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Research Article

Determination of Fair Usage Rate and Sizing Optimization for a Site Houses Photovoltaic-Battery Energy Source

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Standard deviation

Abstract: With this study, it is aimed to meet a part of the total electricity need in a site consisting of 4 houses with the photovoltaic-battery system. Partial energy to be covered by the photovoltaic-battery system has been focused on equitably distributed among these 4 houses. Standard deviation method was used for fair distribution. Standard deviation calculations were made with the conditional flow algorithm, random algorithm and excel solver. Sizing optimization studies were carried out according to this standard deviation value. Conditional flow algorithm and particle swarm optimization algorithms were used for sizing optimization. At the end of the study, the minimum standard deviation value was calculated as 0.219779. Fair usage percentages were calculated as 1.1061%, 9.1814%, 32.3474% and 57.3650% for the minimum standard deviation for each house, respectively. According to the minimum standard deviation value, the optimum result was obtained with conditional flow algorithm.

1. Introduction

In today's society, electrical energy plays an important role in human life. Electrical energy can be generated in many ways. One of these generation methods is electricity generation from fossil fuels. However, this method causes many environmental problems. As a result of the burning of coal and petroleum fuels like fossil fuels, global and local pollution problems occur. Both living lives are threatened and ecological balance is disrupted. In addition, the high cost of fossil fuels is another problem with this method. Due to these problems, it has become necessary to find new energy sources [1-2]. In this context, electricity generation based on renewable energy sources is seen as a promising solution. Solar and wind power systems in particular have become popular choices [3-4]. However, the discontinuity of their energy and their high costs are the downsides of these systems. They must be optimally sized in order to provide continuous energy and minimize costs. For this, algorithms are developed for sizing optimization in hybrid renewable energy systems [5]. The variation of solar radiation values requires PV systems to work with a storage unit. The use of renewable energy systems together with energy storage systems helps to increase the reliability of these systems and to reduce the mismatch between energy consumption and production profiles [6-7]. The optimum dimensioning of BT energy storage systems is an important element in the planning and design of microgrids [8-10]. Choosing battery numbers in a random or non-optimal size can increase the cost and system losses [11]. In addition, a fair distribution should be ensured in case of joint use of renewable energy resources. Here, what is meant by fair usage is to determine the percentage of energy to be drawn from the source according to the average consumption amount, taking into account all consumption amounts at different consumption times. It is assumed that the energy demand of the site considered in the study will primarily be taken from the renewable energy source and then from the main grid in case of the remaining energy demand. For fair usage purpose, methods such as standard deviation can be used. Two main issues should be taken into account while designing the PV-BT system. The first is the loss of power supply probability (LPSP) of the system, and the second is the system annual cost (SAC) that arises due to this possibility. To achieve this, an optimization method have been used [12].

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Ghaffari et al. used a modified crow search algorithm for sizing optimization of a hybrid system consisting of a photovoltaic panel, diesel generator and fuel cell. Total cost and LPSP criteria were taken into account. They concluded that the proposed method had a great effect on the LPSP value and gave better results than the genetic algorithm and PSO [13]. Makhdoomi et al. proposed an algorithm for the optimization of a photovoltaic, diesel generator and pumped hydro storage system. The crow search algorithm produced better results than the genetic algorithm, PSO and the original crow search algorithm [9]. Hemeida et al. worked on the optimization of wind-solar-battery systems. They concluded that it was cheaper to install the hybrid system than to install it separately [14]. Kaabeche et al. aimed to minimize the cost and sizing of a solar-wind system with their study. Ant lion optimizer, gray wolf optimizer, krill herd and jaya algorithms were used in optimization. They had obtained the most suitable solutions with three battery technologies with the jaya algorithm [15]. In the study by Mahmoud et al., optimization was carried out for batteries in a micro grid with solar-wind-battery. PSO, genetic algorithm and flower pollination algorithm methods were used. They concluded that using smart batteries could reduce the annual generation cost of microgrids [10]. In the study by Bukar et al., LPSP and cost optimization were performed for a micro-grid. Grasshopper optimization algorithm was used. It was concluded that the grasshopper optimization algorithm achieved results close to the results of the PSO and cuckoo search algorithms, and reduced the system capital cost by 14% and 19.3%, respectively [16]. In the study by Jamshidi et al., a hybrid system consisting of photovoltaic, fuel cell and diesel generator was designed. It was aimed to minimize the total cost and LPSP. Multi-objective crow search algorithm had been utilized for optimization [17]. In the study by Zhang et al., they analyzed the optimum sizing of a hybrid solar-wind system based on chaotic search, harmony search and simulated annealing algorithms. The reliability of the system was evaluated by LPSP [1]. Zhang et al. optimized a hybrid renewable system that includes hydrogen and battery storage units. Modified simulated annealing algorithm-based chaotic search and harmony search were used. As a result, it was determined that a wind-solar energy-based hybrid system with electrochemical storage offers the most cost-effective and reliable energy [6]. Astaneh et al. proposed a method to find the minimum cost structure of a lithium-ion battery-based and off-grid renewable energy system. All possible combinations were evaluated in the proposed method. It was seen that the cost in the scenario optimized according to the results decreased by 9.7% compared to the basic scenario cost [18]. Mohamed et al. aimed at the cost optimization of the grid-connected hybrid photovoltaic wind energy system with their study. They used the PSO algorithm. It was seen that the proposed algorithm provides a reliable sizing solution and responds well to changes in system parameters [4]. Chauhan et al. focused on the optimal sizing of a stand-alone integrated renewable energy system which comprises the resources of micro hydropower, biogas, biomass, solar and wind energy. A demand response strategy based on the energy consumption planning of the devices was proposed. With this strategy, it was aimed to minimize the highest hourly energy consumption in the study area. They concluded that significant savings were achieved in system size and cost [2]. In the study by Fetanat et al., a sizing optimization was made for the hybrid photovoltaic-wind energy system. Ant colony optimization for continuous domains based integer programming technique was used for optimization. It was observed that this method performs better than the others in terms of reaching the optimum solution and speed [19]. In the study by Bukar et al., an optimization study was carried out for the photovoltaic and wind energy system integrated with a fuel cell. It was aimed to create a cost-effective system with optimization [20]. Al-falahi et al. presented a comparison of single algorithms, hybrid algorithms, and software tools used to determine the number of variables in an independent solar and wind hybrid system. The evaluation parameters of all possible combinations in economic, safety, environmental and social aspects were taken into account [5]. Kerdphol et al. made a sizing optimization using frequency control based on the PSO method in order to prevent instability of the microgrid after power failure and to minimize the total cost of the system. The results showed that the optimum size of the battery energy storage system based PSO method could achieve higher dynamic performance than its traditional size [11]. conducted by Lian, it was aimed to find an equal and lowest-demand profile among all combinations in terms of energy supply. It was aimed to guide the architects to find the most appropriate consumption among different combinations of buildings with various functions and how many buildings should be in a project area. To achieve this, the standard deviation method was used. With this case study, a general methodology was developed that facilitates the work of urban designers [21].

