مجله نخبگان علوم و مهندسی
Journal of Science and Engineering Elites
جلد ۹- شماره ۱ - سال ۱۴۰۳
www.ElitesJournal.ir

Planning and Optimal Size of the Hybrid System with Energy Storage Participation in the Residential Complex

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Received: March 2024 Accepted: April 2024

Abstract

In recent years, attention has been paid to residential complex with renewable energy, to optimally use the distribution network, manage the consumption side, and increase the reliability of the network. The maximum energy consumption of household appliances under load does not need to be done at specific times, but rather during the desired period. If coordination is established among multiple houses so that they do not all occur at the same time. At the same time, by satisfying the duration of the demand of silent customers, the cost of energy and the maximum power demand can be reduced. In this article, the optimal planning of energy consumption using renewable energy has been studied using the proposed linear programming method. It is assumed that renewable energies are used to supply energy locally, which includes photovoltaic systems, wind generators, and energy storage. Numerical samples show that it is possible to save money and planned electricity consumption and reduce the maximum energy consumption through better management. The optimized parameters are obtained by the PSO algorithm.

Keywords: Optimal Planning, Hybrid System, Energy Storage, Residential Complex.

1- Introduction

Buildings play an important role in the energy consumption of existing networks. Therefore, energy management in buildings has been raised as an important issue for engineers and researchers of power systems. Considering the economic and environmental aspects of the issue, it is necessary to use new technologies in this field. But when using different sources of energy at the same time, due to uncertainties related to the performance of each of these parts, we face some problems that can be solved by using an intelligent energy management system. A large number of these systems have been introduced in articles. Some articles have discussed the coordinated planning of the production sector [1-2]. In ref [3], a plan for the use of scattered production for use in a house to increase the consumer's profit is presented. The article [4] has introduced a home energy management system with a focus on controlling the consumption of household appliances and minimizing the household peak load while considering the well-being of the residents of the house. Several energy sources including photovoltaic systems, wind power plants, diesel generators, gas turbines, and micro turbines can form a hybrid energy system [5-6]. Despite these resources, solar cell units and wind power plants are widely used in remote areas [7-8]. Since the characteristics of these systems are almost complementary to each other, they are usually used in combination with each other. Due to the cleanliness and renewable nature of these energies, many organizations and countries are interested in using them and are conducting extensive research in this direction. In ref [9], the optimal planning of smart home energy consumption is studied using a mixed integer linear programming (MILP) method. The proposed model for energy consumption planning has been applied to two numerical examples (smart buildings of 30 houses, and 90 house).In ref [10], how to use household electricity consumption and home energy system techniques have been examined and analyzed. By using smart energy programming, all reports are suggested to save energy and achieve energy saving and optimization. In reference [11], the purpose of smart grids is to manage the power of a general solution to different provincial technologies that are classified in different houses. In addition, several goals are possible in this method and its goals can be different. As a result, the method is very comprehensive and flexible. While there is general purpose and actual control equipment at home that is required for both general and controller areas. In addition, the optimization method should be able to measure very large houses.In reference [12], a home energy management system (HEMS) has been introduced to save energy costs due to the fluctuation of electricity prices in the environment of smart homes.

To reduce the price of electricity and the above technical problem, integrated power flow from the residential complex is necessary. According to the above factors, the idea of residential complex was developed, which creates a balance between the supplied power and the demanded power. By using this idea, we can expect to achieve high efficiency of production power and energy conservation. Due to the two-way interactive relationship between electricity demand and its sales rate during the hours of the day and night of smart networks, how to manage the consumption of electrical appliances in residential complex at different hours becomes very important. In this article, using an operating system-based approach, the provision of residential complex consumption based on rational decision-making for buying and selling power from the electricity market based on the predicted amount of load and power storage has been done.

2- Hybrid system

The diagram of the studied system is shown in Figure 1. In this system, WG and PV are used as energy storage sources. In Figure 1, the outputs of the units are connected to a DC bus. Many batteries are connected to this bus as a storage system. The batteries, which are usually lead-acid, store the energy produced by the WG and PV system and enter the system during peak load times to improve the load curve. The energy stored by the DC/AC converter is transferred to consumers and homes.

