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OPTIMIZATION OF HYBRID ENERGY SYSTEM BASED ON PARETO DIFFERENTIAL EVOLUTION ALGORITHM

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Abstract. *In order to achieve the goal of energy-saving and emission reduction, a hybrid energy system has been proposed compared to the traditional diesel engine power generation, but the technology is still immature and in the process of development. Firstly, the differential evolution algorithm and Pareto optimal strategy are used to optimize the system configuration. Then the simulation analysis is carried out by MATLAB, including comparison of various hybrid energy schemes, comparison of different object number schemes and comparison with traditional diesel engine power generation systems. The simulation results show that the method has better performance in terms of cost, service life and pollutant emissions, and is superior to the traditional scheme.*

Keywords: Differential evolution algorithm, Pareto optimal solution, Hybrid energy system, Optimal allocation, Photovoltaic system, Wind turbine

1. **Introduction.** With the overexploitation of fossil energy by humans, oil reserves continue to decline. In recent years, people began to gradually realize the seriousness of the problem, and turned to the study of green energy, hoping to alleviate this situation. Hybrid energy system is a good solution to this condition. Among these solutions, the hybrid energy system is a good idea, and some research has been done on it. Genetic algorithm is used to simulate and optimize the model of hybrid energy system in [1-4]. Variants of particle swarm optimization are used to optimize the sizing of the hybrid ship power system [5]. Global extremum seeking algorithm is used to optimize the energy of fuel cell system [6]. An improved ant colony optimization is used to optimize the sizing of a stand-alone hybrid power system [7]. Convex optimization approach is used to optimize the sizing of PV-battery-diesel hybrid systems [8]. Firefly algorithm is used to optimize the stand-alone hybrid power system [9]. Crow search algorithm is used to optimize the PV/wind/tidal/battery system [10]. Harmony search algorithm is used to optimize the sizing of a PV/diesel power generation system [11]. Although many optimization methods have been used, the differential evolution algorithm is rarely applied when solving such problems and it has been widely used in many fields recently, such as DC motor speed control, crude distillation, image recognition, image encryption, [12-16]. Majority of the papers above are optimized with the lowest costs as a single objective, and its service life is also one of the aspects that cannot be ignored. If it only considers a low cost, it may

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lead to a short life, which is not reasonable, but if you only consider a long life, the costs may be high. Therefore, this article will more comprehensively take into account both low cost and long life, using the differential evolution algorithm and the Pareto optimal solution optimization method to optimize the bi-object from low cost and long service life. Compared with other algorithms, the differential evolution algorithm has the advantages of simple principle, few controlled parameters, random and parallel implementation, and fast operation speed, which is easy to understand and implement. Therefore, this paper uses the differential evolution algorithm to optimize the configuration of diesel-based island hybrid energy system. The system includes four modules: solar, wind, battery and diesel engines. If it is a small residential area in a low-latitude area with abundant solar energy resources, a hybrid energy system of photovoltaic/battery group can be applied; if it is a rural area with a plain area with abundant wind energy resources, a hybrid energy system of a fan/battery group can be applied; an island-based system such as a ship can be applied to a hybrid energy system of solar/fan/battery/diesel.

The paper is organized as follows. By summarizing the characteristics of different new energy sources, a suitable system model was established and the corresponding mathematical ideas and calculation methods were proposed in Section 2. In Section 3, we describe the differential evolution algorithm and the method of optimizing the configuration. Finally, MATLAB is used to carry out a simulation experiment analysis to verify the effectiveness of the scheme in Section 4 while Section 5 is devoted to the concluding remarks.

2. **Problem Formulation.**

The hybrid energy system should not only meet the requirements of the load on energy but ensure that it has sufficient energy storage as well due to the intermittency of new energy sources such as solar energy and wind energy and the mutability and volatility of power load, no matter when the system works. The characteristics of power produced from photovoltaic (PV) and wind systems are based on the weather condition. Both the systems are very unreliable in themselves without sufficient capacity storage devices like batteries or back-up system like conventional engine generators [17]. The reliability of the system is significantly improved when two systems are mixed with provided storage devices. Therefore, the system in this paper includes four modules: solar energy, wind power, battery storage and diesel engine in Figure 1. Among them, DC/DC/AC is direct current to direct current to alternating current converter; AC/DC/AC is alternating current to direct current to alternating current converter; Bi-directional DC/AC is bi-directional direct current to alternating current converter; AC/DC is alternating current to direct current converter; The DC load is a direct current load; the AC load is an alternating current load.

2.1. **PV module.**

Solar energy is inexhaustible for people nowadays, and the costs are very low. Just one solar panel can be used to convert it into electricity by the "photovoltaic effect". There are three main types of solar panels: monocrystalline silicon, polysilicon, and amorphous silicon. Considering economic factors, polysilicon with high costs performance will be selected for use in the hybrid energy optimization system as a major provider of solar energy.

For PV module, the power generated by solar panels per unit of time $p_{pv}(t)$ can be formulated as

$$p_{pv}(t) = I_t(t) \times A \times j_{pv} \tag{1}$$

where the area unit of the solar panel is m^2 and the intensity of light received by each solar panel at time t is $I_t(t)$. A is the area of the solar panel and j_{pv} is power conversion rate of solar panel.