This study, it was carried out to ensure fair usage of energy from a renewable energy source among loads. To ensure this fair usage, the standard deviation method was used. Three different (CFA, RA, ES) methods were used for calculating the standard deviation. Studies were also made for optimal sizing of the PV-BT system. For this, CFA and PSO methods were used. In the methods, technical LPSP and economically SAC research were done and the number of components was calculated depending on these concepts. In the optimization process, the first mathematical model of the PV-BT system was derived. Then, the system reliability model based on the LPSP technique and economic models based on the SAC concept presented. The optimization process aimed to find a compromise between these two goals. The decision variables were PV and BT numbers. In this respect, it is thought to be a guiding study towards ensuring the fair usage of energy obtained from a renewable energy source among loads.

The next part of the study after this section consists of the following sections. The second section is the materials section where photovoltaic, battery, inverter and load models are defined. The third section is the method section in which the standard deviation calculations performed with CFA, RA, solver and the criteria used in optimization are explained. The fourth section is the results and conclusions section, where results are obtained and discussed. Finally, the results are given in the fifth section.

2. Materials

2.1. Photovoltaic Panel

The solar radiation data of the province of Malatya used in this study were taken from the General Directorate of Meteorology [22]. These were the hourly data of 720 hours for June 2010.

PV panel values used in this study are shown in Table 1.

Table 1. PV panel technical specifications [23]

V_{oc} (V)	I_{sc} (A)	V_{max} (V)	I_{max} (A)	P_{max} (W)	Area (m^2)	Lifespan
45.	5.9	36.6	5.47	200	1.3	25

2.2. Battery

Batteries are electrochemical elements that store energy in chemical form. The amount of energy in the battery is related to the state that the battery changes from t-1 hour to t hour. This can happen in charge, discharge or neutral situations.

Technical specifications of the batteries used in this study were as in Table 2.

Table 2. Battery technical specifications [24]

Capacity (W)	Voltage (V)	Current (A)	Battery efficiency (%)	Lifespan
900	12	75	87	4

Batteries had 12 V/75 Ah characteristics and their lifespan was assumed to be 4 years. The design of the battery system to be installed was planned in a way that it could feed the total electricity for 1 hour. Based on the 720-hour consumption values of four houses determined as the load, hourly average of the demanded load was determined as 1600 Wh. The batteries used in the study were 12 V/75 Ah and the batteries with a maximum charge depth of 87%. Accordingly, the minimum number of batteries that could feed the load for 1 hour:
1600 (Wh) ×1 / 12 (V) = 133,3 Ah,
It is determined as (133,3 Ah) / (0,87×75 Ah) = 2,04.
Accordingly, in cases where energy can't be generated from the main source, 2×(12 V/75 Ah) serial batteries must be used in order for the batteries to feed the load independently for 1 hour. In this case, the string would consist of 2 batteries, and the number of batteries would increase by two while scanning the most appropriate battery number in both CFA and PSO algorithms.

2.3. Inverter Model

It was assumed that the devices used in 4 houses, which were determined as load, operate with 220 V and 50 Hz alternative current in this study. For this reason, direct current generated from PV and batteries must be inverted into alternative current. For this, an inverter was needed. The power value to be taken from the inverter output was obtained by multiplying the power coming to the input of the inverter with the efficiency of the inverter. This situation was shown in equation 1.

In this study, inverter loss was accepted as 8%.

$$\text{Inverter Capacity} = \left(\frac{\text{hourly energy requirement} \times \text{inverter loss compensation}}{\text{Base time (1 hour)}}\right) \quad (1)$$

Accordingly, the inverter capacity that should be in the system was:

$$\text{Inverter Capacity} = \left(\frac{1600\ \text{W} \times 1.08}{(1\ \text{hour})}\right) = 1728\ \text{W}$$

2.4. Load Model

The load is also called the demanded energy. It is waived in kW. The load profile helps to see how the demanded energy is used over time [25]. The data set was collected by Precon [26] with smart meters. It contains data from users of different demographic features and different social and financial backgrounds. The properties of four different houses used in this study are as in Table 3.

Table 3. The properties of four different houses [26]

House	Building Year	Ceiling Insulation	Children	Senior	Refrigerator	Washing Machine	Electric Heater	Iron
1	1992	Yes	3	2	2	1	2	1
2	1985	No	0	1	2	1	1	1
3	2010	No	0	0	2	1	0	1
4	1990	No	1	0	1	1	0	1

Figure 1 shows 720 hours consumption data for four houses.

