Grzegorz KRAWCZYK

ENERGY STORAGE TECHNOLOGIES – POSSIBILITY FOR INDUSTRIAL POWER ENGINEERING FOR EFFICIENT USE OF ENERGY FROM RENEWABLE SOURCES

Abstract

Growing demands on the reliability of supply and an increase in energy produced from RES (Renewable Energy Sources), which are characterized by high variation of production makes that with the networks various kinds of ESD (Energy Storage Devices) are adapted to the cooperation. They are used in order to avoid a possible supply discontinuity, and to improve the quality parameters of energy. The article presents the basic types of energy storage devices.

INTRODUCTION

The main source of carbon emissions is the professional power engineering based on coal. Kyoto Protocol and set out in the quantity of allowances to emit carbon dioxide and emissions charges beyond the allotted powers make it necessary the implementation and development of energy technologies with low or even close to zero carbon emissions [1, 2]. Therefore the share of RES in production of electrical energy will increase. The amount of energy provided by alternative sources depends on the weather, which is the force of the wind in wind power plants, the intensity of solar photovoltaic power plants and the amount of water in hydroelectric power plants, which results in unpredictability of their production. This makes problems related to the efficient use of energy gained, as well as in the situation of the combination of multiple sources to a common network problems related to the control and management of this type of power plant [3].

Storage of electrical energy is an element of market approaches to balancing demand and supply of energy, while ensuring reliability, efficiency and security of the electrical energy supply [4, 5]. Energy storage devices reduce congestion and increase reliability and to improve the quality of supply. Electrical energy can accumulate under the NEPS (National Electric Power System) as well as outside it.

1. ENERGY STORAGE TECHNOLOGIES

Energy storage allows storage of energy during periods of short (milliseconds) and long (hours and days). Regardless of the nature of the physical phenomena occurring in the ESD can be characterized by:

- energy capacity, which should correspond to the size of electric energy accumulated and returned in one cycle to the network,
- maximum power in regimes of accumulation and energy return,
- charging time and energy return,
- efficiency,
- operating time.

We can include to the group of devices accumulating energy ESD such as: Electrochemical Energy Storage, Flywheels, Supercapacitors, Pumped Hydro Energy Storage, Compressed Air Energy Storage, Superconducting Magnetic Energy Storage, Fuel Cells.

1.1. Electrochemical Energy Storage

Electrochemical batteries are the oldest and widely used forms of storing electric energy in chemical form. They usually are characterized by low losses in idle operation and high energy efficiency depending on the application and method of operation. The fundamental features of electrochemical batteries include a substantial service life, high capacity and high current charging.

We can include to the group of electrochemical batteries among others: lead-acid batteries, lithium batteries, high-temperature batteries and hybrid batteries. Battery Energy Storage Systems (BESS) are one of the main electrical energy storage technologies used to support the integration of renewable energy sources with electric power system.

In the lead-acid accumulators electrolyte is dilute sulfuric acid, and the electrodes are in the form of porous lead plates. Their durability depends on the performance and operation. The benefits include low cost of production, versatility, and simple charging, do not require complex control systems. Battery parameters depend on the temperature of the discharging - low temperature results in a decrease of its capacity. In May 2011, together with the team, Professor A. Czerwinski from Warsaw University of Technology new type of lead-acid battery of energy capacity by 50% more than traditional batteries was developed. The traditional lead grate was replaced with a ten times lighter porous conductive glassy carbon [6].

The anode in Lithium-ion accumulators is made of pure graphite, or modified graphite, for example, by silicon or porous carbon, of the order of nanometers, a pore diameter. However, the electrode on which the cathode processes happen, is made of metal oxides, especially manganese, cobalt, and lithium. The role of the electrolyte plays lithium salts dissolved in a mixture of organic solvents. Lithium-ion accumulators have a high specific energy, comprising in the range of from 50 Wh/kg and 410 Wh/kg, and an energy density of from 110 Wh/dm^3 up to 270 Wh/dm^3 [7].

High temperature battery - the battery is characterized by operating at a temperature above ambient temperature. This group may include, among others: vanadium Redox batteries, polysulfide bromide battery, sodium-sulfur batteries.

