An Energy Integrated Dispatching Strategy of Multi-energy Based on Energy Internet

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Abstract. Energy internet is a new way of energy use. Energy internet achieves energy efficiency and low cost by scheduling a variety of different forms of energy. Particle Swarm Optimization (PSO) is an advanced algorithm with few parameters, high computational precision and fast convergence speed. By improving the parameters ω, c1 and c2, PSO can improve the convergence speed and calculation accuracy. The objective of optimizing model is lowest cost of fuel, which can meet the load of electricity, heat and cold after all the renewable energy is received. Due to the different energy structure and price in different regions, the optimization strategy needs to be determined according to the algorithm and model.

1. Introduction
At present, energy that used by people are mainly fossil fuels, such as coal, oil, and natural gas. The large use of fossil fuels raises serious problems, such as energy shortages and environmental pollution. And these problems have a negative impact on people's lives [1]. With the development of human society, energy and environmental issues are getting more and more attention. In order to solve this problem, we should start from two aspects. On the one hand, it is necessary to improve the efficiency of fossil energy and reduce fossil energy consumption. On the other hand, we must continue to develop the use of clean energy [2]. The foundation of energy internet is renewable energy which can achieve a comprehensive utilization of various forms of energy including electricity, heating and cooling. The purpose of energy interconnection is to improve the overall efficiency and reduce the cost. Energy router as energy dispatch equipment of energy internet needs to consider different models of energy forms and then use advanced algorithms to achieve efficient use of energy [3].

2. Five Models of Energy Involved in Energy Internet
The hot and cold power supply system can use different forms of energy to generate electricity, heat and cold. The electrical load of the system is provided by the grid and the power generation equipment [4].
The power generation equipment includes photovoltaic, wind power, coal, natural gas and diesel emergency power generation. The heat load is provided by the extraction of the steam turbine in the coal and the exhaust heat from the gas. The cold load is provided by an absorption chiller in the gas power generation, and electric chiller is equipped when the cold load is big [5]. The structure of energy dispatch is showed in Fig 1.

2.1 Model of Wind Power

\[
P_{\text{wind}} = \begin{cases} 
0, & v < v_{\text{in}}, v \geq v_{\text{out}} \\
\frac{P_{\text{wind0}} \times (v - v_{\text{in}})}{v_0 - v_{\text{in}}}, & v_{\text{in}} \leq v \leq v_0 \\
0, & v_0 < v < v_{\text{out}} 
\end{cases}
\]  

(1)

In the above formula, \(P_{\text{wind}}\) is the power of the wind turbine, \(P_{\text{wind0}}\) is the rated power of the wind turbine, \(v\) is the actual wind speed, \(v_0\) is the rated wind speed, \(v_{\text{in}}\) is the cut in wind speed, and \(v_{\text{out}}\) is the cut off wind speed.

Wind power is directly affected by the wind speed, while the speed of the natural wind has a lot of randomness and volatility [6]. In the energy Internet, wind power as clean energy should be accepted by the grid completely. So wind power constraints should be set:

\[
P_{\text{wind}} = P_{\text{forwind}} \\
0 \leq P_{\text{wind}} \leq P_{\text{wind0}}
\]

(2) (3)

Among them, \(P_{\text{forwind}}\) is used to indicate the predicted power of the wind power, that is to say, the wind power is involved in the dispatching according to the predicted power, and the electricity is accepted by the grid completely.

2.2 Model of Photovoltaic Power

For facilitate calculation, a simple model is used in the optimization, that is, the output power is only affected by light and temperature.

\[
P_{\text{solar}} = \frac{P_{\text{solar0}} \times G \times [1 + k_T(T - T_0)]}{G_0}
\]

(4)

\(P_{\text{solar}}\) is the power of the photovoltaic panels, \(P_{\text{solar0}}\) is the maximum power of the photovoltaic panels in the test environment(25 °C, 1000W/m²), \(G\) is the real-time light intensity, \(k_T\) is the temperature coefficient, \(T\) is the real-time temperature, \(T_0\) is Photovoltaic board design reference temperature, \(G_0\) is standard light intensity of test.
As wind power, photovoltaic power generation is affected by the environment, so photovoltaic power generation also has great uncertainty and volatility [7]. In the energy internet, photovoltaic power generation as clean energy, its power needs to be accepted by grid completely.

\[ P_{\text{sol}} = P_{\text{for}} \text{sol} \]
\[ 0 \leq P_{\text{sol}} \leq P_{\text{sol}0} \]

\( P_{\text{for}} \text{sol} \) is the predicted power of photovoltaic panel.