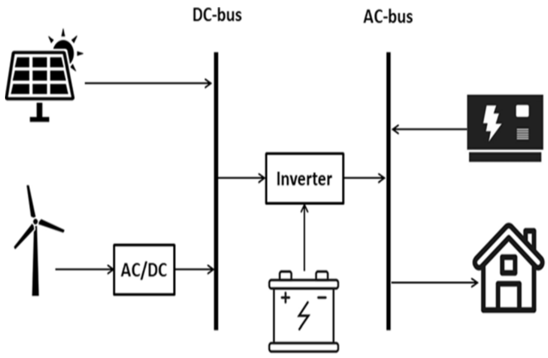

Fig.1- Block diagram of the studied hybrid system

To optimally design and manage energy, as well as observe the performance of the system in different conditions, it is necessary to have enough information about the structure of each component. The studied system consists of many wind turbines, photovoltaic, batteries and converters. In this section,

3-Wind Turbine

A wind turbine is a device that first converts wind energy into mechanical energy, and then this mechanical energy is converted into electrical energy by a generator [13-14]. In Figure 2, the output power of the turbine is plotted according to the wind speed. It can be seen that the output power of the turbine in terms of the turbine is fixed from a certain value of the wind speed onwards, and for speeds greater than the maximum speed, the turbine stops. The output power of the wind turbine is calculated from the following equation.

$$P_{WG} = \begin{cases} 0 & V_w \leq V_c\,, V_w \geq V_F \\ P_R \times \left(\frac{V_W - V_C}{V_R - V_C}\right)^3 & V_c \leq V_W \leq V_R \\ P_R & V_c \leq V_W \leq V_R \end{cases} \tag{1}$$

In relation, P_{WG} is the output power of the wind turbine, P_R is the nominal power of each turbine, V_W is the wind speed, V_C is the low cutoff speed, V_F is the high cutoff speed, and V_R is the nominal turbine speed. Other specifications and parameters of the wind turbine used in the modeling are shown in the following Table 1 [8].

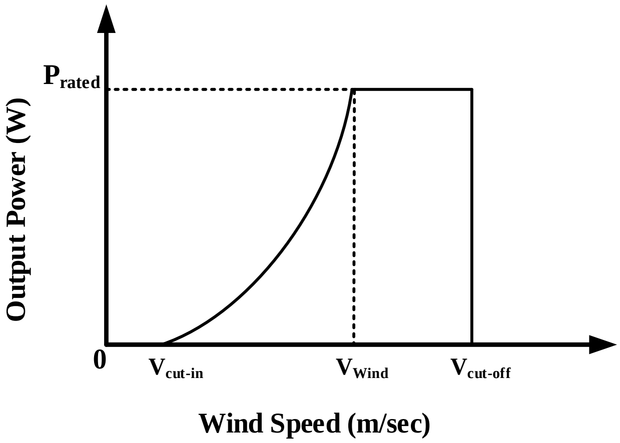

Fig. 2- Turbine output power according to wind speed

Table 1- Values of simulation parameters

wind turbine rated power	1KW
Low cutting speed	2.5 m/s
Rated speed	11m/s
High cutting speed	24m/s
Initial capital cost	2506 €
Maintenance cost and performance	25/06 €/year
Longevity	20 year

4-Photovoltaic panel

The photovoltaic system is a process that converts solar energy directly into electrical energy. In photovoltaic technology, semiconductor cells consisting of a large p-n diode are used. In this way, by shining light on each cell, voltage, and direct current are produced. Several cells are combined to form a module to generate the desired current and voltage. PV production power is obtained from the following equation [15-16]:

$$P_{pv} = \frac{G}{1000} \times P_{pv,rated} \times \eta_{MPPT} \tag{2}$$

In this regard, G is the radiation in watts per square meter, $P_{pv,rated}$ is the nominal power of each photovoltaic panel and $\eta_{MPPT}$is the efficiency of the DC/DC converter of the photovoltaic panel. The concept of MPPT follows the maximum power point [17], which makes the maximum possible power of solar energy extracted by the module in different atmospheric conditions. Since a photovoltaic system costs many times the initial cost of building a conventional power plant, it must be able to receive maximum energy from the sun, otherwise, a large amount of investment will be wasted. In the PV model, the effect of temperature on the panel surface is ignored. Other specifications and parameters of the photovoltaic panel used in the modeling are shown in the Table 2.

