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OPTIMAL DESIGN OF ENERGY SOURCES IN A BUILDING CONNECTED TO GRID IN THE PRESENCE OF ELECTRIC VEHICLES

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ABSTRACT

Fossil fuels can supply the world energy for a limited time, and the huge reserves and resources of these fuels are declining; therefore, in the future, they cannot respond to the growing need of communities for energy. In addition, the production of environmental pollutants caused by these fuels is very harmful. It is therefore clear that a suitable alternative to fossil fuels should be sought, which in addition to mentioned issues can provide high-quality and high-reliability energy for a building. One of these alternatives is using renewable energy and distributed generation sources. The optimized design of energy resources for a domestic consumer connected to grids powered by solar renewable energy sources, energy storage systems, and electric vehicles, is the main purpose of this article. In this structure, the consumer is able to store his excess electricity in the battery so that at peak times and when the price of electricity is high; the required electricity can be supplied through the battery and less electricity will be purchased. The simulation was performed by the means of the gray wolf optimization algorithm and by considering the production and storage constraints of each resource, and the results were compared with genetic optimization and particle swarm algorithms. Simulation results show that the optimum timing of charging and discharging the electric car battery and its application in building power and energy storage in non-peak and low-cost electricity hours reduces the optimal capacity of the energy sources in the building and reduces the related costs.

Keywords: *Building Energy Sources, Renewable Energy, Distributed Generation, Electric Vehicle, Optimization, Optimal Capacity.*

INTRODUCTION

World energy consumption is growing rapidly. In the United States, more than 40% of primary energy and 70% of electricity are consumed in buildings (U.S. Department of Energy, 2008). In addition, the environmental impacts associated with this type of energy consumption have raised serious concerns in various societies and among researchers, engineers, and even politicians. Energy consumption in the building accounts for 38% of CO_2 gas emissions, 52% of SO_2 emissions, and 20% of NO_x emissions to the atmosphere, and in light of global climate change and the effects of greenhouse gas emissions this phenomenon is considered a major catastrophe (Alirezaei et al., 2016).Therefore, in order to achieve greater environmental stability and sustainability, it is imperative to minimize energy consumption of buildings and generate energy through clean energy sources in the building. Integrated intelligent buildings with renewable sources represent the next generation of buildings (Alirezaei et al., 2016; Marszal, et al., 2011; Perivitera et al., 2011; Hamada et al., 2011; Ratlamwala et al., 2012; Wu et al., 2011), which are more convenient and consume less energy (Nair, Garimella, 2010). The two-way

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relationship between electricity companies and consumers through an energy management system allows consumers not only to reduce their energy costs but also improve their performance by even selling their excessive energy (Peng et al., 2011). In the following are some of the procedures that have been done on energy management in residential buildings since 2010. In (Rezaie et al., 2011) an analysis has been provided to compare the various renewable energy options for four different buildings in Canada. Heat pump for heating and cooling, solar collectors for warming up the environment and hot water, and photovoltaic-thermal panels for generating power have been investigated in case studies. The results show that if the goal is to minimize costs, solar water heaters are the best choice, while hybrid systems are the best choice for minimizing CO_2 emissions. This paper lacks energy storage. In (Askarzadeh, 2013) for optimizing the solar-wind hybrid system with battery saver, three discrete annealing algorithms, annealing based on harmonic search and annealing based on chaotic discrete harmonic search were considered. The main objective of this study was to minimize the annual costs of the system. The optimization results have shown that the discrete chaotic harmony search-based annealing algorithm has less cost than the other methods and by determining the optimal capacity of solar units, wind and battery banks the lower cost is achieved. This study considers the optimization of the hybrid system only economically and minimizes the cost of the system, and the reliability index is not well considered.