2.3 Model of Cogeneration
The relationship between coal consumption and electricity load is quadratic function in cogeneration, and that is a kind of highly efficient coal-fired power generation technology [8]. In order to make as much use of coal energy, cogeneration units decide the load of electricity by heat.

The amount of coal consumed by the coal-fired unit:

\[ F_{\text{coal}} = a_{\text{coalf}} P_{\text{coal}} + b_{\text{coalf}} P_{\text{coal}}^2 + c_{\text{coalf}} \]

\( F_{\text{coal}} \) is the amount of coal consumed by the unit, \( P_{\text{coal}} \) is the electrical power of the unit, \( a_{\text{coalf}}, b_{\text{coalf}}, c_{\text{coalf}} \) is the coefficient of the system.

Heat supply of coal-fired units:

\[ Q_{\text{coal}} = P_{\text{coal}} \times \eta_{\text{qcoal}} \times \varphi_{\text{qcoal}} \times \theta_{\text{qcoal}} \]

\( Q_{\text{coal}} \) is the heating rate per unit time of the system, \( \eta_{\text{qcoal}} \) is the heating coefficient corresponding to the electric load, \( \varphi_{\text{qcoal}} \) is the ratio of the heat load required for the current time system to the maximum heat that can be provided, \( \theta_{\text{qcoal}} \) is the heat conversion efficiency.

Thermal power generation is a very mature way of generating electricity, compared to new energy power generation, thermal power is controllable. The constraints are mainly reflected in the electrical power and thermal power, that is, there is a minimum power limit.

\[ \Phi_{\text{cut, coal}} P_{\text{coal0}} \leq P_{\text{coal}} \leq P_{\text{coal0}} \]

\( \Phi_{\text{cut, coal}} \) is the unit’s minimum power factor, \( P_{\text{coal0}} \) is the rated power of unit.

\[ 0 \leq Q_{\text{coal}} \leq Q_{\text{coal0}} \]

\( Q_{\text{coal0}} \) is the maximum heat supply in per time.

2.4 Model of Gas Power Generation System
The gas power system can provide electricity, heat and cooling, and its energy efficiency is higher. The efficiency of the system decreases with the decrease of the output. At present, third-order efficiency model is used to analyze the efficiency of the gas turbine [9].

\[ F_{\text{gas}} = a_{\text{gasf}} + b_{\text{gasf}} P_{\text{gas}} + c_{\text{gasf}} P_{\text{gas}}^2 + d_{\text{gasf}} P_{\text{gas}}^3 \]

\( F_{\text{gas}} \) is the amount of natural gas consumed per time, \( P_{\text{gas}} \) is the electricity power of the gas turbine, \( a_{\text{gasf}}, b_{\text{gasf}}, c_{\text{gasf}}, d_{\text{gasf}} \) is the coefficient of the system.

The heating of the gas unit is mainly provided by the exhaust heat regenerator, whose power is affected by the power of heating load and the output of the gas turbine.

\[ Q_{\text{gas}} = P_{\text{gas}} \times \eta_{\text{qgas}} \]

\[ Q_{\text{qgas}} = Q_{\text{gas}} \times \varphi_{\text{qgas}} \times \theta_{\text{qgas}} \]

\( Q_{\text{gas}} \) is the heat of exhaust, \( \eta_{\text{qgas}} \) is the relationship between the exhaust heat and the electric load, \( Q_{\text{qgas}} \) is the heating load provided by the gas turbine, \( \varphi_{\text{qgas}} \) is the proportion of the heat load provided by the gas turbine, \( \theta_{\text{qgas}} \) is conversion efficiency of heating.

