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Determining the Size of Batteries and Solar Sources in a Zero Cost Building using PSO Algorithm

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Abstract: The production and consumption of non-renewable energy resources have disrupted the environment's biodiversity cycle. Global climate change, including worldwide warming, has made human life both now and in the future. The construction industry in the world has a significant share in the demand for energy consumption in these challenges. Therefore, the primary purpose of this paper is to implement standards to save and prevent energy loss to control and limit the demand for energy requested from the power network. Constructing a building with self-sufficient energy production that meets its energy needs by producing clean energy becomes more important. It also sells the excess energy to the grid, known as zero energy buildings. In the present paper, the issue is a constrained optimization problem that aims to minimize the total annual cost, including the initial investment cost for PV and batteries and their maintenance costs, as well as the cost of network exchanges. Among the limitations, the proposed model can mention the restrictions governing the battery, such as the limitations of the battery state of charge (SoC). The problem under optimization is a mixed integers nonlinear programming (MINLP) that will be solved by a particle swarm optimization (PSO) algorithm considering the total cost minimization.

Keywords: Zero energy building, PV capacity determination, Battery, Power management, Optimization.

Nomenclature

Parameter	Definition
i	Interest rate
n	Duration in years
Cap_{cost}	Annual loan payment for battery and PV installation
C_B	Battery capacity in kW

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C_{PV}	PV system capacity in kW
IC_B	Initial investment cost of battery and inverter in $/kWh
IC_{PV}	PV system investment cost in $/kW
CRF	Return on investment
Exc_{cost}	Annual costs of power interact with the network
T	Duration of operation
$E_{im}(t)$	Power received from the network at the t^{th} hour of the year
$E_{ex}(t)$	Power delivered to the network at the t^{th} hour of the year
$\mathrm{I}_{im}(t)$	Binary variable to determine the state of receiving power from the grid at hour *t*
$\mathrm{I}_{ex}(t)$	Binary variable to determine the status of power delivery to the network at hour *t*
$\rho_{im}(t)$	The price of electricity received from the network in *t* hours
$\rho_{ex}(t)$	The price of electricity sold to the network in *t* hours
$P_{PV}(t)$	PV production power
$P_{grid}(t)$	Upstream network power
$P_{bat}(t)$	Battery production capacity
$P_{load}(t)$	Load capacity
$E_{PV}(t)$	The energy produced by the PV unit at hour *t*
$P_L(t)$	Load per hour t
$SOC(t)$	The amount of battery charge to the total battery capacity
η_c	Efficiency of the charging mode of the converter
$\Delta SOC_C(t)$	Increasing the battery charge status in the current time step
$\Delta SOC_d(t)$	Decreasing the battery charge status in the current time step
η_b	Battery efficiency
η_d	Converter discharge efficiency

1 Introduction

Nowadays, 40 percent of all fossil fuel energy in the United States and the European Union is consumed by old buildings. These buildings are important producers of greenhouse gases. With the advent of modern architecture in the age of modernity, indigenous architecture that formed to adapt to the environment and nature was forgotten, and modern architecture, with its global styles, not only ignored the cultural, social, and historical contexts but also eliminated environmental-climatic conditions such as cold, heat and humidity. Due to technological advances in the extraction of fossil fuels and meeting the cooling and heating requirements of buildings, modern architecture has shifted to the consumption of more kind of these resources and gradually forgotten traditional solutions of compatibility with nature. Following the offensive of technology, beautiful and high-consumption buildings were created, and instead of adapting to nature, buildings were built to overcome it. In fact, the technology that was supposed to be used as a tool gradually targeted. This technology-oriented approach made architecture play a significant role in endangering the environment, which was aware that the issue of sustainable architecture in the important collection of sustainable development topics such as green architecture, ecological architecture, zero energy architecture, zero carbon architecture, pro-environmental movements, and ecological architecture in the current century [1].

In the not-too-distant future, humans will face two major crises: environmental pollution from the burning of fossil fuels and an increasing acceleration in the depletion of these resources. Rising energy demand, limited fossil energy resources, growing prices, and the instability of the energy market in the last decade, pollution, and global warming, are the basis of a new approach to energy. From the new perspective, two basic solutions have been considered [2]:

– Optimization of consumption (reduction or control of demand) and energy production;
– Using alternative energy sources, mainly renewable ones.

Buildings have a huge impact on the environment and energy consumption. The amount of energy consumed in the building sector is increasing rapidly. According to the Annual Energy Survey (AES), residential and commercial buildings consume about 40% of primary energy and approximately 70% of electricity in the United States [3]. On the other hand, reports from the US Department of Energy (DOE) indicate that the share of renewable energy sources in supplying the world's energy needs by 2.3% decreasing in 2020, including the rest includes coal, oil, natural gas, nuclear power plants, large hydropower plants, and industrial biomass [4].

In 2009, engineers began to think about building low-energy houses. Nonetheless, building constructions with zero energy was still a field of study and research. As governments increase their attention to this issue, the United States passed a law in 2007 to support zero-energy buildings; by 2040, half of the commercial buildings, and by 2050 all of them should be categorized in zero energy group. In Europe, in 2010, it was decided to apply the approach of zero energy consumption to public buildings and buildings owned by officials from 2018, and from 2020 onwards, this law will apply to all new buildings [5]. There are several definitions of buildings with zero energy consumption and buildings with zero energy, in most of which only energy consumption during the operation is considered. At the same time, the energy spent to construct the building, equipment, and materials must be paid to balance the production and consumption of energy. Since the largest amount of energy loss occurs in buildings, using photovoltaic modules as a new energy source is recommended. Besides, it should be noted that the losses of photovoltaic panels can be ignored compared to the total losses of the zero-energy building [6]. In the meantime, the fuel cost for the transportation of construction materials and labor must correspondingly be considered. In a building with zero energy, they reduce energy consumption in new ways, and the remained small amount of consumption will be provided by renewable energy. Zero-energy building combines implementable designs and active technologies to balance energy production and consumption.

