Exergy Analysis of Compressed Air Energy Storage System

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Abstract. The supercritical compressed air energy storage system (CAES) is a large-scale energy storage system, which can effectively improve the utilization efficiency of renewable energy power generation, and has the advantages of independent operation, high energy density and friendly environment. In this paper, the exergy efficiency and loss of the main equipment in the system are analyzed. Conclusions are as follows: the heat exchanger has the highest efficiency and air compressor has the biggest exergy loss. However, energy utilization of the CEES can be effectively improved if the efficiency of the air expander is increased. The exergy efficiency of the pump is lowest, but the pump energy loss is the least, so it is not recommended to spend a lot of energy on improvement of pump efficiency.

Introduction

With the development of society and the improvement of people's living standard, the instantaneous power consumption increases, which causing peak valley more and more serious in our country. Abandoned wind rate up to 30% due to intermittent and random characteristics in Northwest Five Provinces according to the National Energy Bureau 2016 annual data [1]. At the same time, the State encourages the wind, solar and other renewable energy power generation consumption. As an intermediate link of the power supply and demand side, the energy storage system can quickly realize the flexible operation system of power supply when the power consumption is low and consumption power when the power consumption is peak.

The supercritical compressed air energy storage system(CAES) has the following advantages: (1) the system can be independently operated, and the heat released during the energy storage process can be used for heating the air during the energy release process, so the energy utilization efficiency is high; (2) the energy density is high, the density of liquid air and gaseous air at atmospheric pressure is about 800:1; (3) The system is suitable for coupling with a renewable energy power generation system, because the system comprises heat storage and cold storage equipment, and can be directly combined with a wind energy or solar power generation system; (4) low carbon and environment friendly, the system for the transmission of energy in the middle link, does not emit any pollutants. With the large-scale renewable energy generation and power grid load fluctuation in our country, this system has good engineering application prospect.

Chen established mathematical model and analyzed system efficiency and optimization parameters from the system pressure ratio, series using thermodynamic method [2,3]. Storage material is an important component of the energy storage system. The literature [4] focuses on the types of energy storage materials, porosity and filling methods, and obtains the law of the influence of materials, physical properties and other parameters on the system. Multi energy complementarity system can effectively improve the system efficiency, and it is the hotspot of research in recent years, literature [5-7] optimization and economy of solar energy complementary system are studied. By studying, the supercritical compressed air energy storage system, as a large energy storage system, is a kind of energy storage system with high efficiency and low pollution, which can provide ideas for the effective regulation of power grid peak and distributed renewable energy consumption. Institute of
Engineering Thermophysics has researched this field for many years, and successfully solved many key scientific problems. They built the world's first 10 MW compressed air energy storage system demonstration and research platform to promote the commercialization [8].

In this current paper, exergy efficiency is used for the main equipment analyzed, the loss and efficiency of the main equipment are obtained, and then the way to improve the efficiency of the system is put forward.

CAES Model

Supercritical compressed air energy storage/energy release system mainly includes air compressor, air expander, heat storage/heat exchanger, cold storage / heat exchanger, cryogenic pump, liquid storage tank and other equipment. Fig. 1 is the simple Diagram of CAES and its working principle is as follows: (1) under the initial conditions, the liquid storage tank is filled with liquid air. At the peak of the power consumption, the liquid air is pumped to the cool storage/heat exchanger by the low pressure pump to the super critical pressure, and then heated to the normal temperature. After absorbing the compression heat, the expansion work is done by the expander. At the same time, the cold energy in the liquid air is recovered and stored in the regenerator/heat exchanger.

When the power grid is low, the air is compressed into a supercritical state and cooled in the regenerator/heat exchanger to normal temperature. The air is cooled and liquefied by using stored cold energy, and stored at a liquid storage tank after throttling. At the same time, the compressed heat of the air is recovered and stored in the heat storage / heat exchanger: in order to compensate for the loss of components and heat dissipation of the system, the flow of compressed air needs to be slightly higher than that of the working air (3-5%), low temperature compressed air can be compensated by a small amount of gasification after throttling, most post liquefaction storage.