The cooling of the gas unit is mainly provided by an absorption chiller, and the absorption chiller needs to be cooled by the heat in the exhaust gas.

\[ Q_{\text{cgas}} = Q_{\text{gas}} \times \varphi_{\text{cgas}} \times \theta_{\text{cgas}} \]

\( Q_{\text{gas}} \) is the amount of cooling provided per time of the gas turbine unit, \( \varphi_{\text{cgas}} \) is the ratio of the total heat of the exhaust gas used for the heat of cooling, and \( \theta_{\text{cgas}} \) is the conversion efficiency between heat and cooling.
As with coal-fired units, the gas unit has the smallest output limit, that is, the power load must be greater than a certain value.
\[ \varphi_{\text{cut, gas}} P_{\text{gas}} \leq P_{\text{gas}} \leq P_{\text{gas}0} \] (15)

\( \varphi_{\text{cut, gas}} \) is the minimum power coefficient of unit, \( P_{\text{gas}0} \) is the rated power of unit.

Heating load constraints:
\[ 0 \leq Q_{\text{qgas}} \leq Q_{\text{qgas}0} \] (16)

\( Q_{\text{qgas}0} \) is the rated calorific value of the load.

Cooling load constraint:
\[ 0 \leq Q_{\text{cgas}} \leq Q_{\text{cgas}0} \] (17)

\( Q_{\text{cgas}0} \) is the rated cooling capacity of the load.

\[ \varphi_{\text{qgas}} + \varphi_{\text{cgas}} \leq 1 \] (18)

The heat used for heating and cooling cannot exceed the total heat in the exhaust.

2.5 Model of Oil Power Generation System

Oil power generation system is generally used as an emergency power supply in a country that lacks oil, and the relationship between fuel consumption and power is quadratic.

\[ F_{\text{oil}} = a_{\text{oil}} + b_{\text{oil}} P_{\text{oil}} + c_{\text{oil}} P_{\text{oil}}^2 \] (19)

\( F_{\text{oil}} \) is the consumption of unit fuel, \( P_{\text{oil}} \) is the unit's electrical power, \( a_{\text{oil}}, b_{\text{oil}}, c_{\text{oil}} \) is the coefficient of system.

Constraints of fuel power system:
\[ \varphi_{\text{cut, oil}} P_{\text{oil}0} \leq P_{\text{oil}} \leq P_{\text{oil}0} \] (20)

\( \varphi_{\text{cut, oil}} \) is the coefficient of minimum power, \( P_{\text{oil}0} \) is the rated power.

2.6 Constraints of System

When the power system is in operation, it is necessary to keep the amount of electricity equal to the load in real time:

\[ P_{\text{wind}} + P_{\text{solar}} + P_{\text{coal}} + P_{\text{gas}} + P_{\text{oil}} = P_{\text{need}} \] (21)

\( P_{\text{need}} \) is the power load of system.

The heating system needs to maintain a balance of heat load; otherwise it will cause the temperature rise or fall:

\[ Q_{\text{qcoal}} + Q_{\text{qgas}} = Q_{\text{qneed}} \] (22)

\( Q_{\text{qneed}} \) is the heating load of system.

In the actual operation of the system, the cooling load needs to maintain balance. If the cooling provided by gas unit cannot meet the demand, it is necessary to put in electric cooling:

\[ Q_{\text{ce}} = P_{\text{ce}} \times \theta_{\text{ce}} \] (23)

\( Q_{\text{ce}} \) is the cooling capacity for electricity cooling, \( P_{\text{ce}} \) is the power used for electrical cooling, and \( \theta_{\text{ce}} \) is the conversion efficiency of the electricity to cold.

\[ Q_{\text{cgas}} + Q_{\text{ce}} = Q_{\text{cneed}} \] (24)

\( Q_{\text{cneed}} \) is the system's cooling load.

