

Application Prospect Analysis of Molten Salt Energy Storage Technology

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Abstract. Molten salt (MS) energy storage technology is one of the key topics of today's research. According to studies, MS energy storage technology is critical to integrating renewable energy and is vital to sustaining a robust and trustworthy contemporary power grid. The research on the benefits and use of MS energy storage still has several limitations, though. This essay provides an organized and thorough overview of MS energy storage. The use and growth possibilities of MS energy storage technology in the sectors of solar power, wind power, and nuclear power are investigated on the basis of an examination of the properties of this technology. This study demonstrates the critical role that molten salt energy storage technology plays in lowering power fluctuations, enhancing the adaptability of power networks, and storing and distributing energy produced by intermittent renewable sources like wind and solar energy. It protects the environment and performs well economically. This technology represents the direction in which energy storage technology will grow in the future and is deserving of widespread use.

Keywords: Molten Salt, Application prospect, Energy Storage Technology.

1. Introduction

From energy shortage and other problems, we can see that there are many types of energy, such as heat and electricity. Numerous new energy sources, including solar, wind, natural gas, and others, are also available but cannot be used extensively due to technical issues with storage and the reliance of some energy sources on their environment. The molten salt energy storage system is more affordable and adaptable than other forms of energy and meets sustainability objectives. The molten salt energy storage system is a cost-effective and incredibly adaptable answer that meets sustainability objectives. For a variety of power generation applications, this technology offers long-duration storage, and the long-duration energy storage it offers helps smooth out swings by retaining excess energy. By helping preserve surplus energy environmentally friendly and sustainably transform thermal energy into electricity, the molten salt power system also contributes to developing sustainable power plants [1]. These advantages can also contribute to the peak regulating of the power system in cities by applying molten salt energy storage technology. The United Nations has developed a set of goals to guide more effective energy sustainability. A set of 17 interrelated global objectives known as the Sustainable Development Goals (SDGs) aims to create a "shared vision for harmony and prosperity for both humans and the environment now and in the future [2]. And molten salt energy storage systems are well suited to meet this set of requirements. It is relatively cheap to build, can produce electricity at a low price, and is suitable for developing countries in Africa and Asia that has geographic conditions with sufficient sunlight. Other than that, the molten salt energy storage technology provides the electric generation industry with new technology and a more sustainable way to store surplus energy. Last but not least, molten salt energy storage technology's ability to help cities regulate the power grid and avoid wasting surplus energy while harmlessly storing energy could contribute a lot to the development of sustainable cities and communities [3].

2. An Overview of Molten Salts Energy Storage

2.1. Typical Types of Molten Salts

Molten salts refer to ionic melts formed by melting inorganic salts at high temperatures. Commonly used molten salts are mainly composed of alkali metals or alkaline earth metals and salts such as halides, carbonates, and silicates. There are more than 80 kinds of cations and more than 30 kinds of anions that can constitute molten salt, and the combined types of molten salt can exceed 2400 kinds, which has a wide range of sources. The need for research into acceptable molten salt combinations for thermal energy storage materials has increased recently due to the good thermal characteristics and affordable price of molten salt. The most frequently used molten salts are nitrate mixes, also known as solar salt, with a weight composition of 60 weight percent NaNO_3 and 40 weight percent KNO_3 to maximize economic and thermal qualities. Hitec salt, a ternary mixture of NaNO_2 , NaNO_3 , KNO_3 , and Hitec XL, a ternary mixture of $\text{Ca}(\text{NO}_3)_2$, NaNO_3 , and KNO_3 , have, however, been proposed as potential replacements for Solar Salt in solar thermal power plants due to their lower freezing points [4].

2.2. Characteristics of Molten Salts Energy Storage System

The molten salt energy storage system is made up of the pump valve, instrument pipeline system, monitor, molten salt heater, molten salt container, molten salt heat exchange device, and other parts. In order to solve the issues brought on by the mismatch between the supply and demand of heat energy in terms of time, space, or intensity, molten salt energy storage technology uses molten salt energy storage materials as the medium to store solar energy, geothermal, valley electricity, and other energy in the form of heat energy and release it when necessary.

