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CONSIDERATIONS ON SOLAR ENERGY STORAGE

C. MÂRZA[1] G. CORSIUC[1]

Abstract: *In the context of sustainable development of communities, the use of renewable energies represent a priority. In our country the solar potential is significant and has not been properly exploited. Due to the fluctuating nature of this source, a storage system is required to ensure the energy security of the consumers. In this paper, after a review of the solar energy storage methods, some energy storage systems are presented. There are also presented the results obtained by the authors in a case study on the storage of solar energy with batteries in the case of an isolated consumer.*

Key words: *solar energy, storage systems, batteries.*

1. Introduction

According with the worldwide trend to decrease conventional energy use, which is both exhaustible and polluting, the use of renewable energy resources becomes a priority. These are considered to be basic components of sustainable development in communities, whose energy demand is steadily increasing.

In this paper aspects regarding the storage of solar energy will be discussed, one of the renewable energies with high potential in our country and which has not been exploited to the maximum capacity until now.

Solar energy can be transformed into other forms of energy, of which, the most common applications are in obtaining thermal and electrical energy. In our country, conversion to thermal energy is mainly used for domestic hot water and local heating of buildings, while conversion to electricity is used by both individual consumers and for power generation and distribution in the national energy system.

The chart in the Figure 1 presents the evolution of electric power installed during 2010-2015 in our country, obtained from solar energy, according to the data taken from the ANRE (The Romanian Energy Regulatory Authority) Annual Report 2016. There is an increasing interest in the use of this type of energy in the last years.

Since solar energy at the Earth's surface has a variable character, the plants based on this type of energy need to be able to store it. By storage, we understand all the means and processes of accumulating energy at certain intervals of time and then to use it according to the requirements of the consumers.

[1] Technical University of Cluj Napoca, Faculty of Building Services

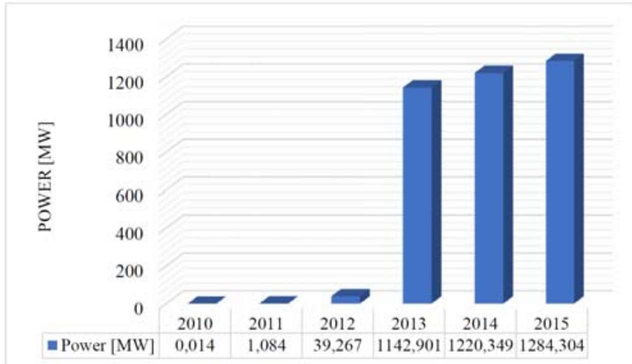

Fig. 1. *The evolution of electric power installed obtained from solar energy*

Generally, depending on the accumulation and restitution time of the stored energy, there are the following systems, useful for various applications [7]:

- slow energy accumulation systems;
- fast energy accumulation systems;
- slow-release storage systems;
- fast release storage systems.

In the case of solar energy storage systems, depending on the type of the application, systems having the following characteristics are preferred:

- to be able to receive energy at maximum speed without excessive thermodynamic forces (for example: temperature, pressure or potential differences);
- to ensure the required energy density;
- to deliver energy at maximum speed without using excessive thermodynamic forces;
- the storage unit must have small losses;
- to support a high number of loading/unloading cycles without consistently reducing its capacity;
- to have the most affordable price.

Storage systems are specific depending on the nature of the stored energy, such as thermal or electrical energy.

In this paper there will be presented some of the methods of storing the electricity obtained from solar energy

2. Methods of Electrical Energy Storage

Storage of electricity can take the form of [8]:

- mechanical energy, which in turn can be:
  - kinetic energy (flywheels - FES) or
  - potential energy (Pump Hydro Systems - PHS and gas storage, such as Compressed Air Energy Storage - CAES);
- electrochemical energy (rechargeable batteries);
- chemical energy (Hydrogen);
- electricity: Double Layer Capacitor (DLC), Superconducting Magnetic Coil (SMES);
- thermal energy - Sensible heat storage (Molten Salt-MS).

2.1 Storing Energy in Flywheels

The flywheels are commonly used for the storage of mechanical energy in the form of kinetic energy - Figure 2. These are based on the storage of mechanical energy in the form of a rotating movement having reduced frictional forces. The flywheel, being a rotational structure characterized by a high moment of inertia, is able to receive and deliver power through the rotation axis. Excessive power is used to rotate a solid (mass) by means of a motor which at discharging becomes an electric power generator.

