/°C                |
| Temperature Coefficient Of \((P_{Max})\) | -(0.423)%/°C              |

**STC**  
Irradiance 1000 \((W/m^2)\), Cell temperature 25 C, Spectrum Am 1.5.

| \( NOCT \)     | 45 ± 2                          |
|----------------|---------------------------------|
| Initial Capital Cost | 188 $                      |
| Replacement Cost Through Life Span Project | 0                    |
| Maintenance Cost  | 0                               |
| Life Cycle       | 25 Years                       |
| Average reduce in efficiency through 25 years \((RF)\) | 91 %                           |

2.3.2 Wind Turbine System

The datasheet of wind turbine that used in this study shown in Table (2) and fig.3.[19]

| Type                        | Mono Crystalline                  |
|-----------------------------|-----------------------------------|
| Module                      | GSUN-60M                          |
| Maximum Power \((P_{Max})\) | 310 W                             |
| Open Circuit Voltage \((VOC)\) | 40.1V                            |
| Short Circuit Current \((ISC)\) | 9.82A                            |
| maximum Power Current \((IMP)\) | 9.51A                            |
| Module efficiency %        | 19.09 %                           |
| Temperature Coefficient Of \((ISC)\) | +0.039%/°C                     |
| Temperature Coefficient Of \((VOC)\) | -(0.307)%/°C                |
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| Initial Capital Cost | 188 $                      |
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| Maintenance Cost  | 0                               |
| Life Cycle       | 25 Years                       |
| Average reduce in efficiency through 25 years \((RF)\) | 91 %                           |
| Manufacturer       | Sunning power |
|--------------------|---------------|
| Power Rated        | 5 kW          |
| Power Maximum      | 5.1 kW        |
| Wind speed (Start-up) | 1.50 m/s    |
| Wind speed (Cut-in) | 3.0 m/s       |
| Wind speed (Cut-out) | 20.0 m/s     |
| wind speed (Rated) | 12.0 m/s      |
| Height (hub)       | 15.0 m        |
| Cycle life         | 20.0 years    |
| Initial capital cost | 3000 $      |
| Replacement cost   | 3000$         |
| Maintenance cost   | 10 $/year     |

![Fig.3. Curve of the wind turbine power output](image)

The power output of the WT at time \( t \) can be calculated using [19]–[22]:

\[
P_{WT}(t) = \begin{cases} 
0 & \text{if } V(t) \leq V_{cin} \text{ or } V(t) \geq V_{cout} \\
 Pr \times \left( \frac{V(t) - V_{cin}}{V_{r} - V_{cin}} \right) & \text{if } V_{cin} \leq V(t) \leq V_r \\
 Pr & \text{if } V_r \leq V(t) \leq V_{cout} 
\end{cases}
\]  

(3)

Where \( P_r \) represents the rated power of single WT, \( V(t) \) is the speed of wind at time \( t \), \( V_{cin} \) \( V_{cout} \) and \( V_r \) are the cut-in, cut-off, and rated wind speeds of the WT.

The hub height of the WT is 15 m; so, the wind speed at height 10 m is converted to wind speed at height 15 m using [23]:

\[
V(t) = V_{ref}(t) \times \left( \frac{h}{h_{ref}} \right)^{\frac{5}{3}}
\]  

(4)
Where $V(t)$ is the speed of wind at the designated height $h$, while the wind speed at a reference height is represented as $(V_{ref}(t))$.

2.3.3 Battery Storage

The datasheet of Battery that used in this study shown in Table (3)

| Battery Storage       | Description |
|-----------------------|-------------|
| Type of Battery       | Gel Battery |
| Description           | UKS Battery |
| Nominal Capacity (ah) | 200 ah      |
| Efficiency (%)        | >= 90%      |
| Self-discharge rate in one hour | $7 \times 26 \times 10^{-4}$ (W) |
| Initial Capital Cost  | 275 $       |
| Replacement Cost      | 275 $       |
| Maintenance Cost      | 0           |
| $C_{Max}$             | 2400 W      |
| No of charge-discharge cycle battery can give during it is entire life | |
| At 20 % DOD           | 3800 cycles |
| At 30 % DOD           | 2400 cycles |
| At 40 % DOD           | 1600 cycles |
| At 50 % DOD           | 1300 cycles |
| At 60 % DOD           | 1100 cycles |
| Expected Life in ideal float condition | 10 years |

2.3.3.1. State of charge of battery(SOC)

The $SOC$ is the charge quantity of the battery storage. $SOC(t)$ is the state of charge at time (t); it is bounded by $SOC_{min}$ and $SOC_{Max}: SOC_{min} \leq SOC(t) \leq SOC_{Max}$; Where $SOC_{min}$ is the minimum SOC of battery based on the depth of battery and is equal to $((1 - DOD) \times C_{Max})$; $SOC_{Max}$ is the maximum SOC of battery and is equal to $C_{Max}$. $C_{Max}$ is the nominal battery capacity (W).

