

The feasibility of conducting compressed air energy storage system

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Abstract. Energy storage has been a crucial component in human energy utilization, with the compressed air energy storage system (CAES) emerging as a significant and indispensable aspect of the conversation around energy storage solutions. Historically, the understanding of CAES was confined to theoretical models, but recent years have witnessed an increase in practical applications and constructions, bringing the technology into the public eye. These developments have yielded valuable and precise data that researchers can leverage. Utilizing these data points, this paper employs both qualitative and quantitative analysis to thoroughly evaluate the viability of implementing CAES systems. The aim of this article is to provide some insights that can significantly contribute to the advancement of CAES technology, offering a comprehensive assessment that informs future development strategies. Furthermore, the difficulty of the technology is analyzed and some solutions are provided. Finally, the further development trend of compressed air energy storage system is conducted.

1 Introduction

Energy has always been a topic closely related to the development of human beings for thousands of years, and energy has penetrated into all aspects of human life, greatly improving the convenience of human life. Energy is constantly transforming each other, and with the in-depth exploration of science, human beings have a deeper understanding of energy. From 1984 to 2004, the consumption of the energy around the world has annually increase, the primary energy has grown by 49% and the emission of the carbon dioxide has climbed by 43% [1]. The obvious climb of using energy means that investigators are supposed to focus on fixing the predicaments of generating energy and storing energy, to matching the needs of industrial electricity and household energy consumption. With the advancement of the technologies and scientific researches, people is able to invent more advanced energy storage systems, hence, researchers could find the most suitable way to balance complicated situations, such as the efficiency of operating systems, the cost of conducting systems and the pollution of maintaining systems. Over past decades, the researchers have already introduced dozens of technology choices, back in 1883, the first flywheel energy storage system has been introduced, it means people can convert the energy into various formations and easily storage them [2]. After that, the idea of using water

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elevation to storage energy came into view, the first pragmatic construction of pumped hydro energy storage was built in Switzerland in 1907 [2], this energy storage medium necessitates the damming of water bodies, which entails additional initial capital during project development. It is absolutely an effective way but this system has the limitation of the geographical position and constrain of the scale. In 1978, investigator conducted first compressed air energy storage system which can put into real lives in Germany through compressing air into a cavern of roughly 300,000 m³ [3]. Until now, plenty of compressed air energy storage systems are operating to storage and regenerate the energy which utilizes in diverse facets of our lives. The basic mechanism of the CAEs is not complicated, compressed air energy storage system uses air as the carrier of the energy, large-scale compressed air energy storage used excess electricity to compress and store air in an underground structure (such as underground caves), and then mixes compressed air with natural gases when needed, burning expansion to promote gases turbine power generation. CAEs is already a relatively mature technology, but there are still many potential problems and improvements in construction and maintenance. Both the environmental impact and cost considerations still need to be comprehensively considered and reasonably solved.

More comprehensive contents are needed to generally analyze the pros and cons of the CAEs, potential application, utilization and the status of this storage technology. This study aims to collect and assemble the information that investigators got, as well as presenting the conclusion and estimating the feasibility of constructing CAEs successfully.

2 The effect of the environment

No matter what kinds of energy storage system, the consideration of the effect to the environment is a undoubtedly crucial step, not only being useful to make sure the suitability, but also guaranteeing the basic protection to the environment. Of course, the protection of the environment can be subdivided into multiple aspects, in this essay, the aim is to describe the environmental impact during the construction of the system and the environmental impact during the maintenance of the normal operation of the energy storage system. At the beginning of this technology, low efficiency has led to greater limitations of the technology, and has not received widespread social recognition and attention, one of which is because of the dependence on additional heat sources such as fossil fuels. With the invention of the Advanced Adiabatic Compressed Air Energy Storage (AA-CAES), building crews can build compression heat to indirectly reduce the use of fossil fuels that have increased the efficiency of system operation [4], this change not only effectively depict the consumption of the natural fuel, but also decrease the emission of the carbon dioxide, nitrogen dioxide, sulfur dioxide and other harmful substances, this allows the system to be built without the need for additional large-scale space to store fossil fuels and build massive conversion tools. Isothermal compressed air storage system, a new relative technology, through slow movement of the piston to keep the stability of the temperature [5]. Under this application, the system can be effectively dropping the possibility of the technological risks which caused by the fast physical friction. Thus, the system can be utilized for a long period of time.

