Journal of Engineering and Sustainable Development
http://jeasd.uomustansiriyah.edu.iq/index.php
https://doi.org/10.31272/jeasd.25.3.6

Vol. 25, No. 03, May 2021
ISSN 2520-0917

USING PARTICLE SWARM OPTIMIZATION TO FIND OPTIMAL SIZING OF PV-BS AND DIESEL GENERATOR

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Received 10/10/2020 ***Accepted in revised form 15/11/2020*** ***Published 1/5/2021***

Abstract: This paper explores the sizing optimization of stand -alone hybrid energy system (HES) in southern Iraq (Thi Qar province) for supply stand-alone households by the electricity. HES consist of three components (solar cell (PV), diesel generator (DG) and battery storage (BS)). Particle swarm optimization (PSO) used in this study for find optimal sizing of the HES to minimizing multi-objective, first objective is to minimizing the total system cost (TSC) that lead to minimizing cost of energy (COE). Second objective is to minimizing total emission CO2 (TECO2). The constraint of the optimization is the reliability (100 %) mean continuous provide the load demand by the electricity. The results of the optimization show the ability the algorithm to minimizing the multi-objective with continuous supply the load by the electricity through life cycle of the project (25) years.

Keywords: *Renewable Energy, Solar Energy, Particle Swarm Optimization, Artificial Intelligence Technique*

1. Introduction

In the world today the key problems are to increase electricity demand, increase electricity prices, increase non-renewable energy usage, global warming and environmental issues. This led to the beginning in the world of a significant political and economic crisis. Therefore, all states across the world are making efforts to generate renewable energy. Renewable energy production will enable countries to achieve their sustainable development goals by access to healthy, reliable and secure energy [1-5]. Despite the great advantages of renewable energy, but they share common limitations, such as weather fluctuations, weak stability, and extreme randomness contributes to poor generation reliability and low performance. Therefore, the hybrid energy system can be overcoming of the main problems and limitations in terms of the efficiency, reliability, and the economics, which can possibly be considered an important solution to fulfil load demands, support and improve the system [6-9]. In order to improve system stability and fluctuation, various sources and storages such as diesel generators, batteries, and super capacitors should be incorporated into the HES [10,11]. The optimum design of HESs requires the proper size of the components and a viable plan for energy management. Selection of an effective energy management strategy is important because it determines the conduct of the system by regulating the energy flow and evaluating a priority each variable in the system [12]. Thus, the right energy management strategy can help improve the reliability of the energy system, ensure continuity of power supply, minimize energy costs, protect components against surcharged damage, and

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minimizing the global warming [13-15]. The HOMER software is used in some studies to assess the HES performance. In pursuit of an optimal design, the HOMER program optimizes HES uses enumerative technique. The technique guarantees the best possible solution, but an amazingly high processor time is needed. The academic community and industry have paid greater attention to algorithms for optimization in recent years. These algorithms have been used for many problems and have produced extremely good results [16]. The metaheuristic algorithms are currently used as the primary way of achieving optimal solutions to real problems of optimization. Such methods benefit primarily from stochastic operators who differentiate them from deterministic algorithms that efficiently solve some problems by using comparable starting points. In addition, several engineering applications check the ability of the meta-heuristic algorithms for the optimization process [17-19]. The particle swarm is metaheuristic algorithm used in this study to minimizing TSC, and TECO2.

3. Mathematical Model of HES

3.1. PV Model

The output power of the PV dependent on the temperature and solar radiation. The data collected of the Thi Qar weather forecast for a full year, to clarify take the first ten days of the January month as shown in "Fig. 1,2", The output power of the PV given by Eq.1 [20]

$$P^{PV}(t) = P_r \times D_r \times \left(\frac{S_{rad}}{S_{rad-STC}}\right) \times (1 + F(T^C - T^{STC}) \quad (1)$$

Where $P^{PV}(t)$ is output power of the PV in time (t) (W), P_r is rated power of the PV (W), D_r is PV derating factor (%), S_{rad} is solar radiation in time (t) (W/m^2), $S_{rad-STC}$ solar radiation in standard test condition (W/m^2), T^C cell temperature (C), F reduce of the PV output power with increase one Celsius of the T^C (%/°C), T^{STC} is cell temperature in STC (°C). This is parameters shown in Table.1.