Table 2- Technical specifications of solar modules

rated power	110W
voltage in	17V
flow in	6.47 A
Open circuit voltage	21V
short circuit current	7.22A
Initial capital cost	519.14 €
Maintenance cost and performance	5.19 €/year
Longevity	20 year

5- Battery and converter

The battery selected for simulation is lead-acid type, which has high efficiency, low cost, and low self-discharge compared to its types [18]. The input power of the battery can be positive or negative according to the charging or discharging performance. The state of battery charge, according to the calculations of production power and consumption load, is obtained as follows:

If $P_{PW}(t) + P_{PV}(t) = P_L(t)$ then the battery capacity remains unchanged.

If $P_{PW}(t) + P_{PV}(t) > P_L(t)$ then the excess production power of the hybrid system is used to charge the battery bank and the new capacity of the battery is obtained from the following equation.

$$P_b(t) = P_b(t-1) + [P_z(t) - P_l(t)/\eta_{inv}]/\eta_{bf} \quad (3)$$

To improve the consumption pattern $P_{PW}(t) + P_{PV}(t) < P_L(t)$, the battery is usually discharged. Of course, the battery bank with nominal capacity is only allowed to be discharged to a limited extent. The maximum allowable depth of discharge (DOD) is determined by the system designer at the beginning of the optimization process. The new capacity of the battery in this case is obtained from the following relationship.

$$P_b(t) = P_b(t-1) + [P_l(t)/\eta_{inv} - P_z(t)]/\eta_{bf} \quad (4)$$

In these relationships, $P_b(t)$and $P_b(t-1)$are the battery capacity at the moment t and t-1. $P_z(t)$is the production power set of the hybrid system and $P_l(t)$ is the required power of the load at time t. $\eta_{bf}$and $\eta_{inv}$are the discharge efficiency and the inverter efficiency, respectively. Other characteristics and parameters of batteries and converters used in modeling are shown in Tables 3 and 4.

Table 3- characteristics of the studied batteries

Nominal capacity	230Ah
Rated voltage	12V
DOD	80%
Charging time efficiency	100%
Discharge time efficiency	95%
Initial capital cost	264€
Maintenance cost and performance	2.64 €/year
Longevity	3 year

Table 4- Specifications of the studied converters

rated power	1500 W
Returns	80%
Initial capital cost	1942 €
Maintenance cost and performance	19.4 €/year
Longevity	4.5 year

6-The objective function

Considering the non-continuous characteristics of wind and solar radiation and their high dependence on weather conditions, the most important issue is the design of a system with adequate reliability in load supply. In this regard, it is inevitable to pay attention to the cost of the system, so the goal of the optimal design of the hybrid system is to modify the load pattern by reducing the peak load and increasing the reliability of the network. In the studied system, the number of wind turbines, PV panels, and battery capacity should be optimally determined. For this purpose, the PSO algorithm has been used to calculate the cost of all system components in acceptable states according to the system performance. In the proposed method, the output of the algorithm is the number of wind turbines, photovoltaic panels, and batteries. This number should be optimized in such a way that in addition to providing energy consumption, it also minimizes the 20-year cost of the system. The cost of the system includes the cost of purchase and installation, and the cost of maintenance and repairs of components during the 20 years of system operation, which is calculated from the following equation [8].

$$C_i = N_i[\mathrm{Ccost}_i + \mathrm{RCcost}_i \times K_i + \mathrm{O\&Mcost}_i] \quad i = \mathrm{WG, PV, Battery} \tag{5}$$

where $N_i$is the number or size of the system equipment, $\mathrm{Ccost}_i$is the initial capital including purchase and installation costs, $\mathrm{RCcost}_i$is the placement cost, $K_i$is the number of placements in 20 years of system operation, $O\&Mcost$ is the operation and maintenance cost in 20 years of system operation.The objective function that should be minimized is the cost function of the entire system during the operation period, which is expressed as follows. In the above relationship, PF is a coefficient that is added to the cost function as a penalty (penalty factor) if one of the above constraints is not satisfied.

