An Experimental Study on Compressed Carbon dioxide Energy Storage

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Abstract

The massive use of renewable energy has driven the development of energy storage. Compressed CO2 energy storage technology is a promising technology. To gain a deeper understanding of the process of compressing carbon dioxide energy storage (CCES) technology, in order to support technological advances, this paper experimentally studied the performance of compressed CO2 energy storage system. The key parameters, such as the pressure of the storage tanks, the power consumption of the compressor, and the power of the expander were investigated.

Keywords: compressed CO2 energy storage; experimental study; feasibility Analysis

1. Introduction

With the growing concern about global warming caused by the over-exploitation of fossil fuels, the use of renewable energy is growing rapidly. According to ‘Renewable Energy Installed Capacity Statistics 2019’ published by the International Energy Agency released the development of photovoltaics is rapid, accounting for 1/3 of the new installed capacity of renewable energy [1]. In the past five years, the total installed capacity of photovoltaics in the world has increased 3.5 times. In terms of wind power, the cumulative installed capacity of wind power in the world has almost doubled from 2014 to 2018. [2-4].

In the meantime, the intermittent characteristics of wind power and solar power generation also bring a big challenge to the electricity grid [5]. According to the National Energy Administration (NEA) report, in 2017, China's abandonment rates of wind and photovoltaic power generation were 12% and 6% respectively due to the stability issues.

At present, it is widely believed that energy storage is a necessary means to solve the discontinuous, unstable and uncontrollable power generation of renewable energy, to achieve tracking and planned power generation, and to achieve safe and stable power supply [6]. Among the available energy storage technologies, compressing air energy storage (CAES) is a promising energy storage technology. Even though CAES has been commercialized, it is still limited by many factors such as geological restrict, and low round trip efficiency [7]. Therefore, to improve system performance, enhance the economics of energy storage systems and eliminate these limitations, energy storage system using CO2 instead of air as working fluids has been proposed and studied [8]. Compressing carbon dioxide energy storage (CCES) can reduce the dependence on large caves compared to CAES [9]. CO2 has some unique advantages Compared with air. On the one hand, it has a higher dew point than air, which makes it easier to condense, therefore, pumps can be used instead of compressors to lift the pressure for storage; on the other hand, it offers a possibility for large-scale utilization of CO2, which contributes to the CO2 emission reduction [10].

Currently, to the authors’ knowledge, most of the research has focused on the thermodynamic analysis of the compressed carbon dioxide energy storage (CCES) technology through modelling [11, 12]. There are very few studies that carry out experimental studies. To deeply understand the performance of compressed CO2 energy storage operation and its actual operating conditions, in this work, a test rig of CCES was built up and experiments were conducted to investigate the energy charging and discharging. The objective is to provide experimental data for the future research.

2. Experimental system

2.1 Experimental setup

The schematic diagram of the compressed CO2 energy storage (CCES) system is shown in Fig.1 and the corresponding test rig is shown in Fig.2. This system mainly consists of a high-pressure tank, a
low-pressure tank, a CO\textsubscript{2} expander, and a CO\textsubscript{2} compressor. The details of the components are listed in Table 1.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Schematic diagram of CCES}
\end{figure}

2.2 Experimental procedures

The operation of CCES can be divided into two processes: energy charging, in which CO\textsubscript{2} from the low pressure storage tank is compressed, and energy discharging, in which CO\textsubscript{2} from the high pressure storage tank is expanded.

During energy charging, along with compression, the pressure in the low-pressure storage tank drops, and the pressure in the high-pressure storage tank rises. The compressor is shut down until the next compression process begins, when the pressure in the high-pressure storage tank rises to the set value.

During energy discharging, the high pressure CO\textsubscript{2} enters the expander and expands to a low pressure entering the low-pressure gas storage tank. The expander is directly connected to the electricity generator.

\begin{table}[h]
\centering
\caption{Equipments and parameters in the test rig}
\begin{tabular}{|l|l|l|}
\hline
Item & Model & Key parameters \\
\hline
CO\textsubscript{2} compressor & CDS101B & Rated power: 1.11kW  \\
& & Flow rate: 1.89m\textsuperscript{3}/h  \\
& & Maximum inlet pressure: 2.6MPa  \\
\hline
CO\textsubscript{2} expander & Air Squared Semi-Sealed Scroll E15H022A-SH & Rated power: 1kW  \\
& & Flow rate: 2.592m\textsuperscript{3}/h  \\
& & Max. Inlet pressure: 1.2MPa  \\
\hline
High pressure storage tank & & Tank volume: 0.29*2 m\textsuperscript{3}  \\
& & Wall thickness:1.25cm  \\
& & Height:1.65m  \\
& & Pressure level:0.73~0.95MPa  \\
\hline
Low pressure storage tank & & Tank volume: 0.325*2 m\textsuperscript{3}  \\
& & Wall thickness:1.25cm  \\
& & Height:1.85m  \\
& & Pressure level:0.2~0.38MPa  \\
\hline
Load & Electric heaters & Rated power: 3kW  \\
\hline
Generator & & Maximum speed :3000 rpm  \\
& & Rated output power: 2.4kW  \\
& & Rated voltage: 240V  \\
& & Rated current:10A  \\
\hline
\end{tabular}
\end{table}
3. Results and discussions

3.1 Charging process

The experimental results of the charging process are shown in Fig. 3. The pressure in the high-pressure storage tank rose more rapidly in the beginning. This is mainly due to the pressure drop in the low-pressure tank, so that the suction of the compressor is more difficult. The increase of the pressure ratio between high pressure and low pressure storage tank can also slow down the pressure increase in the high pressure tank. The pressure in the low pressure tank decreased in a similar trend. For the compressor, the power consumption of the compressor had an upward trend at the beginning, increasing from 360.6 J to 382.4 J, and then dropped. This is owing to the start-up process. The further drop of the power consumption is due to that the flow rate of the compressor decreased.

In the later stage of compression, the power consumption of compression dropped rapidly is due to the flow rate in the compressor decreased, as the pressure ratio increased.

3.2 Discharging process

During the discharging process, the inlet temperature of the expander remained at 25°C. The experimental results are shown in Fig. 4. The changes of the pressures in both the low and high pressure tanks were almost linear. In addition, the output power of the expander decreased overall. The fast power increase in the beginning, in which the output power increased from 165.8 J to 191.5 J, is a transition process from the start-up to the full load of the expander, as the increase of the flow rate of the expander caused the expander power to rise in a short time at the beginning. After this, as the pressure ratio decreased, the output power of the expander also dropped. Finally, the power of expander dropped to 46.8J

3.3 System performance evaluation

In order to evaluate the performance of CCES, the round-trip efficiency is used as a key parameter, which is defined as the ratio of energy retrieved from storage to energy put:

\[ RTE = \frac{W_{out} + f_{ex}}{W_{in} + f_{es}} \]  

(1)

where \( t \) denotes the working time, \( W_{out} \) is the total energy output of the system, and \( W_{in} \) is the total external energy input.

The round-trip efficiency of the compressed CO\(_2\) storage experiment system is calculated to be 15%. The main reason for the low round-trip efficiency of this system is that in the experiment the suction temperature of the expander is 25 °C, which is relatively low, resulting in a lower isentropic efficiency of the expander.

4. Conclusions

This paper experimentally studied the performance of a compressed CO\(_2\) energy storage system.

The power consumption of the compressor and the power output of the expander were measured dynamically. The round trip efficiency was calculated based on the measurements, which was 15%.

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References