Vanadium Redox Batteries store energy by means of the phenomenon of oxidation and reduction of vanadium. As a result, there is a deficiency of electrons on the positive electrode, and the negative excess of electrons [7]. The advantages of this batteries include: the possibility of complete discharging, high durability, quick charge by replacing the electrolyte, and very high output power, reaching tens of kW. Their disadvantages are: high costs associated with a short time of development of the cell structure of the experimental system for commercial applications and low energy density. For batteries of the flow, such as VRB, power and specific energy are not dependent of each other.

Polysulfide bromide (PSB) batteries are a regenerative fuel cell technology that provides energy by a reversible electrochemical reaction between two electrolyte mixtures of salts (sodium bromide and sodium polysulfide). They work at room temperature, and their efficiency is about 75% [8]. An important feature of these batteries is the ability to regulate the flow power and size of accumulated energy.

Sodium-sulfur battery is composed of sulfur, which is the positive electrode and molten sodium, which is the negative electrode. The electrodes are separated by a ceramic electrolyte called "beta-alumina" [9]. This battery electrolyte allows the flow through the layer only positive sodium ions, but is impervious to sulfur. When a battery is charging, by penetrating the sodium ions of the electrolyte layer they combine with the sulfur, thereby forming a sodium polysulphide. The main advantages of this type of batteries are: high energy and power capacity, high efficiency (75%), a large number of charge cycles-discharge (up to 1500 cycles) and also low cost of manufacture and operation compared to other advanced battery technologies. However, the disadvantages are: toxic elements, and high costs associated with obtaining a substance which is a ceramic electrolyte and the need to work at higher temperatures (300 ÷ 450 °C).

The group of hybrid batteries include bateries, where the process of one of the reactants is in the gaseous state. These ESD are intermediate between classical electrochemical accumulators and fuel cells, for example, oxygen and hydrogen. Such cells include cells such as: Zinc-air and Iron-air.

1.2. Flywheels

The kinetic energy storage is a mechanical accumulator which, rotor in the regime of accumulation performs rotation. It is characterized by a special implementation of housing, bearings and auxiliaries equipment that are designed to reduce energy losses. The basic elements of inertial energy storage system (Fig. 1) are: the shaft on which the rotor of electrical machine is mounted to, which can operate as a motor for the ESD charging and as a generator of electricity when it is discharging, flywheel – rotor, vacuum housing and bearings.

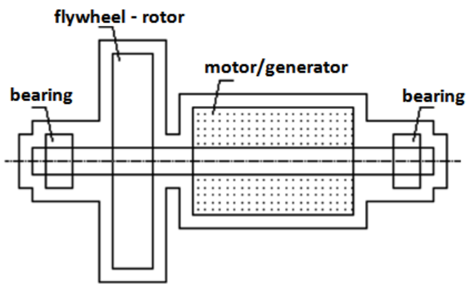
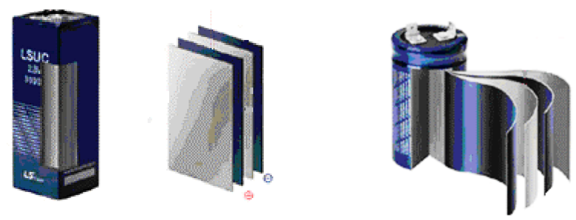


Fig.1 *Mechanical accumulator*

The possibility of accumulating mechanical energy depends on many factors such as: shape, mass distribution of the rotor, mechanical strength of the rotor material and resistance arising in the environment in which mechanical accumulator moves i.e. aerodynamic resistance which contributes to an increase of energy losses. Flywheel are able to return very high power, but in short time.