The T^C calculated by Eq.2 [21,22]

$$T^C = T^a + \left[\left(\frac{NO^{CT}-20}{800}\right) \times S_{rad}\right] \quad (2)$$

Where temperature of the air (°C), NO^{CT} is normal operating of the T^C(°C).

Table 1. PV Parameters

Type	Poly Crystalline
$\mathbf{P_r}$	355 W
$\boldsymbol{D_r}$	94 %
$\boldsymbol{F}$	- 0.38 %
$\mathbf{S_{STC}}$	1000 W/m^2
$\boldsymbol{T^{STC}}$	**25** ℃
Maintenance Cost (M^C)	0 $
Life Span (L^S)	25 years
Cost of Capital (C^{Cap})	220 $

3.2. BS model

The BS used to storage the excess energy of the PV $(E\ S/D > 0)$, when the output energy of the PV greater than the load demand and losses and BS state of charge less than maximum$(C^{BS}(\mathrm{t}) < C^{BS}_{max}(t))$. The load demand data collected of the Thi Qar Electricity Distribution Directorate for a full year, where maximum load is 180 kW, and average load is 96.268 kW. To clarify take the first ten days of the January month as shown in "Fig. 3". The capacity of the BS given by Eq.3 [23,24]

$$C^{BS}(\mathrm{t}) = C^{BS}(\mathrm{t}-1) \times (1 - S^D) + (E^{PV}(t) - \frac{E^D(\mathrm{t})}{\varepsilon^{INV}}) \times \varepsilon^{BS} \quad (3)$$

$$E\ S/D = E^{PV}(t) - \frac{E^D(\mathrm{t})}{\varepsilon^{INV}} \quad (4)$$

Where: is $C^{BS}(\mathrm{t})$ BS state of charge in current hour (Wh), $E^{PV}(t)$ is output energy of the PV in time (t), $C^{BS}(\mathrm{t}-1)$ BS state of charge in pervious hour (Wh), S^Drate of self-discharge (%),$E^D(\mathrm{t})$ demand energy by the load (Wh), ε^{INV} efficiency of the inverter (%),ε^{BS} efficiency of the BS (%), $E\ S/D$ is deficit or surplus of the PV energy (Wh),and C^{BS}_{max} maximum BS state of charge (Wh).

The BS will be discharging, when there is a deficit of the output energy of the PV ($E^{S}_{D} < 0$), and $C^{BS}(\mathrm{t})$ greater than minimum ($C^{BS}(\mathrm{t}) > C^{BS}_{min}$), the discharging BS given by Eq.5 [23,24]

$$C^{BS}(\mathrm{t}) = C^{BS}(\mathrm{t}-1) \times (1 - S^{D}) + (E^{PV}(t) - \frac{E^{D}(\mathrm{t})}{\varepsilon^{INV}}) \tag{5}$$

Where: C^{BS}_{min} minimum BS state of charge (Wh). The parameters of the BS given by Table 2

Table 2. BS Parameters

Type	12 V Monoblock -Tubular
$\boldsymbol{\varepsilon^{BS}}$	>=90%
$\boldsymbol{C^{max}}$	2400 Wh
$\boldsymbol{C^{BS}_{min}}$	960 Wh
$\boldsymbol{C^{BS}_{max}}$	2400 Wh
$\boldsymbol{S^{D}}$	1.488 $\times 10^{(-2)}$ %/h
M^{C}	0 $
C^{Cap}	250 $

Where C^{max} is maximum capacity of the BS (Wh).

