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Power Comprehensive Energy Optimization Scheme Based on Improved PSO Algorithm

Ying SHAN[a,1], Di CHANG[b]
[a] *Jibei Electric Power Company Limited Skill Training Center (Baoding Electric Power Voc.&Tech. College), Baoding, 071000, China*
[b] *PowerChina Hebei Electric Power Design Research Institude CO.Ltd., Shijiazhuang, 050031, China*

Abstract. To better analyze the power energy optimization problem in the integrated energy system, this paper uses PSO algorithm with good global search ability as the scheduling model solution. Firstly, we propose the joint optimal scheduling model of power integrated energy system with the participation of user side, and provide corresponding algorithm objectives and constraints. Then, PSO algorithm using inertia weight to control the learning factor is adopted to improve its convergence speed and obtain the optimal solution of equipment output and performance index. Finally, through specific examples, the model is verified and the optimal scheduling scheme of the integrated energy system under the objectives of economy and environmental protection is acquired. The results show that the scheme can effectively avoid particles falling into local optimization, and accurately calculate the reliability quantitative index of the comprehensive energy system in the target area, which ensures the coordinated interaction of endogenous, storage and load in the power system.

Keywords. PSO algorithm; IES; power energy optimization; inertia weight; constraint conditions

1. Introduction

With the development of energy Internet, the correlation and complementarity of various energy sources on different time scales have deepened. How to dispatch the output of each unit in the integrated energy system (IES) to reduce the system operation cost, and improve energy utilization and reduce environmental pollution have become an important technical problem to be solved urgently. In the distribution network system, IES exists in many forms [1,2]. It has the characteristics of multi energy coupling, which can realize the comprehensive utilization of energy such as electricity, heat and natural gas, and maximize the synergy and complementary benefits among various energy sources. However, there is a variety of unreasonable power allocation in the existing technology and there is a waste of resources in the initial investment, annual operation cost, payback period and so on, resulting in a waste of a large number of power resources. [3]. Particle swarm optimization(PSO) algorithms are commonly used to solve optimization problems, but for multivariable high-dimensional optimization problems, the convergence of particle swarm optimization algorithms is limited.

[1] Corresponding Author: San Zhang; Department of Traditional Chinese Music, Xi'an Conservatory of Music, Xi’an, 710061, China; 13991297185@139.com

Therefore, in view of the unreasonable energy allocation in the power integrated energy system, the particle swarm optimization algorithm is introduced into the power integrated energy collaborative optimization scheme. Firstly, we discuss the basic process and power conversion rules of IES, and provide the energy balance framework required in this paper. Then, the mathematical model is used to describe the research objectives, conditional constraints and the feasibility of particle swarm optimization algorithm, and the PSO is optimized by setting the initial inertia function to realize the sharing of particle swarm information. Finally, the empirical analysis is used to test the scheme proposed in this paper. The results show that the power integrated energy scheme based on the improved PSO has high operation efficiency and stability performance, and can provide meaningful technical reference for the further research of the later configuration of regional comprehensive large-scale power grid.

2. Power Demand Response Model of Integrated Energy System

It makes comprehensive use of Internet and other technologies, deeply integrates the energy system and information communication system, realizes the mutual transformation and optimal allocation of multiple energy sources, and realizes energy conservation, consumption reduction, low-carbon and green. At the same time, the coupling and balance state between different systems are considered to ensure the safe and stable operation of the comprehensive energy system including power, gas and heat, so as to realize the coordination and optimization of both supply and demand, as shown in figure 1.

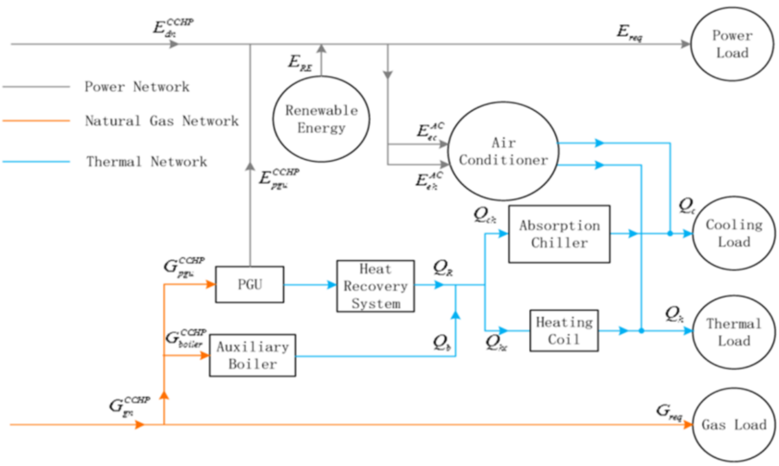


Figure 1. IES power consumption characteristics.