In (Milo et al., 2009), a hybrid microgrid composed of renewable sources and simultaneous producer of the heat and power along with the energy storage system has been simulated. Although electric vehicles are not considered in this study, microgrid optimization is considered in both connected and independent state in line with the grid, and the constraints and modeling of the problem have become more complete. In (Niknam et al., 2012), in order to optimize energy management, the gravity search algorithm has been used. In (Sheikhi et al., 2016), energy management is provided for a household consumer. In this paper, the most important converter of energy is the source of the simultaneous generation of electricity and heat, which in practice is a micro turbine with a heat recovery system. The results presented in this reference represents a significant reduction in costs and energy consumption in the peak hour so that the total cost of the system decreased by 20% and the power consumption of the network at peak hours decreased by 24%. However, the environmental pollutants produced by the microturbine cannot be ignored. In (Moghaddam et al., 2016), an innovative method for modeling an energy hub has been proposed based on the energy flow of its equipment. After modeling, an optimization problem is presented for optimal 24-hour operation of the energy hub, which is modeled as a nonlinear hybrid problem with an integer. In this paper, the inputs of the energy hub are electric power and natural gas, and the consumption includes electric, heating and cooling charges. In (Ooka, Komamura, 2009), a method based on the Genetic Algorithm (GA) was used for optimal measurement of building energy supply systems. The main objective of their method is to determine the best combination of components, capacity, and performance planning for cooling, heating, and load power by taking into account the minimum CO_2 emission. However, the proposed method yields close to optimal responses, but in terms of computational procedure it is heavy and its convergent is slow.

In (Yang et al., 2007), a model is provided for determining the optimal capacity of wind-solar systems for optimizing the various capacities of components of wind-solar power generation systems by taking into account the capacity of the batteries. In this study, the optimal design of the hybrid system has been made with the aim of reducing the cost of the hybrid system and achieving the desired load-carrying capacity. In this study, the probability of performance of the energy producing units is considered to be 100%. This means that the units in the studied system are always in a stable and working state. Regarding the fact that each unit has a repair and failure rate that determines the probability of performance or the availability of equipment based on that, by taking into account 100% availability level, the optimal design detaches these systems from a realistic perspective. In this paper, the effects of energy storage resources such as electric vehicle battery and household battery storage will be assessed in consumption management and smart house cost management with gray wolf algorithm and economic and technical effects of management of consumption and resources on using God-given resources and reducing losses and increasing the reliability of the grid.

MATHEMATICAL MODEL

The configuration of the building under study is shown in Figure 1. It is seen that this intelligent building, connected to the grid, includes photovoltaic arrays, storage devices (in this paper, namely, batteries), and home intelligent load management system, and an electric vehicle.

In this paper, the problem of optimal design of energy sources in the intelligent building is defined as an optimization problem in which the total cost of the overall energy cost and the cost of domestic batteries in the horizons of optimization is minimized.

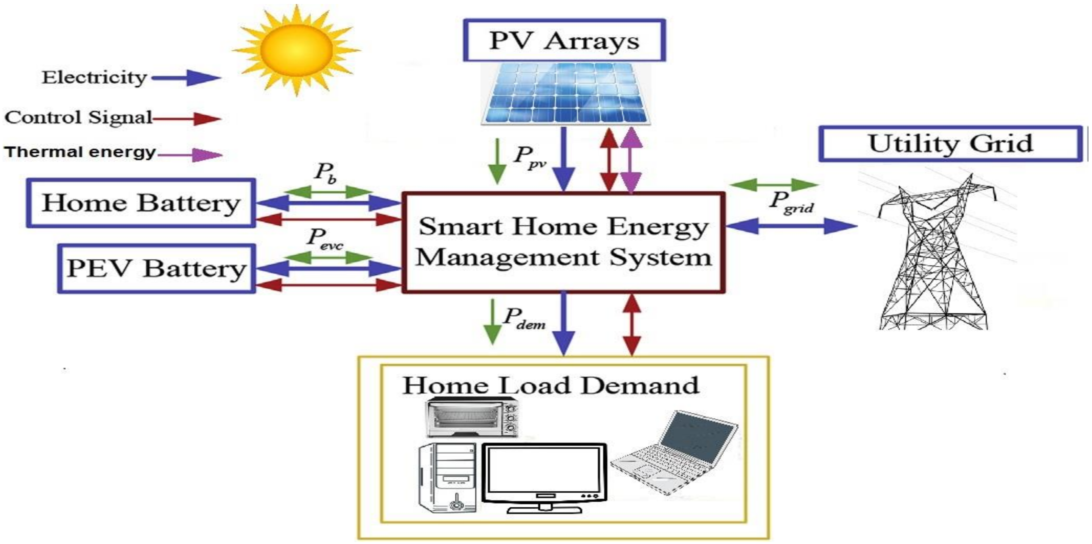

Figure 1: Configuration of the studied building

The objective function

Intelligent home management system is based on the optimal design of the home battery capacity to minimize the power received from the distribution network in terms of electricity tariffs so that at a time of high tariffs, the share of power received from the grid is minimized, and at the time of cheap tariffs, the share of power received from the grid will be maximized and the total economic cost C_{ny} of monthly and daily will be optimized.