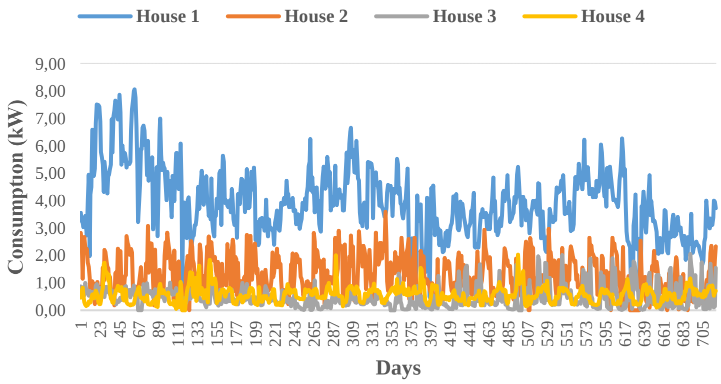


Figure 1. 720 hours consumption data of four houses

3. Method

The aim of this study was to ensure that part of the total electricity need in a site consisting of four houses was met by the PV-BT system with the minimum cost within the framework of fair usage. The standard deviation method was used for this. The standard deviation value was obtained by finding the minimum and maximum values from the combinations of the 720×1 matrix, which was the result of multiplying the values of 720-hour electricity consumption of four houses by four different percentages. Table 4 shows the unknowns in the study and the limitations of these unknowns.

Table 4. Unknowns and restrictions

Unknown values	H_1	H_2	H_3	H_4
Restrictions	$0 <= H_n <= 100$,			
	$H_1+H_2+H_3+H_4=100\%$			

There were 720 hours of data for four houses separately. These data form a 720×4 matrix consisting of 720 rows and 4 columns. H_1, H_2, H_3 and H_4 were the parameters that determine the percentage ratios of the electrical energy obtained from the PV-BT system used by the houses. These parameters form a 4×1 matrix consisting of 4 rows and 1 column. As a result of the multiplication of these two matrices, a 720×1 matrix consisting of 720 rows and 1 column was formed. This matrix gives total load amounts with minimum and maximum standard deviation. It was ensured that these load amounts were met fairly by the PV-BT system.

Standard deviation is defined as the standardised measure of the distance of each data from the mean in a data set. It is a statistic calculated based on the average. Its value is desired to be the smallest. It is calculated as in equation 2 [27].

$$A = \sqrt{\frac{\sum (X_i - \bar{X})^2}{n-1}} \quad (2)$$

Flowchart of the study is as in Figure 2.

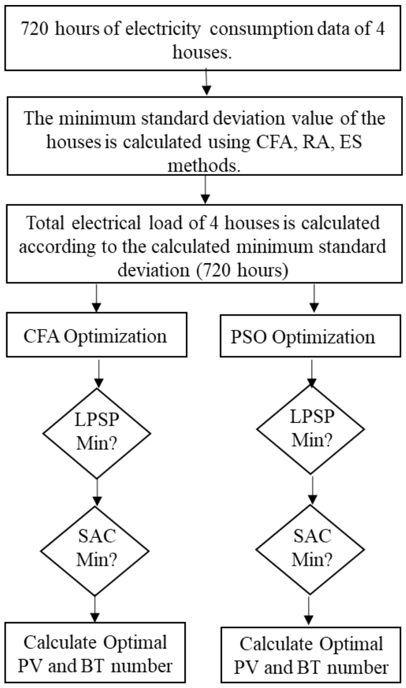


Figure 2. Flowchart of the study

3.1. Minimum Standard Deviation Calculation with CFA

In the conditional flow algorithm, there is no need for any extra information about the objective function. It is a method used in solving optimisation problems. Unlike traditional optimisation methods, it searches for a point lower than the value of the objective function for the moment in the set of points [28]. It is a method that guarantees to reach the target result. It works on the principle of scanning all values in the range that must be scanned to achieve the target result. The ability to scan only two parameters, such as solar panels and battery numbers and to guarantee to find the global minimum are the features that make this algorithm superior. At this stage, the result obtained with CFA is the actual minimum deviation value result. This is due to the fact that it was obtained as a result of scanning the entire range. While making standard deviation calculations with CFA, the variables H_1, H_2, H_3 and H_4 were scanned between 0 and 100 with 1 number increment. Scanning ranges were as follows:

H_1=0:1:100
H_2=0:1:100
H_3=0:1:100
H_4=0:1:100

In this direction, the result obtained with CFA was as in Table 5.

Table 5. Minimum standard deviation and usage percentages with CFA (Integer)

H_1 (%)	H_2 (%)	H_3 (%)	H_4 (%)	Min. Std. Dev.
1	9	32	58	0.219799

3.2. Minimum Standard Deviation Calculation with RA

The calculation was made by assigning random values to the relevant variables in the specified range in the random algorithm. The results were obtained by considering the restrictions in Table 4 and assigning random values to each variable. Scanning ranges for variables were done as follows:

$$H_1=0:1:100$$
$$H_2=0:1:100$$
$$H_3=0:1:100$$
$$H_4=0:1:100$$

The results were obtained by running the program 10 times. All results are shown in Table 6.

Table 6. Minimum standard deviation and usage percentages with RA (Integer)

Run	H_1 (%)	H_2 (%)	H_3 (%)	H_4 (%)	Min. Std. Dev.
1	1	20	25	54	0.234196
2	3	23	5	69	0.263518
3	9	3	40	48	0.245961
4	4	1	38	57	0.230273
5	8	11	34	47	0.237975
6	1	31	23	45	0.272449
7	5	8	48	39	0.238395
8	***2***	***14***	***26***	***58***	***0.223898***
9	6	1	23	70	0.239731
10	13	20	19	48	0.281758

The best result was obtained with the eighth run. The minimum standard deviation was achieved as 0.223898, while the percentages were 2%, 14%, 26% and 58%, respectively. When the results obtained with the conditional flow algorithm were compared with the results obtained by assigning a random value, it was seen that the random algorithm also obtained a value close to the minimum result.