In IES, the load can be divided into non-transferable load and transferable load according to the power consumption characteristics of various electrical equipment. According to many factors such as the operation characteristics of the system, capacity increase decision-making, natural conditions and social influence, load forecasting enables the power consumption in each period to participate in load adjustment according to the system operation conditions and optimization objectives, so as to improve the power supply and consumption efficiency and reduce the load cost.

Using the price type demand response, the substitution coefficient is proposed to describe the replaceable load, so as to make use of the load substitution effect of the demand side, and establish detailed models for the price type power load demand response and natural gas load demand response [4]. The power load demand after the implementation of demand side response can be expressed as:

$$L_p = L_p^0 + \Delta L_p + \tau G_p^l \tag{1}$$

where L_p^0 is the power load demand before response; τ is the substitute parameter; G_p^l is alternative natural gas load; ΔL_p is power load change after response and the relation between it and market price is:

$$\Delta L_p.nor = E_{ele} \Delta pnor$$
$$\Delta pnor = [\frac{\Delta p_1}{p_1^0}, \frac{\Delta p_2}{p_2^0}, \ldots, \frac{\Delta p_T}{p_T^0}]^T \tag{2}$$

where $\Delta L_p.nor$ is the normalization matrix of power load change; $\Delta pnor$ is the normalization matrix of market change; $L_{p,i}^0$ and p_i^0 is the power load demand and market price at time i; $\Delta L_{p,i}$ and Δp_i are power load demand after response and market price change; T is the total time.

3. Power Comprehensive Energy Optimization Based on PSO Algorithm

3.1 Optimization Objectives

Combined with each unit cost model, the goal of economic dispatching of integrated energy system is to coordinate the output of power supply with different response speed and reduce the additional consumption of wind power, photoelectric and so on. The objective function is depicted as follows:

$$\min Cost = \sum_{t=1}^{N_T} [C_{Fu}(t) + C_{ME}(t) + C_{ES}(t)] \tag{3}$$

where cost is total regional operation cost; ME is total number of scheduling times; $C_{ES}(t)$ is the operation and maintenance cost of each unit at time t, as computed in (4)

$$C_{ES}(t) = \sum_{t=1}^{N_M} K_i \,|\, P_i(t) \,|\, \Delta t \tag{4}$$

where N_M is the total number of device unit; K_i is the maintenance cost parameter; $P_i(t)$ is the output power of the i_{th} device at time t.

3.2 Constraint Conditions

(1) Power system equilibrium constraints

$$\sum_{n=1}^{N} P_n(t) + P_w(t) + P_v(t) + P_e(t) + P_{vat.disch}(t) - P_{bat.disch}(t) - P_e b(t) = P_D(t) \tag{5}$$

where $P_n(t)$ is $P_n(t)$; $P_w(t)$ and $P_v(t)$ are predicted output of power generation for wind power or photovoltaic cells; $P_D(t)$ is the power load demand after optimization adjust at time t when satisfying system constraints.

(2) Optimal allocation decision variables number constraint

$$\begin{cases} 0 \le N_{PV} \le N_{PV,MAX} \\ 0 \le N_{WT} \le N_{WT,MAX} \\ 0 \le N_{BAT} \le N_{BAT,MAX} \\ 0 \le N_{DE} \le N_{DE,MAX} \end{cases} \tag{6}$$

where N_{PV} N_{WT}, N_{BAT}, N_{DE} are the limit of each kind of distributed power installation, and they are decided by objective cost estimation or power transmission conditions.

(3) Battery restraint

$$\begin{cases} SOC_{\min} \le SOC \le SOC_{\max} \\ P_+, P_- \le 1/5 E_{bat} \end{cases} \tag{7}$$

where P_+, P_- denote the charge and discharge efficiency each hour ; $SOC_{\min}$ and $SOC_{\max}$ are the minimum value and maximum value of the battery state of charge

(4) Reliability constraints

When all the power cannot satisfying the load demand with the maximum power generation, power shortage occurs and the probablity computation is:

$$L = \frac{\sum_{t=1}^{8760} [P_{PV}(t) + P_{WT}(t) + P_{BAT}(t) < P_L(t)]}{8760} \tag{8}$$

where L is annual power shortage probability.