The most advanced flywheel energy storage systems have the rotors of high resistance carbon fiber composite materials. Friction forces are reduced by using magnetic bearings and by placing the rotating structure in enclosure or filled with inert gas shields.

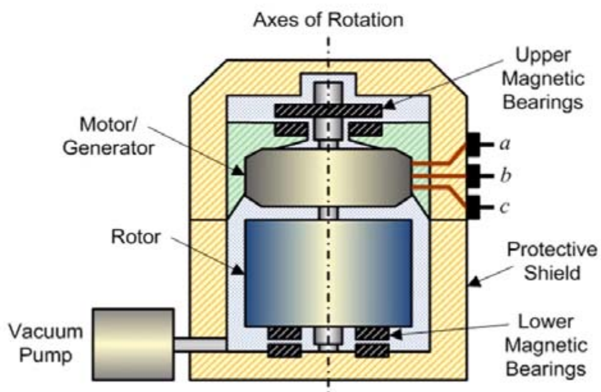

Fig. 2. *Structure of a conventional flywheel [5]*

The energy that can be stored in a flywheel energy storage systems is given by the formula [7]:

$$E = \frac{1}{2} \cdot I \cdot \omega^2 \tag{1}$$

where ω is the rotation speed;

I - the moment of inertia of the mass in the rotation movement and is determined with the formula [6]:

$$I = \int \rho(x) \cdot r^2 \cdot dx \tag{2}$$

where ρ is the density under the load of the material;

r - distance from the axis of rotation.

Taking into account the mechanical efforts that occur in the material from which the flywheel is made, the energy stored by it can be determined with the relation [7]:

$$E = \frac{1}{k} \cdot m \cdot \rho \cdot \sigma \tag{3}$$

where m is the mass of the flywheel;
σ - the mechanical effort;
k - constant depending on the wheel geometry; usually k≥1.

The disadvantage of the flywheels is the reduced storage time and the high cost compared to other solutions. These systems have evolved over time and have various applications such as thermal engine and gyroscope.

2.2 Compressed Air Energy Storage Systems

In the case of compressed air storage systems, the excess energy produced by the solar system is used to compress the atmospheric air. Compression can be done in one or more compression stages. Further, compressed air is used together with a gas turbine to generate electricity [1].

Depending on system capacity, compressed air is stored in tanks or naturally occurring underground reservoirs. Recently, a Canadian company invented a compressed air storage system using under pressure, underwater balloons.

The compressed air storage system functions as a conventional gas turbine [8], except that compression and decompression phenomena occur independently and at different times – see Figure 3.

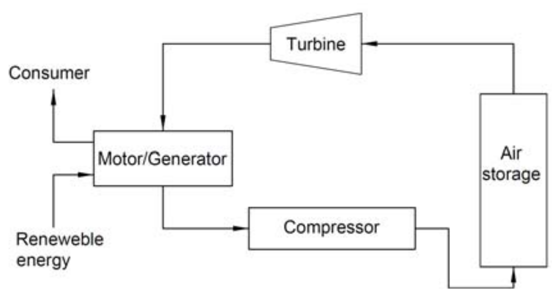

Fig. 3. *Compressed air energy storage system*

On a small scale, storage can be done in steel containers. In this case, compression can be assimilated to that of ideal gases, according to the law:

$$P \cdot V = \nu \cdot R \cdot T \tag{4}$$

where V - the occupied volume of air - given by the size of the container;
P - gas pressure;
T - absolute temperature of the gas;
ν - the quantity of gas in moles;
R - the universal constant of the ideal gas.

If the storage of air takes place in cylindrical recipients, the amount of stored energy is determined by the formula [6]:

$$W = A\int_{x_0}^{x} f_x dx = -\int_{V_0}^{V} PdV \quad (5)$$

where: A - the cross section of the cylinder;
` x_o - initial position of the piston corresponding to the volume Vo;
x - the position of the piston corresponding to the volume V;
f_x - the force applied to the piston;
P - the pressure of the enclosed air.

Storage of energy in compressed air, on large-scale is conditioned by the existence of underground cavities suitable for this purpose, such as salt mines, rock cavities or aquifers

2.3 Pumped Hydro Storage Systems

Another way to store solar energy is in the form of potential hydraulic energy. The excess electricity produced by solar panels is used to pump water from a lower basin to a higher one, and in peak hours the water is released and energy conversion takes place via hydroelectric path.