$$C_{ny} = n\sum_{k=0}^{n-1} \frac{C_{e,k} P_{grid,k}}{100} \tag{1}$$

And the total cost of a smart home considering the cost of storing and charging-discharging of the battery C_c and the initial cost C_b of purchasing a battery with a nominal capacity is as follows.

$$F = C_{ny} + c_b Q_{b,eap} + c_c P_b^{\max} \tag{2}$$

In this way, the smart home management problem involves scheduling, the charging-discharging status of the home battery and managing the power of the electric car battery in order to reduce the cost of the household economy and reduce the cost of tariffs received from the grid. To this end, by considering the above relationships, it is necessary to minimize electrical relations. The mathematical form of the problem-solving procedure is as follows.

$$\begin{array}{l} \min imize \quad F(x) \\ S.t. \quad f_i(x) \le 0 \qquad i = 1,\dots,P \\ h_j(x) = 0 \quad j = 1,\dots,q \\ x \in Z \end{array} \tag{3}$$

And $f_i(x)$ is electric constraints on the grid, which will be mentioned below, and $h_j(x)$ is the power exchange and power exchange sources relationships that need to be integrated with the intelligent search algorithm to minimize the total cost of the system, and for this purpose, the gray wolf algorithm is used for optimizing and we compare the optimization results with other popular search algorithms such as genetic algorithms and birds.

Constraints

A) Smart house nano-grid power balance equation is as follows:

$$P_{grid,k} = P_{dem,k} + P_{b,k} + P_{evc,k} \times S_k - P_{pv,k} \qquad K = 0,\dots,N-1 \tag{4}$$

$$0 \le P_{grid,k} \le P_{grid}^{\max} \tag{5}$$

$$S_k = \begin{cases} 0 & for \;\; t_d \le k \le t_a \\ 1 & \quad otherwise \end{cases} \tag{6}$$

Where we assume $P_{grid,k} \ge 0$ which means that the home is not allowed to deliver electricity to the grid (Sun et al., 2016). The variable S_k also represents the level of the electric vehicle at k time, so that if it is equal to 1, that is, it is connected to the power supply and in the case when it is equal to 0, that is, it is not connected to the power supply. In this work, we assume that the car is connected to the electricity only once a day and it is disconnected.

B) Dynamics and car battery constraints are obtained by the following relations:

$$P_{grid,k} = P_{dem,k} + P_{b,k} + P_{evc,k} \times S_k - P_{pv,k} \qquad K = 0,\dots,N-1 \tag{7}$$

$$E_{ev}^{plug-out} = SOC_{ev}^{\max} Q_{ev,eap} \tag{8}$$

$$E_{ev}^{plug-in} = SOC_{ev}^{\max} Q_{ev,eap} - E_{dr} \tag{9}$$

$$E_{dr} = 0.4 Q_{evc,eap} \tag{10}$$

$$Q_{evc,eap} SOC_{ev}^{\min} \le E_{ev,k} \le Q_{evc,eap} SOC_{ev}^{\max} \quad k = 0,\ldots,N \tag{11}$$

$$P_{evc}^{\min} \le P_{evc,k} \le P_{evc}^{\max} \quad k = 0,\ldots,N-1 \tag{12}$$

In which we assume that E_{dr} is equal to $0.4Q_{evc,eap}$ and the power of the vehicle battery is positive in accordance with the conventional values.