Many countries have implemented plans to construct places with zero or almost zero energy consumption, and some of them have specific regulations in their plans or standards. In these areas, several standards have been installed so far, such as the construction of zero-energy buildings or predicting the parameters of the energy consumption model; examples have been mentioned [5]. For example, in the technical standard for near zero energy building in China [7], intelligent control requirements for the construction management system are based on user demand. They need for lighting, cooling, heating, or hot water, in which the main equipment in the network can be controlled automatically. An artificial intelligent (AI) based approach that is more commonly used in real-world applications must be standardized to use more efficient facilities. Totally, the innovation of this paper can be mentioned below:

- Determining profitability for the owners of zero energy houses in such a way that depends on whether the price of selling power to the grid. This can be done by exchanging the power where it is lower than the price of absorbing power from the grid or vice versa. Thus, the use of batteries can reduce costs or increase profits due to the interaction of power with the grid.
- One of the components of the presented objective function is the minimization of investment costs. Depending on whether the price of

selling power to the network is lower than the price of absorbing power or vice versa. Therefore, another component of the objective function can be a set of cost-minimization terms or profit maximization. In the other part, the optimal PV and battery capacity is obtained using the optimization algorithm.

1.1 Introducing a building with zero energy

There are many different definitions of zero energy building in industry and technology, some of which are mentioned here. These definitions are given intuitively in Fig. 1 [8].

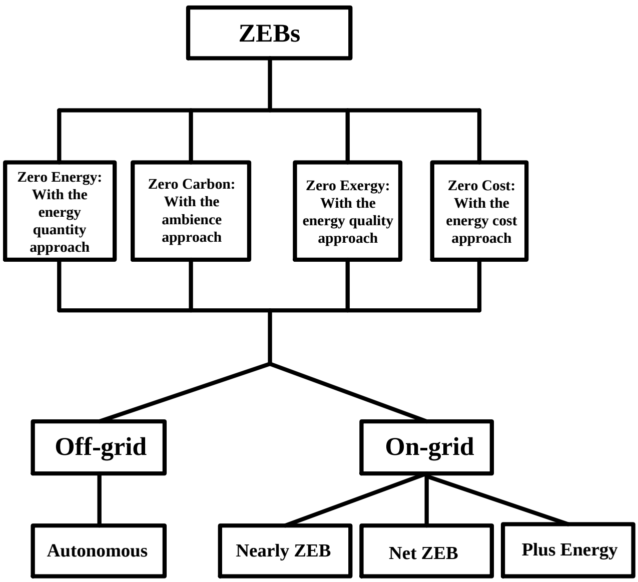

Fig. 1 – *Classification of zero energy buildings* [8].

In the first definition, a building with the result producing zero annual carbon pollutants is called zero energy building [9]. Buildings that generate extra energy throughout the year are called double-energy buildings. Buildings that consume relatively more energy than generated energy are called near-zero buildings or very low-energy houses. Most zero-energy buildings use electrical grids to store energy, but others are also grid independent. The energy consumption of buildings is usually supplied through a combination of renewable energy generators such as solar technology and wind. Total energy consumption can likewise be reduced by designing an efficient heating, ventilation, and air conditioning (HVAC) system and lighting apparatuses. Zero energy use will influence the cost of renewable energy technologies and fossil fuels consumptions. These buildings can be independent to the energy supply network, in which case, energy is supplied locally through a combination of new energy generation equipment such as solar, wind, fuel cells, etc. At the same time, energy consumption can be reduced by using special technologies for high-efficiency lighting, heating, and cooling systems. In other words, in a zero-energy building, before the production of clean energy, energy consumption is optimized in different parts of the building. With the intelligent use of renewable technology, a power balance is established between energy production and consumption [10].

1.2 Literature review

Energy optimization, whose main goal is to provide a robust optimization method for planning smart units, was done for an apartment and presented in [11]. The optimization algorithm used in this paper is linear-robust programming mixed with integer, which has been implemented in several case studies that aim to increase building efficiency. But this study has neglected goals such as building safety and comfort in providing thermal energy. The advantage of the method presented in this paper is the algorithm's simplicity in implementing the formulation. At the same time, the disadvantages are a lack of attention to the reaction between different forms of energy in the building and a lack of load prediction.

Hakimi, et al. in [12] present a framework for exchanging energy between the building and renewable energies while the power consumption is optimized in a building as a home applicant. The objective function is to optimize the thermal and electrical load profile of the house, which of course, does not consider securing the building. But this paper pays attention to increasing energy efficiency and comfort in the thermal energy of residents. One of this work's advantages is providing a suitable and detailed model for thermal loads, while not using real data is the only disadvantage of the reference.

In [13], Han et al. consider energy optimization in a public building, is energy monitoring to increase the profitability of using an intelligent control module for an intelligent sensors network. This paper aims to optimize energy in air conditioners, sensors network, and lighting systems, which increases energy efficiency and provides thermal energy comfort. This study similarly does not pay attention to the security of the building. Several disadvantages of this research include not using smart and useful sensors such as infrared, internet of things (IoT)-based sensors, etc.