2.3.4 Inverter

The inverter that used in this study is (Bidirectional inverter & MPPT) that connect between DC bus and AC bus to convert DC power to AC power to provide load and convert AC power to DC power to charge
battery and also work as max power point tracking (MPPT). The number of inverter required in system is
determine by equation: [24]

\[
N_{inv} = \frac{P_{G-Max}}{P_{Inv-Max}}
\]

(5)

where \(P_{G-Max}\) represents the maximum power generated of the hybrid system and \(P_{Inv-Max}\) is the
power maximum of the inverter. The data sheet of inverter that used in this study as shown in Table (4).

| Table 4 Bidirectional inverter datasheet |
|------------------------------------------|
| Model                  | MPI HYBRID SERIES |
| Rated Power            | 10000w            |
| Efficiency             | >=90%             |
| Output Frequency       | 50/60 HZ          |
| Initial Capital Cost   | 3367 $            |
| Maintenance Cost per year | 20 $/year      |
| Replacement cost through life span of project | 0 |
| Life cycle             | 25 years          |

3-The proposed algorithm

In this study used is a new swarm-based metaheuristic (Nomadic People Optimizer(NPO)) that mimics the
life pattern of nomads as they move around in search for sources of the life such as water and the grass for
their animal; the NPO also captures the way the nomads have live d and existed for several years and
keeps migrating continuously in search of comfort. The design of the NPO primarily based on the multi-
swarm approach as it is comprised of different clans and each clan has a clan leader (the best member of
the clan). Nomads are herders who spend the whole of their life moving from place to place with their
animals in search of natural life sources. The animals graze nearby water sources and in return serve as a
major source of food and other necessities (such as skin and wool) to their owners. The herders also rely
on the milk from the animals serve them their protein and calcium needs. Nomads does not live in a
particular environment for long and does not cultivate crops within their settlement since they normally
settle in an area for a short while. It could be nomads categorized to different kinds, such as Berbers,
Gypsy, and Bedouins. Development of the NPO adopted in this study was inspired by the Bedouins and
their lifestyle. The Bedouins comprise of the Sheikh family and the rest are considered normal families.
The position of a sheikh is often hereditary but in cases where there is conflict, a normal family can
contest for the position and it succeed, will become the new Sheikh. It is the duty of the sheikh as the clan
leader to determine where and when the families will move to ensure their survival; the sheik also
determines the pattern of positioning the normal families around the sheik’s family. The family tents are
normally distributed in a semicircular form around the tent of the Sheikh. The sheikh selects the families
that will go in search of a new suitable position; selected families are required to move randomly in
different directions and distances in search of the best location for resettlement. During the time of
conflict, it is the duty of the sheikh to settle the dispute among the clans; the differences can among the
clans can either be resolved in a peaceful way or through fights. The Bedouins spend their whole life
travelling with their animals in search of better location that will sustain their existence. The migrate
mainly during the summer and winter periods as slight territorial and climatic variations are exploited
using periodic or seasonal migrations between the winter and summer grazing zones [16]. Where flow chat of Nomadic People Optimizer (NPO) shown in fig (4)

**Fig. 4 Flowchart of NPO**

The proposed algorithm in this work is aimed at achieving optimal sizing of the number of each of the needed energy subsystems in the HES such that the total life cycle cost (TLCC) and total dump energy (DET) of the system are minimized over a service life of 25 years. A typical system configuration X is a row vector of positive integers of four elements \(x_1, x_2, x_3\) where each element represents the required number of energy subsystems in the HES. The row vector \(X\) is represented thus:

\[
X = [x_1 \ x_2 \ x_3]
\]

(6)

Where \(x_1\) = number of PV modules required, \(x_2\) = number of WT required, \(x_3\) = number of battery modules required. Where \(x_1, x_2, x_3 \geq 0\).

Objective function and constraints of the optimization function are given by.

Minimize \(Q(X^i) = [f(\text{Optimal}(\text{TLCC}, \text{DET}(X^i)))]\)

(7)

Constraints subject to:

\[
E_{Total}(t) \geq \frac{EL(t)}{eff_{inv}}
\]

(8)

Where \(E_{Total}(t)\) is the system’s total energy output at time \(t\), and is mathematically given as:

\[
E_{Total}(t) = x_1 \times E_{PV}(t) + x_2 \times E_{WT}(t) + x_3 \times E_{Batt}
\]

(9)
Where \( E_{PV}(t) \) is the PV output energy at time \( t \) (W h), \( E_{WT}(t) \) is the WT output energy at time \( t \) (W h), \( E_{Batt}(t) \) is battery storage output energy at time \( t \) (W h).