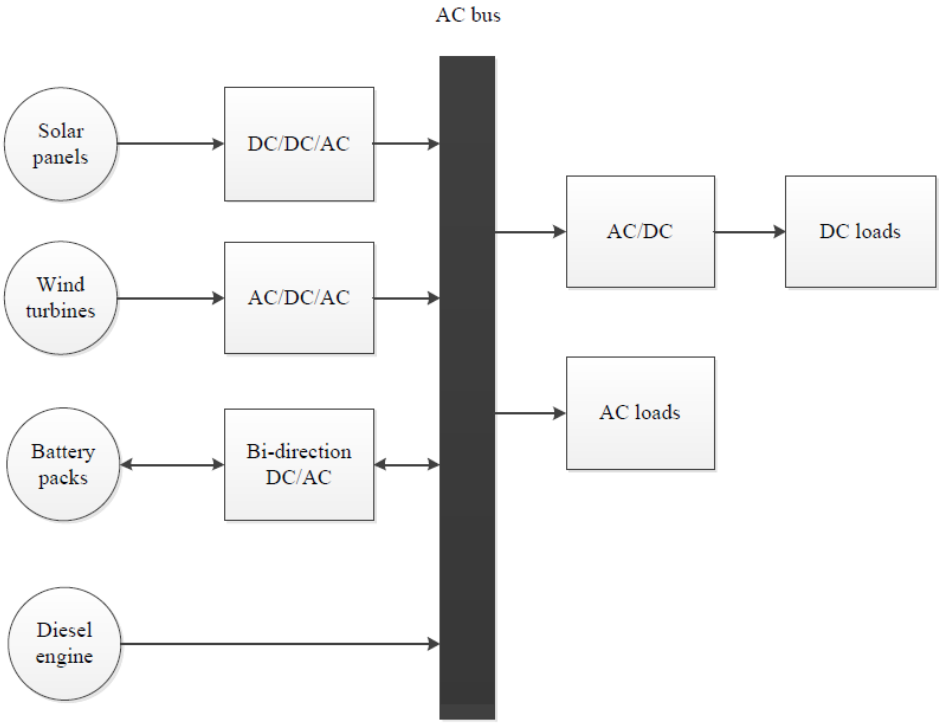

FIGURE 1. Hybrid energy system

The total power generated by the system's PV module at time t is $P_{pv}(t)$ that can be formulated as

$$P_{pv}(t) = N_{pv} \times p_{pv}(t) \tag{2}$$

where the total number of solar panels in the system is N_{pv}.

2.2. **Wind power module.** Wind power generation technology has been applied to land for a long time. It has developed very well and the technology is relatively complete. Wind turbines are generally divided into two types: horizontal axis generators and vertical axis generators. The vertical axis wind turbine does not need to change phase when the wind direction changes, which is more advantageous than the former, and it is easy to maintain as well. Therefore, after comprehensive consideration, it is found out that it is feasible to apply wind energy to the hybrid energy optimization system.

For wind power module, the power generated by the fan in unit time $p_{wt}(t)$ can be formulated as

$$p_{wt}(t) = \begin{cases} 0 & v_t \le v_{\min} \text{ or } v_t \ge v_{\max} \\ P_{r\_wt}\dfrac{v_t - v_{\min}}{v_r - v_{\min}} & v_{\min} \le v_t \le v_r \\ P_{r\_wt} & v_r \le v_t \le v_{\max} \end{cases} \tag{3}$$

where the wind speed at time t is v_t. The rated wind speed of the fan is v_r and the corresponding fan rated power is P_{r_wt}. In actual work, the fan can only work within a certain range of wind speed. When the actual wind speed is greater than the start-up wind speed $v_{\min}$, the fan starts to work. If the wind speed is too large and exceeds the warning wind speed $v_{\max}$, the fan will stop working in order to protect the fan.

The total power generated by the system's wind power module at time t is $P_{wt}(t)$ that can be formulated as

$$P_{wt}(t) = N_{wt} \times p_{wt}(t) \tag{4}$$

where the total number of fans in the system is N_{wt}.

2.3. **Battery energy storage module.** The battery packs play a very important role in this system. In these days when the amount of green energy is sufficient, they can not only fully support the consumption of the load, but also have some margin which could be stored. It can be used when the amount of green energy is insufficient. So the battery packs can maximize the use of clean energy.

For battery energy storage module, the maximum amount of energy a battery can store is $e_{\max\_batt}$ and the minimum amount of energy a battery can store is $e_{\min\_batt}$, which can be formulated as

$$e_{\min\_batt} = (1 - DoD) \times e_{\max\_batt} \tag{5}$$

where the maximum depth of discharge of the battery is DoD. Normally, the battery will specify its maximum rated capacity when it leaves the factory.

The maximum amount of electricity stored in all batteries is $E_{\max\_batt}$ and the minimum amount of electricity stored in all batteries is $E_{\min\_batt}$, which can be formulated as

$$E_{\max\_batt} = N_{batt} \times e_{\max\_batt} \tag{6}$$

$$E_{\min\_batt} = N_{batt} \times e_{\min\_batt} \tag{7}$$

where the total number of batteries in the system is N_{batt}.

At time t, if the sum of the power generated by the PV module and the wind power module is higher than the load demand, the batteries will be charged. The total battery power at this time is $E_{batt}(t)$ that can be formulated as

$$E_{batt}(t) = E_{batt}(t-1) + \left(P_{pv}(t) \times \Delta t + P_{wt}(t) \times \Delta t - \frac{E_l(t)}{j_{inv}} \right) \times j_{batt} \tag{8}$$

In other words, if the sum of the power generated by the PV module and the wind power module is lower than the demand of the load, the batteries will be discharged. At this time, $E_{batt}(t)$ should be modified as

$$E_{batt}(t) = E_{batt}(t-1) - \left(\frac{E_l(t)}{j_{inv}} - P_{pv}(t) \times \Delta t - P_{wt}(t) \times \Delta t \right) \times j_{batt} \tag{9}$$

where the load demand for electrical energy is $E_l(t)$. Inverter conversion rate and battery pack charging efficiency are j_{inv} and j_{batt} respectively. The amount of time change is Δt.