Life span of BS deepened on the BS depth of discharge (D^{OD}). Table 3, show relation D^{OD} with life span of the BS.

Table 3. Life cycle of the BS

$\boldsymbol{D^{OD}}$	Life cycle
Expected life in ideal float condition	10 years
At 60 % of D^{OD}	1500 cycle
At 50 % of D^{OD}	2000 cycle
At 40 % of D^{OD}	2600 cycle
At 30 % of D^{OD}	3600 cycle

3.3. DG model

The DG run, when there is a deficit in output energy of the PV($E^{S}_{D} < 0$), and BS state of charge at a minimum ($C^{BS}(\mathrm{t}) = C^{BS}_{min}$) .The DG depend on the fuel fossil, the consumption of the fuel in time (t) calculated by Eq.6 [25,26]

$$\mathrm{F}^{C}(\mathrm{t}) = (0 \cdot 246 \times P^{adg}) + (0 \cdot 08415 \times P^{rdg}) \tag{6}$$

Where $\mathrm{F}^{C}(\mathrm{t})$ consumption of the fuel in time (t) P^{adg} average of output power DG (Kw), P^{adg} rated power of the DG. Total consumption of the fuel calculated by Eq.7

$$F^{C}_{T} = \sum_{t=1}^{n} F^{C}(t) \tag{7}$$

Where n is life span of the project (219000 h). This is parameter shown in Table 4.

Table 4. DG Parameters

Type	Perkins
$\boldsymbol{P^{rdg}(kVA)}$	250 kVA
$\boldsymbol{P^{rdg}(kW)}$	200 kW
f	50 HZ
$\boldsymbol{C^{BS}_{max}}$	2400 Wh
$\boldsymbol{L^{S}}$	15000 h
M^{C}	0.309 $/H
C^{Cap}	29200 $

3.4. Inverter Model

The inverter that used in this study is bi-directional inverter with maximum power point tracking (MPPT). The number of the inverter calculated by Eq.8

$$N^{INV} = \frac{P^{max}_{G}}{P^{max}_{INV}} \tag{8}$$

Where: is P^{max}_{G} maximum power that generated of the components that connected with the inverter (W), P^{max}_{INV} maximum power of the inverter (W). The parameters of the inverter given by Table 5

Table ٥. DG Parameters

Type	$\boldsymbol{P^{max}_{INV}}$	$\boldsymbol{L^{S}}$	M^{C}	$\boldsymbol{\varepsilon^{INV}}$	C^{Cap}
Bi-directional INV	10Kw	25 years	20$/year	>=90%	3367$