C) Dynamics and home battery capacities are obtained by the following relationships:

$$E_{b,k+1} = E_{b,k} + \Delta t(P_{b,k} - \eta_b |P_{b,k}|) \quad k = 0,\ldots,N-1 \tag{13}$$

$$Q_{b,eap} SOC_{b}^{\min} \le E_{b,k} \le Q_{b,eap} SOC_{b}^{\max} \; k = 0,\ldots,N, \tag{14}$$

$$-P_{b}^{\max} \le P_{b,k} \le P_{b}^{\max} \quad k = 0,\ldots,N-1 \tag{15}$$

In the solar systems to transfer thermal energy of the sun which is absorbed by the collector, a heat exchanger is used, and surplus electrical energy is obtained according to (2-18) relation, which is used for building consumption. N_c is the number of solar panels, I_a is the power produced by the photovoltaic-thermal panel and α is the vibrational coefficient of solar absorption and η is the solar panel's electrical efficiency.

$$P_{pvtotal} = N_c \times \eta \times S_c \times \alpha \times I_a \times (1 - 0.005 \times (T - 25)) \tag{16}$$

$$Q_c = \eta \times I_a \times Therm \tag{17}$$

$$P_{pv} = P_{pvtotal} - Q_c \tag{18}$$

Simulation results

Regarding the microgrid system of Figure 1, a numerical example is used to verify the feasibility of using the proposed optimization model. The important parameters of the system are shown in Table 1. Information about the daily consumption of houses and information on the average daily power supply of home power resource in US, California (Wu et al., 2017) is shown in Figure 2. The production capacity of a solar source varies from 0 to 2.81 kilowatts and the solar power production is centered from 9:00 to 15:00, and it is sometimes more than home demand. The demand for daily loads varies from 0.8 to 1.9 kW and the lowest electricity price is (10 cents / kWh) from 22:00 to 7:00 when demand is low. The basic price of electricity at peak times is 43 cents/kilowatt-hours and at most of the times, it is 22 cents/kilowatt hours. An electric car can be connected to a charger from 00:00 to 07:00 and from 20:00 to 24:00 to supply battery power or power supply of the grid or home. It is obvious that the home can supply surplus electrical energy to the grid and purchase it at high prices when the consumption is very high. With these conditions, if there is a rechargeable and dischargeable home battery, in addition to optimizing the power consumption of the photovoltaic-thermal panel, it can reduce the cost of domestic electrical energy and deliver electricity to the home throughout the year. It should be noted that the required hot water for the building for washing and domestic consumption is also provided by the thermal energy of the photovoltaic-thermal panel and the connection of the water tank with an electric heater adjacent to the photovoltaic-thermal panel and using the solar thermal energy of the daytime and electrical energy of the heater brings the required hot water to the normal temperature of the home and in the building under study, at 6 to 8 in the morning, also during16 to 20 hot water is required, solar thermal power is required to be transferred to the cold water.

Table 1: Important Parameters of Smart Home

Parameter description	symbol	value	unit
Duration of each step	D_t	1	hour
Maximum SOC of PEV battery	SOCemaxv	0.90	e
Minimum SOC of PEV battery	SOCeminv	0.20	e
Maximum SOC of home battery	SOCbmax	0.90	e
Minimum SOC of home battery	SOCbmin	0.20	e
PVE disconnection time	t_d	7:00 a.m.	e
PVE connection time	t_a	8:00 p.m.	e
Lost efficiency	$h_evc=h_b$	0.10	
The maximum power that is taken from the grid	$P_{gridmax}$	10	kW