Of course, no matter what happens, the batteries' total capacity must always be between $E_{\max\_batt}$ and $E_{\min\_batt}$. If the battery is full, it cannot be recharged. Conversely, if it has no electricity, the battery will not be reduced to 0. At most, it will drop to $E_{\min\_batt}$. Then the battery can provide power at time t, $P_{batt}(t)$, that can be formulated as

$$P_{batt}(t) = \frac{E_{batt}(t) - E_{\min\_batt}}{\Delta t} \tag{10}$$

2.4. **Diesel power supply module.** Although providing electrical energy by diesel engine will be contrary to the concept of sustainable development, it is necessary to use the diesel engine to meet the load requirements in case of insufficient supply of green energy. So, the diesel engine is only used as a backup energy source.

For diesel power supply module, if the energy provided by the three parts above is less than the load requirements at time t, the output power of diesel engine $P_d(t)$ can be formulated as

$$P_d(t) = \frac{E_l(t)}{\Delta t} - P_{pv}(t) - P_{wt}(t) - P_{batt}(t) \tag{11}$$

Otherwise, it is not necessary to supply power from the diesel engine and $P_d(t)$ is equal to 0.

The fuel consumption of diesel is $F_D(t)$ whose unit is l/h, this can be formulated as

$$F_D(t) = B_D \times P_N + A_D \times P_d(t) \tag{12}$$

where the rated output power of diesel engine is P_N. Parameter $A_D = 0.246$ (l/kWh), $B_D = 0.0845$ (l/kWh) [18].

According to the unit price of fuel P_F, the price of diesel fuel consumption at time t is $C_{f\_d}(t)$ that can be formulated as

$$C_{f\_d}(t) = P_F \times F_D(t) \tag{13}$$

2.5. **Objective function.** Firstly, in order to save costs, there are three parameters that need to be considered: annual input costs C_c, annual maintenance costs C_m, and annual fuel consumption costs C_f.

The annual input costs C_c can be formulated as

$$\begin{aligned} C_c = & \frac{i(1+i)^{n_{pv}}}{(1+i)^{n_{pv}}-1} C_{pv} N_{pv} + \frac{i(1+i)^{n_{wt}}}{(1+i)^{n_{wt}}-1} C_{wt} N_{wt} \\ & + \frac{i(1+i)^{n_{batt}}}{(1+i)^{n_{batt}}-1} C_{batt} N_{batt} + \frac{i(1+i)^{n_d}}{(1+i)^{n_d}-1} C_d \end{aligned} \tag{14}$$

where the depreciation rate of equipment is i. The lifetimes of solar panels, fans, batteries, and diesel engine are n_{pv}, n_{wt}, n_{batt}, and n_d. The initial input costs are C_{pv}, C_{wt}, C_{batt}, and C_d respectively.

The maintenance costs C_m can be formulated as

$$C_m = N_{pv} \times C_{mtn\_pv} + N_{wt} \times C_{wtn\_wt} + C_{mtn\_d} \tag{15}$$

where the annual maintenance costs per unit of solar panel, fan and diesel engine are C_{mtn_pv}, C_{mtn_wt} and C_{mtn_d}.

The annual maintenance of diesel engine C_{mtn_d} above can be formulated as

$$C_{mtn\_d} = \sum_{t=1}^{N_{data}} P_{mtn\_d} \times P_d(t) \tag{16}$$

where the number of samples taken in a year is N_{data}. For convenience of calculation, the data are fetched by the hour. In this case, $N_{data} = 8760$. The maintenance charges per watt of diesel engine is P_{mtn_d}.

The annual fuel consumption of diesel engine C_f is as follows

$$C_f = \sum_{t=1}^{N_{data}} C_{f\_d}(t) \tag{17}$$

Combined with the above analysis, C_T is the total costs of the hybrid energy optimization system, which is given by

$$C_T = C_c + C_m + C_f \tag{18}$$

Secondly, in order to make the service life become longer, availability should be proposed. It is one of the key components that determine whether the system can operate stably and continuously. The availability T can be formulated as

$$T = 1 - \frac{DNM}{\sum_{t=1}^{N_{data}} E_l(t)} \tag{19}$$

The DNM which means demand not met (kWh/year) can be formulated as

$$DNM = \sum_{t=1}^{N_{data}} (e_{\min\_batt} - E_{batt}(t) - (P_{pv}(t) \times \Delta t + P_{wt}(t) \times \Delta t - E_l(t)) \times u(t)) \tag{20}$$

where $u(t)$ is a step function that is equal to zero if the sum of the power generated by the PV module and the wind power module is higher or equal the load demand and one if the demand not met.

Since the prototype of the hybrid energy system has been established, the practicality of the system needs to be considered. If the single object is to minimize costs, service life may not be long, it will be unlikely to apply in reality. On the contrary, if the single object is to maximize service life, costs may be high, it will not be applied in real life. It is vital to choose a system construction plan both with the low costs and the long service life. Therefore, the values of variables N_{pv}, N_{wt}, and N_{batt} are determined by the minimum of C_T and the maximum of T in the objective function.

The working process of the hybrid energy system at time t is shown in Figure 2. Firstly, calculate the total power of the PV module and the wind power module. Then compare the magnitude of the power with the load power. If the former is larger than the latter, the excess power is charged to the battery pack. Otherwise, the battery pack is added to assist the power supply. Finally, calculate the total power of the above three modules. If the load demand is still not met, start the diesel engine for auxiliary power supply.