From equation (7) it is found that units not equal where life cycle cost total unit in dollar, while dump energy unit in watt or kW, hence, the units must be converted to the same unit to achieve optimization and the chosen unit for easy analysis is cost ($). For the dump total energy (W h), it was only considered for the RES. The conversion of the dump energy to a monetary value was done by computing the hourly contributions (%) of the PV and WT to the dump using their related energy costs for 25 years.

In this study used Weighting sum method (Multi-Objective) to minimize (TLCC) and (TDE) where used following equation:

\[
Optimal(TLCC,TDE) = W_1 \times TLCC(S) + W_2 \times TDE(W) \times COD \left( \frac{\$}{W} \right) \tag{10}
\]

Where \( Optimal(TLCC,TDE) \) is equation connected between Total Life Cycle Cost (TLCC) and Total Dump Energy (TDE), \((W_1,W_2)\) are Weights of (TLCC) and TDE that used in this study to minimize the objectives together and (COD) is percentage contributions of Solar cell and the Wind turbine to the dump were computed on hourly bases using their respective costs of energy through life cycle of project.

To initialize the algorithm, a cluster of configurations called a generation is first created, where the \( i^{th} \) generation, \( (G^i) \) consists of the possible solutions \( (j) \) that are competing towards meeting the objective of the algorithm. each family \( (X) \) consist of \( (x_1,x_2,x_3) \) that represent number of PV cell, WT and Battery Storage which are limited between minimum and maximum

Each Family (configuration) in a generation is subjected to the NPO’s objective function for the evaluation of its fitness for a period of 25 years.

The fitness of a Family (configuration) is dependent on the system’s TLCC and TDE

\[
Fitness of X^i = Q(X^i) = f( Optimal(TLCC,TDE(X)^i) \tag{11}
\]

Hence \( Optimal(TLCC,TDE(X^i)) \) are computed for each family (configuration) \( (X^i) \) The best Families are families with the minimum \( Optimal(TLCC,TDE) \).

### 3.1. Objectives of The Proposed Algorithm

#### 3.1.1 Minimizing Life Cycle Cost Total (TLCC)

\( TLCC \) is one of the objectives of the \( (NPO) \) it is total cost of the system through 25 years. The implemented \( LCCT \) in this study considered the total initial capital cost of the components of the system (PV system, wind turbines, batteries and inverter), and also include Total Replacement Cost of system component through 25 years and also include Total Maintenance Cost of system component through 25 years and is calculated by equation.

\[
TLCC = C_{Capital}T + C_{Rep}T + C_{Maint}T \tag{12}
\]
The Capital Cost of subsystem components is including Purchase cost, connection cost, cost of work, cost of operation, and all it takes to work in order for the system to work well. The Total Replacement Cost that used in this studying include Replacement Cost of components that used in the system through 25 years. The Total Maintenance Cost that used in this study include Maintenance Cost of components that used in the system through 25 years. Minimizing Life Cycle Cost Total lead to Minimizing Cost of Energy (\(\text{COE}\)) that given by following equation [25]

\[
\text{COE} = \frac{\text{TLCC}}{\text{useful energy produced by the system}}
\]

(13)

### 3.1.2 Minimizing Total Dump Energy (\(TDE\))

Dump Energy is one of the objectives of the (NPO). Dump Energy occur when there are Excess of Renewable Energy and \(\text{SOC}(t) = \text{SOC}_{\text{Max}}\). This condition is not desirable as there is energy wastage. The dump energy \(DE(t)\) can be calculated at any time \(t\) within the system’s lifecycle using:

\[
DE(t) = E_{\text{EX/Def}}(t)
\]

(14)

The Total Dump Energy through life cycle of studying (25 years) is given by equation:

\[
TDE = \sum_{t=1}^{n} DE(t)
\]

(15)

Where \((n)\) is Life Cycle of project in hours and equal (219000) h

Also continuous provide the load by electricity through Life Cycle of Project (25 years) as constrained.

### 3.2. Energy flow and balance

Renewable energy (RE) sources considered the primary source of energy in meeting the energy demand of users. The total available RE at time \(t\) is given as:

\[
E_{\text{Renw}}(t) = x_1 \times E_{\text{PV}}(t) + x_2 \times E_{\text{WT}}
\]

(16)

Since these sources depend on solar radiation and wind speed, there is a chance of energy deficit or excess \(E_{\text{EX/Def}}(t)\) and can be calculated using:

\[
E_{\text{EX/Def}}(t) = E_{\text{Renw}}(t) - \frac{EL(t)}{eff_{\text{inv}}}
\]

(17)