There are many parameters that affecting the energy internet evaluation indicators, but the key is economic [10]. The original intention of energy internet is to improve energy efficiency and maximize the use of energy. The minimum cost of running is chosen as the optimization target, and the cost includes electricity costs and fuel costs. Set the objective function as:

\[ \min C_{\text{total}} = C_e + C_{\text{fuel}} \] (25)

\[ C_e = r_e \times P_e \times \Delta t \] (26)
\( C_{\text{fuel}} = C_{\text{coal}} + C_{\text{gas}} + C_{\text{oil}} \)

\( C_{\text{coal}} = r_{\text{coal}} \times F_{\text{coal}} \times \Delta t \)

\( F_{\text{coal}} = a_{\text{coal}} + b_{\text{coal}} P_{\text{coal}} + c_{\text{coal}} p_{\text{coal}}^2 \)

\( C_{\text{gas}} = r_{\text{gas}} \times F_{\text{gas}} \times \Delta t \)

\( F_{\text{gas}} = a_{\text{gas}} + b_{\text{gas}} P_{\text{gas}} + c_{\text{gas}} p_{\text{gas}}^2 + d_{\text{gas}} p_{\text{gas}}^3 \)

\( C_{\text{oil}} = r_{\text{oil}} \times F_{\text{oil}} \times \Delta t \)

\( F_{\text{oil}} = a_{\text{oil}} + b_{\text{oil}} P_{\text{oil}} + c_{\text{oil}} p_{\text{oil}}^2 \)

\( C_{\text{total}} \) represents the total cost of the system, \( C_e \) represents the cost of electricity purchased from the grid, \( C_{\text{fuel}} \) represents the total cost of purchasing the fuel, \( C_{\text{coal}} \) represents the cost of coal purchase, \( r_{\text{coal}} \) represents the coal price, \( C_{\text{gas}} \) represents the natural gas purchase cost, \( r_{\text{gas}} \) represents natural gas price, \( C_{\text{oil}} \) means oil cost, \( r_{\text{oil}} \) means oil price. \( a_{\text{coal}}, b_{\text{coal}}, c_{\text{coal}}, a_{\text{gas}}, b_{\text{gas}}, c_{\text{gas}}, d_{\text{gas}}, a_{\text{oil}}, b_{\text{oil}}, c_{\text{oil}} \) are the coefficients of the system.

3. Improved Particle Swarm Optimization

PSO simulates the behavior of birds’ predation, like a group of birds looking for food; they only know the distance between themselves and food. In order to get food, they will learn from the nearest birds, and gradually close to food.

In order to make the particle swarm algorithm faster convergence, and higher accuracy, improvements could be done as follows:

\[
\omega = \omega_{\text{max}} - \frac{\omega_{\text{max}} - \omega_{\text{min}}}{N} \times n
\]

\( \omega_{\text{max}} \) and \( \omega_{\text{min}} \) represent the maximum and minimum values of \( \omega \), \( n \) and \( N \) denote the current iteration number and the maximum number of iterations respectively.

\[
c_1 = c_{1e} + \frac{n(c_{1e} - c_{1s})}{N}
\]

\[
c_2 = c_{2e} + \frac{n(c_{2e} - c_{2s})}{N}
\]

\( N \) and \( n \) represent the number of iterations and the maximum number of iterations, \( c_{1e} \) and \( c_{2e} \) represent the final values of \( c_1 \) and \( c_2 \), \( c_{1s} \) and \( c_{2s} \) represent the initial values of \( c_1 \) and \( c_2 \).

4. Conclusion

For energy internet is based on renewable energy, and energy dispatch needs to ensure renewable energy is accepted. The energy structure and price are different in different regions. So the energy optimization strategy needs to be calculated based on the energy models and algorithms. Through the comprehensive optimization of five forms of energy, it can improve energy efficiency and reduce costs. In the use of Coal-fired units and gas units’ waste heat, will not improve their own energy production costs, but can produce benefits by fully used.

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