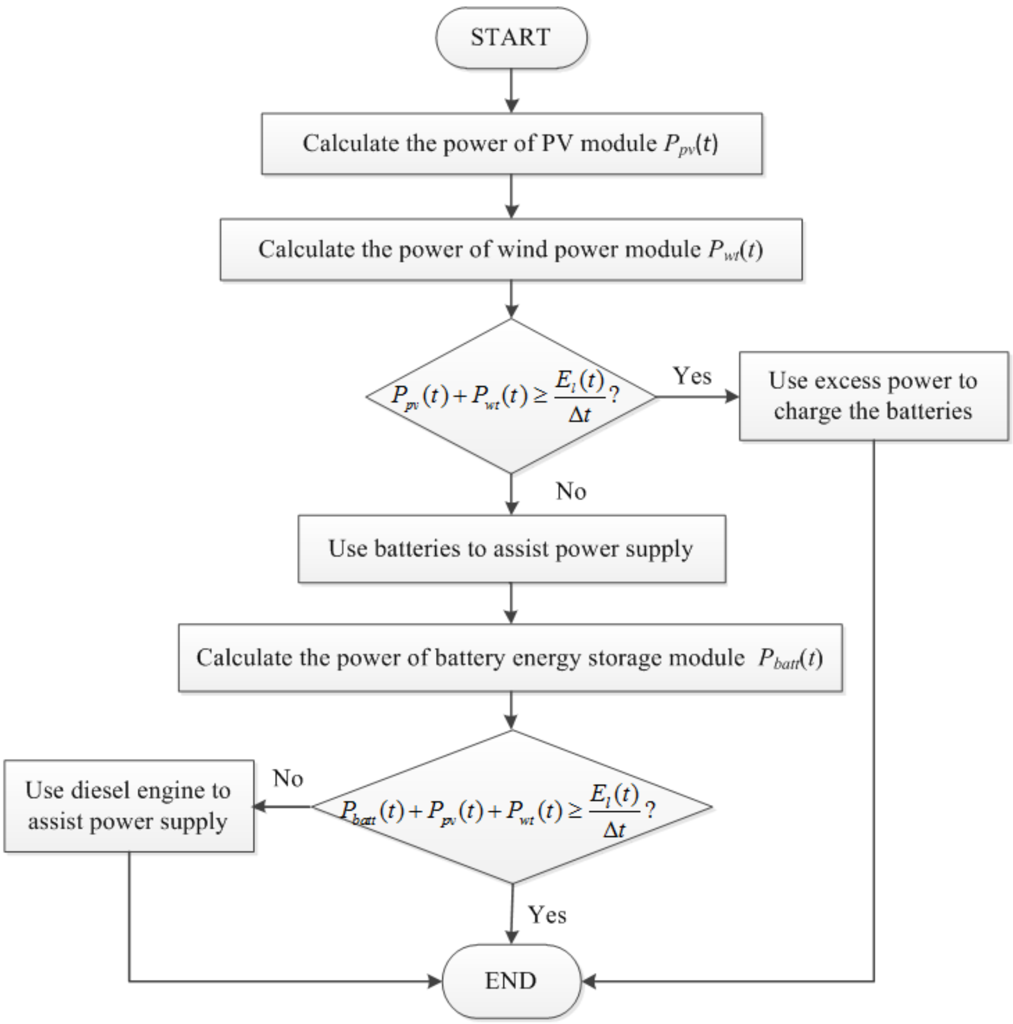

FIGURE 2. The flow chart of system working process

3. Differential Evolution Algorithm and Application of Pareto Optimal Solution.

3.1. Differential evolution algorithm. The differential evolution algorithm is an optimization algorithm based on floating-point vector coding for random search in continuous space, which was jointly proposed by Rainer Store and Kenneth Price in 1995 [19]. It is divided into four stages of initialization, mutation, crossover and selection. After k times of iterative operation, it will achieve the goal of optimization.

During the initialization phase, the program needs to randomly generate the initial value of solutions to be optimized whose number is N_P. N_P is the size of colonies. The solutions to be optimized $x(l,d)$ can be formulated as

$$x(l,d) = x_{\min}(d) + rand \times [x_{\max}(d) - x_{\min}(d)] \tag{21}$$

where $x_{\max}(d)$ and $x_{\min}(d)$ are their maximum and minimum values. l is the lth solution to be optimized and d represents that there are d parameter variables in this solution to be optimized. $rand$ is a random number from 0 to 1.

During the mutation phase, new solutions to be optimized $z(l,d)$ can be formulated as

$$z(l,d) = x(r_1,d) + F \times [x(r_2,d) - x(r_3,d)] \tag{22}$$

where r_1, r_2 and r_3 are mutually different random integer indices selected from 1 to N_P and are not equal to each other. F is a real random constant from 0 to 2, which determines the value of $[x(r_2,d) - x(r_3,d)]$. Since $x(l,d)$ has a maximum value and a minimum value, $z(l,d)$ may be calculated to exceed the range of $x(l,d)$. If it happens, it is necessary to abandon this solution and to get a new one in (21).

During the crossover phase, new solutions to be optimized $f(l,d)$ can be formulated as

$$f(l,d) = \begin{cases} z(l,d), & \varphi \le C_R \text{ or } l = d \\ x(l,d), & \text{else} \end{cases} \tag{23}$$

where C_R is the predefined crossover rate constant ranging from 0 to 1, and φ is a random number from 0 to 1. In order to ensure that at least one value in $f(l,d)$ is from $z(l,d)$, a condition of $l = d$ is added during the update process.

During the selection phase, the objective function values are compared by the strategy of the greedy method and a better solution will be selected. After k times of iterative calculation, the best objective function value can be obtained, and the corresponding solution is the global optimal solution.

The implementation process of the differential evolution algorithm is shown in Figure 3. First, an initial solution is randomly generated within the range of values, and the initial solution is updated by Equations (22) and (23). Then calculate the objective function value, save the optimal function value and the corresponding solution. Finally, after the $k_{\max}$ iteration, the global optimal solution x_{fin} can be obtained.