If the geographic location naturally ensures the existence of the two reservoirs, the investment costs are lower [2]. Otherwise the reservoirs are artificially constructed – see Figure 4.

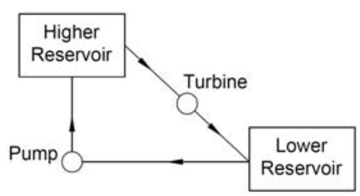

Fig. 4. *Pumped hydro storage systems*

Depending on the capacity of the solar system, the pumping station is chosen, resulting the level difference between the two reservoirs and the volume of the storage tanks.

2.4 Storing Energy in Batteries

The most used form of electricity storage obtained from solar energy is in batteries which are based on electrochemical principles, namely the generation of an electromotive force obtained on chemical bases as result of electrode- electrolyte combination of different materials from an electrochemical point of view.

The two electrodes delivering or receiving power to or from the outside are called *negative* and *positive electrode*. Within the battery, ions are transported between the negative and positive electrodes through an *electrolyte.* This as well as the electrodes may be solid, liquid or, in theory, gaseous [6].

Batteries can be primary or secondary. Considering that primary batteries can be used at a single discharge, it is an expensive way and can be used in limited, low-energy applications. Consequently, the batteries that are used to store solar energy are secondary batteries, whose operating principle consists of a reversible reaction, which allows for a large number of charging / discharging cycles over the lifetime. For the same purpose, flow batteries are used, which are constructively made up of two separately stored electrolytes that circulate through an electrochemical cell. These batteries are similar to electrochemical cells, with the particularity that the electrolyte (ionic solution) is not stored around the electrode but outside the cell that is subsequently fed with this solution in order to generate electricity. The total amount of energy that can be generated by the battery depends on the size of the electrolyte reservoirs.

Among the types of flow batteries developed, it can be mentioned: redox, hybrid or non-membrane batteries.

Their performance is assessed by the following features: energy efficiency, efficiency, life span, operating temperature, depth of discharge, and self-discharge [8].

Table 1 lists the construction features and the main energy performance for several commercial battery types [6], [8].

Characteristics of the main types of batteries Table 1

Battery type	**Electrolyte**	**Efficiency [%]**	**Energy density [Wh/kg]**	**Life span [cycles]**	**Observations**
Lead-acid	H_2SO_4	75	20-35	200-2000	Oldest and most mature type, low cost but low energy density
Nickel Cadmium	KOH	72-78	45-80	3000	High discharge rate, easy maintenance but noxious
Sodium Sulphur	B-Al_2O_3	89	100	2500	High energy density, high efficiency of charge/discharge, long cycle life but corrosive
Lithium ion	$LiPF_6$	100	90-190	3000	High energy density, suitable for portable devices but high cost
Metal-air	water-based	50	450-650	<100	Low cost, high energy density but difficult to recharge
Vanadium redox	$V+H_2SO_4^2$	85	30-50	10000	Currently used for grid energy storage but low energy density
Zinc-Bromine	$Zn+Br_2$	75	70	N.A.	Low power, voluminous, dangerous components

Among these, lead-acid batteries, despite their small capacities and energy densities, are the most common method for storing electricity, mainly because of the relatively low cost and of the various thermal regime coverage.

3. Case Study

In this paper the authors present the results of a simulation study using the iHOGA software on the role of the energy storage system obtained by photovoltaic panels for an isolated consumer. IHOGA (Hybrid Optimization by Genetic Algorithms) is a simulation and optimization software based on genetic algorithms used for generating electricity from renewable sources [4].

The consumer is located in Alba County, where the annual solar radiation is between 1430 and 1580 kWh / m^2. The configuration of the autonomous solar-photovoltaic system is shown schematically in Figure 5. It is noted that the system has as fundamental components PV panels, batteries and inverter - for the conversion of the continuous current generated by the panels into the alternating current required by most consumers.