The model for identification of optimal location of wireless sensor in zero-energy buildings was studied in [14]. The disadvantage of this paper is the lack of attention to the control system, but they have met the goals of increasing energy efficiency and providing the comfort of thermal energy. It is worth noting that the purpose of building security has also been neglected here.

Casado-Vara, et al. in [15] studies a zero-energy building that improves the accuracy of IoT sensors despite heterogeneous input data. The optimization method used in this paper is based on cutting IoT sensors that analyze heterogeneous data in a building. The main goal here is to provide thermal comfort to residents, while the disadvantages are not considering the combined efficiency of electrical and thermal energy throughout the building during optimal operation.

In [16], the authors have chosen a residential use for energy management to realize the exchange of energy between several intelligent buildings through consumption management programs. They used a distributed algorithm method to control the load, which ultimately optimized the objective function using the sliding mode method. The only purpose of this work is to increase energy efficiency, and the other two objectives have been ignored. The only drawback of this paper is the lack of attention to the prediction of characteristics of the proposed energy consumption model.

To manage energy consumption in the daily time horizon, Van Cutsem et al. have examined the energy exchange between residential buildings [17]. The method of this paper is based on load response programs implemented based on blockchain technology. Despite the novelty of the method used, they have only studied the increase in energy efficiency and neglected thermal energy. The disadvantage of this paper is the lack of a clear energy consumption system.

In a different study [18], the authors studied the energy consumption of metal buildings. The main purpose of this paper is to evaluate the performance of these buildings with new connections. The proposed method is based on an instantaneous resistance frame and an abnormal restraint frame. The most important drawback is not providing a security model and predicting the parameters affecting it.

To reduce energy consumption, passive methods such as determining the orientation of the building, intense quality materials in their construction, and optimal design of the building have been used in [19]. Difficulties to these methods are Unreasonable costs and the appropriateness of designing the shape of the building to suit the climate. The types of use studied in this work are high-rise (tall) buildings with good efficiency against pleasant light and photovoltaic arrays.

Pallis et al. in [20] have examined the periodic costs of residential buildings and the cost gap between NZEB buildings and their optimal cost. This paper examines the conditions of single-family and multi-family houses, and its main goal is to increase energy efficiency in two different climates. The method used is implemented by Law 2010/31/EU and EN 15459-1.

In [21], the authors have used renewable energy sources to manage energy consumption in ZEB homes to minimize thermal energy consumption. In this research, Degree Days (DD) method has been used to model heating loads, and its applicability in several case studies and cities has been investigated. The output results show that input data and climatic conditions in non-residential buildings play an important role in determining the energy efficiency of the building. The most important advantage of this paper is considering multiple relationships with high coefficients in the proposed model between different points under study.

Jurasz et al. [22] examine whether a city can fully supply its buildings with energy on its own. The energy sources considered in this paper are all photovoltaic with the ability to be installed on the roof. After applying the simulations, it results that 29% of the total annual power can be supplied by solar energy, which is a very large number. This case study in Poland shows that air pollutant gases can be reduced by up to 31%. If storage resources are not used, this rate will reach 28%.

In [23], studies on the role of renewable energy sources in supplying the energy required by ZEB and NZEB buildings and their technologies are reviewed. The research used PV sources, air source heat pump system, ground source heat pump system, and wind turbine to supply electrical and thermal charges. Energy life cycle analysis, changes in parameters affecting the model, and intelligent buildings to improve their performance have been exploited using storage resources in different climates. The most important disadvantage of this reference is the lack of a specific model for the load and consumption of the building.

The authors Sayary et al. [24] have studied energy management in houses with energy consumption close to zero using building information modeling (BIM). The proposed model estimates the building consumption model, the amount of power required by the PV arrays, and the tools to achieve sustainable development. The implemented method is based on data and simulated in a network-connected building, which is finally tested on a building set. This paper examines the reduction of electricity consumption but clearly avoids providing a way to improve and optimize heating consumption.

A new method called weighted sum based on the evolutionary difference (ED) is presented in [25], in which multi-objective optimization is implemented to reduce the consumption pattern of buildings in India. In the objective function of this paper, the reduction of carbon and pollutants is also mentioned and occupies an important weight in optimization. Another important point of this work is using renewable sources for energy self-sufficiency in the building, the answers of which have been evaluated using the Pareto method. Other features of this paper include customer discomfort, which can play an important role in reducing consumption. One of the main drawbacks of this paper is the lack of attention to the heating release of the building.

The research of the sizing of batteries and PV in zero energy buildings using the mixed integer non-linear programming optimization method was presented in [26]. The proposed objective function includes investment costs and maintenance of PVs, similarly for batteries, power purchased from the distribution network and power sold to it at light load intervals. The most important parameter in determining the capacity of batteries is their charge and discharge rate and battery efficiency, which is an essential parameter for PVs, including their thermal limit (maximum current that can be injected into the network). One of the most significant drawbacks of this paper is the lack of attention to the thermal load, which they have postponed their study to their next studies. **Table 1** summarizes the reviewed papers.

Table 1

Summarized the reviewed papers.