3.2. Application of Pareto optimal solution. There are two goals to be solved, the lowest cost and the longest life, and they will affect each other. It requires an effective way to judge whether it is good or bad, and Pareto optimality can be very effective to distinguish them.

Suppose there are two sets of solutions S_1 and S_2. If each element in S_1 is not worse than S_2, and at least one element in S_1 is better than S_2, then it can be said that S_1 dominates solution S_2. If the solution S_1 is not dominated by all other optimization solutions, it can be said that S_1 is a Pareto optimal solution.

Of course, the Pareto optimal solution is not unique. If some of the elements in the solution S_3 are better than S_1 but others are worse, then the relationship between them

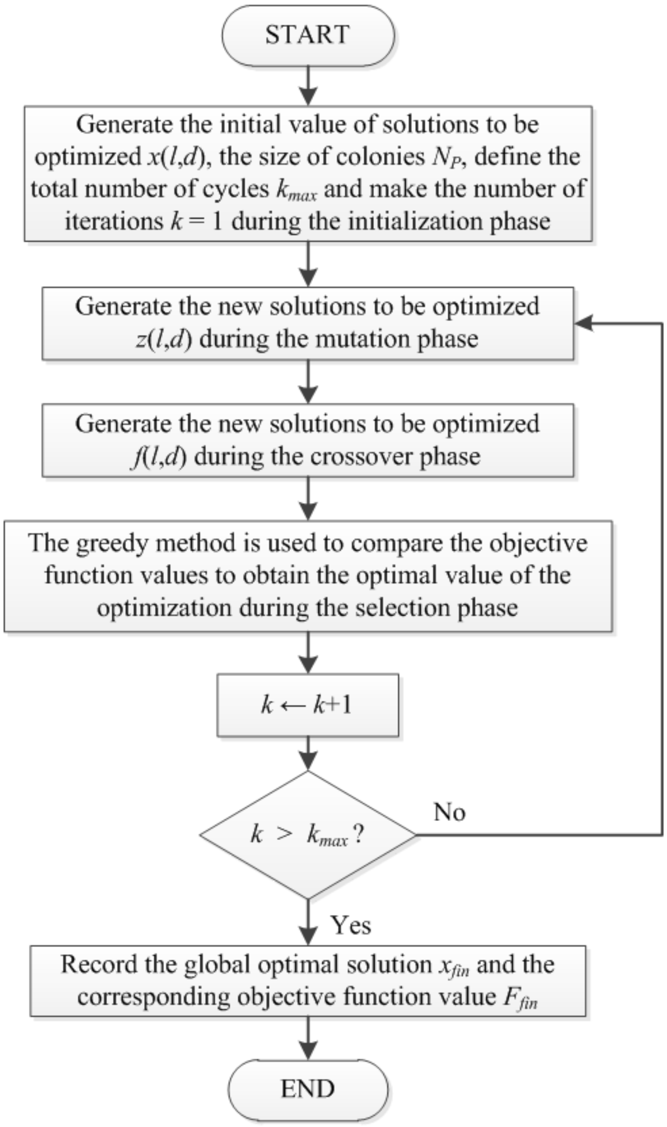

FIGURE 3. The flow chart of differential evolution algorithm

cannot be determined. If S_3 is not dominated by all other optimization solutions, then S_3 is also a Pareto optimal solution.

The set of these optimal solutions is the Pareto front which can be shown in Figure 4.

Using this method, the solution distributed on the Pareto front can be obtained in each iterative optimization. However, the importance of the costs and service life of a hybrid energy system is not necessarily equal after considering various factors in practical applications. It is necessary to define a function $u(C_T, T)$ that describes the performance of the system according to the requirements to find the global optimal solution after k iterations which is given by

$$u\left(C_T, T\right) = \lambda_1 \frac{C_T - Min\left(C_T\right)}{Max\left(C_T\right) - Min\left(C_T\right)} - \lambda_2 \frac{T - Min(T)}{Max(T) - Min(T)} \tag{24}$$

which could convert all attributes to the same scale. λ_1 and λ_2 are self-defined parameters that simply represent the importance of C_T and T in the system. In this paper, λ_1 is equal to λ_2 which means the costs and availability are equally important. Then, the final optimization result can be obtained by using MATLAB to find the minimum value of

FIGURE 4. Pareto dominance schematic for low costs and long service life system

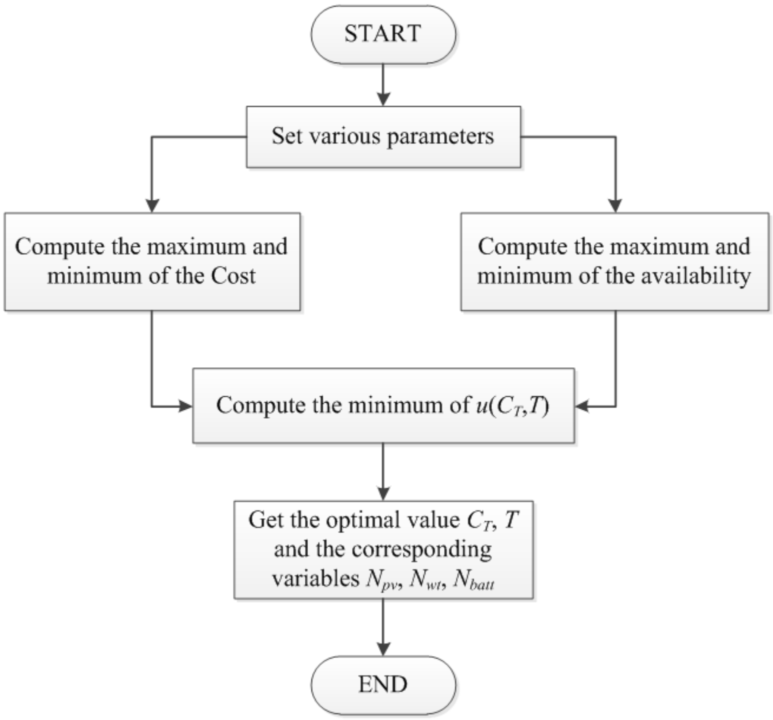

FIGURE 5. The process of bi-objective optimization

$u(C_T, T)$. The corresponding solution is distributed on the Pareto front where S_1 and S_3 are located in Figure 4 and the process of optimization can be shown in Figure 5.