**Exergy efficiency is used to evaluate the performance of the system equipment. The efficiency of each main equipment in the system is expressed as follows:**

The exergy efficiency of expander and compressor can be expressed as:

\[
\eta_{\text{ex}} = \frac{m_{\text{air}} \cdot (h_f - h_{i0})}{m_{\text{air}} \cdot [(h_f - h_{i0}) - T_0 \cdot (s_f - s_{i0})]} \quad (1)
\]

\[
\eta_{\text{com}} = \frac{m_{\text{air}} \cdot (h_{s} - h_{i1})}{m_{\text{air}} \cdot [(h_{s} - h_{i1}) - T_0 \cdot (s_{i} - s_{f})]} \quad (2)
\]

Exergy efficiency of refrigerant pump:
Taking the high temperature heat exchanger as an example, the exergy efficiency of the heater can be expressed as:

$$\eta_{ex} = \frac{m_{air} \cdot (h_3 - h_5 - T_0 \cdot (s_3 - s_5))}{m_{air} \cdot V_6 \cdot (p_2 - p_5) / \eta}$$

where: $m_{air}$ is the working mass flow of through the expansion, [kg/s]; $h_5$ is the enthalpy corresponding point in Fig. 1, [kJ/kg]; $s_5$ is the entropy of the corresponding points in Fig. 1 [kJ/(kg K)]; $p_5$ is the pressure of the corresponding points in Fig. 1 [kPa]; $V_6$ is the quality of the volume of pump inlet refrigerant [kg/m$^3$]; $T_0$ is Kelvin temperature [K], $\eta_p$ is the efficiency of the pump.

In single stage compression single-stage expansion system, the exergy analysis parameters is as follows: the compressor outlet pressure is 4000kPa, the expander inlet pressure is 6000kPa, the air temperature in the tank is -194.5°C and the pressure is 100kPa [9]. Assume that the compressor and expander efficiency were 85% and 80%, the pump efficiency is 75%, the energy storage system outlet temperature of high temperature heat exchanger is 26°C, hint temperature for high heat exchanger temperature is 9°C, hint temperature of low heat exchanger temperature is 6°C, refrigerant flow rate of energy storage and energy release system the is 1kg/s.

### Results and Analysis Results

The exergy loss can indicate the distribution of equipment loss and the proportion of exergy loss in each link to the total loss of the system. It directly reveals the weak link in the system, and points out the direction for improving the efficiency of the system. As shown in table 1, the system's main equipment exergy consumption, exergy efficiency and per equipment exergy loss account for total exergy loss of the system.

As shown in the table, the exergy efficiency of the air expander and pump is lower than other equipments, the exergy loss of air compressor and expander is the highest account for most proportion of exergy loss, but the exergy efficiency of air compressor is higher than the air expander. Through the above analysis, the efficiency of the system can be remarkably improved if the efficiency of the air expander can be increased.

According to the exergy loss of the pump is smaller but special lower exergy efficiency, so exergy efficiency of a pump with the pump outlet pressure changing is analysis, as shown in Fig. 2. The exergy efficiency of the pump decreases with the increase of the pump outlet pressure, but little change; under the same pump outlet pressure, the different pump efficiency has little influence on the pump exergy efficiency. Therefore, system exergy efficiency improvement space of expander is relative maximum from the point of view of exergy loss and exergy efficiency.

### Table 1. Exergy efficiency and the lose exergy.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Total exergy</th>
<th>Exergy efficiency /%</th>
<th>Each equipment account for total exergy loss /%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air compressor</td>
<td>560</td>
<td>94</td>
<td>57.3</td>
</tr>
<tr>
<td>Air expander</td>
<td>533</td>
<td>79</td>
<td>20.9</td>
</tr>
<tr>
<td>High temperature heat exchange</td>
<td>190</td>
<td>95</td>
<td>8.3</td>
</tr>
<tr>
<td>Low temperature heat exchange</td>
<td>362</td>
<td>96</td>
<td>9.7</td>
</tr>
<tr>
<td>pump</td>
<td>0.47</td>
<td>48</td>
<td>3.8</td>
</tr>
</tbody>
</table>
Summary

In this paper, the loss and efficiency of primary equipment in single-stage compression single-stage expansion supercritical compressed air energy storage system are analyzed by using exergy analysis method. The conclusion is that the heat exchanger has the highest efficiency and the biggest air compressor has biggest exergy loss. However, after comprehensive analysis, energy utilization of the system can be effectively improved if the efficiency of the air expander is increased. The efficiency of the utility pump is lowest, but the pump energy loss is the least, so it is not recommended to make the main improvement the pump equipment.

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References