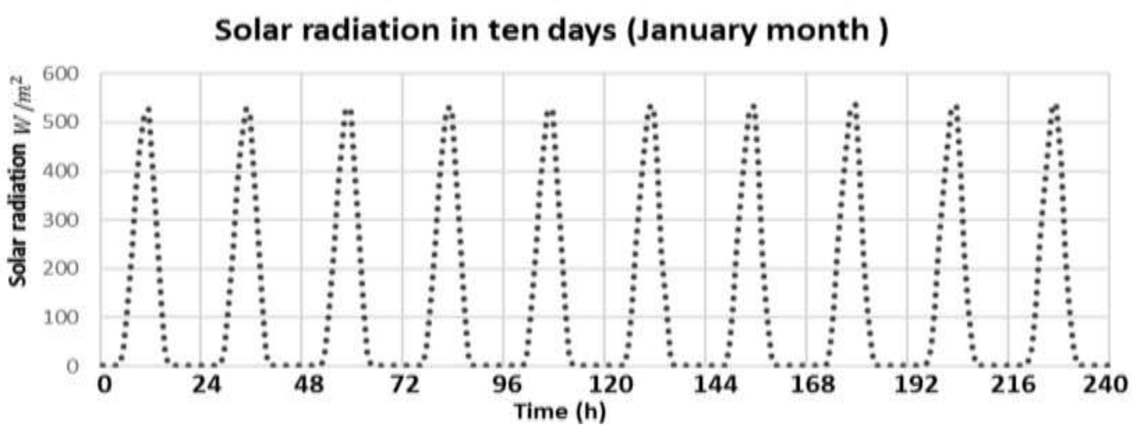

Figure 1. Solar radiation in the first ten days of January

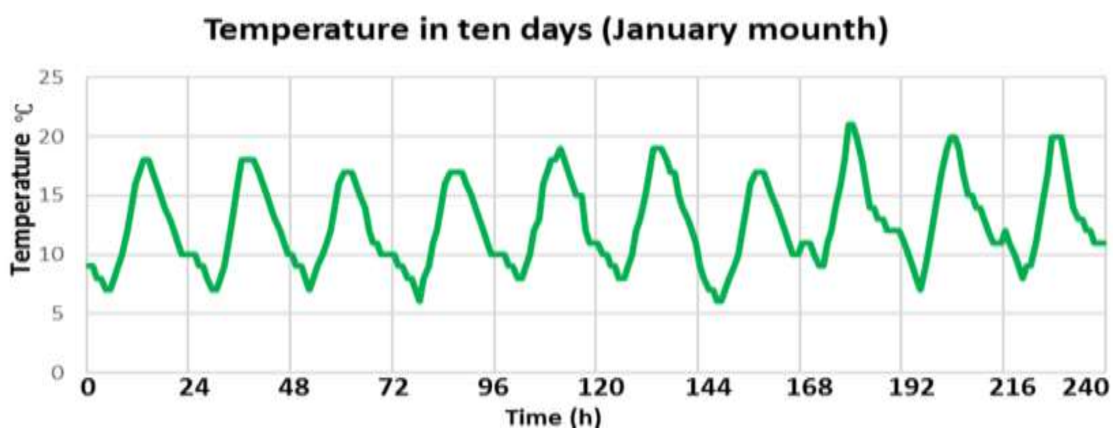

Figure 2. Air temperature in the first ten days of January

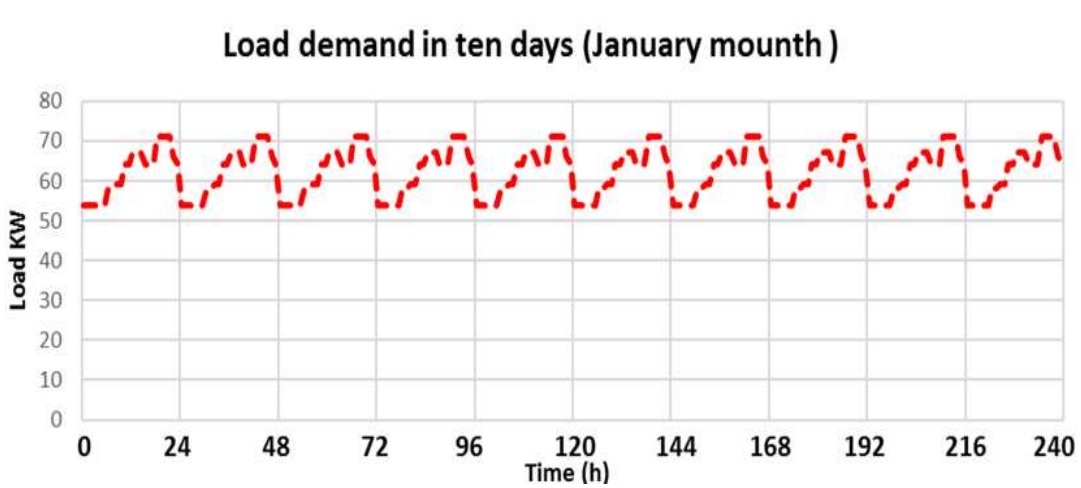

Figure 3. Load demand in the first ten days of January

4.The Proposed Algorithm

There are many of techniques and algorithms that used to find optimal sizing of the HES. The Particle Swarm Algorithm is one of the most important algorithms and it is a modern technique based on stochastic technique which Kennedy and Eberhart introduced in 1995 [27]. The PSO uses the individual improvement called particles, this technique is influenced by some animal's social behaviors, including fish schooling, bird fluttering and swarm theory. Each individual in PSO represents a potential solution that has two properties: speed and location. These two variables are modified by the experience of its neighbors and its own experience [28]. Each particle goes through the solution zone and recalls the best objective function value (position) already found, the fitness value is saved and Pbest is known. [29].