3 feasibility of conducting this energy storage system

3.1 Cost

When calculating the cost of conducting compressed air energy storage system, there are several main facets which associated with budget. The most important one is about the capital cost, this investment includes equipment cost and installation cost. Taking a 100MW CAE

system with the lifetime of 30 years as an example, the cost of equipment cost plus installation cost is 198.38 million USD without interest rate [6]. Except capital cost, another significant investment is annually operational cost, which includes normal maintenance and the consumption of the fuel. With the fixed operation cost of 5.123 million USD per year and the assumption of interest rate of 5%, so the general investment of activated system is roughly 200 million USD and maintain cost is 15.042 million USD per year. Of course, these data are based on the normal operation of the system, and do not consider the occurrence of unexpected circumstances, such as security accidents or disruption of operating funds, etc. Additionally, the estimation of the funds refers to the cost of construction and operation, and does not include the cost of land.

3.2 Policy

This section only classifies specific policy of certain countries because of the different limitation of the laws. In China, the trend of energy storage development is focusing on accelerating the construction of a clean, low-carbon, safe and efficient new energy storage system [7], providing a strong energy guarantee for economic and social development, and constantly meeting the people's growing needs for a better life. In the European Green New Deal proposed in recent years, it is mentioned that by 2050, Europe will become the world's first near-zero emission state, mainly through the provision and storage of clean, cheap and safe energy, the development of green construction and industry, and the development of sustainable transportation. Energy storage links all aspects like a chain, becoming an indispensable to all aspect of the strategy. No matter what the specific policies and restrictions are, human beings have gradually realized the important role of protecting the environment, and making changes to protect the environment has become a trend around the world. On the basis of this energy storage system is clean and environmentally friendly and relies less on fossil fuels, it has better development prospects and potential than many traditional energy storage systems.

3.3 The difficulty of construction

3.3.1 The limitation of geography

In this portion, the researcher presents a relative assumption about the volume of the cavern, the researcher hypothesizes that the shape of the cave used to store the compressed gas was an ideal oval shape, with an abc axis length ratio of 2:2:1 (a being the major axis of the ellipse, b the minor axis of the ellipse, and c the thickness of the ellipse), therefore, if we need a cave with a volume of almost 300.000 cubic meters, we need to find a cave where a is about 52.4 m, b is about 52.4 m, c is about 26.2 m. Therefore, the cave has a cross-sectional area of about 8625.805 square meters and a vertical area of about 2156.451 square meters. Comparing with other conventional energy storage metrics, it does not require a very large land area, but to make sure there is enough pressure to store the gas safely, so the caves which are made by the salt, hard rock and highly permeable materials become very strong in development [8].

3.3.2 The difficulty of the technology

For the initial CAEs, the efficiency of the operator was relatively low, only 29%, with a pressure requirement of 48-66 bar, and later, with improvements to ensure higher and stable pressure, the efficiency could be increased to 36% [9]. In 1991, a large CAEs system built

for commercial profit in Alabama, USA, has increased the efficiency of the advanced system to 54% by building additional heat recovery units that reduce the amount of fuel consumed during system operation [10]. In 2008, AA-CAES, a new CAES technology that reduces heat release through adiabatic systems to improve efficiency, began to be noticed and put into use, this technology successfully made the efficiency of CAES systems can be as high as 70% [11]. Until today, CAES technology has been studied and developed for nearly 27 years, and significant progress has been made in the research and improvement of compressor or caves. For this technology, the technology has been relatively mature, so there is no strong technical limitations.

4 The stage of the energy system

Based on the technology readiness level [12], the corresponded level of the compressed air energy storage system is TRL 8-9, this value means that the technology has already passes the phase of TRL 7, the system prototype demonstration under scenario, begins to construct in a relatively stable environment. Additionally, this value illustrates that the technology is under the process of real system development through handling bugs to make sure the better performance of the machine. From 1978 to the present, the traditional CAES has long lagged the trend of The Times, and it will be replaced by a more advanced and more integrated new CAES, whether it is cooperating with other energy systems, or the integration of part of the system structure, it has achieved a very significant effect in improving the performance and role of energy storage.

5 The prediction of the future development

Indeed, numerous intricate issues remain unresolved, heavily reliant on technological progress, including the expansion of system capacity and the assurance of converter safety. Until today, there are already German power companies in Germany to carry out the world's first large-scale AA-CAE project, called ADELE[10]. When many technical problems have been properly solved, I believe that large-scale and systematic work will also be carried out in the near future.

6 Conclusion

The article presents the comprehensive content of the compressed air energy storage system, collaborating the previous information with the brand technological advancement. By quantifying and defining obscure concepts, further clarification of potential issues regarding the feasibility of system construction. It is undeniable that based on the limited amount of literature read by the author, there will be some important content or new technology in the article more or less not mentioned or clearly described. In addition, the technology is still in the stage of rapid development, so this article only describes and evaluates the content before 2024. The description of the year beyond that is a forecast of the CAES technology with relatively strong uncertainty. The author expects and firmly believes that in the near future, there will be better and better technology applied to CAES, making the technology to a higher level and better serving human beings and society.

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