Technical Features and Development Trends of Liquid Air Energy Storage

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Abstract. Liquid Air Energy storage (LAES), as an innovative approach to energy storage, utilizes the cryogenic properties of air to provide long duration of energy storage. Through the process of cooling air and storing it in liquid form, LAES systems can release energy when in need, expanding the air and driving turbines to generate electricity. This paper assesses LAES technology's potential, especially in grid balancing and as a back energy storage, noting its compatibility with renewable sources with a discontinuous energy supply, like wind and solar. While LAES systems provide high energy density, long operational lifetimes, and minimal environmental impact, they face challenges that include low round-trip efficiency, scalability issues, and high capital costs. Current research focuses on improving efficiency through thermal storage integration, reducing material costs, and developing hybrid systems to enhance LAES performance. Future advancements in thermal management and modular designs are expected to address existing challenges, placing LAES as a feasible solution for grid stability and renewable energy integration.

1 Introduction

Liquid air energy storage (LAES) is a type of energy storage that uses the thermodynamic properties of air for energy storage and output. In LAES systems, air is cooled down to cryogenic temperatures and then transformed into liquids. When energy is required, liquid air kept in insulated tanks at low pressures is exposed to higher ambient temperatures, which causes it to quickly expand into a gas that powers a turbine to produce electricity [1]. LAES technology provides a possibility for long-term energy storage since it can be integrated with other clean energy sources like solar and wind.

LAES technology has multiple areas of possible application, especially in large scale energy systems. One of its main areas of implantation is grid balancing in where LAES systems balance fluctuations in the supply and demands of electricity [2]. LAES can help maintain grid stability by storing excess energy during times of comparatively low consumption and releasing it during times of increased demand. This function is particularly useful in integration with other types of renewable sources, for example wind and solar energy systems, where the intermittent nature of these sources can disrupt constant energy

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supply. LAES can capture and store surplus renewable energy and enable steady, long duration energy availability during periods of low energy generation.

LAES can also be used as a source of energy backup. During power outages or when other sources of energy are unavailable, LAES can be used to provide energy supply. Additionally, industrial applications of LAES, particularly in areas that require constant energy flow such as manufacturing, can benefit from LAES as it reduces energy costs and prevents operational disruptions.

LAES technology faces many obstacles despite its great potential. Among the main problems is its low energy efficiency. Air must be liquefied and then expanded to produce electricity, which takes a high amount of energy and has a low efficiency when compared to other energy storage systems [2]. There are also challenges in the scalability in LAES as these systems are typically designed for large-scale applications, making them less practical for smaller installations due to the high infrastructure costs and space requirements. Furthermore, the capital costs of building LAES systems can be large, with the need for large cryogenic storage tanks, compressors, and turbines [3]. As a new, emerging technology, LAES is still in its early stages of commercial deployment, making it essential for further development to enhance efficiency, reduce costs, and increase its competitiveness with other energy storage solutions.

The aim of this paper is to analyze and assess the feasibility and practicality of LAES technology, evaluating its advantage and disadvantage, current status, and areas of improvement.

2 Working Principles and Performance

2.1 Working principle

Based off the principle of thermodynamics, the three main phases of LAES system operation are liquefaction, the storage of energy, and energy release. During the liquefying stage, air is cooled to cryogenic temperatures-temperatures of about-196 ºC, at which it turns into a liquid-using energy, usually excess or extra energy produced from other renewable sources like wind and solar energy systems. The system first draws in air, which subsequently passes through a number of compressors. The air's temperature and pressure rise throughout this process. The compressed air is then cooled down while impurities such as carbon dioxide and water vapor are removed to prevent the equipment from freezing, which can result in damage of these equipment. After the purification process, the the air is further cooled until it reaches the desired temperatures. After that, the liquefied air is kept in low pressure, well insulated cryogenic tanks. The liquid air from the tanks is pumped into greater pressures and exposed to higher temperatures when power is needed, which causes it to quickly expand and transform back into a gas. During this process, the air can expand over 700 times its volume in the liquid state, producing a large amount of gas with high pressure. Turbines are driven by the expanding gas, which converts its mechanical energy into electrical energy [4].