The main objective of optimization is to find optimum size of stand-alone HES (PV system, DG system and BS system) in order to minimize the total system cost (TSC), this is an economic factor, which in turn reduces energy costs (COE), the second target is to minimize total emissions CO_2 ($TECO_2$) with the continuous supply the load. A typical system configuration P is a three element row vector (p_1 to p_3) in which each element represents the required number of HES subsystem components. The P is row vector thus represented:

$$P = [p_1 \ \ p_2 \ \ p_3] \tag{9}$$

$$0 \le P \le max \tag{10}$$

Where: p_1 is PV number required of the HES. p_2 is BS number required of the HES, p_3 is DG number required of the HES.

the first objective TSC is represent total system cost and include total cost of capital C_T^{Cap}($), total cost of the maintenance (M_T^C) ($), total cost of the replacement(R_T^V)($), and total cost of the fuel (F_T^C)($). The TSC calculated by Eq.11

$$TSC = C_T^{Cap} + M_T^C + R_T^V + F_T^C \tag{11}$$

Where: C_T^{Cap} total cost of capital for system components (PV, BS, DG and inverter) ($), M_T^C total cost of the maintenance for system components ($), R_T^V total cost of the replacement for system components ($), and F_T^C total cost of the fuel ($).

The COE calculated by Eq.12 [16]

$$COE = \frac{TSC}{\sum_{t=1}^{n} E^D(t)} \tag{12}$$

Where: COE is cost of energy ($\$/kWh$)

The second objective is $TECO_2$ happen when the DG run, and calculated by Eq.13

$$TECO_2 = \sum_{t=1}^{n} ECO_2(t) \tag{13}$$

Where: $TECO_2$ total CO_2 emissions (kg), $ECO_2(t)$ CO_2 emissions in time (t) (kg) and calculated by using Eq.14 [23,24]

$$ECO_2(t) = 2.7 \times \ F^C(t) \tag{14}$$

The constraint of the optimization is (reliability) (100 %) mean continuous supply the load demand by the electricity through life span of the project (25) years, and given by Eq.15

$$E^T(t) \ge \frac{E^D(t)}{\varepsilon^{INV}} \tag{15}$$

Where $E^T(t)$ is total energy of the HES in time (t) (Wh), and given by Eq.16

$$E^T(t) = E^{PV}(t) \times p_1 + E^{BS}(t) \times p_2 + E^{DG}(t) \times p_3 \times \varepsilon^{INV} \tag{16}$$

Where: $E^{PV}(t)$ is PV output energy in time (t) (Wh), $E^{BS}(t)$ is BS output energy in time (t) (Wh), and $E^{DG}(t)$ is DG output energy in time (t) (Wh).

The sum weighting method (multi-objective) used in this study to minimize $TSC,$ $and\ TECO_2$ by Eq.17

$$Q(P^i) = TSC(P^i) \times W_1 + TECO_2(P^i) \times W_2 \times C^{CO2} \tag{17}$$

Where: $Q(P^i)$ is fitness function that used to minimize the objectives, (W_1, W_2) are the weights that used to minimize the objectives ,and C^{CO2} is tax carbon ($/ton).In this study take Sweden tax carbon as (150 $ /ton) ,because the Sweden considered of the most the countries that have tax carbon. The optimal sizing of the HES have minimum $Q(P^i)$. The flow chart of the optimization shown in "Fig. 4".