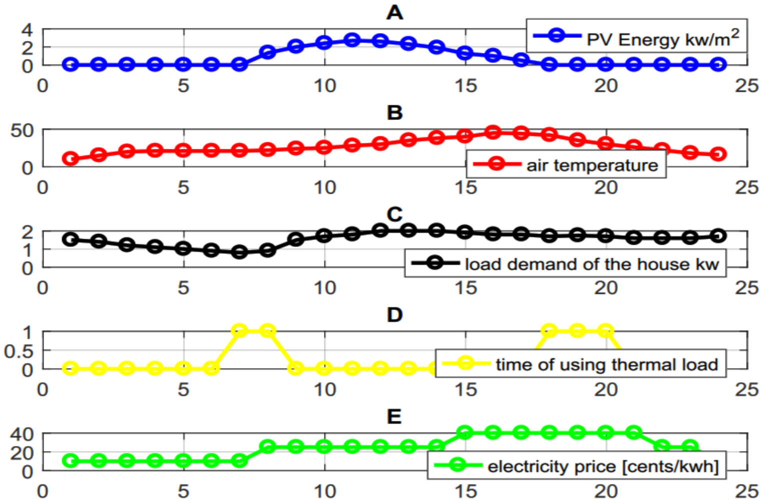

Figure 2: Input parameters of the smart house diagram

Here, we assume that the optimization horizon is 6 years and the home battery and charging costs are $ 100 per kilowatt hour and $ 1000 per kilowatt-hour, respectively. Two control modes are considered for the vehicle, including H2V and V2H modes. In H2V mode, the car battery cannot inject power into the home, that is, $0 \le P_{evc,k} \le P_{evc}^{\max}$. In the V2H mode, the vehiclw battery can inject power into the home, $-P_{evc}^{\max} \le P_{evc,k} \le P_{evc}^{\max}$ (Wu et al., 2017).

Based on the optimization model mentioned earlier, one can find that the proposed model is a complex nonlinear optimization problem. To solve this problem, the Gray Wolf Optimization algorithm has been used. This algorithm mimics the leadership hierarchy and hunting mechanism of gray wolves in nature proposed by Mirjalili et al. (2014). The steps for this algorithm are summarized below and Figure 3:

1. Generate an initial population of wolves (search agents) randomly;
2. Evaluate the position and calculate the fitness function of each wolf;
3. Assign the second best solution as Beta wolf;
4. Assign the third best solution as Delta wolf;
5. Update the position of each search agent;
6. Calculate the fitness value of the new search agent;
7. The fitness value of the new wolf is better than wolf Alpha;
8. Compare with Beta and Delta wolves;
9. Consider the new wolf as Alpha wolf;
10. Is termination criterion met?
11. Choosing the wolf Alpha as the best solution;
12. End.

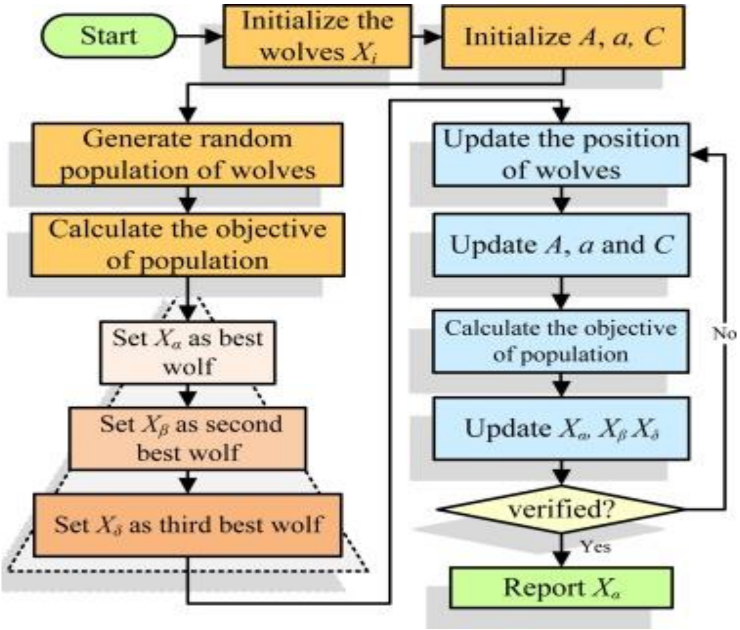

Figure 3: Flowchart of Gray Wolf Algorithm

The smart home has a Nissan LEAF that is modeled on two modes of operation, including H2V and V2H modes. The allocation of hourly power is described in Figures 4 and 5, which includes house hourly power demand (P_{dem}), photovoltaic power production (P_{PV}), home battery power (P_b), vehicle battery power (P_{evc}), and electrical power that is taken from the grid (P_{grid}).