3.3. Minimum Standard Deviation Calculation with Solver

The result obtained in the study with ES was the same the result obtained with CFA. Considering that CFA calculates the global minimum standard deviation by calculating among all combinations, ES's reaching the same result showed that it was also a successful method. The result obtained with ES is as in Table 7.

Table 7. Minimum standard deviation and usage percentages with ES (Integer)

H_1 (%)	H_2 (%)	H_3 (%)	H_4 (%)	Min. Std. Dev.
1	9	32	58	0.219799

In the studies up to this stage, the results were obtained by scanning with integer values. After this stage, the study was carried out according to the decimal status of the variables. Accordingly, all the minimum standard deviation results obtained with CFA, RA and ES are as in Table 8.

Table 8. Minimum standard deviation with all methods (Integer and Decimally)

Method	H_1	H_2	H_3	H_4	Minimum Standard Deviation
CFA (Integer)	1	9	32	58	0.219799
CFA (Decimally) (From 0 to 100 with 0.50 steps)	1.0000	9.0000	32.5000	57.5000	0.219788
ES (Integer)	1	9	32	58	0.219799
ES (Decimally)	***1.1061***	***9.1814***	***32.3474***	***57.3650***	***0.219779***
RA (Integer)	2	14	26	58	0.223898
RA (Decimally) (The lowest after 10 times of running)	0.6643	15.5541	16.7632	67.0172	0.233042

When Table 8 is examined, it is seen that the lowest value among the minimum standard deviation results in the use of decimals scenario was produced by ES. The minimum standard deviation value obtained as a result of this scenario was 0.219779, and fair usage percentages for each house were 1.1061%, 9.1814%, 32.3474% and 57.3650%, respectively. In other words, if 1.1061% of the energy received from the PV-BT system were used by house 1, 9.1814% by house 2, 32.3474% by house 3 and 57.3650% by house 4, the energy to be obtained from the PV-BT system would be used fairly.

3.4. Maximum Standard Deviation Calculation

While calculating the minimum standard deviation, since the best result was obtained with decimal numbers in the ES application, only ES application and decimal numbers were studied in the maximum standard deviation calculation. Accordingly, the result obtained by ES was as in Table 9.

Table 9. Maximum standard deviation and usage percentages with ES (Decimally)

H_1 (%)	H_2 (%)	H_3 (%)	H_4 (%)	Max. Std. Dev.
100	0	0	0	1.240993

Considering these results, the graph of the total load values required to be fed by the PV-BT system at the minimum and maximum standard deviation values is as in Figure 3.

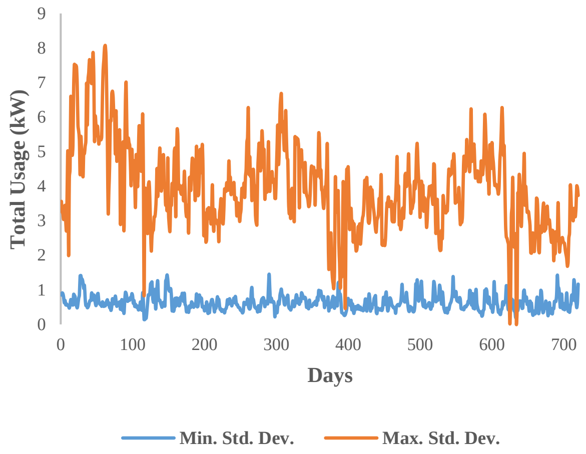


Figure 3. Total consumed load values according to the minimum and maximum standard deviation values

3.5. Technical Criteria

The technical criteria can also be called LPSP. The system that provides reliable electrical power means having enough power to supply the power demanded by the load in each period. In other words, it is the case where the LPSP value is zero. When the power system cannot meet the energy demanded by the load, the probability of the load being de-energized is calculated. If the value of the variable used in the calculation does not change, it means that the power demanded by the load is provided by the power system. An increase in its value means that the energy generated by the power system at that hour is not sufficient to feed the load. LPSP is a statistical parameter. The calculation of LPSP value is not only related to the solar radiation value. It is also related to the condition of the batteries at that time. For this reason, the system is largely powerless at times when these data are bad. In this study, LPSP, one of the target functions, is calculated as a percentage and determined according to equation 3.

$$\text{LPSP}\ (\%) = (A/720) \times 100 \tag{3}$$

Variable A indicated the total number of hours in which the energy supplied by the PV panel and battery string could not meet the demanded energy. The load remain powerless during these hours. The number 720 refers to the total hours from 00:00 on June 1, 2018 until 23:00 on June 30, 2018.

The power required by the load is calculated as in equation 4:

$$P_{iht}(t) = P_{ACload}(t)/\eta_{inv}(t) \tag{4}$$

For the specified hour, if the energy generated by the PV panels was more than the load, the excess energy was stored in the batteries and the new state of the battery was determined according to equation 3. The remaining energy was not used. The LPSP value remains at its final value. (LPSP=LPSP).

If the energy demanded by the load were more than the energy generated by the PV panels, the batteries would be activated to meet the energy demanded by the load. The batteries would be discharged according to equation 3 and would feed the load. If the total amount of energy in the batteries were enough to feed the load, the LPSP value would remain in its final state. If the energy in the batteries were insufficient, the load would be weak, and the LPSP value would be increased by 1. (LPSP=LPSP+1).