Ref.	Electrical load	Thermal load	Optimization method	Battery capacity determination	PV capacity determination	Power exchange with upstream network
10	√	-	Robust	-	-	-
11	√	√	MILP	-	-	√
12	√	√	Smart network-based demand control	-	-	√
13	√	√	MIP	-	-	-
14	√	√	IoT Slicing	-	-	-
15	√	-	SMC	-	-	√
16	√	-	Block chain	-	-	√
17	√	√	MRF-EBF	-	-	-
18	√	-	-	-	-	√
19	√	-	-	-	-	√
20	√	√	Empirical correlations	-	-	√
21	√	-	Light Detection and Ranging (LiDAR) data	-	√	-
22	√	√	-	-	√	-
23	√	-	BIM	-	-	-
24	√	-	Weighted sum method and DE	-	-	-
25	√	-	MINLP	√	√	√

2 Formulation

To present the proposed model, a grid-connected building equipped with solar arrays on the roof is considered. Electricity tariffs in that area also use the time of use (ToU) model. To solve the energy optimization problem in near-zero energy buildings (NZEBs), batteries or electrical energy storage systems equipped with inverters have been used. Since our goal is to optimize cost reduction and energy consumption, it is important to determine the amount of energy consumed by loads and the share of load provided by renewable sources. According to the load profile diagram, which includes a local peak, a global peak, and a valley (base load), there are times when the load capacity is less than the production of PV resources. Therefore, this excess energy must be stored in the battery during peak times. Measuring equipment is also installed at the input of the upstream network connection bus to collect information from intelligent sensors to monitor the price and power exchanged. To reduce the customer's annual cost, PV can be operated in parallel with BESS. The type of battery considered is also lithium-ion. PV power is not constant in this study, and its optimal amount is determined according to the optimization algorithm. The input of the problem in question is a graph of the solar irradiative power in that area over one year (8760 hours). According to [24], the energy consumption of the studied building in 2021 is estimated at 4758 kWh. The losses of the converters are considered 5% of the rated power, and PV arrays are installed on the roof at an angle of 32 degrees.

The formulation of this paper is divided into three sections: battery charge and discharge, annual net cost, and objective function, all described below.

A) Battery Charging and Discharging: This parameter is specifically related to the production capacity of PVs. If the solar power generation capacity is greater than the load, the excess power in the battery must be stored (1), derived from [26, 27].

$$\begin{gathered} P_d(t) = P_{PV}(t) - P_L(t), \\ E(t) = P_d(t)\Delta t, \end{gathered} \tag{1}$$

where $P_{PV}(t)$ is the PV output power, $P_L(t)$ is the demand required, $P_d(t)$ represents the difference between PV power and the load, and $E(t)$ is the energy required in each time step of Δt. Many PVs no longer connect to a separate inverter and use the "internal battery-inverter" set. Therefore, the efficiency of the battery and inverter assembly is considered together. It's also been a while since this happened. In this case, the battery charge status will be expressed by (2) [27]

$$SOC(t) = \begin{cases} SOC(t-1) + \Delta SOC_c(t), & \Delta SOC_c(t) \le SOC_{\max} - SOC(t-1); \\ SOC_{\max}, & \text{otherwise.} \end{cases} \tag{2}$$

The charge difference (because the battery is currently charging) is expressed using (3) [27],

$$\Delta SOC_c(t) = \frac{\eta_c E(t)}{C_B}. \tag{3}$$

The C_B of battery capacity in kWh and battery energy $E(t)$ corresponds to the same unit. η_c is also the efficiency of the converter charging mode. Now if the SOC of the battery exceeds the maximum value, some of the battery energy must be taken out of it, which will be expressed using equation (4). It should be noted that SOC is also dimensionless because it shows the ratio of battery charge to total charge in full-charged mode. According to equation (1), $E_{ex}(t)$ is the energy injected by PV into the circuit, in this case, because the capacity to produce PV power is greater than the load, some of it is stored in the battery. But after the correction, we will have derived from [26, 27],

$$E_{im}(t) = \begin{cases} E(t) - \dfrac{SOC_{\max} - SOC(t-1)}{\eta_c} C_B, & SOC(t-1) \le SOC_{\max}; \\ 0, & \text{otherwise.} \end{cases} \tag{4}$$

Now, suppose the output power of PVs is less than the load power. In that case, the battery must also cooperate in supplying the load power, in which case, the battery charge status and the difference in its charge level (which is reduced) according to (5) and (6) are expressed derived from [26, 27].

$$SOC(t) = \begin{cases} SOC(t-1) + \Delta SOC_d(t), & \Delta SOC_d(t) \ge SOC_{\max} - SOC(t-1), \\ SOC_{\min}, & \text{otherwise,} \end{cases} \tag{5}$$

$$\Delta SOC_d(t) = \frac{E(t)}{\eta_b \eta_d C_B}. \tag{6}$$

The parameters shown in the denominator of (6) are battery efficiency (η_b), converter discharge efficiency (η_d), and battery capacity, respectively. If, in this case, the SOC of the battery is reduced to a minimum, some energy must be applied to it not to be less than the specified level, which is expressed using (7) derived from [26, 27].

$$E_{ex}(t) = \begin{cases} E(t) + \left(SOC_{\max} - SOC(t-1)\right)\eta_b \eta_d C_B, & SOC(t-1) \ge SOC_{\max}, \\ 0, & \text{otherwise.} \end{cases} \tag{7}$$

If the power of the PVs is exactly equal to the load, the battery will go out of the circuit.