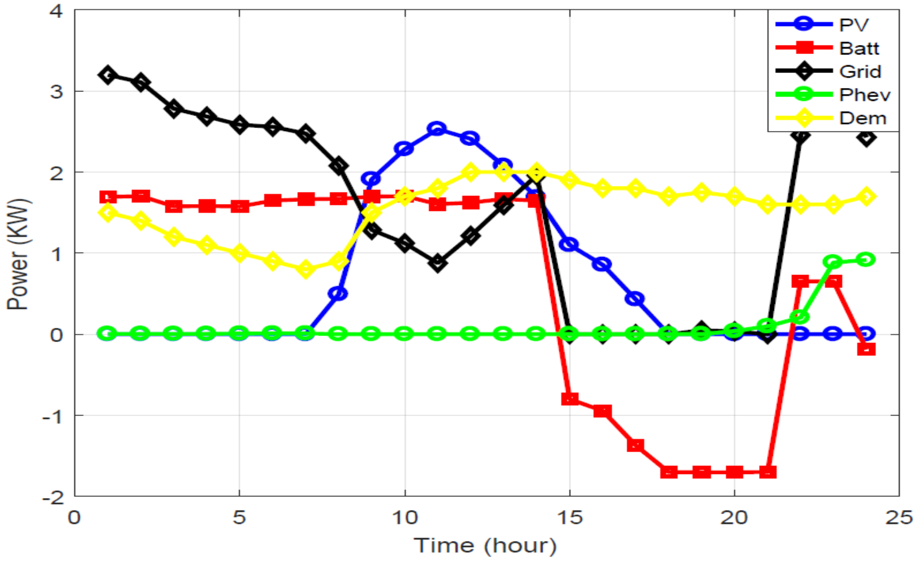

Figure 4: Home power hourly changes chart in mode 1

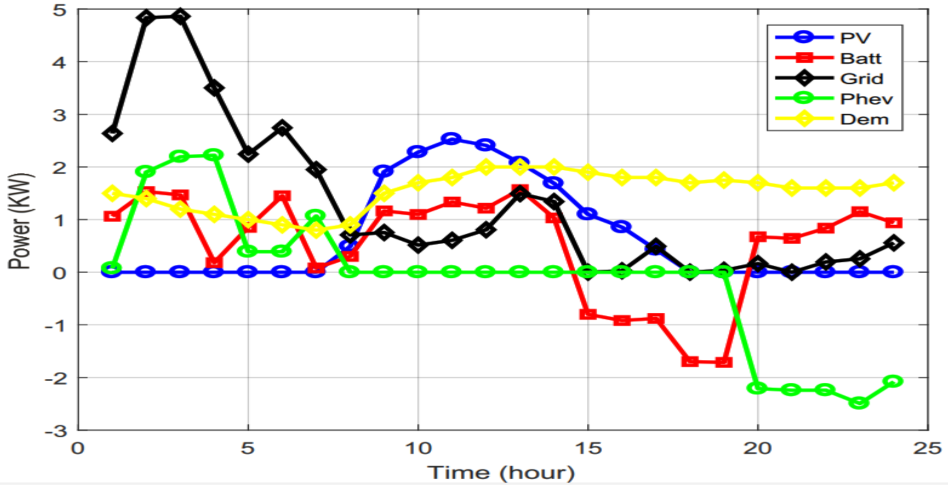

Figure 5: Home power hourly changes chart in mode 2

In both H2V and V2H modes, it is clear that home battery charge occurs mainly when the electricity price is low, from 22:00 to 07:00, or the power output is high by the photovoltaic-thermal panel: from 10:00 to 15:00. Home battery discharge is also happening when the electricity price is high: 14:00 to 22:00. Most battery charging takes place during the low electricity period, from 24:00 to 07:00. In the V2H mode, vehicle power discharges to home occur when the price is high and there is a high household power demand, from 21:00 to 24:00. The power output taken from the grid is approximately zero during 15:00 and 21:00 and in H2V mode. In short, in both H2V and V2H modes, the house does not buy electricity from the power grid during peak hours.

In order to demonstrate the economic benefits of smart home, we compare the optimal capacities of energy sources and the cost of electrical energy in both cases. The cost of hourly energy for six years is shown in Table 2. According to this, the gray wolf algorithm has a better performance than two particle swarm and genetic algorithms, and both algorithms offer more cost than the proposed algorithm, and both algorithms are caught in the local minimum trajectory of economic cost, but the proposed algorithm is well out of the optimal local trajectory and has reached a global economic optimum. According to the proposed algorithm, the total cost of electricity for six years in H2V mode is $ 3412 and in the V2H mode, it is $ 3322. Hence, the total cost of the V2H is 2.6% lower than the H2V.