$$C_{system} = C_{WG} + C_{PV} + C_{BAT} + PF \tag{6}$$

$$N_{PV} = \text{Integer}, \quad 0 \le N_{PV} \le N_{PV}^{max} \tag{7}$$

$$N_{WG} = \text{Integer} \quad , \quad 0 \le N_{WG} \le N_{WG}^{max} \tag{8}$$

$$N_{Bat} = \text{Integer} \quad , \quad 0 \le N_{Bat} \le N_{Bat}^{max} \tag{9}$$

$$P_{Supply} \ge P_{Demand} \tag{10}$$

$$P_{b\,min} \le P_b \le P_{b\,max} \tag{11}$$

$$P_{b\,min} == (1 - DOD).\ P_{b\,max} \tag{12}$$

$P_{b\,max}$ is the maximum battery capacity and $P_{b\,min}$ is the minimum battery capacity. Also examines the ability of the obtained combination for the system to respond to the load demand. Based on the amount of power produced by the photovoltaic-wind system, the monthly and annual peak load of the desired station, after the effect of the PV system and wind turbine for each of the selection stages, the number of batteries, the number of PV system and the number of wind turbines are calculated (Figure 2). The output of this section is the algorithm for determining the optimal number of batteries based on the PSO algorithm to optimize the objective function.

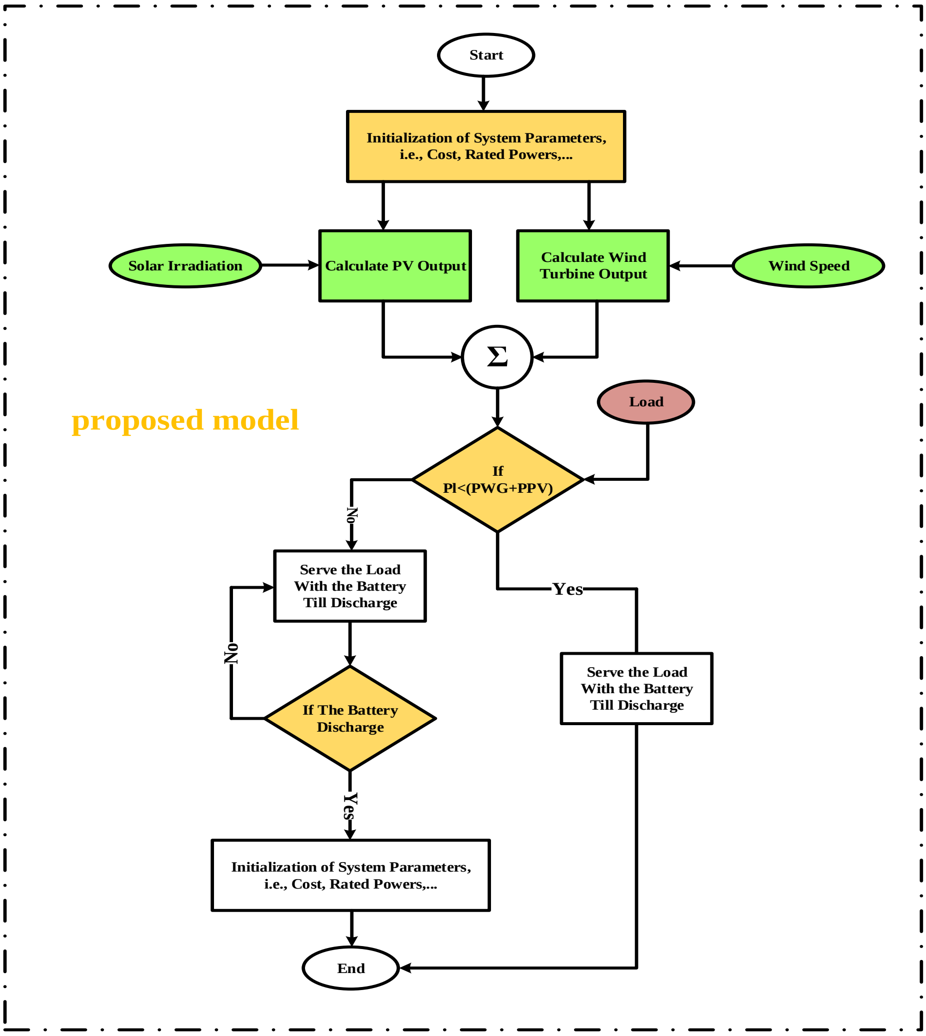

Fig.2- Hybrid system control flowchart

7- Numerical studies and simulation results

For In Table 5 information about distributed production units, storage systems, and networkCome.The residential complex load demand and utility for a 24-hour time horizon are shown in figures 3 and 4. In this example, it is assumed that all sources of energy produce active power at a power factor of one, they neither request reactive power nor produce reactive power. In addition, the operational reservation requirement is determined equal to 5% of the load demand in each time step. The fixed and maintenance cost for installation and operation of BES is assumed equal to 465 (€ Ct / kWh) and 15 (€ Ct / kWh). The lifetime and interest rates for financing the installed BES are 3 and 0.06, respectively. A tax equal to 10% is chosen in this study. BES charging and discharging rates are the same and 90%. The minimum capacity of BES is set equal to 10% of the full capacity.