1.3. Supercapacitors

Double Layer Supercapacitors (DLC) storage energy in the form of an electrostatic field energy. They have characteristics of both electrochemical accumulators and conventional capacitor. A double-layer capacitor consists of two electrodes separated by an electrically separated electrodes constructed from specially prepared active carbon on the surface of per gram to 2000 m^2, the structure of which is similar to a sponge [9]. The higher the surface area, the greater the electrical charge can accumulate on the surface (60 to 100 F/g). The surface layer of carbon is modified by conductive polymers, such as oxides of titanium, chromium and manganese or polyaniline. The capacitor electrodes are impregnated with liquid electrolyte and are separated by a thin porous membrane, called a separator which prevents direct electrical short circuit of both electrodes. The supercapacitors accumulates electric charge on the surface of the electrode, as a result of production of the ions from the solution of the equivalent load of opposite sign to the charge, accumulated at the surface of electrode as a result of the electrical polarization. Electrical layer formed at the electrode-solution interface is called a double layer. Ultracapacitors due to the type of construction can be divided into: folding supercapacitors (Fig. 2a) and roll capacitors (Fig. 2b).



a) folding b) roll

Fig. 2 *The type of construction of supercapacitors [10]*

The advantages of this type ESD are: quick charge, the number of charge / discharge cycles 10000 ÷ 500000, long service life, up to 10 years, lack of environmentally harmful chemicals and wide temperature range from - 40° C to + 65 °C (with the exception of Tecate Group supercapacitor series TPLE Power Burst temperatures up to 85 °C) [10, 11]. The main disadvantages of supercapacitors are: low voltage operation (2,5 ÷ 2,8 V) and self-discharge.

Double-layer capacitors are able to take instantaneous power strokes and to maintain voltage during mains failure. This feature is particularly used in supply systems that are subject to significant fluctuations and random power.

The team Santhakumara Kannappana from the Institute of Science and Technology, Gwangju, South Korea has developed a supercapacitor with graphene (high theoretical specific surface area of 2675 m2/g and the corresponding theoretical specific capacitance of 550 F/g [12]), which accumulate almost as much energy as lithium-ion batteries used in electric vehicles. Creation of graphene supercapacitor rely on introducing the graphene dust to the cell like as coin, which is then dried at temperature 140 °C [12].

1.4. Pumped Hydro Energy Storage

Power plants of this type allow the accumulation of energy during low demand for it by pumping water from the lower reservoir to the upper, gathering in this way the potential energy resources. As for the period of high demand the energy is released by draining water from the upper reservoir to the lower, which causes the water flow driving the turbine. Then a water turbine put in motion drives a generator that produces electrical energy supplied to the electrical grid. Pumped Hydro Energy Storage (PHES) in addition to energy storage, plays an important role in case of failure of the electric power system. At the time of the sudden shortage of power plant starts in turbine mode, but if it suddenly occurs excess of power, the plant takes a pumped work [13]. Possible applications of this type of ESD are limited by the terrain and specific hydrological conditions. These plants are expensive sources of energy, but very good ESD.

1.5. Compressed Air Energy Storage

Compressed Air Energy Storage (CAES) provide power during peak demand and improve grid stability. They can be used in case of increase installed capacity (installed power) of renewable energy due to their periodicity production. This technology uses electrical energy during periods when it is cheap, for example, at night, for compressing air (pressure to the order of 7 - 10 MPa) in abandoned mines, caves, etc. At the time when demand for energy is high, the compressed air is released from the tank and used with the conventional gas turbine burning fuel for production electrical energy [14].

Currently are two CAES systems in the world [15]: one in Huntorf in Germany (tank with a capacity of 5320000 m3 which allows operation of the turbine 290 MW power for up to 3 hours), and the other in Macintosh, Alabama, USA (tank with a capacity of 5 320 000 m3, which enable to work the turbine of 110MW at the time of 26 hours). The third installation is in Norton, Ohio, USA. Energy storage with compressed air can be an alternative to PHES.

1.6. Superconducting Magnetic Energy Storage

The basis of SMES - Superconducting Magnetic Energy Storage is the accumulation of energy in the magnetic field of the induction coil made of a superconductor. The use of superconductivity largely eliminates the resistance and inductance losses, allowing energy to be stored for many hours or even several days. To the advantages of SMES we can include high value power and fast loading. While the disadvantages are: a low value accumulated energy and high costs [16].

1.7. Fuel Cells

Hydrogen, as a primary fuel for fuel cells creates some problems of its production, transport and storage. As technology advances, hydrogen can become one of the key primary sources for electricity generation, among others, in distributed systems.