Sensible heat preservation and latent heat preservation are the two main strategies for preserving thermal energy. Phase changes of a solid into other solids or solids into liquids are the basis for latent heat preservation, whereas the sensible heat reservation approach is centered on heating and cooling a liquid or solid storage medium. A sensible heat presentation method called molten salt heat storage makes use of the material's temperature variation throughout the heating or cooling operation to store thermal energy. The heat storage material remains liquid throughout the entire working temperature range. Molten salt is one of the most common heat conservation and transfer mediums and has been used for decades in many industries, such as heat treatment. Molten salt has many characteristics of high energy efficiency, high energy density, long lifetime and so on, which can ensure good performance in molten salt energy storage systems. The lower and higher temperature restrictions must be taken into account since molten salt has a large operating temperature range. The melting temperature, which may vary greatly depending on the mix of anions and cations, determines the lower limit, while thermal stability, corrosion rate, and other thermophysical limitations can define the upper limit. Molten salt corrosion is a key factor affecting the safe operation of molten salt energy storage systems. Corrosion could be caused by a variety of factors, including thermodynamics of corrosion reactions, impurity effects, and activity and temperature gradients [5].

2.3. Advantages of Molten Salts

First, molten salt has a high energy storage density. By choosing the thermal properties of the storage material, such as its capacity and thermal conductivity, a storage system with minimal heat loss can be designed to increase global efficiency. Second, molten salt energy storage technology has a wide operating temperature range which provides a large temperature difference, so the energy storage density has obvious advantages. Also, in the operating temperature range, the fluidity of molten salt is strong, and its viscosity is almost similar to that of water. Good fluidity can greatly reduce the flow resistance of the pipeline, pump consumption and save energy. Third, it has long service life and good stability. In principle, molten salt energy storage uses the sensible heat storage of the molten salt material itself, and no chemical changes occur. The thermal energy may be kept productively preserved for up to 7 days with sufficient tank insulation. In addition, from past

experience, molten salt has stable properties and has been regarded as an excellent heat transfer and storage medium for nuclear reactors, and it has a service life of more than 30 years. Fourth, excellent heat transfer fluids and perfect for thermal storage causes a substantially lower cost storage system. Additionally, according to data sheets produced by the German Energy Storage Association, the cost of storing a kilowatt-hour in molten salt tanks is about 33 times lower than that of electric batteries [6]. Fifth, molten salt energy storage works by converting low-cost electric energy into thermal energy for storage during the off-peak period at night and supplying steam to the outside through the heat exchange device during the day. The molten salt energy storage system enables the provision of constant electrical production. Therefore, molten salt energy storage is clean and environmentally friendly. Sixth, molten salt has high thermal conductivity and strong heat transfer capacity at the working temperature. At the same time, it has more convective heat transfer when exchanging heat with other media, and its heat transfer capacity is stronger than solid heat storage and phase change heat storage, which can greatly reduce the volume of the heat exchanger.

2.4. Disadvantages of Molten Salts

Molten salt energy storage materials have significant advantages and have broad application prospects. However, the shortcomings of molten salt energy storage mainly come from the inherent defects of molten salt itself, such as low thermal conductivity, low specific heat capacity, corrosiveness and liquid leakage during phase transition. These shortcomings are the main reason for the limited development of molten salt energy storage, so it requires the corresponding heat storage device materials to have high corrosion resistance requirements. Molten salts have high freezing points as a storage medium. Numerous precautions are made to reduce the likelihood of freezing and to prevent dangerous heat gradients during startup. The salts must therefore be kept from freezing long after the system has been fully drained, which requires more energy.

3. Current Application of Molten Salt Energy Storage Technology

3.1. Wind Power Plant

Due to the intermittent, fluctuating and seasonal characteristics of wind energy resources, when wind power generation is connected to the power grid under the conditions of large-scale and regional concentration, it will not be able to operate in dispatching operation, peak regulation and frequency regulation, and wind power consumption capacity, and causes a series of problems. The aforementioned issues can be successfully resolved by molten salt power storage technology, which is advantageous for the long-term evolution of new energy. Because molten salt could be utilized as both a heat transport fluid and a thermal energy storage medium, it is essential for the wind power production system. This allows excess electrical energy produced by the wind to be stored as thermal energy and released when necessary to increase the system's overall energy utilization rate.

Liu et al. proposed a wind-heat energy storage system that may effectively increase the utilization rate of all wind energy and include the power generation cycle and molten salt storage [7]. Wind energy thermal storage devices can store wind energy as thermal energy for continuous operation by using thermal storage tanks and molten salt and provide a more efficient and economical energy solution.