Table 5- information about the system

Type of equipment	Lower power limit (kW)	upper power limit (kW)	Maintenance factor ($/kWh)	Start-up and stop costs ($/kWh)
PV	0	25	0.2082	0
WT	۰	15	0.5052	0
BES	-30	30	---	0
Utility	-30	30	---	---

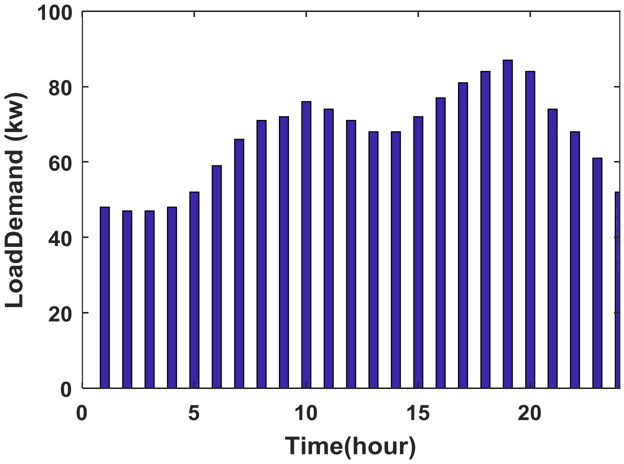

Fig.3- Load demand profile of the studied system in residential complex

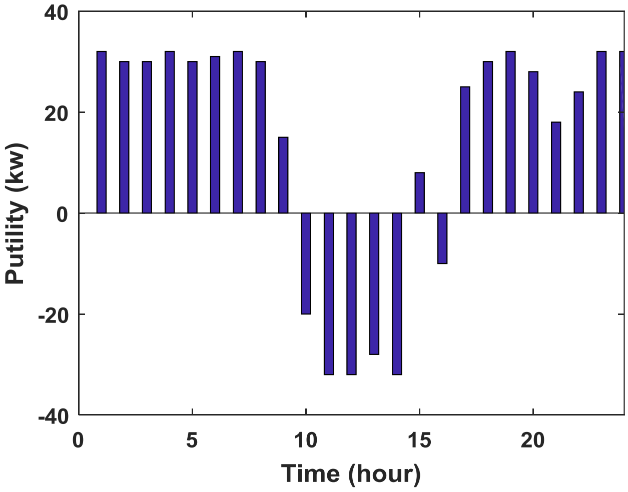

Fig.4- Converter utility

In general, in this system, the battery is considered the basic unit of the network, which can make the system stable in emergencies and also improve the power quality of the system. In this case, the battery is placed in the circuit in such a way that its discharging action is limited to the amount of battery charge in the previous hours. The main advantage of BES in wind and photovoltaic system is to maintain stability, facilitate the integration of RES, and improve power quality and evaluation. The Li-ion BES starts the period without any charge, so at any stage of the day, the BES discharge is limited by how much it has changed in the past hours. In this case study, to check the efficiency of BES selection with appropriate and optimal capacity, maximum battery size (CBESmax) is used as a control variable. The minimum BES capacity is set equal to 10% of the full capacity. The full capacity is set to 500 kilowatt hours. It means that CBESmax is a variable that should be optimized in the range [50,500]. This means that after determining these variables by the algorithm, the energy is stored in the BES under [CBES, min, CBES, max] ranges. CBES, max is changed by 100 kWh in each step and the problem is executed step by step to determine the optimal size of the battery. The main disadvantage of this idea is its high execution time. Based on the above discussion, the microgrid energy management system is used for the wind and photovoltaic system test system to optimize the total operating costs to obtain the optimal size of BES and the best distribution for equipment. Figures 5 and 6 show the production power of the wind system and the photovoltaic system in 24 hours. The charge and discharge mode of energy storage is shown in Figure 7. The convergence results of algorithm 8 are shown. The optimal results of Algorithm are shown in Table 6.