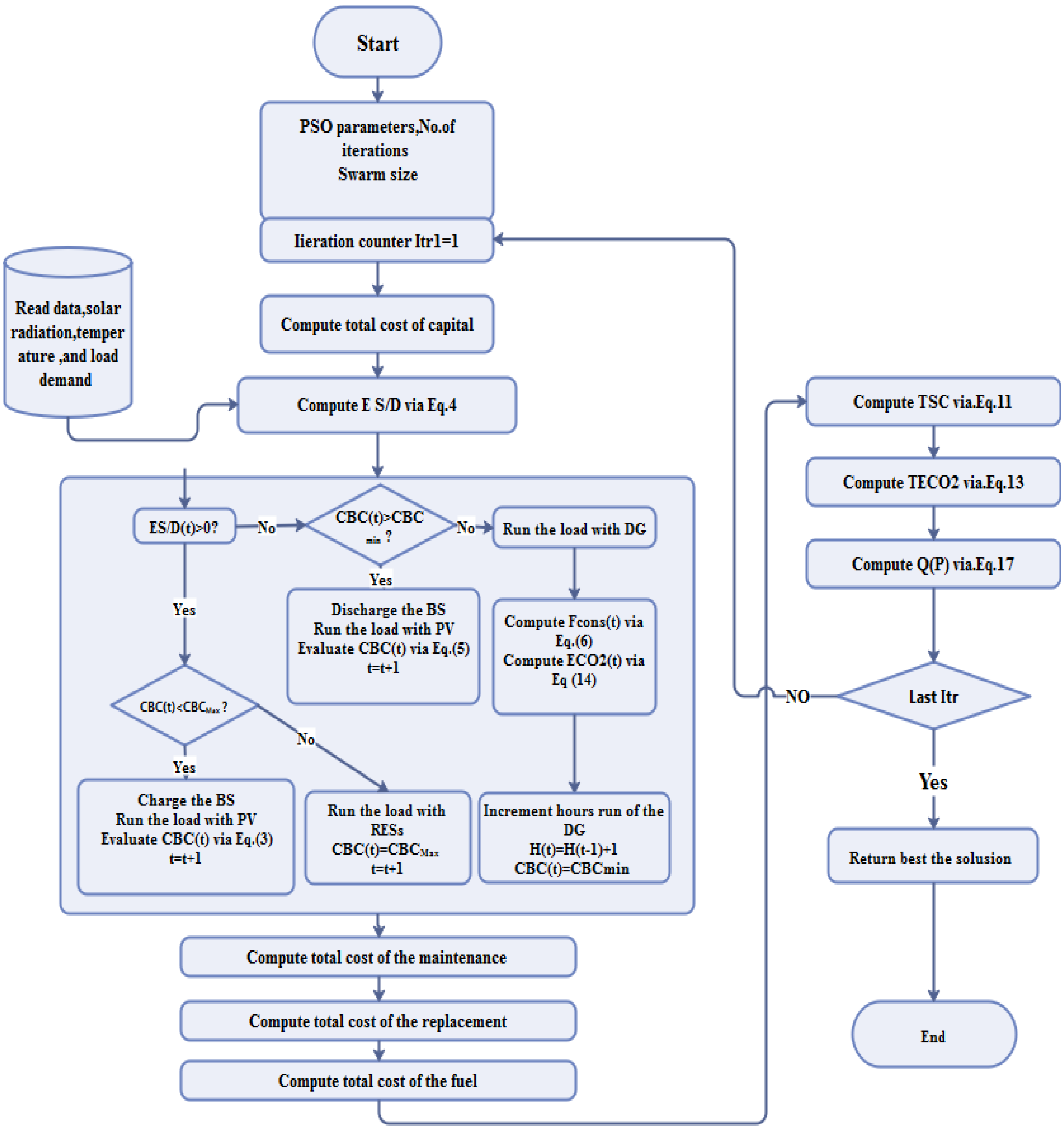

Figure 4. Flow chart of the optimization process

5. Results and Discussions

The PSO used in this study to minimize multi-objective TSC, and TECO2 with continuous supply the load by the electricity for 25 years. The optimal sizing of the HES achieved 1442 number of the PV, 503 number of the BS, and single big DG. The DG in this study used to cover a deficit of the RESs without charge the BS. Table.6 shows performance of the PV-BS-SG system for 25 years. The "Fig. 5", shows behavior of the HES for the first ten days of the January month.