2.2 Output and performance

2.2.1 Round-trip efficiency

The ratio of energy recovered to energy used and stored is known as the round-trip efficiency, or RTE. For LAES systems, the round-trip efficiency is 45% to 60%, which is relatively low compared other types of energy storage. Lithium-ion batteries, for example, can reach round-trip efficiencies over 90%. Multiple energy losses during the energy storage and release processes are the cause of LAES systems' low round-trip efficiency. First, compressing and cooling air to cryogenic temperatures requires a significant quantity of energy. Inefficiencies result from the waste of the heat power used during the compression and liquefaction process. Furthermore, inefficient use of heat sources during the gasification process can result in thermal energy losses of the liquid air [5].

2.2.2 Energy density

The quantity of stored energy per unit volume is measured by energy density. Densities of 50-200 Wh/L are found in LAES systems, which are less than lithium-ion batteries but more than compressed air energy storage (CAES), pumped hydro energy storage (PHES) systems, and pumped thermal energy storage (PTES) [1].

2.2.3 Response time

The response time measures how fast a system from switch from its inactive state to actively producing or releasing energy. LAES systems present a moderate response time of a few minutes [1]. In contrast to batteries, which can release stored electrical energy virtually instantly, the LAES system requires it to pump, heat, and expand liquid air in order to produce electricity. This process involves multiple mechanical processes and causes delay in the system.

2.2.4 Operational lifetime

The operational lifetime measure how many cycles or years that a system can continue operating efficiently before a significant degradation occurs. LAES systems are known for their long operational lifetimes, ranging from 30-40 years, with minimal performance degradation [6]. The primary contributor to this extended lifetime is the use of well-established mechanical components such as compressors and turbines which are durable and long lasting. Unlike batteries which degrade over time because of chemical reactions that occur in the cells, LAES systems do not face electric and chemical degradation. Furthermore, the components that might suffer from mechanical wear down can be easily maintained or replaced, further extending its operational lifetime.

2.3 Advantages

LAES technology serves as a potential technology for large-scale energy storage due to its many benefits. Its energy density is one of its primary benefits. The energy density offered by LAES systems, which range from 50 to 200 Wh/L, is greater than that of many other renewable energy storage options [1]. LAES systems can store a lot of energy in comparatively compact spaces attributed to their high energy density.

The minimal environmental impact that LAES technology offers is yet another significant benefit. Since there is no combustion involved in the energy storage process when using air as the medium, there are no greenhouse emissions and therefore little environmental impact.

In addition, LAES system is not limited by geographical constraints [7]. LAES systems can be deployed almost everywhere as the energy in cryogenic tanks, making it a site-free storage. This is a significant advantage over other technologies like PHES that require specific terrains and large water reservoirs. This flexibility makes it suitable for urban areas, remote locations, and places where terrain might limit the installation of traditional energy storage systems.

Moreover, LAES systems can provide storage over a long period of time. This feature is especially helpful for balancing the intermittent nature of renewable energy sources, such as solar and wind. LAES systems also possess a long operational lifetime of 30-40 years, making them a durable and cost-effective option for long periods of energy storage [6].

3 Current and future and development

LAES technology has had significant progress over the years but still remains in its early stage of commercial use. LAES systems have progressed over the conceptual and experimental phases and has pilot projects and small-scale demonstration projects. Researches are currently working on improving the efficiency, scalability, and cost reductions of LAES systems.

3.1 Current Focus Areas

3.1.1 Improving round trip efficiency

The heat energy lost during compression and liquefaction is one of the primary causes of energy loss in LAES systems. Wasted heat during the gasification process can be gathered and recycled by incorporating thermal energy storage, such as advanced thermal energy storage (TES) [8]. However, designing efficient heat exchangers and thermal storage that can retain heat for extended periods of time is a difficulty. The energy needed to reheat the liquid air can be decreased by employing latent heat storage, which uses phase-change materials to store a significant amount of heat during the liquefaction process and release it after regasification. Other techniques include sensible heat storage, which involves heating material such as rocks or molten salts and then using them to help liquid air expand.

Another significant source of energy losses is the liquefying process, which uses a large amount of energy. The efficiency of the expanders and compressors employed in the liquefaction and power generation processes is the one of the main focuses of current efforts [9]. Compression technology advancements like multi-stage compressors and cooling techniques are meant to lower the energy required for liquefaction. To improve the efficiency of the liquefaction process, research is also being done on ways to use waste heat from other sources, such as combined heat and power systems [8].