3.5. Economic Criteria

It is the economic criterion used in optimisation in this study. The aim was to minimise the cost based on the SAC concept. CFA and PSO algorithms were used to minimize the SAC. The total cost of the system consisted of the initial main costs, replacement costs and maintenance costs. While calculating these costs, PV, BT, inverter (INV), charge control unit (CCU), panel and installation costs were taken into consideration. Accordingly, the total cost is as in equation 5.

Total Cost (for 25 years) =Initial Main Costs + Replacement Costs + Maintenance Costs (5)

PV panel, battery group, inverter, charge control unit, panel and installation costs were taken into account in the initial cost of each component. This is as in equation 6.

Initial Main Costs = (PVinitialcost×PV)+(BTinitialcost×BT)+(INVinitialcost×1)+(CCUinitialcost×1)+(PANELinitialcost×1)+Installation (6)

Replacement costs are calculated by considering equation 7.

Replacement Costs = (BTinitialcost × BT× number of replacement) + (INVinitialcost × 1× number of replacement) (7)

Considering that the life span of PV is 25 years, the number of changes was taken as 5 for BT (since its life span is 4). For INV (since its life span is 10), the number of changes was taken as 1.5. Considering the life span of the components, only the battery and the inverter need to be changed periodically during the life of the system.

Maintenance costs (25 years) are calculated by considering equation 18.

Maintenance Costs (25 years) =(PVannualmaintenance×PV× number of maintenance)+(BTannualmaintenance×BT× number of maintenance) (8)

Since the life span of PV is 25, the number of maintenance for PV is 24. It will complete its life without maintenance in the last year. Since the life span of BT was 4 years, 5 times change was required for BT in 25 years. There will be no maintenance during these replacement years. For this reason, there will only be BT maintenance in the intervening 3 years. Accordingly, the string of the battery feeding the load will change 6 times. In this case, the number of maintenance for BT will be 18 (6×3).

Unit price, full price, maintenance cost and lifespan of PV panel, battery and other devices in this study are shown in Table 10.

Table 10. All cost of the system component [23-24]

Component	Unit Price ($)	Price ($)	Maintenance Cost ($)	Lifespan (year)
PV (200 W)	0.85	85	0.85 (1%)	25
BT	-	115	1.15 (1%)	4
Inverter	-	700	-	10
Charge Control Unit	-	1000	-	-
Panel (Electric Panel)	-	300	-	-
Installation Cost (cable etc.)	-	1500	-	-

Accordingly, the final version of the above cost equations was as follows:

Initial Main Costs ($) = (85×PV) + (115×BT) + (700×1) + (1000×1) + (300×1) + 1500

Replacement Costs ($) = (115×BT×5) + (700×1×1.5)

Maintenance Costs ($) = (0.85×PV×24) + (1.15×BT×18)

Accordingly SAC value was:

SAC = (Initial Main Costs + Replacement Costs + Maintenance Costs) / (25 year);

SAC = ([(85×PV) + (115×BT) + (700×1) + (1000×1) + (300×1) + 1500] + [(115×BT×5) + (700×1×1.5)] + [(0.85×PV×24) + (1.15×BT×18)])/25;

SAC= (105.4×PV + 710.7×BT + 4550)/25

For determining the number of PV and BT that could feed load value at an optimum level, minimum LPSP and min SAC values will be taken into account. Two different algorithms were used for optimisation. These were CFA and PSO. CFA was described in section 3.1. PSO is a meta-heuristic algorithm often used in discrete, continuous and combinatorial optimisation problems. It was developed in 2001 by Kennedy and Eberhart [29]. It imitates the social behaviour of food-seeking bird flocks. The only solution is called a particle. The sum of all solutions is called a herd. The algorithm is started with randomly generated particles looking for the most suitable solution. Every particle has a position and velocity. The velocity of each particle is updated according to the following equation 9 [30-31]:

$$v_{i,j}(t+1) = w \times v_{i,j}(t) + c_p \times r_p \times \left(pBest_{i,j} - x_{i,j}(t)\right) + c_g \times r_g \times \left(gBest_j - x_{i,j}(t)\right) \tag{9}$$

v_{ij} is the velocity of i th particle in the j th dimension. x is the current particle position, and w is the constant called momentum, which sets from the previous time step how much the velocity will affect the velocity in the current time step. c_p and c_g are predefined constants. r_p and r_g are random numbers in the range (0, 1). The position of particle i in the j_{th} dimension is updated as in equation 10:

$$x_{i,j}(t+1) = x_{i,j}(t) + v_{i,j}(t+1) \tag{10}$$

Excel solver (ES) is an excel application that can be used for simulation analysis. The aim **is** to find the optimum value for a formula in the cell. ES works with a group of cells used in calculation formulas in objective and constraint cells. Values in the decision variable cells are set to accommodate the constraints in the constraint cells and create the desired value for the objective cell [32].

4. Results and Discussions

4.1. Minimum SAC with Minimum Standard Deviation

While scanning with CFA to calculate the minimum cost in the minimum standard deviation, the number of PV was obtained with 1 increment in the range of 0-200. The number of BT was obtained by scanning with two increments between 2-50. Considering these range, a total of 306 LPSP values out of 500 (200×25) probabilities were calculated as 0%, and among these values, the value of 1850.576 $ in the 97th rank was calculated as the minimum SAC value. This situation is seen in Figure 4 (a). According to the cost of 1850.576 $, the number of PV and BT was calculated as 180 and 32, respectively. In order to calculate the minimum cost with PSO according to the minimum standard deviation, the number of PV was scanned in the range of 0-200, and the number of BT was scanned in the range of 0-100. The SAC value was obtained as 1759.992 $. This value could only be obtained at a minimum value of 0.83% LPSP. As can be seen in Figure 4 (b), the minimum cost had calculated by PSO from the 63rd iteration out of 100 iterations in total. According to the cost of 1759.992 $, the number of PV and BT was calculated as 172 and 30, respectively.