B) Net Annual Cost: According to the interest rate *i* and the duration of n years of battery operation, the annual cost of batteries for each kWh consumed is equal to what is derived from [26, 27]:

$$A_B = IC_B CRF(i,n)\,, \tag{8}$$

where IC_B is the installation cost, and *CRF* (*i*, *n*) indicates the amount of return on investment according to the choice of battery capacity as shown in (9) derived from [26, 27]:

$$CRF(i,n) = \frac{i(1+i)^n}{(1+i)^n - 1}\,. \tag{9}$$

The annual cost (A_p) will also be calculated by (10) derived from [26, 27]:

$$A_p = A_B C_B + \sum_{t=1}^{T} E_{im}(t) RP\,. \tag{10}$$

Revenue from the sale of battery power (A_R) is also calculated by (11) derived from [26, 27]:

$$A_R = \sum_{t=1}^{T} E_{ex}(t) FIT\,. \tag{11}$$

Finally, to calculate the total annual cost of the battery, we will have derived from [26, 27]:

$$A_{NP} = A_B C_B + \sum_{t=1}^{T} E_{im}(t) RP - \sum_{t=1}^{T} E_{ex}(t) FIT\,, \tag{12}$$

where retail price (RP) and feed-in tariff (FIT) parameters are also the battery's price and the electricity tariff's cost.

C) Objective function: The objective function that is minimized in this paper is shown using equation (13).

$$Min\left\{ A_B C_B + A_{PV} C_{PV} + OM_{PV} + \sum_{t=1}^{T} E_{im}(t) RP - \sum_{t=1}^{T} E_{ex}(t) FIT \right\}, \tag{13}$$

where A_{PV} is the capacity of PVs, C_{PV}^{inv} is the investment cost, and OM_{PV} is the maintenance cost of photovoltaic arrays. Therefore, the main goal of this project will be to minimize the number and capacity of PVs and batteries. Formerly the implementation of the formulation presented under the PSO optimization algorithm using MATLAB software results is obtained.

D) Methodology: The problem in question is a linear programming problem with constraints related to hard time (constraints related to charging and discharging batteries). The decision variables include the optimal capacity of the battery, the optimal capacity of the PV system, as well as the binary to choose them. The particle swarm optimization algorithm is used to solve the problem, which will be explained in the next section. The following steps will be used to solve the problem of determining the optimal PV and battery capacity:

– Loading the PV production power and demand in the desired area and the electricity price in that area, as input data.

– Variables of battery capacity and photovoltaic array capacity are selected as two unknown parameters for the PSO optimization algorithm using MATLAB software. It is worth mentioning that these two parameters are continuous.
– In the first step, the particles are taught how to be distributed and the search space to start the optimization.
– Since each particle represents a capacity for the battery and a capacity for the photovoltaic array (in two-variable problems) in each iteration, it must move in a way in the search space to minimize the objective function.
– The initial population and minimum and maximum values are determined for each variable.
– Recording initial values; First, we set $t = 1$ h and $\Delta t = 1$ h. We will also have for battery charging mode: $SOC(0) = SOC_{min}$.
– Power $P_d(t)$ and $E(t)$ are calculated according to the relationships shown in equation (1).
– Based on the power sign $P_d(t)$, the state of SOC is specified, and the input and output energy will be determined as follows:
– If $P_d(t) > 0$, SOC value and output energy are determined according to equations (2) to (4).
– If $P_d(t) < 0$, SOC value and output energy are determined according to equations (5) to (7).
– We go to the next time step: $t = t + 1$. Then we will repeat the finding process in the search space.
– The number of iterations is terminated and the convergence graph is drawn.
– The amount of annual cost of PV and battery is calculated.
– According to the above values, the value of the objective function specified in equation (12) will be optimized, and the capacity of the battery and PV will be determined.

3 Simulations

The assumptions made for this simulation are briefly listed below:
– It is assumed that a 10-year loan with a 20% interest rate has been used to finance the project.
– The tariff for purchasing electricity in the hot period, i.e., from the first of April to the end of October, is equal to 0.00077$ per kilowatt hour, and in the non-hot period, from the beginning of November to the end of March, is assumed to be equal to 0.00301$ per kilowatt hour as shown in [21]. Also, the selling price of energy to the grid is assumed to be equal to 0.0341$ per kilowatt hour following the existing protection laws for

renewable products. Fig. 2 shows the cost of buying and selling electricity from/to the grid.

– The cost of purchasing, installing, and operating the battery is estimated at 55.43$ [4];

– The purchase and installation cost of the solar system is estimated at 1662.84$ [4].

– Based on [26, 27], the annual consumption pattern of home subscribers is shown as normalized in Fig. 3.

