SMALL-SCALE ENERGY STORAGE SYSTEMS

RĂILEANU Anton, DEMIAN Gabriel
Faculty: Industrial Engineering and Robotics, Specialization: Industrial Economic Engineering, academic year: first year, e-mail: anton.raileanu@stud.fiir.upb.ro

Scientific coordinator: Ass. Prof., Dr. Eng. Marinela Nicoleta MARINESCU, Ass. Prof., Dr. Eng. Larisa BUTU, I.C.T.I Department

Summary: Electricity generation has lately become more accessible than ever before, but its storage is becoming an increasingly acute issue. Current energy storage technologies have become more and more inaccessible over time, involving limited natural resources, high production costs, declining practical use, and an acute problem in terms of storing and recycling after use. Small-scale energy storage systems are meant to solve these emerging problems, as an alternative to traditional batteries. Molecular solar thermal systems - MOST - is a technology that allows the storage of solar energy through photo-switchable molecules, which once exposed to the sun, end up getting an electric charge. Even though this technology is at an early stage, research has shown its usefulness as an effective solution to the above problems.

KEY WORDS: energy storage, solar energy, molecular system, photo-isomer.

1. Introduction

Following the 2015 “Paris Agreement”, 195 states responsible for 99.75% of global greenhouse gas emissions have committed to keep the average global temperature rise in this century below 2°C above pre-industrial levels, aiming to limit this rise to 1.5°C. Electricity generation, storage and climate change are closely linked, thus, counteracting the threat posed by climate change requires radical renunciation of the current energy system, dependent on fossil fuels, and of energy storage in traditional batteries. In order to achieve the targets and objectives in terms of greenhouse gas emission, these sectors need to increasingly use renewable energies and new technologies for storage of energy from alternative sources.

Solar energy can also be stored naturally, through photosynthesis, but with an extremely low efficiency, up to 0.3%. An alternative way for storing solar energy is storage by using photo-switchable molecules, a concept introduced back in 1909. Since the concept of solar energy storage was introduced, a series of photo-switchable molecule systems were developed. These energy storage technologies are called ***Molecular solar thermal systems (MOST).***

2. The current stage

Although the cost of renewable energy, such as wind or solar energy, has relatively fallen compared to a few years ago, energy storage is still becoming more expensive. Renewable energy is not always available, as it exists either when the sun shines or when the wind blows, therefore, storing energy for other situations is essential. The most used types of batteries are lead-acid and lithium-ion, with a wide applicability nowadays. New versions of these technologies are being developed, however their use is becoming more and more difficult over time. Along with the fact that a multitude of natural resources are used in manufacturing, which end up being exhaustible in time, and the relatively large size of batteries, the biggest current problem is storage when they are out of use, given that now they cannot be recycled and reused.

3. The problem subjected to the analysis

The current challenge is to manufacture energy storage devices not only as small as a microchip, but also to develop energy storage devices that are part of a microchip, easy to integrate into the current chip manufacturing processes. The miniature technologies come as an efficient energy storage solution, primarily due to their low weight, good density (volume/capacity ratio) of stored energy and longevity. The use of photo-switchable molecules as a method for energy storage is a technology that involves elements of a very small size, which can be easily integrated into microchip systems and which can be used particularly for storing solar power.

4. Theoretical issues

One of the innovative miniature technologies for solar energy storing is the *MOST* concept. So, following three stages that take place, a cycle of operation of the system is formed, namely energy storage. The steps are as follows:

1. Photonic stimulation;
2. The transition of the molecule to its photo-isomeric state;
3. The opposite process, triggered by a thermal or catalytic stimulus, of return of the molecule to its initial state (heat release).

The repetition of these successive stages ensures a cyclical deployment of the energy storage-use process. The process of energy storage takes place under the action of sunlight and, through the process of photo-absorption, the molecule of the system passes from the normal state to the stimulated state, determined by the penetration of photons into the molecule. Due to this stimulation, the molecule passes, as a result of a photo-conversion process, to its photo-isomeric state. In order to release the stored energy by the means of a thermal or catalytic process, an opposite process of conversion from the photo-isomeric state to the initial state is intentionally triggered. During this process, heat is released, which can be converted into electricity by the means of a generator.

In order to ensure the effective storage of energy, the molecule must be maintained in its photo-isomeric state, keeping its enthalpy below the barrier of triggering the opposite photo-conversion process of transition to the initial state. At the same time, in order to have a considerable energy storage capacity, the barrier of the process of passing the photo-isomer into the initial state must have values much higher than the enthalpy of the molecule in the initial state. In addition, the molecule must withstand a series of such cycles in order to be efficiently reused for energy storage. At the same time, the molecule must be able to absorb a spectrum of as many photons as possible in order to be able to take up much of the photon flux brought by sunlight, what will increase the use of the exposed solar energy. The system’s molecules can also exist in an environment formed by a solution with a special chemical composition, through which it will be able to foster the efficient development of the processes that take place.

Thus, it results that the functionality and the efficiency of a *MOST* system largely depends on the molecule underlying the system. So, in order to obtain an efficient *MOST* system, we must start from a molecule that best meets the criteria set out above.

A series of eligible molecules have been identified to form an efficient *MOST* system. They are usually noted together with the name of their photo-isomeric state. Two of the best-known molecule/photo-isomer pairs used in the experiments with *MOST* systems are: azobenzene – E/Z (E/Z - AZO), norbornadiene/quadricyclan (NBD/QC).

The first pair listed above, azobenzene - E/Z (E/Z - AZO), is a *MOST* system in which the initial molecule, to be subjected to solar radiation, is in fact also an isomer (azobenzene - E), which, by photon absorption, passes into another meta-stable photo-isomeric state (azobenzene - Z), much more energetically charged than the initial state. However, this combination is more difficult to apply, because the opposite transition, from state Z to state E, is easily triggered by exposure to light, which means that heat can be unwantedly released, so there is a higher risk of loss of stored energy.