To solve the issue of abandoned wind energy, molten salt heat storage systems were developed. These systems included high/low-temperature molten salt tanks, high/low-temperature molten salt distribution pipes arranged in the two tanks, high/low-temperature molten salt pumps for a molten salt drive, an electric heat generator for heating molten salt, and a molten salt vaporizer for generating steam, etc. The invention makes use of the characteristics of molten salts, such as high liquid phase temperature, wide temperature range, high heat capacity, good flow and heat transfer characteristics, etc., and can realize heat storage with large-capacity and low-cost, which can then be used for heat supply or power generation. To a certain extent, this model can help with the issue of wind farm abandonment and can partially replace the traditional heating method mainly based on coal combustion,

reducing the environmental pollution. The system has a good application prospect in areas with excess wind power load and a large number of abandoned wind.

Based on the advancement of renewable energy and the technology for wind power storage, Liu looked into the features, application trends, and conditions of molten salt energy storage [8]. And based on the characteristics of wind power resources and the requirements of various forms, the double-tank molten salt energy preservation technology was selected for the wind power energy storage technique. Additionally, a thermal power supply system for heated molten salt thermal energy conservation and an electric power supply grid for wind power are each separately constructed. The study discovered that the heated molten salt thermal storage wind power system's design scheme might efficiently increase the rate at which wind energy is utilized, as well as enhance the system's economics when there are significant power shortages and wind energy curtailments. When comparing the operational performance and economics of the electric power supply grid of wind power and high-temperature molten salt thermal power storage with the thermal power supply system of wind power and MS thermal power storage, it was simpler to reflect the advantages of the molten salt heat storage technology in the application of wind power heating. To increase the percentage of wind power usage, reduce dependency on fossil fuels, and improve the flexibility of the power system, the high-temperature molten storage wind power system must employ minimal cost, environmentally friendly, and high thermal molten salt energy storage technology. It can be utilized as one of the methods for addressing the issues of reduced wind and electricity production, energy efficiency, and pollution reduction.

3.2. Solar Power Plant

One of the best alternatives to coal-fired power plants for generating energy is solar power plants, which have long been recognized as such. But on the other hand, in terms of stability for generating energy, it is also the poorest substitute. Solar power plants, as the name suggests, are flooded with sunlight. However, the sunlight doesn't always shine brilliantly everywhere in the world. But that might not be a problem if there were a molten salt plant. Salt refineries can act similarly to solar power plants in order to generate electricity even at night. The same sun that powers solar panels also powers the molten salt power plant. Thus, it offers the same benefits as before. The two, nonetheless, have a significantly different approach to energy gathering. Instead of using the sun's photovoltaic effect, molten salt power plants utilize its heat. Heat is obtained by concentrating sunlight to a single point using mirrors positioned to reflect sunlight to only one point. This technique of concentrating the sun in only one area accumulates a large amount of heat. The location the heat concentrates at is the tower of the brine tank. The salt in the tank is melted by the heat and flows like water through pipes to the steam boiler. The rest of the energy production process is similar to how coal is burned to produce energy. However, the steam cooking process does not produce carbon dioxide. Only the salt is cooled in this process and returned to the tank tower for reheating [9].

Molten salt power plants still have many advantages over the traditional method of generating sunlight with solar panels when it's used for moderate power generation. The point of this power plant is that it can generate electricity even when there is little sunlight. The reason is that they don't "collect" the photons emitted by the sun like solar panels do. Instead, it "harvests" the heat produced by the sun. Even if it's cloudy outside, the sun's rays will always generate heat. This power plant collects heat and uses mirrors to focus it to a point. A second advantage is energy storage. The tank can store the heat of the molten salt for a more extended period of time (usually about 6-10 hours). This is enough to provide enough energy to light the lamp at night.

Molten salt power generation at SolarReserve's second power plant, which will be built in Australia, has shown to be reliable and economical. When compared to the solar energy project at CrescentDunes, the cost of it is only 6 cents per kilowatt-hour. Both are inexpensive and continue to become more so. But once more, the coal plant—not the solar farm—is the primary foe. And the molten salt power plant triumphs in this instance by a wide margin. This is not only less expensive, but it's also good for the environment. Additionally, there are no issues with solar panels' stability of energy supply. Its

capability is the only item that needs upgrading. One hundred ten megawatts of electricity can be produced by the most extensive solar energy facility using molten salt in the United States. Compared to the greatest coal power station, which has a capacity of 6720 Megawatt, the largest solar power plant can generate more than 2000 Megawatt of electricity. They are both located in China. However, 110 Megawatts of power is sufficient to provide more than 35,000 residences with significant electrical needs. That's enough electricity to power a small metropolis. But a larger power plant could be required to support a metropolis like London [10].