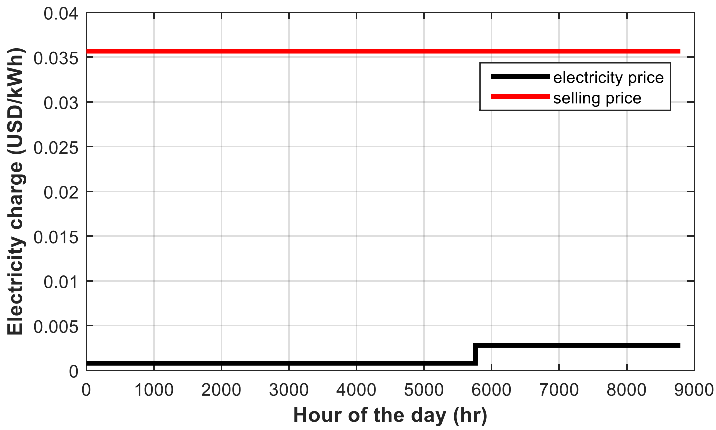

Fig. 2 – *The cost of buying and selling electricity from/to the upstream grid.*

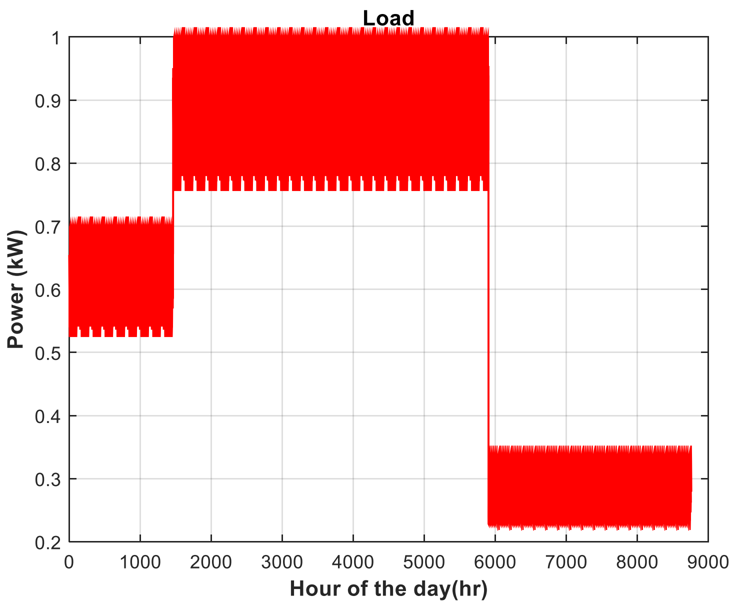

Fig. 3 – *The annual consumption pattern of home subscribers in a normalized way.*

– Based on [11 – 13], the annual production pattern of PV units per kilowatt of capacity is shown in Fig. 4.

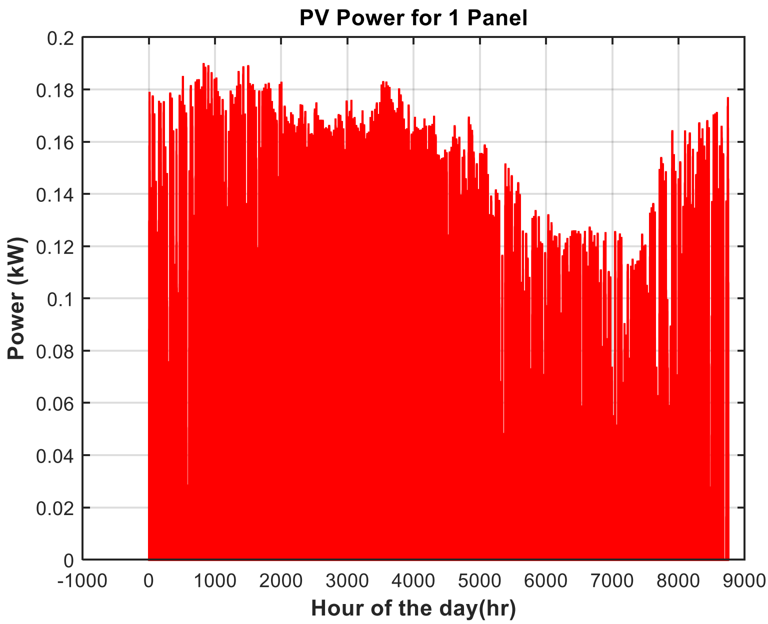

Fig. 4 – *The annual production pattern of normalized PV units.*

Other constants are given in **Table 2**.

Table 2
Constants and variables used in this paper.

Parameter	**Value**
SOC_{min}	30 %
SOC_{max}	90 %
η_{inv}	97 %
η_{bat}	94 %
η_{ch}	90 %
η_{dis}	90 %
Δt	1 hour
i	15 %
N	12 years

3.1 Numerical Results

In this section, a residential 5 kW house is considered, and the size of the PV and the battery is determined for each. Finally, the interest rate and efficiency of the battery and inverter will be changed, and different scenarios will be considered.

A) Fixed Electricity Prices

In this study, it is assumed that a residential house with a maximum load of 5 kW is available, and must be provided with the optimal capacity of batteries and PV to achieve NZEB. Due to the fact that the selling price of electricity to the network is low compared to the investment costs of batteries and PV, so in this case, study, buying electricity from the upstream network is more cost-effective than buying PV and batteries. The convergence diagram of the output objective function of the PSO algorithm is shown in Fig. 5, which shows the total cost of 31.49$ per year. Fig. 6 displays a diagram of the other capabilities involved in this discussion. It is observed that the battery and PV power are zero, and the entire load is supplied by the upstream network (the green and red diagrams are perfectly matched).

The red graph shows the network load in these figures, while the PV and battery power are in blue and black, respectively. The green chart also symbolizes the energy purchased from the grid upstream or injected into it.