The norbornadiene/quadriciclan (NBD/QC) pair was introduced between 1958 and 1961. Over time, great efforts have been made to increase the performance of this pair, but it still has a main unresolved disadvantage: norbornadiene can only absorb the spectrum of ultraviolet rays, so it cannot absorb all the energy emitted by the sun's rays. However, it has an advantage over the E/Z - AZO pair due to the inactivity of the quadricyclan photo-isomer under the action of solar irradiation, so the risk of potential unwanted energy loss is excluded, if the system remains exposed to light action after energy storage.

4. Development of miniature energy storage technologies

Although no highly efficient molecule to store all solar energy has been found yet among all the pairs eligible to form the basis for *MOST* systems, new and new experiments are being done to develop functional and really efficient solar energy storage technologies through *MOST* systems. Thus, in 2018, researchers at Chalmers University of Technology in Sweden revealed to the world their invention, the so-called "fuel liquid" [4]. It is based on the molecule shown above, norbornadiene (NBD). This "fuel liquid" is in fact a *MOST* system and it operates based on the same principles and can store solar energy for up to 18 years.

In order to use the stored energy, a reaction for transition to the initial state is triggered by the means of a cobalt-based catalyst. The researchers estimated that, in the isomeric state of norbornadiene, the quadricyclane (QC), the liquid can store 250 Wh (watt-hours) per kilogram. The advantage of the invention of Chalmers researchers is that the system supports a very large number of energy storage-use cycles. According to researcher Kasper Moth-Poulsen [4], their *MOST* system went through 125 such cycles without any significant degradation of the system.

The fuel liquid developed by Chalmers researchers opens wide opportunities for use in the industry and even in the life of the average consumer. For example, such a system can power a heating system for a living area, based entirely on energy from the sun's rays (Chart 1). In addition, the researchers of fuel liquid succeeded to renounce the flammable solution. So, the toluene, in addition to being a system with zero pollutant emissions, is also a very safe system.

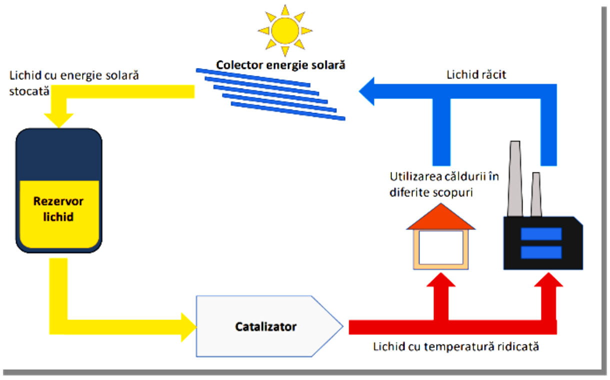

Chart 1 *Scheme of the use of solar energy stored by a MOST system*

This year, researchers at Chalmers University of Technology succeeded to transform the chemical energy stored in their *MOST* system into electricity. This transformation was accomplished by the means of an extremely small heat generator, which could be "integrated into electronics, such as headphones or telephones" [4], according to this university's researcher, Zhihang Wang.

Although the Chalmers research team brings very promising solutions in terms of zero-emission energy technologies, there is still a long way to go in order to bring the *MOST* system to the best possible cost-effectiveness ratio, so that it can be applied on a large scale.

5. Conclusions

In conclusion, we can say that miniature electricity storage devices have proven their applicability and usefulness, especially in a society in continuous digitalization. At the same time, the small size and the relatively low resources required for production make these technologies cost-effective and widely applicable in the digital device manufacturing sector. Even though there is a long way to go until they are integrated as basic elements of some devices, research shows that these systems will be found in many electrical devices of the future.

The molecular solar thermal system is one of the solutions that allows the storage of energy in miniature components, making possible the storage of relatively large electrical charges compared to the size. The main purpose of this miniature energy storage technology is to provide efficient and environment-friendly possibilities for the storage of energy from alternative sources to fossil fuels, a rapidly developing energy sector. The second important goal of *MOST* systems is to replace the traditional batteries with alternative miniature technologies, which do not pollute the environment and which, when out of use, can be recycled. At the same time, the integration of this technology in mass consumption will further enhance the global development of the energy sector due to alternative energy sources. So, *MOST* systems could be one of the technologies that will move humanity away from the old energy system, a major cause of global pollution, and from the traditional batteries, towards alternatives with better prospects.

6. Bibliography

[1]. „World Energy Outlook 2019", (2019), International Energy Agency, OECD.
[2]. P. Erhart, T. Li, Z. Wang, Z. Y. Zhang, D. Sampedro, Z. Hu, H. A. Wegner și K. Moth-Poulsen, . (2021), "Joule", volume 5, issue 12, pagini 3116-3136.
[3]. Z. Wang, A. Roffey, R. Losantos, A. Lennarston, M. Jervic, A. U. Petersen, M. Quant, A. Dreos și K. Moth-Poulsen. (2019), "Energy Environ. Sci.", 12, pagini 187-193.
[4]. Wang, Z. şi Moth-Poulsen, K. (2022), "Convert solar energy to electricity on demand", în: Chalmers University of Technology, Goteborg, 12 Apr. 2022, https://www.chalmers.se.
[5]. Organizația Națiunilor Unite, "Acordul de la Paris", 2015.
[6] "Technology Roadmap Solar Thermal Electricity", 2014, International Energy Agency.
[7] https://www.eca.europa.eu/
[8] https://newatlas.com/
[9] https://www.weforum.org/