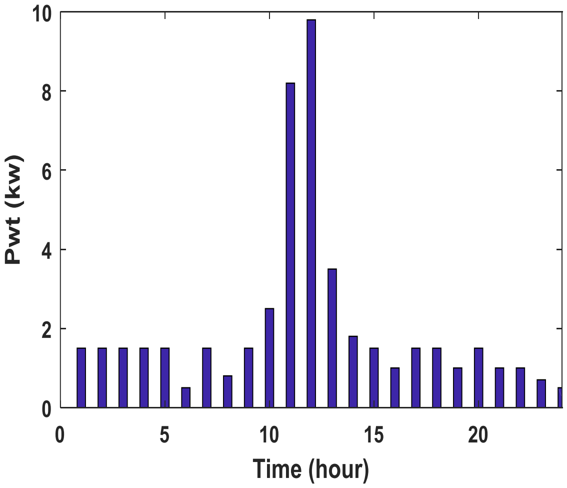

Fig.5- Power of the wind system

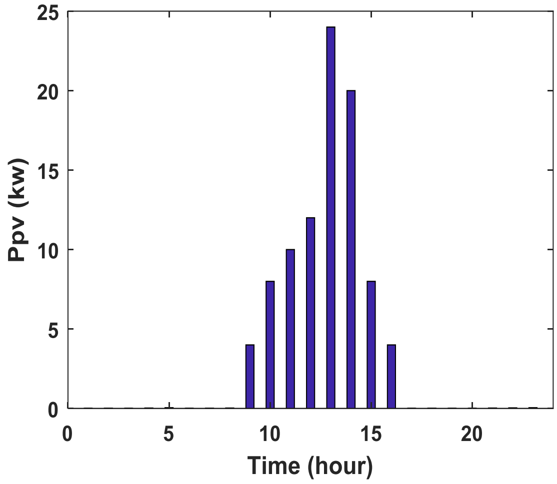

Fig 6- Power of the solar system

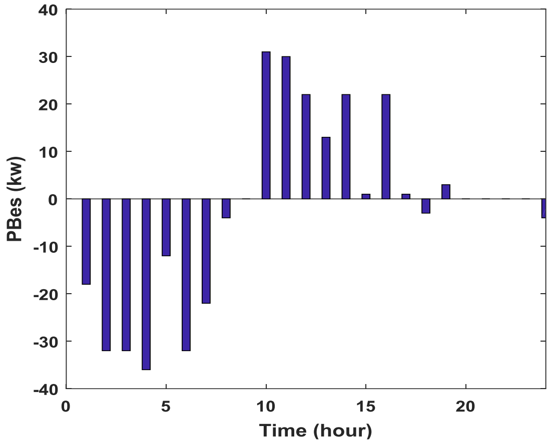

Fig 7- Energy storage

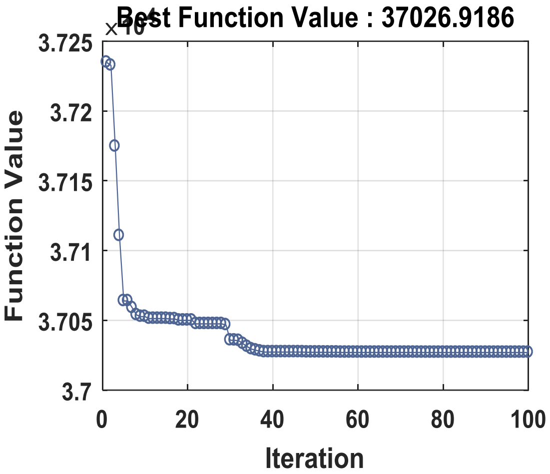

Fig 8- Convergence results of algorithm

Table 6- Optimal results of PSO algorithm

Optimization methods	Description	Time (S)	The number of repetitions	Number of population	Optimized parameters			Cost($)
					N_{WG}	N_{PV}	N_{bat}	
PSO	$C_1=2$ $C_2=2$	33	100	20	4	3	5	37026.9186
GA	$P_m = 0.7$ $P_c = 0.3$	73	100	20	4	4	6	37114.5204

8- Conclusion

The results of the simulations show that by using the simulation method based on the PSO algorithm and having different input variables, the best output can be selected based on the inputs. Intelligent energy management and comprehensive control strategy for the photovoltaic-wind hybrid system with storage A battery bank device was introduced to feed the shared load with the network. Also, particle community algorithm has been used to select the optimal combination of the system with the aim of minimizing costs and fully covering the shared load demand with the network in different weather conditions and load changes during 20 years of system operation. The economic analysis of the modeling results clearly shows the advantages of the designed hybrid system compared to the mentioned modes, both economically and technically.

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