3.3 Improvement and Implementation of PSO Algorithm

The position and speed of the search point are usually generated randomly within the allowable range, which may make the initial position of each particle too concentrated, which is not conducive to the later search [5,6]. Considering that the convergence efficiency is affected by the diversity of the initial group, this paper reassigns the initial position of particles and adjusts the speed weight to improve the later exploration ability of the algorithm. Supposing there are S particles and the search space is $[a,b]^D$, then the initial position of each particle X_1^0, X_2^0,…, X_s^0 can be set as the following equation:

$$X_i^0 \in [a+\frac{b-a}{S}(i-1), b+\frac{b-a}{S}i]^D \tag{9}$$

where D is the spatial dimension, and the speed setting method is the same as the position setting method. The improved PSO algorithm is described as follows:

Step 1: set the population scale S and particle dimension D of the algorithm to acquire p_{best} and g_{best}

Step 2: compute the inertia weight and learning factor and update particle speed and position;

Step 3: The fitness of each particle is evaluated, and the position and fitness of each particle are stored in the p_{best} t of each particle;

Step 4: determine if the terminal condition of evolution is satisfied. If it is, turn to step 5; otherwise, turn to step 2;

Step 5: output the fitness value of g_{best} and the come to an end.

4. Case Analysis

The typical IES equipment selected in this paper includes: four 300MW gas combined cycle waste heat boilers, five dual efficiency absorption chillers supplied by condensers, and one inverter, controller and battery connected to the positive energy battery module are set in the tower; 3 sets of heat storage equipment with maximum capacity of 500kwh. Uniform output between the same equipment and grid connected operation. Figure 2 shows the basic structure of ices selected in this paper.

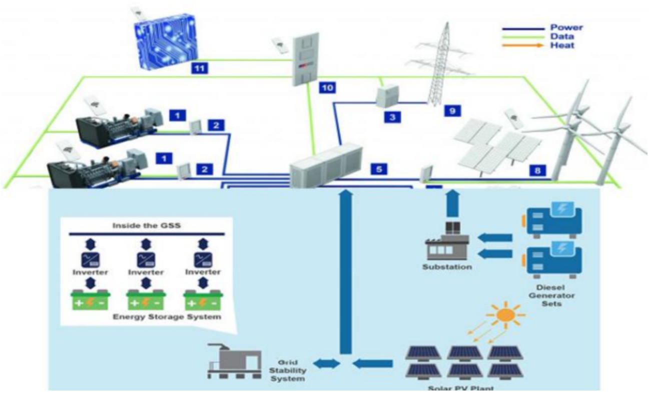


Figure 2. IES structure diagram

The project can make full use of low valley electric heat storage heating, and the actual operation effect is moderate [7]. The collected data were simulated and analyzed in MATLAB through Yalmip+CPLEX, and the corresponding operation strategy was formulated. The price parameters of power market in actual operation are used to guide the operation optimization strategy of energy storage equipment participating in auxiliary services in IES, to maximize profits.

When solving the above examples, the key problem of iterative method is its convergence and convergence speed We compare the convergence performance of PSO algorithm before and after optimization, and find that the global adaptability after 100 iterations is significantly higher than that before improvement. In the experimental test, the iteration time is only 1/4 of that before improvement, as depicted in figure 3.

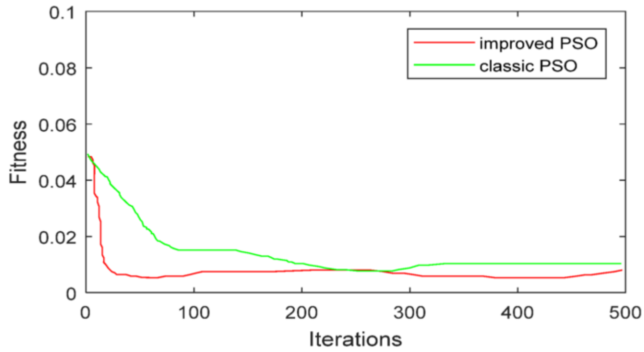


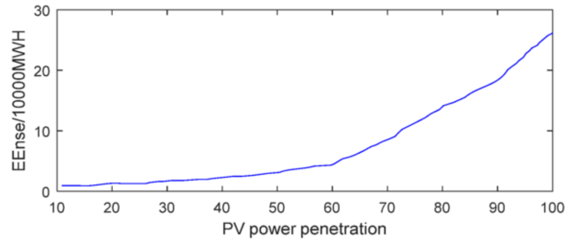
Figure 3. Comparison of convergence curves before and after PSO algorithm improvement.