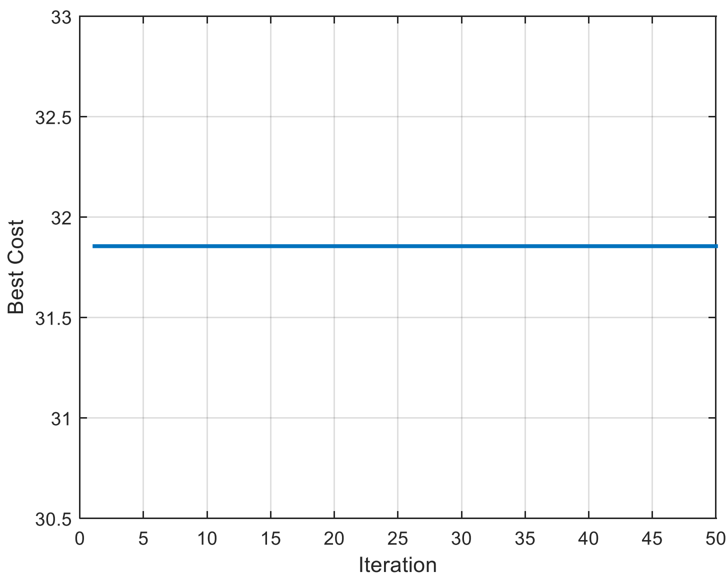

Fig. 5 – *Convergence diagram of the output function of the PSO algorithm for the* 5 *kW branch.*

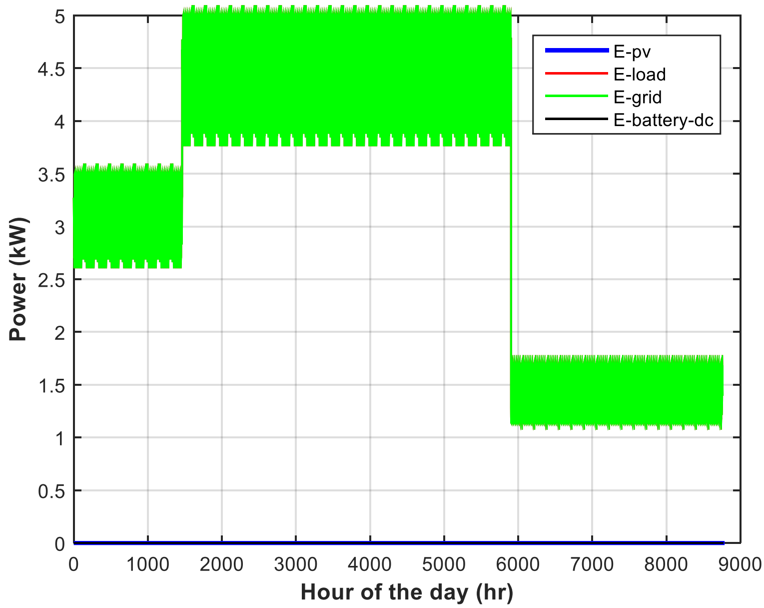

Fig. 6 – *Capacities of PV, load, upstream network and battery in the first case study* (5 *kW branch*).

B) Increase in Electricity Sales Prices

In this case study, to reach the NZEB, the selling price of electricity to the global grid must be increased so that it is profitable for the homeowner when there is the potential to sell PV power and batteries to the upstream grid. The profits should cover the entire cost of investing in batteries and PV and offset the cost of purchasing electricity from the upstream network. The output of the PSO algorithm determines the battery capacity with a value of 0.4284 kW and PV with a value of 4.1554 kW. The diagrams in Fig. 7 show the PV, load, upstream, and battery capacities for the 5 kW branch. It is observed that according to these plots (PV power generation diagram), there is a potential to sell electricity to the grid.

As shown in Fig. 7, respectively, on hot and cold days of the year when electricity tariffs change, when PV can generate power, the energy purchased from the upstream grid decreases. Instead, the battery can be charged and discharged at low prices. Therefore, the power balance is always maintained, and the PV output power, in addition to the power purchased from the upstream network is equal to the power stored in the battery (the battery is charged in positive power and discharged in negative power) plus the network load profile.

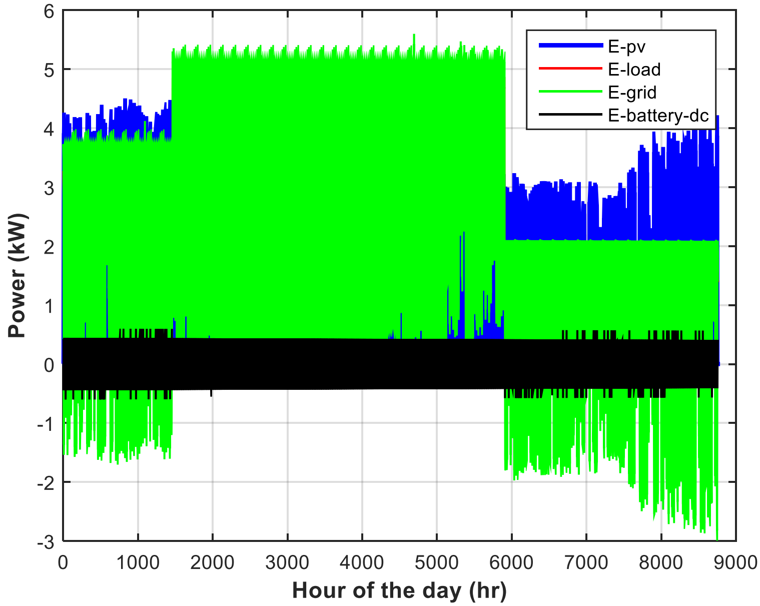

Fig. 7 – *PV, load, upstream network, and battery capacities in the first case study considering the sale of electricity to the network (5 kW branch).*

3.2 Validation

To verify the proposed method, the output results are compared with results from [26] as shown in **Table 3**. It is represented that the error computed is very diminutive in the very lowest time for simulation.

Table 3
Validation.