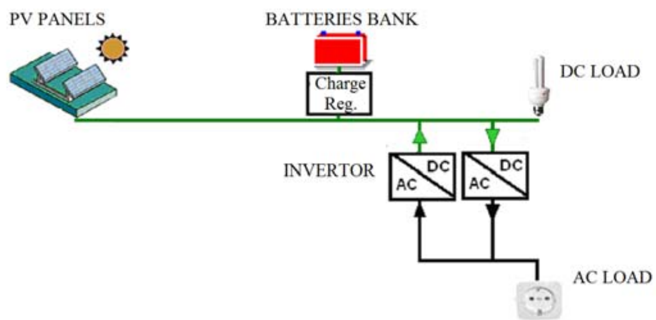

Fig. 5. *Schematic diagram of the solar PV system [3]*

Table 2 shows the monthly energy indicator values for one year of system functioning, regarding the total energy demand, the energy provided by the photovoltaic panels, batteries, and the excess energy.

Average monthly energy indicators Table 2

Month	Energy Demand	PV Energy	Energy charged by Batteries	Energy discharged by Batteries	Excess Energy
	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]
January	189.8	341.2	196.6	169.8	75
February	169.7	418	170.6	144.7	177.5
March	180.6	544.4	174	147.3	285.5
April	175.6	523.4	155.4	132	275.5
May	190.1	602.6	159.5	135.2	337.6
June	177.2	605.8	140.5	119.1	358.6
July	174.3	659.1	142.4	121.2	411.4
August	171.9	671.7	152.2	129.1	422.4
September	168.1	536.1	156.9	133.3	294.1
October	190.1	454	187.3	159.5	188.8
November	168.4	306.3	179.6	152.8	60.2
December	191.4	268.7	202.5	176.3	3.4

Analysing Table 1, one can see that the energy demand is covered in proportion of 87% by discharging the batteries, while the photovoltaic panels provide only 13% of the energy demand. This highlights the special importance of a storage system for autonomous power generation systems.

The software also allows an economic analysis of the cost of equipment over the lifetime of the system, namely 25 years. Thus, the following percentages were obtained: PV panels 34%, batteries 45% and inverter and auxiliary equipment 21%. One can observe that the batteries hold the highest share of the total cost.

4. Conclusions

Solar energy storage is a necessary condition due to the varying nature of both the source and the energy consumption. In order to achieve energy independence and to reduce the environmental impact, it is important to choose a suitable energy storage system. Storage solutions are diverse and need to be known by specialists with their advantages and disadvantages. Depending on the specific situation, geographic area and existing facilities, different storage methods can be selected.

Today, the most common methods of solar energy storage, especially for residential consumers, are batteries. Research in this area focuses on optimizing energy performance, finding environmentally friendly materials, and lowering the costs to affordable values.

References

1. Corsiuc, G., Mârza, C.: *Consideraţii privind sistemele de stocare a energiei sub formă de aer comprimat (Considerations on the Compressed Air Energy Storage Systems)*, Conferinţa "Ştiinţa modernă şi energia", Cluj-Napoca, 18-19 mai 2017, Ed. Risoprint, p. 300-308.
2. Dănescu, Al., Bucurenciu, S., Petrescu, Şt.: *Utilizarea energiei solare (The Use of Solar Energy)*, Editura Tehnică, Bucureşti, 1987.
3. R. Dufo-López, J. Bernal-Agustín, *iHOGA Software Version 2.2*, Electrical Engineering Department, Faculty of Engineering, University of Saragossa, Spain.
4. Mârza C., Corsiuc G.: *Study Regarding the Electricity Production of a Photovoltaic Solar System,* Proceeding of the international scientific conference „CIBV 2015", 30-31 oct 2015, Brasov, Romania, Bulletin of the Transylvania University of Brasov, Vol. 8 (57) Special Issue No.1 – 2015, Series I, p. 377-382.
5. Molina, M.G.: *Dynamic Modelling and Control Design of Advanced Energy Storage for Power System Applications*. In: Dynamic Modelling, Brito, A.V. (Ed), INTECH, 2010, https://www.intechopen.com/books/dynamic-modelling, Accessed: 25.09.2017
6. Sorensen, B.: *Renewable Energy. It's Physics, Engineering, Use, Environmental Impacts, Economy and Planning Aspects*, Third Ed., Elsevier Science, 2004.
7. Zaides, E.P., Zaides I.A.: *Conversia energiei. Tehnologii si resurse (Energy Conversion. Technologies and Resources)*, Bucharest, ICPE, 2001.
8. *** *Report on Solar Energy Storage Methods and Life Cycle Assessment, Energy Research and Development Division, May 2012.*