3.1.2 Reducing capital costs

The high capital costs related with LAES systems, particularly the building of the cryogenic tanks, is one of the largest barriers to commercial deployment. Researchers are finding ways to reduce the cost of material used in LAES systems, especially those of cryogenic tanks and compressors. This includes developing more affordable and also durable alloys for cryogenic storage or using new materials that can stand temperature changes without compromising system integrity. Improving the manufacturing process for the key components such as turbines, compressors, and heat exchangers can assist in reducing the capital costs.

3.1.3 Hybrid LAES systems

Hybrid LAES systems combine the use of LAES systems with other energy storage to improve the performance [10]. For example, LAES systems can be paired with other battery type storage to provide rapid and short energy discharge while supporting long duration storage. In addition, the round-trip efficiency of LAES systems can be enhanced through connection with thermal energy systems.

3.2 Future trends

In the future, with improvements in the thermal management and waste heat utilization, enhancing the efficiency and sustainability of LAES system, making them more competent in addressing situations of energy needs. LAES technology can provide long-term storage while utilizing batteries' quick response times and balancing the intermittent nature of solar and wind energy sources in hybrid LAES systems, which combine LAES systems with other storage like batteries and other renewable storage like wind and solar.

LAES systems are expected to present higher scalability in the future, enabling a larger range of application, from micro grid integration to large scale grid balancing. In addition, artificial intelligence (AI) may also be used in integration with LAES systems, where AI systems can help in meeting changing energy demands and maximize the efficiency of LAES systems. LAES systems have a large space of improvement and can continue to develop into a more resilient and mature technology.

4 Conclusion

In conclusion, LAES present a solution to long duration storage and grid balancing. Key advantages of LAES systems include its long storage duration, high energy density, environmental sustainability, and flexible applications. The goal of ongoing research is to increase round-trip efficiency, reduce capital costs, and develop hybrid LAES systems that combine the advantages of several energy storage types to enhance energy storage performance overall. Furthermore, modular LAES designs can make LAES systems even more affordable and accessible, and improvements in the materials utilized and efficient manufacturing processes should lower initial capital costs. Ultimately, LAES systems provide a solution to grid balancing and can potentially become a major energy storage technology in the future.

References

1. Vecchi, A., Li, Y., Ding, Y., et al. Liquid air energy storage (LAES): A review on technology state-of-the-art, integration pathways and future perspectives. Advances in Applied Energy, **3**, 100047 (2021)

2. Legrand, M., Rodríguez-Antón, L. M., Martinez-Arevalo, C., et al. Integration of liquid air energy storage into the spanish power grid. Energy, **187,** 115965 (20119)

3. Borri, E., Tafone, A., Romagnoli, A.,et al. A review on liquid air energy storage: History, state of the art and recent developments. Renewable and Sustainable Energy Reviews, **137,** 110572 (2021)

4. Damak, C., Leducq, D., Hoang, H. M., et al. Liquid Air Energy Storage (LAES) as a large-scale storage technology for renewable energy integration-A review of investigation studies and near perspectives of LAES. International Journal of Refrigeration, **110,** 208-218 (2020)

5. O'Callaghan, O., & Donnellan, P. Liquid air energy storage systems: A review. Renewable and Sustainable Energy Reviews, **146,** 111113 (2021)

6. Borri, E., Tafone, A., Zsembinszki, G., et al. Recent trends on liquid air energy storage: a bibliometric analysis. Applied Sciences, **10**, 2773 (2020)

7. Luo, X., Wang, J., Dooner, M., et al. Overview of current development in electrical energy storage technologies and the application potential in power system operation. Applied energy, **137,** 511-536 (2015).

8. Nabat, M. H., Zeynalian, M., Razmi, A. R., et al. Energy, exergy, and economic analyses of an innovative energy storage system; liquid air energy storage (LAES) combined with high-temperature thermal energy storage (HTES). Energy Conversion and Management, **226,** 113486 (2020).

9. Morgan, R., Nelmes, S., Gibson, E., et al. Liquid air energy storage – analysis and first results from a pilot scale demonstration plant. Applied energy, **137**, 845-853 (2015)

10. Bernagozzi, M., Panesar, A. S., & Morgan, R. Molten salt selection methodology for medium temperature liquid air energy storage application. Applied Energy, **248,** 500-511 (2019)