Energy flow analysis of the multi-energy energy router

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Abstract. Energy routers have become a hot topic in recent years as a key link to realize the wide interconnection of multiple energy sources in the energy Internet. Firstly, this paper analyzed the operation mode of the multi-energy energy router and summarized its typical structure. Then based on the interaction between the energy router and the grid, the energy flow was analyzed from the energy router to the grid and the grid to the energy router. Finally, the energy interaction of the above two aspects was simulated, and the conclusion that the multi-energy energy router can realize various energy interactions in the energy Internet is obtained.

1. Introduction

As a general-purpose agent in the energy Internet, energy router is the main equipment for energy Internet energy and information interaction [1]. It combines power electronics technology and information technology, with precise control, remote coordination, communication, computing and autonomy [2]. The function realizes the complementary exchange of different forms of energy in the energy Internet, including input, output, conversion and storage between energy sources. Therefore, the analysis of the energy flow of energy routers is of great significance for the wide interconnection of multiple energy sources [3]. This paper summarizes the structure of the multi-energy energy router and analyzes its energy flow through simulation.

2. Structural analysis of the multi-energy energy router

The electric-hot-gas integrated energy system is an important part of the modern energy Internet [4], and the multi-energy conversion equipment is the smallest multi-energy energy router.

2.1. Typical structure of the multi-energy energy router

A multi-energy energy router consists of the following structures: gas network, heating network, power grid, wave energy, mixing chamber in energy conversion equipment, gas thermoelectric conversion equipment (CHP) [5], gas-electricity conversion equipment, thermoelectric conversion equipment, electric energy conversion equipment, gas storage equipment in energy storage equipment, heat storage equipment, the storage structure[6]. Its typical structure and port settings are shown in Figure 1.
2.2. Operational analysis
The multi-energy energy router contains different types of energy flow and conversion. The natural gas in the gas network is primary energy, which is used for CHP after being transferred into the mixing chamber. In a CHP, gas is usually converted into heat by a gas turbine. A part of the heat is input to the heat network through a pipe, or stored, and the other part is converted into electric energy by a generator and transmitted to the inside of the power energy router [7].

The power energy router is the main place for power conversion and transmission. In addition to connecting CHP power production, it also connects wave energy, power storage equipment and power grid. The energy in the power grid can also be converted into heat energy by the electric boiler and transferred to the heat network. The heat energy can also be used to generate electricity. The excess or lower-priced power can be transferred to the electrolysis-water device to generate hydrogen gas.

![Diagram of multi-energy energy router structure and port settings](image1)

**Figure 1.** The multi-energy energy router structure and port settings.

3. Energy flow composition of the multi-energy energy router
In order to simplify the research process, this paper mainly focuses on the interaction between the multi-energy energy router and the grid, and does not consider the situation that multiple energy flows work together.

3.1. Energy router output energy to the grid

![Diagram of energy flow when outputting electrical energy to the grid](image2)

**Figure 2.** Energy flow when outputting electrical energy to the grid.

When the multi-energy energy router outputs electrical energy to the grid, the upstream energy sources of the energy router are mainly gas grids, energy storage devices and fluctuating energy sources, and the downstream energy output is the grid. At this time, there are three energy flow modes A, B, and C as shown in Figure 2.
3.1.1. Mode A. In mode A, for the CHP combustion chamber, according to the mass balance:

\[ G_{cb, out} = G_{cb, in} + G_f \]  

(1)

\( G_{cb, out} \) is the gas flow of combustion chamber outlet, \( G_{cb, in} \) is the air flow of combustion chamber inlet, \( G_f \) is the fuel flow required for combustion. According to the law of conservation of energy, the output energy \( E_g \) of the combustion chamber is:

\[ E_g = G_{cb, out} h_3 = G_{cb, in} h_2 + G_f h_j + G_f \cdot LHV \cdot \eta_b \]  

(2)

\( E_g \) is the energy of gas, \( h_3 \) and \( h_2 \) are comparison value of combustion chamber outlet, and \( h_j \) is the comparison value of fuel, \( LHV \) is the low calorific value of fuel, \( \eta_b \) is the efficiency of fuel combustion. The energy generated by the combustion of the combustion chamber can be used for the driving of the steam turbine, and the output power of the steam turbine is \( W_s \):

\[ W_s = G_{cb, out} \left( h_j - h_{st, c} + \alpha_r \Delta h_{st} - \sum h_{st, j} \alpha_j \right) \]  

(3)

\( h_{st, c} \) is the steam turbine outlet vapor ratio enthalpy, \( \alpha_r \) is the reheated steam share with reheat, \( \Delta h_{st} \) is the coma before and after reheat steam reheating, \( h_{st, j} \) is the j-th level extraction devaluation, \( \alpha_j \) is the j-level extraction share. The mechanical energy generated by the steam turbine can be converted into electrical energy by the generator, and the conversion efficiency of the generator is \( \eta_1 \). Then, when the CHP is working, the ET1 energy input \( E_{e1} \) is:

\[ E_{e1} = \eta_1 W_s \]  