Table 2: The cost of electrical energy obtained from three algorithms

	Particle Swarm	Genetic	Grey wolf
H2V	3510	3446	3412
V2H	3352	3390	3322

In H2V mode, in Figure 6 and according to Table 3, you can see that the received power battery in the particle swarm algorithm is optimally optimized to a maximum level of 1.75 kV, and during a day it is accompanied by intense fluctuations but in optimal mode with the gray wolf and genetic algorithm, the maximum charge/discharge power of the home battery is 1.70 and 1.73 kilowatts respectively, and the fluctuation of the battery life cycle is very mild, and you can expect a longer battery life and the cost of repairing and maintaining the family is minimized throughout the year. The Grey wolf algorithm also offers a lower battery capacity than two other algorithms.

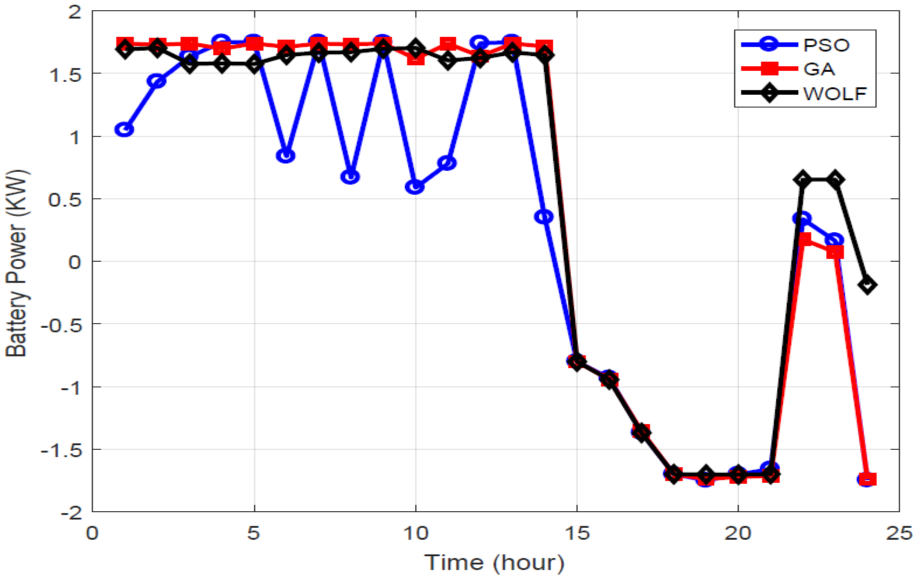

Figure 6: Comparison chart of the power of the battery in mode1

Table 3: Optimal values of home battery energy capacity and its maximum power in h2v mode

Algorithm Mode	Particle Swarm	Genetic	Grey wolf
$Q_{b,eap}$ in h2v mode	14.3457	16.7343	16.7184
$P_{b\max}$ in h2v mode	1.7497	1.7389	1.7031

In the V2H mode, the home battery power chart is shown in Figure 7 and its values are mentioned in Table 4, this factor plays an important role in reducing family expenses and in optimal mode with the proposed algorithm, consumes or produces a maximum power of 1.57 kilowatts and in each of the algorithms in electricity tariff peak hours take responsibility of home main power and in addition to the better electrical grid stability, the optimum battery capacity is reduced by 48% compared to the h2v mode, which results in lower the primary household costs in order to buy a battery.