3.3. Nuclear Power Plant

In order to fulfill the increasing demand for energy and reduce the global warming that fossil fuels are contributing to, alternative energy sources are needed. Because of the great energy density and stability, nuclear power has become a valuable base load power generating source in recent decades. Though, High capital costs, load monitoring in an erratic system, and negative public perception are some of the difficulties of nuclear power. Another potentially clean energy source is renewable energy. However, it has drawbacks due to its high cost and sporadic availability. The United States is attempting to create a more effective energy infrastructure to get beyond the imperfections of nuclear and renewable energy sources. One answer to these problems and the general need for energy is nuclear hybrid energy systems (NHES) [11]. By making it more feasible to economically deploy non-fossil energy sources, such as hybrid nuclear-renewable energy systems, these cutting-edge energy systems can help the transition to sustainable energy production.

The NHES architecture taken into account in this study consists of a number of components, including an energy storage system, a nuclear reactor, extra process heat applications, and a renewable energy source. The nuclear reactor used in this hypothetical NHES is hot. With the help of this high-temperature reactor, the NHES may utilize a portion of its thermal energy for process heat applications, such as the high-temperature steam electrolysis used to produce hydrogen (HTSE). This design will make the system more ecologically friendly and considerably lower its carbon footprint [11].

The fuel utilized in the nuclear power sector is uranium-based, and there are two categories of fission nuclear fuel: thorium-based and uranium-based. Due to the high energy demand growth and the increasing demand for nuclear fuel, the importance of developing and utilizing thorium-based nuclear fuel, which has more significant reserves than uranium-based nuclear fuel, has become increasingly evident. Like uranium-based nuclear fuel, thorium-based nuclear fuel was the subject of early American research during the Manhattan Project. The scientific community has developed specific application technologies and understood the pertinent knowledge after decades of research. These technologies have been used in molten salt reactors, spherical bed-type gas-cooled reactors, light water reactors, and heavy water reactors.

The molten salt reactor, thorium nuclear fuel, and integrative nuclear power utilization are the three components that make up the thorium molten salt reactor nuclear system. Utilizing thorium-based fuel, which has a lot of reserves, strong proliferation resistance, high fuel utilization, and little nuclear waste is the strategic aim of research and development to meet the demand for long-term sustainable development of nuclear energy in the country.

The molten salt reactor is the basis and core of the entire system technology chain, and two types of molten salt reactor concepts have been developed: liquid fuel and solid fuel. Due to its high temperature, low pressure, great stability, enormous heat conductivity, and other features, molten salt is utilized as a coolant in molten salt reactors; this eliminates the need for bulky, expensive pressure vessels, allowing for the construction of small modular reactors that are small, light, and inexpensive; Molten salt reactors employ waterless cooling technology, which requires very little water to operate and may be used to generate power effectively in arid regions; The molten salt reactor can produce high-temperature nuclear heat above 700 °C, which may be applied to industry, power generation, high-temperature hydrogen production, and hydrogen absorbing of carbon dioxide to produce methanol, among other things. By realizing the extensive use of nuclear energy, it can enormously alleviate the problems of carbon emission and environmental pollution [11].

However, since this is a new type of reactor, there are still many technical problems that need to be developed and solved: there is no mature reactor design theory, safety analysis method and safety assessment specification for molten salt reactors; structural alloy materials used in commercial molten salt reactors, their resistance to high temperature, corrosion and irradiation problems need to be further verified; fuel, graphite, and molten salt are chemically compatible, but the nuclear data of the thorium-uranium refining process remains far from flawless in compared to the refining process for uranium-plutonium. Additionally, the dry fuel reprocessing technology is only at the laboratory stage and has no real-world application experience [10].

4. Conclusions

In conclusion, the molten salt energy storage technology has many advantages in different aspects. This technology not only satisfies the sustainable goals set by the United Nations to help countries develop better communities, but it can also bring benefits of energy storage efficiency on power grids to many countries. With the future development and expansion of the electricity generation market, there will be more demands on such technology as molten salt energy storage systems [12]. With the widespread use of new energy sources, molten salt is also used in new energy fields such as solar thermal power generation, new energy batteries, and molten salt reactors, which not only reduce environmental pollution but also reduce energy consumption and will certainly be used in more fields in the future. However, the application of molten salt also faces many problems. For example, molten salt is highly corrosive, and it demands that the materials employed in the reactor have high thermal stability, chemical resistance, effective insulating, and other characteristics; the current material issues still need to be explored and improved [13].

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