Perhaps clean energy has a great advantage over petroleum fuels and should be widely used. There must be a degree because everything cannot be overextended. Therefore, it is necessary to make reasonable plans for the three new types of equipment and to impose certain restrictions that can be formulated as

$$0 \le N_{pv} \le N_{\max\_pv} \tag{25}$$

$$0 \le N_{wt} \le N_{\max\_wt} \tag{26}$$

$$0 \le N_{batt} \le N_{\max\_batt} \tag{27}$$

The maximum value of these three variables is artificially set, and specific values need to be considered in combination with the characteristics of each region in practical application. In order to facilitate the simulation, their maximum values are equal to 500 in this paper.

4. **Simulation Analysis.** It requires a large amount of basic data in order to verify the effectiveness and rationality of the hybrid energy system. Due to the availability of data, the basic data are based on the hybrid energy system for solar, wind, battery, and diesel engine in a remote area of Idaho, USA, which was obtained from January to December 2014 [20].

The hardware parameters of the solar panel/fan/battery pack/diesel generator are determined by the experimental environment and the parameters of the available experimental equipment. The specific parameters in the calculation are given from Table 1 to Table 4.

Figure 6 illustrates the data of solar radiation (I_t) per hour of the year in the PV module. Figure 7 illustrates the data of wind speed (v_t) per hour of the year in wind power module. Figure 8 illustrates the data of load demand (E_l) per hour of the year. Figure 9 illustrates the data of battery storage (E_{batt}) per hour of the year in battery energy storage module. The electricity in batteries changes with the load, which can be

Table 1. Numerical value of PV module parameters

Parameters	Values
P_{pv}	120 W
A	1.07 m^2
C_{pv}	614 \$
j_{pv}	12%
n_{pv}	120 years

Table 2. Numerical value of wind power module parameters

Parameters	Values
P_{r_wt}	1000 W
$v_{\min}$	2.5 m/s
$v_{\max}$	13 m/s
v_r	13 m/s
C_{wt}	3200 \$
C_{mtn_wt}	100 \$
n_{wt}	20 years

Table 3. Numerical value of diesel power supply module parameters

Parameters	Values
P_N	1900 W
C_d	1713.15 \$
P_{mtn_d}	0.01258 \$/kW·h
P_F	1.24 \$/l
n_d	5 years

TABLE 4. Numerical value of battery energy storage module parameters

Parameters	Values
$e_{\max\_batt}$	1.35 kW·h
j_{batt}	85%
C_{batt}	130 $
DoD	0.8
j_{inv}	95%
i	5%
n_{batt}	5 years

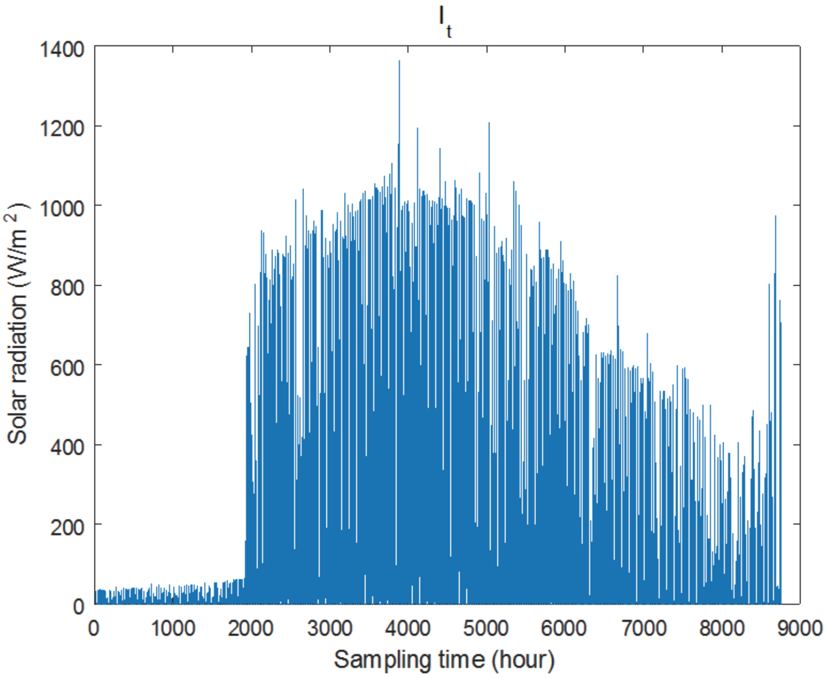

FIGURE 6. Annual solar radiation

found by comparing these four figures. In the 2900th to the 7300th hour, the load demand is large and the electric energy fluctuation in the batteries is also frequent. Due to the lower light intensity before the 2900th hour, the electrical energy in the batteries was not stabilized compared to the one after the 7300th hour. Since the light intensity before the 2900th hour is lower and the wind speed is slower, the charge and discharge of the battery pack is more frequent than after the 7300th hour.

The optimization process of the differential evolution algorithm is shown in Figure 10. λ_1 and λ_2 in Equation (24) take 0.5, and the optimal value found at this time is -0.4185. The curve tends to be constant when k is greater than 250. It is appropriate to take $k_{\max}$ equal to 500 because the optimal solution has been obtained after the previous calculation.