Scenario	Proposed method	Mehrtash, et al., [26]	Error (%)
Demand = 20 kW	PV = 63.35 kW Battery = 19.45 kW	PV = 63.41 kW Battery = 19.03 kW	Difference < 1 %
Demand = 50 kW	PV = 154.66 kW Battery = 47.95 kW	PV = 154.92 kW Battery = 47.95 kW	Difference < 1 %
Demand = 100 kW	PV = 310.37 kW Battery = 94.68 kW	PV = 310.66 kW Battery = 94.31 kW	Difference < 1 %

3.3 Changes in inflation (interest) rates with increasing electricity sales prices

In this case, study, to reach the NZEB house, interest rate changes lead to the results presented in **Table 3**. According to the results obtained from **Table 3**, it can be stated that the increase in the inflation rate increases the capacity of PV. Consequently, the capacity of the battery also increases. This is because more money has to be paid for electricity consumption. Therefore, the desire to use PV and batteries will increase among consumers.

Table 3

Determining the optimal capacity of PV and batteries according to interest rate changes.

Inflation rate	PV capacity	Battery capacity
15 %	4.1455	0.3957
25 %	4.1772	0.4325
30 %	4.1985	0.4436

3.4 Changes in battery efficiency with increasing electricity sales prices

In this case study, to reach the NZEB house, battery charging, and discharging efficiency changes lead to the results presented in **Tables 4** and **5**, respectively.

Table 4

Determining the optimal capacity of PV and batteries according to charging battery efficiency changes.

Charging battery efficiency	PV capacity	Battery capacity
93 %	4.1522	0.4255
95 %	4.1589	0.4136
98 %	4.1624	0.4025

Table 5

Determining the optimal capacity of PV and batteries according to discharging battery efficiency changes.

Discharging battery efficiency	PV capacity	Battery capacity
93 %	4.1677	0.4258
95 %	4.1705	0.4175
98 %	4.1785	0.4026

As the efficiency of the battery increases, its internal losses decrease. Therefore, the battery capacity is expected to decrease, but it will be able to show the same function as before. This decrease in battery capacity will increase PV capacity slightly.

3.5 Changes in inverter efficiency with increasing electricity sales prices

In this case study, to reach the NZEB house, inverter efficiency changes lead to the results presented in **Table 6**. Considering the increase in efficiency of the inverter, it can be said that the internal losses of the inverter are less than before. This issue can reduce the capacities of the battery and PV at the same time and show the same performance with a lower capacity. Of course, it is worth mentioning that increasing the efficiency of the inverter means spending more money to buy better-quality equipment.

Table 6
Determining the optimal capacity of PV and batteries according to inverter efficiency changes.

Inverter efficiency	PV capacity	Battery capacity
96 %	4.1370	0.4268
98 %	4.1235	0.4142

3.6 Applicability

Zero energy buildings are those with zero annual energy consumption and do not produce carbon emissions. In today's world, due to the limited resources of fossil fuels, buildings, industries, and other organizations are moving towards using existing energies. The main idea and consumption of net zero energy have attracted a lot of attention because it is one of the energy sources, a method, and a solution to eliminating pollutants and greenhouse gases. Due to the increasing costs of fossil fuels and their destructive effects on the environment and, at the same time, using ecological methods, the plans related to the principles of zero energy are very practical and have special popularity. Zero-energy buildings can meet all their energy needs cheaply, with local access to renewable resources and without pollutants. No fossil fuel is consumed in a zero-energy building, and its annual energy consumption is equal to its annual production. A zero-energy building may or may not be connected to the city grid. A zero-energy building connected to the grid has equipment for storing large amounts of energy, which is usually of the battery type. Currently, private and residential office buildings account for 40% of the country's fossil energy consumption. Buildings with zero energy consumption are very rare even in today's advanced. Still, it is proven that they are growing from fossil fuels and helping to reduce carbon pollution and have attracted a lot of attention. In these buildings, energy consumption is needed as little as possible using special technologies for efficient lighting and heating and cooling systems. In other words, in the zero-energy building, before the production of clean energy, the optimization of energy consumption in different parts of buildings is addressed. With the intelligent use of energy-efficient technologies, the balance between energy production and consumption becomes sustainable. As result, the applicability of the obtained results can be used in the following topics:

– where a ZEB will be constructed and designed, the proposed results shown in this paper can be used to determine the PV and battery size;
– where pollution needs to be reduced, the applicability of the proposed results can be used to convert conventional buildings to ZEB;
– where the smart city is planned, all buildings have to make them smarter using resource control as our results can be applied;
– where the Internet of Things (IoT) is used to control the devices remotely, and
– where block-chain technology is entering our life, controlling our ZEB resources is vital using peer-to-peer approach.

4 Conclusions

In this paper, a comprehensive framework for PV and battery sizing is proposed to minimize planning costs. Meanwhile, in determining the optimal capacity of batteries and PV for a NZEB building, the selling price of electricity to the upstream network is of great importance and should be considered. So that in this paper, several scenarios are considered to show that batteries can be attractive to manufacturers with active participation. Current electricity prices cannot compete with the investment cost of batteries and PV unless the selling price of electricity to the upstream network is accompanied by high correction factors. Otherwise, the total cost of power supply for 5 to 15 kW branches is estimated at 30$ to 95$ per year. Increasing interest rates will increase the capacity of PV and batteries. Therefore, battery utilization is not suggested in countries with high inflation or unsuitable economic manner. Increasing the charge and discharge efficiency of the batteries slightly reduces the battery capacity due to less active power loss. Finally, it is concluded that increasing the efficiency of the inverter reduces the capacity of all equipment, which indicates an improvement in the total cost.

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