(4)

Then the power router sends the electrical energy to the grid through ET3, the transmission efficiency is \( \eta_{o, e} \), then the energy \( E_{e3} \) transmitted to the grid is:

\[ E_{e3} = \eta_{o, e} E_{e1} \]  

(5)

3.1.2. Mode B. Energy storage \( E_{e4} \) inputs electrical energy to the energy router. The input efficiency is \( \eta_{i, e} \), and the energy \( E_{e3} \) transmitted to the grid is:

\[ E_{e3} = \eta_{o, e} \eta_{i, e} E_{e4} \]  

(6)

3.1.3. Mode C. Because only wave energy generation is sent to the grid through an energy router, its energy flow equation is:

\[ E_{e3} = \eta_{o, e} \eta_{i, e} E_{e5} \]  

(7)

\( \eta_{i, e} \) is the input efficiency of the input energy of the wave energy to the power energy router, and \( E_{e5} \) is the energy of the wave energy.

3.2. The grid supplies energy to the energy router

![Figure 3. Energy flow mode when the grid is powered.](image)

When the grid supplies power to the energy router, the upstream energy source of the energy router is the grid, and the downstream energy is mainly the gas grid and the energy storage device. At this time, there are two types of energy flow modes A and B as shown in Figure 3.
3.2.1. Mode A. In the mode A, the power grid inputs power to the energy router. The input efficiency is $\eta_3$. The energy input to the power router is $\eta_3 E_{i3}$. The power router sends power to the electrolysis-water device, the output efficiency is $\eta_2$, and the energy $E_{e2}$ sent to the electrolyzed water is:

$$E_{e2} = \eta_3 \eta_2 E_{i3}$$  \hspace{1cm} (8)

3.2.2. Mode B. At this time, the efficiency of the power router to transfer energy to the energy storage device is $\eta_{o4}$, and the energy $E_{e4}$ obtained by the final energy storage device is:

$$E_{e4} = \eta_{o4} \eta_3 E_{i3}$$  \hspace{1cm} (9)

4. Simulation and analysis

For the interaction between the multi-energy energy router and the grid, this paper uses MATLAB to simulate the energy flow between them. In order to meet the flow of energy flow, this paper set the energy router parameters for AC 220V power supply with a capacity of 10000W, the LHV of natural gas is 8600 kcal/m$^3$.

4.1. Energy flow simulation when outputting electrical energy to the grid

There are three main types of energy flow when outputting electrical energy to the grid. The simulation results are shown in Figure 4, Figure 5, Figure 6, Figure 7.

![Figure 4](image1.png)

**Figure 4.** Natural gas transmits power to the energy router through port ET1.

![Figure 5](image2.png)

**Figure 5.** The wave energy transmits power to energy router.

![Figure 6](image3.png)

**Figure 6.** The energy storage device transmits power to the energy router.
Through simulation, when the simulated load exceeds 70%, natural gas inputs energy to the energy router through CHP. At this time, the input power waveform of the gas network to the energy router is 4700W as shown in Figure 4. The wave energy transmission power is 5600W as shown in Figure 5. The energy storage device stabilizes and inputs energy to the energy router, the transmission power is 1000W as shown in Figure 6. Finally, the grid receives power is 9040W as shown in Figure 7.

When the gas network inputs gas to the energy router, the energy router also outputs electric energy to the grid, and at this time, the gas-electricity conversion is realized; when the wave energy outputs energy to the energy router, the output electric energy can also be changed. The energy storage device compensates for the fluctuations of both and maintains the stability of the energy input to the energy router. In the end, the transmission efficiency reaches 80%, and the flow of various energies is realized.

4.2. Energy flow simulation when power grid is supplied
When the grid supplies power to the energy router, there are two ways of flowing energy. The simulation results are shown in Figure 8, Figure 9, and Figure 10.
Figure 10. The power that the energy router outputs to the energy storage device.

Set the power supply of the grid to the energy router as 11300W. At this time, the electrolyzed water device generates H2, realizes electro-pneumatic conversion, and is transmitted to the gas network, and uses simulation software to simulate that the energy transmission of the energy router to the electrolyzed water device as shown in Figure 9 is 8800W. The energy storage device receives the remaining energy, and the power is 1240 W as shown in Figure 10. According to the simulation, the energy realizes the process of transmitting from the power grid to the gas network and the energy storage device through the energy router, and realizes the flow conversion of various energy, and the transmission efficiency reaches 80%.

5. Conclusions
Based on the interaction between the multi-energy energy router and the grid, this paper analyzes the flow of energy between the upstream and downstream of the energy router. It is verified by simulation that a variety of energy sources are transformed during the energy flow process, and the transmission efficiency can be 80% in the energy flow process. The next step can be to conduct more in-depth research by considering the simultaneous flow of multiple energy sources and considering the factors of the heat network.

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