When \(E_{\text{EX/Def}}(t) > 0\) is implies a case of excess RE while \(E_{\text{EX/Def}}(t) < 0\) is a case of deficit RE. Charging of Battery is initialized when \(E_{\text{EX/Def}}(t) > 0\) and \(\text{(SOC}(t)\text{)}\) is less than the maximum \(\text{(SOC}(t) < \text{SOC}_{\text{Max}}\text{)}\). During charging, the SOC of the battery at time \(t\) (SOC \(t\)) is calculated using equation[20], [26]:

\[
\text{SOC}(t) = \text{SOC}(t-1) \times (1 - S) + E_{\text{EX/Def}}(t) \times eff_{\text{batt}}
\]

(18)
In case of deficit RE and the battery storage is above the battery’s minimum SOC \( E_{Ex/Def}(t) < 0 \) and \( SOC > \text{minimum} \), the battery power will be discharged to compensate for the deficit as follows:[20,26]:

\[
SOC(t) = SOC(t - 1) \times (1 - S) + E_{Ex/Def}(t)
\]  

(19)

Fig. 5 presents the flowchart of the operation of the proposed algorithm in this study. The block for energy source selection in Fig. 6 has been expanded in Fig. 6 for clarity.

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**Fig. 5. Flowchart of the optimization**
4. Results and discussion

In this study a New algorithm is used (Nomadic People Optimizer) (NPO) to find optimal sizing of system consist of energy source (PV system, wind turbine system, Battery storage) with number of inverter dependent on power maximum generated by the hybrid system and the power maximum of the inverter to minimizing Total Life Cycle Cost (TLCC), and Total Dump Energy (TDE) where used data of load solar radiation, wind speed and temperature for a period of a year. This is studying for 25 years. The results shown for 12 day of year (every one day represent of one month) for clarify.

Note: Take \( DOD = 60\% \times C_{Max} \), \( SOC_{min} = 40\% \times C_{Max} \), \( SOC_{Max} = C_{Max} \)

4.1 Optimal configuration

The proposed system in this study was implemented for a period of 25 years considering all energy sources to arrive at the optimal configuration that would match the load demand of the users while minimizing the Life Cycle Cost Total (TLCC), Dump Energy Total (TDE). The result of optimization was \( X = [2022 \ 52 \ 1553 \ ] \) (2022) PV cell, (52) wind turbine, (1553) battery storage with 64 inverter used to provide load by electricity. Considering this configuration, the behavior of the system for 12 days of a year (every one day represent average of one month) as shown in Fig.7.
Fig. 7. System behavior for optimal configuration \( (X = [2022 \ 52 \ 1553 \ ] ) \) with (64) inverter

Fig. 7 shows optimal sizing of Hybrid Supply System consists of (PV system, WT system, Battery system) with number of the inverter (64). The result of optimization when the algorithm run for 25 years to continuous provide the load by electrically for 25 years, where reliability of the system is (100\%) to reduce Total Life Cycle Cost \( (TLCC) \), Dump Energy Total \( (TDE) \).

The performances of optimal configuration for a 25-year lifecycle is shown in Table.5.

**Table.5. Performance of optimal configuration**

| configuration | \( TLCC \) (\( \$ \)) | \( TDE \) (\( \text{GWh} \)) | \( COE \) (\( \$/\text{kWh} \)) |
|---------------|------------------------|-------------------------|------------------|
| \( X = [2022 \ 52 \ 1553 \ ] \) | \( 2 \times 210554 \times 10^6 \) | 9.5117 | 0.1048506325 |

The table showed improvements in \( LCC \) and \( DE_{\text{Total}} \).

Fig. 8 showed the fitness of NPO in minimizing the objectives.
Fig. 8 showed that the algorithm succeeded in minimizing the \( TLCC \) and \( DET \).

5. Conclusions

This study presented the use of a new multi-objective optimization model for optimal sizing of a PV cell/wind turbine/battery HES. In this system, PV cells and wind turbines were adopted as the primary energy sources while a battery was adopted as an intermediary source of energy. The algorithm was based on the multi-objective of minimizing \( TLCC \) and \( DET \). Based on the results of this study, it is concluded as follows:

1- The optimal HES configuration was comprised of a PV/wind/battery system. Where number of inverter dependent on maximum power generated of the hybrid system and power maximum of the inverter, where optimum configuration that give minimum \( TLCC \) and minimum \( TDE \) is (2022) number of PV Cell, (52) number of wind turbine, (1553) number of battery and (64) number of inverter.

2- The NPO could accept different energy inputs, such as wind speed and solar irradiation data; a user load profile for developing an optimally sized HES was developed in this study. The NPO has a peculiar attribute of finding a balance between exploration and exploitation. Furthermore, the NPO requires no control parameters whose values can have influence on the algorithmic search process.

3- The ability of the algorithm to reduce Total Life Cycle Cost \( TLCC \) and Total Dump Energy \( TDE \) together.
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