Table 1 shows the cost of the system after adjustment and the cost comparison of each period. Through optimization calculation, the values of some control variables in the system are determined to find when all constraints are satisfied It is found that there is a certain connection and coupling between the two systems, which reflects the coupling of the integrated energy system., Adjusting the load curve of power grid and improving the load rate play an important role in power grid loss reduction and energy saving. However, in the peak period, due to the reduced power consumption of the system and the high transaction price of electric energy, the system can sell electric energy to the power grid to obtain income, which greatly reduces the cost.

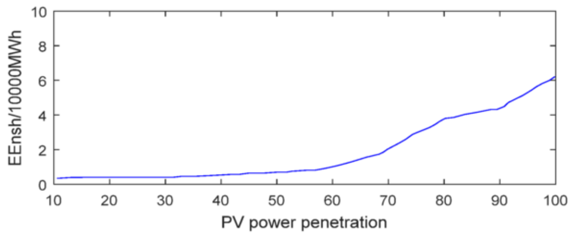
Table 1. Cost of integrated energy system before and after optimization and adjustment

Item category	Before adjustment(¥)	After adjustment(¥)
Fuel	1079.65	1125.05
Power purchase	154.38	162.29
Revenue from sales	99.74	195.60
Maintenance cost	52.31	58.01
Start/stop cost	7.82	7.82
Load scheduling	0	23.65

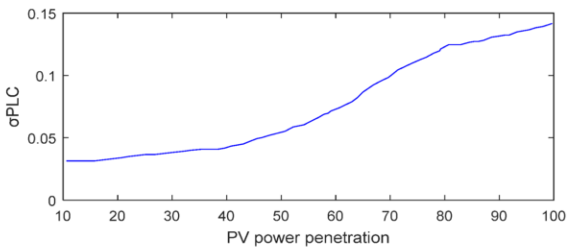
The penetration of renewable energy will also affect the reliability of IES. Figure 4 shows the comparison of index values of grid elasticity optimization, load grading response and collaborative interaction of four types of resources of energy storage system under different PV power supply permeability. As can be seen from figure 4(a), due to the different generating capacity of various units, and the wind power photovoltaic belongs to the type with low capacity factor, in order to achieve the same power generation under the same carbon emission intensity, for example, the higher the wind and solar penetration rate, the greater the installed capacity on the power generation side. In addition, with the increase of PV power permeability, the ENse index value calculated by algorithm 2 is more accurate. As can be seen from figure 4(b), since the heat load is mainly supplied by the boiler, the power generated by the boiler or cogeneration has a certain correlation with the output of the distributed photovoltaic power supply. When the penetration rate of photovoltaic power supply is greater than 70%, the rising trend of FENSi index is gradually obvious. As can be seen from figure 4(c), with the increase of photovoltaic capacity permeability, the impact of photovoltaic power generation on the net load of the system increases gradually. Due to the randomness and volatility of photovoltaic power generation, the grid connection of a large number of photovoltaic power sources will not only increase the fluctuation range of net load, but also reduce the accuracy of load forecasting σPLC indicators show an upward trend. The improved PSO proposed in this paper will calculate the non convergence, to obtain a relatively more accurate reliability index value. The results fully prove the advantages of the proposed method.



(a) E_{Ense} index of system



(b) E_{Ensh} index of system



(c) σPLC index of system

Figure 4. System index changes under different PV power penetration.

5. Conclusion

Aiming at the unreasonable energy allocation in power integrated energy system, an optimization scheme of power multi energy cooperation is proposed by using the optimization convergence of particle swarm optimization algorithm with changing inertia weight. The scheme mainly divides the information particle swarm of different energy forms into sub populations of different forms, and uses the weight coefficient called inertia weight to make the particles track their historical optimal value. Through joint calculation, evolution and matching, until the best evolutionary algebra is realized, and finally the optimal value after comparison is obtained. The experimental results show that the energy configuration based on the improved PSO algorithm has good stability, and can provide a meaningful technical reference for the further research of later configuration.

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