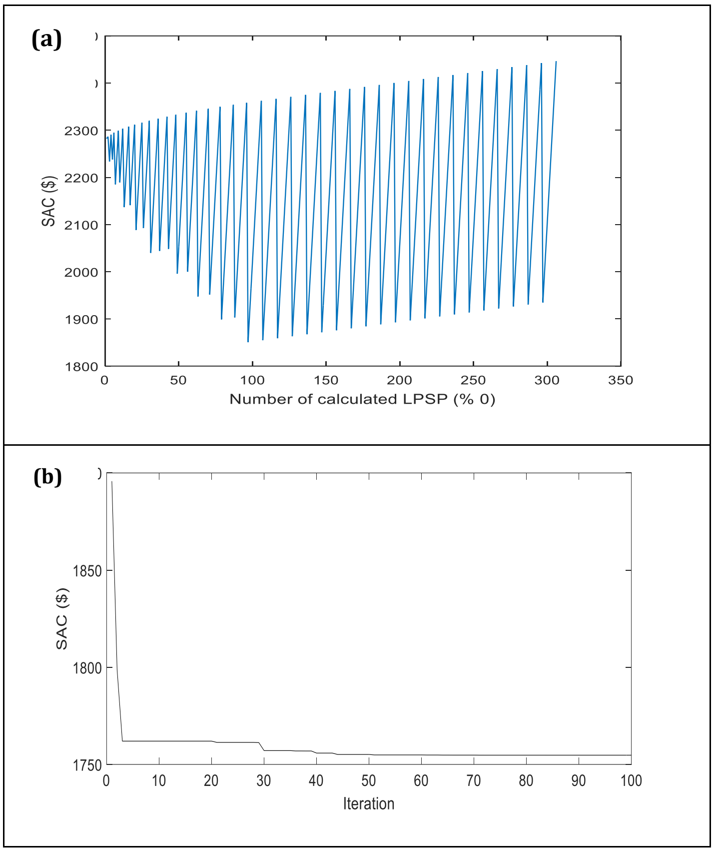
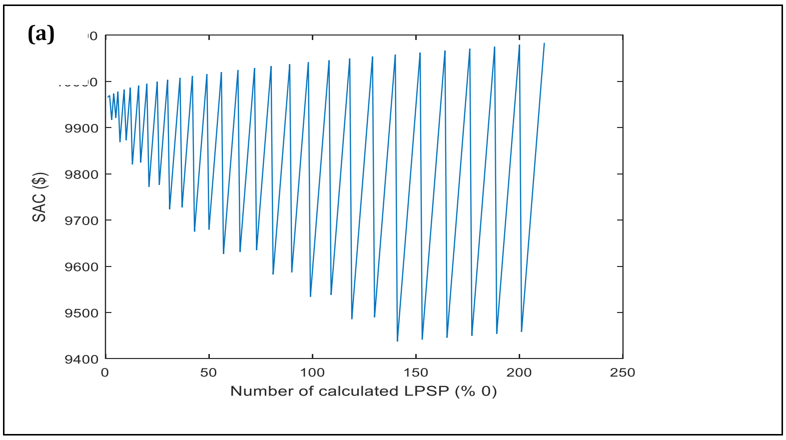


Figure 4. (a) Graph of calculating the minimum SAC value with CFA
(b) Graph of calculating the minimum SAC value with PSO

4.2. Minimum SAC with Maximum Standard Deviation

In order to calculate the minimum cost according to the maximum standard deviation with CFA, the number of PV was obtained by scanning with one increment in the range of 0-1000, and the number of BT was obtained by scanning with two increments in the range of 2-200. Considering these ranges, a total of 212 LPSP values among 1000 × 100 = 100.000 probabilities were calculated as 0%, and among these values, the value of 9437.104 $ in the 141st row was calculated as the minimum SAC value. This situation is seen in Figure 5 (a). According to the cost of 9437.104 $, the number of PV and BT was calculated as 995 and 178, respectively. With PSO, according to the maximum standard deviation, the number of PV was scanned between 0-1000 and the number of BT between 0-200, and the minimum cost was obtained as 8918.896 $. This value could be obtained at 0.83% LPSP value. As can be seen in Figure 5 (b), the minimum cost calculation had been made by PSO from the 59th iteration out of 100 iterations in total. According to the cost of 8918.896 $, the number of PV and BT was calculated as 953 and 166, respectively.



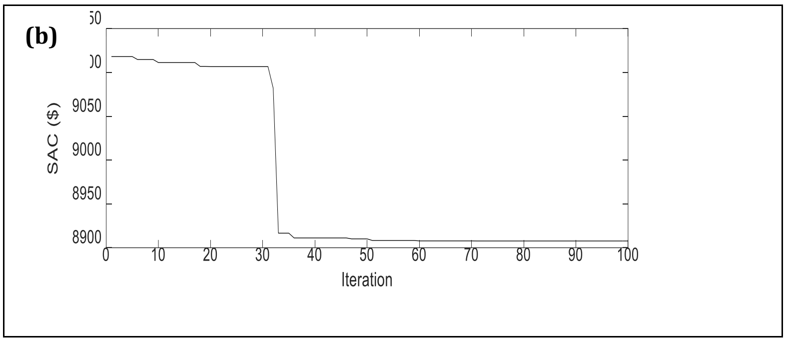


Figure 5. (a) Graph of calculating the maximum SAC value with CFA
(b) Graph of calculating the maximum SAC value with PSO

The results obtained for both cases (case 1 and case 2) are as in Table 11.