In order to better verify the effectiveness of the method in this paper, the results of the comparison between the bi-objective optimization system and single-objective optimization system are shown in Table 5.

The bi-objective optimization system has obvious advantages compared to the system optimized on a single object. When the lowest costs are achieved, the availability is very low. However, if the availability is maximized, the costs will be extremely high. The optimization result of bi-objective system configuration shows that the availability can

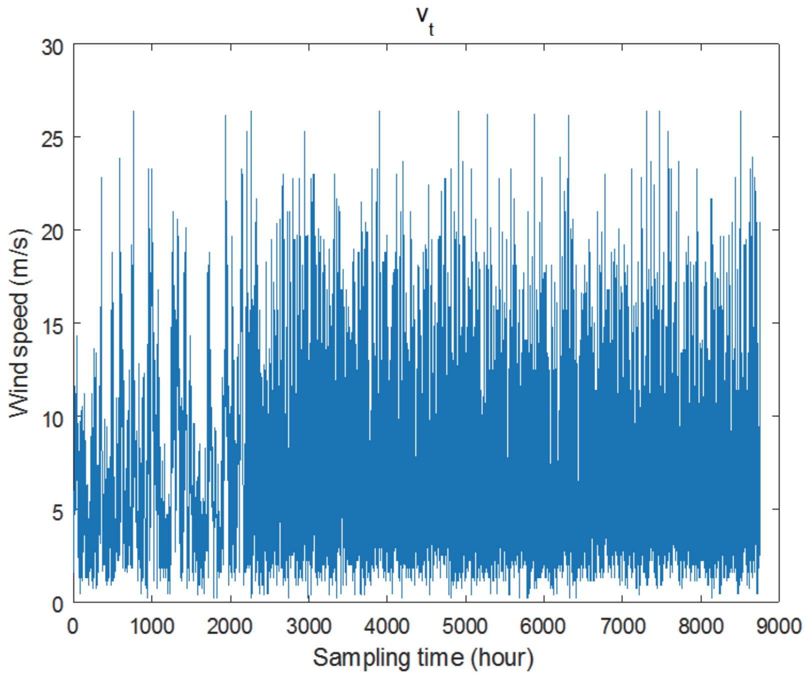

FIGURE 7. Annual wind speed

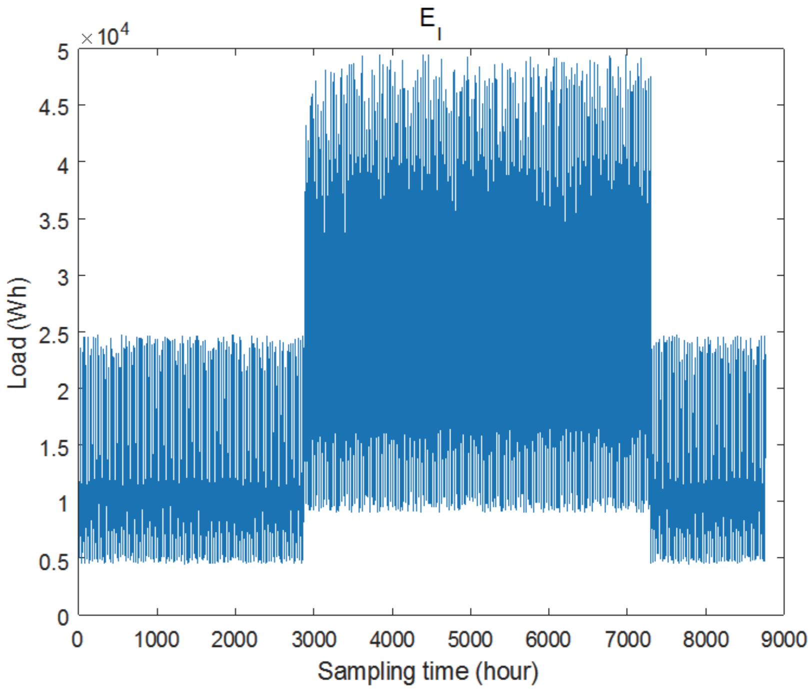

FIGURE 8. Annual load curve

be greatly improved by adding a certain fee on the basis of the lowest costs and the configuration scheme is more reasonable.

Then, the results of the optimized configuration compared with the hybrid energy systems of different modes are shown in Table 6.

Comparing the PV/WT/DE system and PV/DE system, it could be found that the former is better than the latter both in costs and availability. In the same way, comparing the PV/WT/DE system and WT/DE system, it could be found that the latter is lower