Table 6. Performance of the PV-BS-SG system for 25 years

Configuration (P)	[1442 503 1]
TSC ($)	2.1097×10^6
$TECO_2$ (kg)	6.820279×10^6
COE ($/kWh)	0.100066943

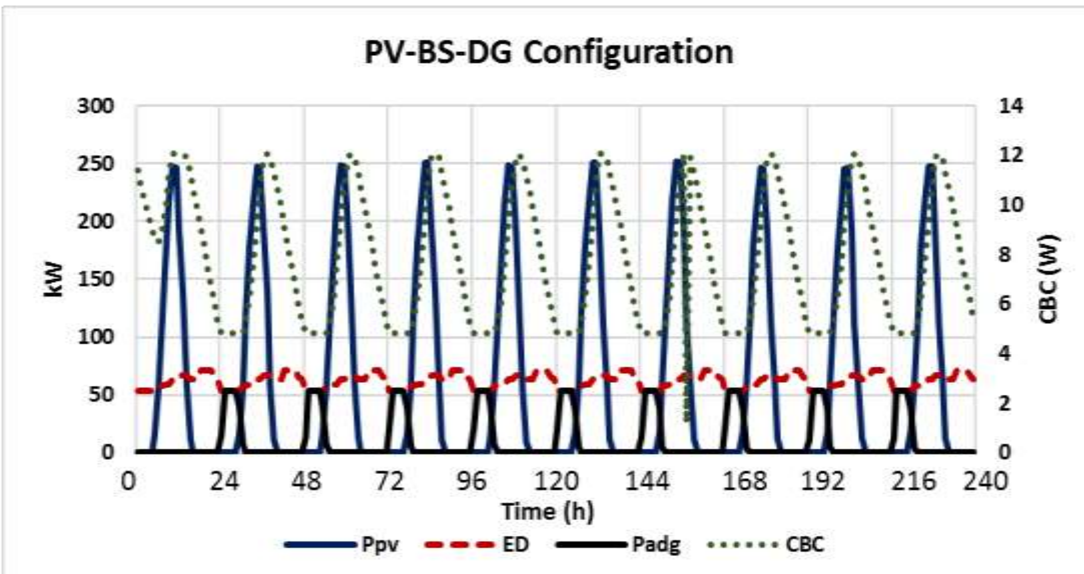

Figure 5. Behavior of the HES for the first ten days of the January month

6. Conclusions

The optimal sizing of the HES of PV/DG/BS based on metaheuristic algorithm named particle swarm optimization (PSO). The sizing of the HES is optimized to fully meet load demand of the stand-alone households in Thi Qar province (south Iraq), and the find of the optimal number of PV, BS and DG, that give minimum total cost of the HES, and minimum total CO_2 emissions with continuous supply the load demand by the electricity for 25 years. The data of air temperature, and solar radiation collected from the forest weather department in Thi Qar for a full year that used in the optimization process, and the data from load collected from electrical distribution directorate in Thi Qar for same period. The optimal HES consists of 1442 PV, which each PV is 355 W, 503 of the BS which each BS is 2400 Wh, with single big DG (200 kW). The PV, and the BS supply about 79 % of the load, while the DG supply 29%, Furthermore, the TSC could be minimized to (2.1097×10^6) ($), the lead to reduction in the cost of energy of (0.10006) ($/kWh), also $TECO_2$ will minimized of (6.820279×10^6) (kg)for 25 years.

Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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