When the studies in the literature were reviewed, it wasn't possible to see studies regarding the fair usage of energy resources by loads. In this study, unlike the studies in the literature, it was aimed to ensure fair usage of the power obtained from the renewable energy source among the loads. The standard deviation method was used for this. CFA, RA and ES methods were used to calculate the standard deviation. Ghaffari et al. [13], Bukar et al. [16] and Astaneh et al. [18] achieved their goals by using different algorithms for LPSP and minimum cost calculations in their studies. In this study, after calculating the minimum standard deviation, LPSP and SAC research was done with CFA and PSO for optimum sizing of the PV-BT system.

Table 11. Results of case 1 and 2 (LPSP= % 0 – 1)

Case	Standard Deviation Method	H_1 (%)	H_2 (%)	H_3 (%)	H_4 (%)	Standard Deviation	Optimization Method	PV (200W)	BT (12 V 75 Ah)	Min. SAC ($)	LPSP (%)	Load (kW) (720 hours)
1	Excel Solver (Decimally)	1.1061	9.1814	32.3474	57.3650	0.219779 (min)	CFA	180	32	1850.576	0.00	456.58
							PSO	172	30	1759.992	0.83	
2		100.00	0.00	0.00	0.00	1.240993 (max)	CFA	995	178	9437.104	0.00	2836.23
							PSO	953	166	8918.896	0.83	

This study, unlike the studies in the literature, it was aimed to ensure fair usage of the power obtained from the renewable energy source among the loads. Standard deviation method was used for this. CFA, RA and ES methods were used to calculate the standard deviation. Ghaffari et al. [13], Bukar et al. [16] and Astaneh et al. [18] achieved their goals by using different algorithms for LPSP and minimum cost calculations in their studies. In this study, after calculating the minimum standard deviation, LPSP and SAC research was done with CFA and PSO for optimum sizing of the PV-BT system.

5. Conclusions

In this study, in order to benefit from a renewable energy system consisting of PV and BT both fairly and economically, an optimum design was made according to the electrical energy data of a site consisting of 4 houses. Seven different standard deviations were calculated. Among these, the minimum standard deviation value obtained in the study of ES with decimal numbers had the lowest value. This value was calculated as 0.219779. The fair usage percentages of the energy to be obtained from the renewable energy source on the basis of houses were calculated as 1.1061%, 9.1814%, 32.3474% and 57.3650%, respectively. The maximum value of the standard deviation was 1.240993, with fair usage percentages being 100%, 0%, 0% and 0%. Optimisation studies were carried out considering the partial consumption amount obtained according to these standard deviation values. Results were obtained with both CFA and PSO to calculate the number of PV and BT where both criteria were minimum. Considering the minimum standard deviation value, in the optimization study with CFA, 306 combinations with an LPSP value of 0% among 500 probabilities were calculated. Among these, the minimum SAC value was calculated as 1850.576 $. The numbers of PV and BT calculated for this cost were 180 and 32, respectively. Considering the minimum standard deviation value, the LPSP value was calculated as 0.83% in the study with PSO. The minimum SAC value was calculated as 1759.992 $. The numbers of PV and BT calculated for this cost were 172 and 30, respectively. The same studies were also carried out on the basis of the maximum standard deviation. According to the optimisation with CFA, the minimum SAC value was calculated as 9437,104 $. The numbers of PV and BT corresponding to this SAC value were calculated as 995 and 178, respectively. In case study, the standard deviation was maximum, and the minimum SAC value was obtained as 8918.896 $ in the optimisation with PSO, while this value was obtained at 0.83 % LPSP value. The calculated numbers of PV and BT were 953 and 166. Considering the results obtained, although the CFA algorithm obtained the global minimum for the minimum LPSP value, a minimum LPSP value above this value was obtained by the PSO algorithm. The algorithm's inability to catch the global minimum can be seen as a shortcoming. However, the difference of only 0.83% ensures that both the number of PV and BT are lower and, accordingly, the total cost is lower. As a consequence, it is thought that this study will be a guide in ensuring fair usage and sizing optimisation of renewable energy in places where there is collective energy usage.

Conflict of Interest

Author has declared no conflict of interest.

References

[1] Zhang, W., Maleki, A., Rosen, M.A. and Liu, J. (2019). Sizing a stand-alone solar-wind-hydrogen energy system using weather forecasting and a hybrid search optimization algorithm. *Energy Conversion and Management,* 180, 609-621.

[2] Chauhan, A. and Saini, R.P. (2017). Size optimization and demand response of a stand-alone integrated renewable energy system. *Energy,* 124, 59-73.

[3] Sobek, W. (2018). Building as renewable power plants: Active houses for the electric City, Urban Energy Transition (Second Edition). *Renewable Strategies for Cities and Regions,* 131-138.

[4] Mohamed, M.A., Eltamaly, A.M. and Alolah,A.I. (2017). Swarm intelligence-based optimization of grid-dependent hybrid renewable energy systems. *Renewable and Sustainable Energy Reviews,* 77, 515-524.

[5] Al-falahi, M.D.A., Jayasinghe, S.D.G. and Enshaei, H. (2017). A review on recent size optimization methodologies for standalone solar and wind hybrid renewable energy system. *Energy Conversion and Management,* 143, 252-274.

[6] Zhang, W., Maleki, A., Rosen, M.A. and Liu, J. (2018). Optimization with a simulated annealing algorithm of a hybrid system for renewable energy including battery and hydrogen storage. *Energy,* 163, 191-207.

[7] Al-Ghussain, L., Samu, R., Taylan, O. and Fahrioglu, M. (2020). Sizing renewable energy systems with energy storage systems in microgrids for maximum cost-efficient utilization of renewable energy resources. *Sustainable Cities and Society,* 55, 102059.