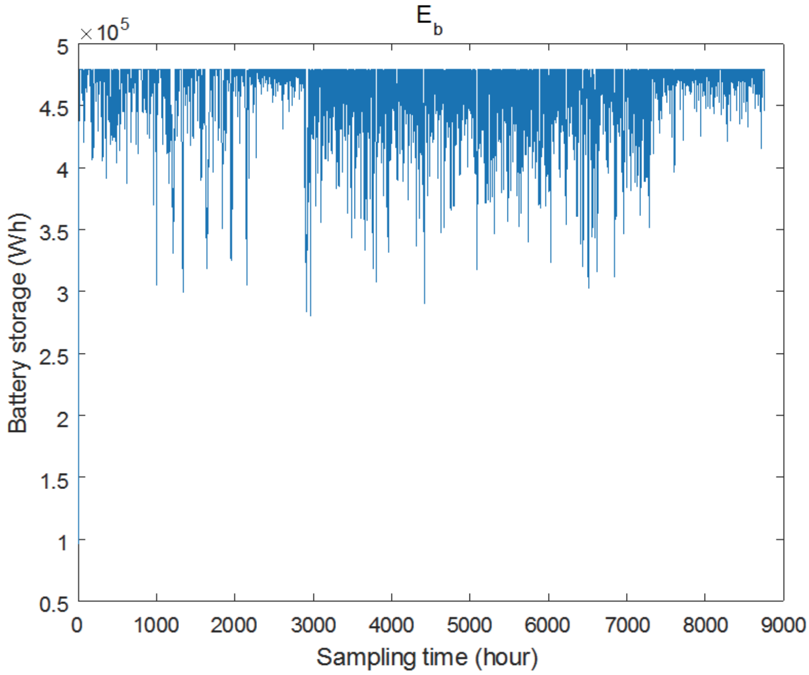

FIGURE 9. Annual battery storage

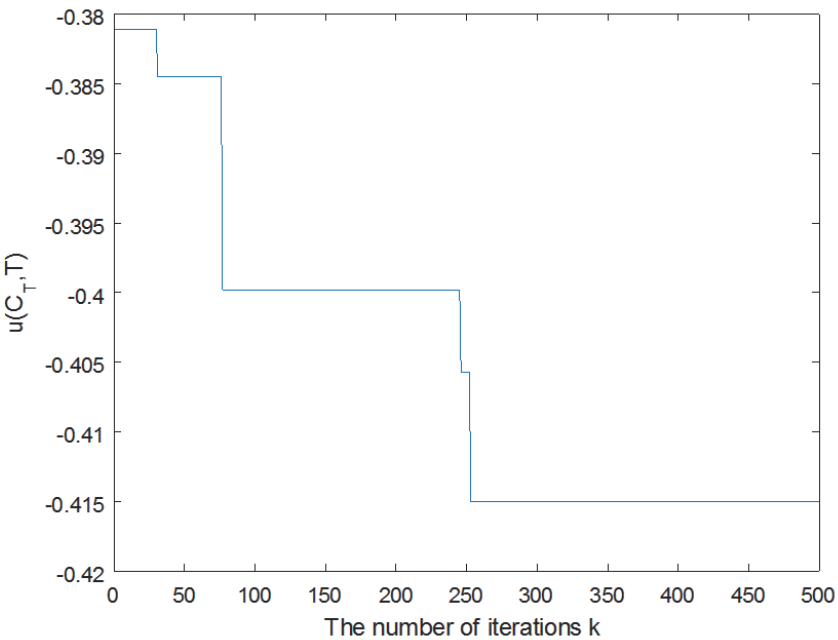

FIGURE 10. The optimization process of $u(C_T, T)$

than the former both in costs and availability. However, under the condition that cost and reliability are equally important, the solution with a low value of $u(C_T, T)$ is better, so the former is slightly better than the latter. The combination of photovoltaic power generation modules and wind power generation modules can make more efficient use of new energy sources, reduce the use time of diesel generators, reduce the use of petroleum fuels, and thus reduce the harmful gases generated by the burning of petroleum fuels.

TABLE 5. The optimization configuration of different cost functions

System configuration	The object of optimization		
	Low costs and high availability	Minimize costs	Maximize availability
N_{pv}	116	1	500
N_{wt}	114	48	500
N_{batt}	497	69	500
C_T	6.3314×10^4	4.4700×10^4	2.2018×10^5
T	34.1936	2.7076	36.2582

TABLE 6. The optimization configuration of different hybrid mode energy systems

System configuration	Hybrid energy system models		
	PV/WT/DE	PV/DE	WT/DE
N_{pv}	116	481	/
N_{wt}	114	/	125
N_{batt}	497	477	495
$u(C_T, T)$	−0.4185	−0.0741	−0.4181
C_T	6.3314×10^4	6.7416×10^4	6.1593×10^4
T	34.1936	10.0772	33.8120

Types of pollutants, emissions and treatment costs from the burning of petroleum fuels [21] are shown as follows.

TABLE 7. Emissions of different pollutants and their treatment costs

Types of pollutants	Emissions	Treatment costs
NO_x	21.8 lb/Mwh	4.2 $/lb
SO_2	0.454 lb/Mwh	0.99 $/lb
CO_2	1.432 lb/Mwh	0.014 $/lb

The comparison of pollutant emissions and treatment costs between the hybrid energy system and the traditional diesel engine power generation system is shown as follows.

TABLE 8. Comparison of pollutant emissions between different systems

Types of pollutants		Hybrid energy system	Traditional diesel engine power generation system
NO_x	Pollutant emissions (lb)	0.49	3.60×10^3
	Treatment costs ($)	2.08	1.51×10^4
SO_2	Pollutant emissions (lb)	0.01	74.98
	Treatment costs ($)	0.01	74.23
CO_2	Pollutant emissions (lb)	0.03	236.51
	Treatment costs ($)	4.55×10^{-4}	3.31

It is apparent from the table that the hybrid energy system has a significant advantage over the traditional diesel engine power generation system. Therefore, the hybrid energy system can not only save costs, but also greatly reduce the amount of pollutants discharged, and achieve the goal of energy-saving and emission reduction.

To sum up, through the analysis and design of the system's ideas, the hybrid energy optimization system was set up, and the system was simulated by MATLAB that obtain the optimal value of the objective function and its corresponding optimal solution. By comparing different systems with each other, the data show that the hybrid energy system achieves better results and also proves the effectiveness of this optimization method.

5. **Conclusion.** This paper proposes a bi-objective optimization method for the problem of the hybrid energy system. Based on the advantages of this algorithm, differential evolution algorithm was decided to use for optimization calculations. Clean energy sources are selected in island systems by reviewing the literature to summarize their characteristics and application occasions. The appropriate green energy is included in the hybrid energy system, and the optimized configuration is performed using the differential evolution algorithm. The simulation is performed with MATLAB to obtain the data optimized by the system. Overall, the superiority of the hybrid energy optimization system can be verified and the accuracy of the solution can be proved by comparing these data in different ways.

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