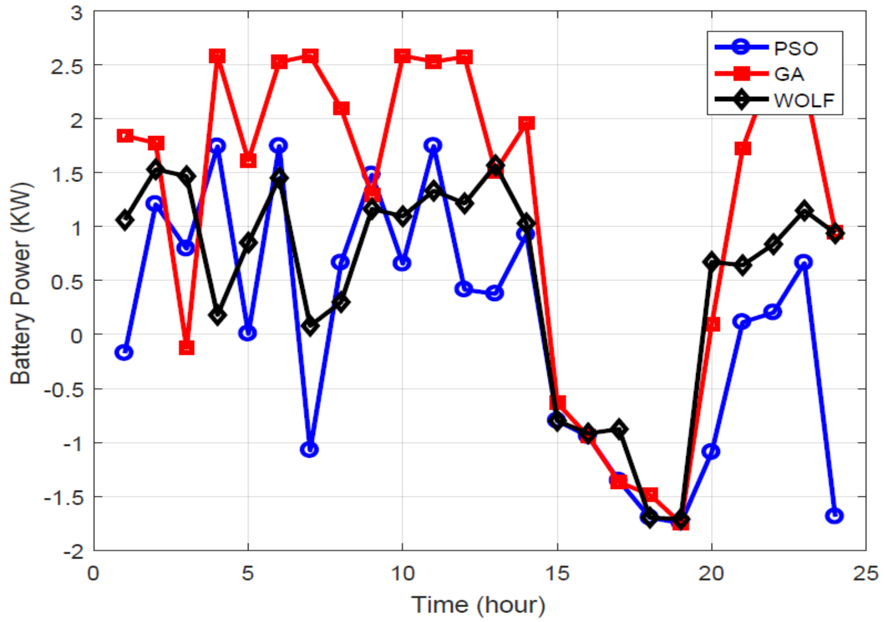

Figure 7: Comparison chart of the power of the home battery in mode2

Table 4: Optimal energy consumption of the home battery and its maximum power in v2h mode

Algorithm Mode	Particle swarm	Genetic	Grey wolf
$Q_{b,eap}$ in v2h mode	15.6987	7.7028	8.6146
$P_{b\max}$ in v2h mode	1.7484	2.5873	1.5697

CONCLUSION

In this paper, the design and optimal management of energy resources in a building that is connected to a grid and equipped with a solar renewable energy source and a battery storage source are studied in the presence of an electric vehicle. The building was considered in a way that in addition to supplying it needed power, it can also store excess electricity in the battery, so that at peak time and when the cost of electricity is high, it will supply its electricity through the battery and buy less electricity. The proposed model is solved by using the gray wolf algorithm. Finally, the positive effects of optimized energy consumption design in the part of the results of the paper indicate the optimal efficiency of using this algorithm for optimization operation; 48% reduction in home battery optimal capacity and 2.6% reduction in the energy cost when the electric vehicle is used to supply home power.

List of Symbols and Abbreviations:

	Coefficient	Unit		Coefficient	Unit
Target function, energy cost	F	[$]	Total electricity cost in n- [$] year	C	[$]
The price of the home battery per kilowatt-hour	C_b	[$/kWh]	Charger Price Per Kilowatt Hour	C_c	[$/kWh]
Electricity price	$C_{e,k}$	[cents/kWh]	Primary Energy of Vehicle Battery	$E_{ev,init}$	[kWh]
Vehicle Battery Energy	$E_{ev,k}$	[kWh]	Vehicle battery power when the connection is lost	$E_{ev}^{plug-out}$	[kWh]
Energy consumed for driving on a full day	E_{dr}	[kWh]	Home Battery Energy	$E_{b,k}$	[kWh]
Primary home battery energy	$E_{b,init}$	[kWh]	Time Index	-----	K
The final year step of the year	N	[year]	Optimizing Time Horizon	n	[year]
Electrical power of the grid	$P_{grid,k}$	[kW]	Electricity Demand of Home	$P_{dem,k}$	[kW]
House battery electric power	$P_{b,k}$	[kW]	Electric Vehicle Battery Power	$P_{evc,k}$	[kW]
Power supply from photovoltaic arrays	$P_{pv,k}$	[kW]	Maximum power of the grid	[kW]	$P_{grid}^{\max}$
Vehicle battery maximum power	$P_{evc}^{\max}$	[kW]	House battery maximum power [KW]	$P_b^{\max}$	[kW]
Vehicle Battery Power Capacity	$Q_{evc,eap}$	[kWh]	*House battery power capacity*	$Q_{b,eap}$	[kWh]
Coefficient of determining the vehicle charge status at time k	S_k	~~~~~	Vehicle plug out time	T_d	[S]
Vehicle connection time	T_a	°C	Minimum battery charge level	$SOC_{ev}^{\min}$	~~~~~
Maximum battery charge level	$SOC_{ev,\max}$	~~~~	Minimum battery charge level	$SOC_b^{\min}$	~~~~~
House Maximum battery charge level	$SOC_{b,\max}$	~~~~	Time step	Δt	[h]
The lost efficiency of the vehicle battery	η_{evc}	~~~~	The lost efficiency of the home battery	η_b	~~~~~~

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