[8] Mehrabankhomartash, M., Rayati, M., Sheikhi, A. and Ranjbar, A.M. (2017). Practical battery size optimization of a PV system by considering individual customer damage function. *Renewable and Sustainable Energy Reviews,* 67, 36-50.

[9] Makhdoomi, S. and Askarzadeh, A. (2020). Optimizing operation of a photovoltaic/diesel generator hybrid energy system with pumped hydro storage by a modified crow search algorithm. *Journal of Energy Storage,* 27, 101040.

[10] Mahmoud, T.S., Ahmed, B.S. and Hassan, M.Y. (2019). The role of intelligent generation control algorithms in optimizing battery energy storage systems size in microgrids: A case study from Western Australia. *Energy Conversion and Management,* 196, 1335-1352.

[11] Kerdphol, T., Fuji, K., Mitani, Y., Watanabe, M. and Qudaih, Y. (2016). Optimization of a battery energy storage system using particle swarm optimization for stand-alone microgrids. *International Journal of Electrical Power&Energy Systems,* 81, October, 32-39.

[12] Baran, B. (2012). *Cost optimization of solar - wind hybrid systems,* Inonu University Electrical and Electronic Engineering Department. Master of Science Thesis.

[13] Ghaffari, A. (2020). Design optimization of a hybrid system subject to reliability level and renewable energy penetration. *Energy,* 193, 116754.

[14] Hemeida, A.M., El-Ahmar, M.H., El-Sayed, A.M., Hasanien, H.M., Alkhalaf, S., Esmail, M.F.C. and Senjyu, T. (2020). Optimum design of hybrid wind/PV energy system for remote area. *Ain Shams Engineering Journal,* 11:1, 11-23.

[15] Kaabeche, A. and Bakelli, Y. (2019). Renewable hybrid system size optimization considering various electrochemical energy storage Technologies. *Energy Conversion and Management,* 193, 162-175.

[16] Bukar, A.L., Tan, C.W. and Lau, K.Y. (2019). Optimal sizing of an autonomous photovoltaic/wind/battery/diesel generator microgrid using grasshopper optimization algorithm. *Solar Energy,* 188, 685-696.

[17] Jamshidi, M. and Askarzadeh, A. (2019). Techno-economic analysis and size optimization of an off-grid hybrid photovoltaic, fuel cell and diesel generator system. *Sustainable Cities and Society,* 44, 310-320.

[18] Astaneh, M., Roshandel, R., Dufo-López, R. and Bernal-Agustín, J.L. (2018). A novel framework for optimization of size and control strategy of lithium-ion battery based off-grid renewable energy systems. *Energy Conversion and Management,* 175, 99-111.

[19] Fetanat, A. and Khorasaninejad, E. (2015). Size optimization for hybrid photovoltaic–wind energy system using ant colony optimization for continuous domains based integer programming. *Applied Soft Computing,* 31, 196-209.

[20] Bukar, A.L. and Tan, C.W. (2019). A review on stand-alone photovoltaic-wind energy system with fuel cell: System optimization and energy management strategy. *Journal of Cleaner Production.,* 221, 73-88.

[21] Lian, Y (2020). Energy optimization potential for interconnected buildings in a new urban development project. Master of Science Thesis TRITA-ITM-EX 2020:4, *KTH Industrial Engineering and Management,* Sustainable Energy Engineering.

[22] Turkish State. 2020. Meteorological Service, Solar radiation data of Malatya. www.mgm.gov.tr, (Accessed Date: 30 June 2020).

[23] PV Panel. 2020. https://www.terasolarsatis.com/200w-polikristal-fotovoltaik-panel (Accessed Date: 07 July 2020).

[24] Battery. 2020. Solar Systems, 100Ah Full Energy accumulator. https://www.mutlu.com.tr/full-enerji-akuler (Accessed Date: 07 July 2020).

[25] Garson, S. What is a Load Profile and why is it Important?. Retrieved from: http://bettercostcontrol.com/what-is-a-load-profile-andwhy-is-it-important, (Accessed Date: 27 July 2020).

[26] Precon. 2020. Pakistan Residential Electricity Consumption Dataset. https://opendata.com.pk/dataset/precon-pakistan-residential-electricity-consumption-dataset, (Accessed Date: 30 March 2020).

[27] Standard Deviation. 2020. https://acikders.ankara.edu.tr/pluginfile.php/1379/mod_resource/content/2/B6_Merkezden%20Da%C4%9F%C4%B1lma%20%C3%96l%C3%A7%C3%BCleri.pdf, (Accessed Date: 16 May 2020).

[28] Yang, H., Zhou, W., Lu, L. and Fang, Z. (2008). Optimal sizing method for stand-alone hybrid solar–wind system with LPSP technology by using genetic algorithm. *Solar Energy,* 82, 354–367.

[29] Kennedy, J. and Eberhart, R.C. (2001). Swarm Intelligence. Academic Press, San Diego, CA.

[30] Junior, F.E.F. and Yen, G.G. (2019). Particle Swarm Optimization of Deep Neural Networks Architectures for Image Classification. *Swarm and Evolutionary Computation,* 49, 62-74.

[31] Shamshirband, S., Mosavi, A. and Rabczuk, T. (2020). Particle swarm optimization model to predict scour depth around a bridge pier. *Frontiers of Structural and Civil Engineering,* 1-12.

[32] Excel Solver. 2020. https://support.microsoft.com/tr-tr/office/%C3%A7%C3%B6z%C3%BCc%C3%BC-y%C3%BC-kullanarak-bir-sorunu-tan%C4%B1mlama-ve-%C3%A7%C3%B6zme-5d1a388f-079d-43ac-a7eb-f63e45925040, (Accessed Date: 22 May 2020).