Fuel cells are electrochemical devices transforming chemical energy directly into electrical energy. The main structure of the basic features of the physical layer is an electrolyte that is in contact with a porous anode on one side and on the cathode of the other. Due to the lack of combustion and pollution emissions and the production of energy by the synthesis of water from hydrogen and oxygen, cells of this type are classified as renewable sources [17]. The operating time of the fuel cell depends on supply of electrochemically active materials and the degree of degradation as a result of physical and chemical processes occurring in the cell (e.g., corrosion, changes in the properties of the electrolyte, etc.).The main types of fuel cells are: Molten Carbonate Fuel Cell (MCFC), Phosphoric Acid FC (PAFC), - Proton Exchange Polymer FC (PEMFC), Solid Oxide Fuel Cell (SOFC).

2. MAIN FEATURES OF SOME OF THE ENERGY STORAGE DEVICES

Energy storage devices are characterized by a number of parameters that determine the performance of these devices. The main parameters determining the energy storage devices include, among others, energy density [J/kg] and power density [W/kg].

Electrochemical accumulators are used as the emergency power source and to stabilization of load. These devices can deliver provided the amount of current for a long time, however have a limited ability to respond to changes in load. Electrochemical accumulators allow storage of energy from renewable sources in periods of its overproduction, and its return in times when there is peak demand of energy.

Double-layer capacitors are combine the ability to quickly adapt to changes in load and high stored energy. Increasingly, these ESD are used instead of the battery, because of the possibility of rapid charging and long-term operation of equipment, regardless of the ambient temperature. In comparison with various ESD, they are characterized by high efficiency and significant peak powers. The possibility of unlimited number of charging and discharging cycles without degradation of supercapacitors, distinguishes them clearly from the typical electrical energy storage devices, which are accumulators. Supercapacitors also have an advantage over the SMES because their installation doesn't require additional hardware in the form of cooling systems needed in superconducting systems.

The use of combined energy storage systems means that the ESD are complementary (e.g. battery with high energy density and low power density and supercapacitor featuring high power density and low energy density). A supercapacitor takes over short strong overload, not allowing to spikes discharge current of the battery.

The development of nanotechnology and the widening spectrum of applications and DLC operating parameters, indicating their advantages compared to other ESD makes, that supercapacitors can become one of the most commonly used energy storage.

SUMMARY

An important aspect of the electric power system is the balance of energy production and consumption, taking into account factors introducing variability and uncertainty of its proper functioning. These factors can include, among others.: changes in demand for electrical energy, power fluctuations of renewable energy sources associated with the unpredictability of their production and breakdowns of generators and networks [18]. RES instability causes a lot of concern in association with the planned increase their share in energy production. Compared with conventional sources of heat used for energy production are characterized by: frequent lack of correlation between the amount of electricity production, dependent on weather conditions and the level of demand end users. In order to mitigate the negative effects of work on a large number of renewable energy sources for electric power system energy storage systems can be applied. ESD are capable for efficiently storing of energy and its use in order to maintain the high reliability of the electric power system.

Energy storage systems can be used to equalize the load leveling in the electric power system. This avoids starting the peak sources with a sudden increase in demand for power and the respective weighted system blocks with the low load, which results are lower carbon emissions and reduced energy transmission losses. Electrical energy storage can be used to compensate for fluctuations in the production of renewable generation, occurring in a very short period of seconds and minutes, and in the medium term, while the hourly variation. ESD also allow to maintain appropriate levels of voltage to keep the stable operation of the electric power system. Moreover they can be used to reduce power fluctuations and harmonic currents and voltages [19]. The purpose of the magazine is to compensate fluctuations in the production of energy from renewable sources and reducing the rapid load changes.

The development of the use of energy storage technologies in the context of the integration of renewable energy sources with electric power system is conditioned by the technological progress in the field of solutions used in energy storage systems, and further improve of their operational performance and a reduction in the unit cost of investment. The use of ESD can benefit all energy sub-sectors from conventional and renewable sources by transmission to the end users [20]. However, the final selection of the types of ESD, the number and the installation site suitable technical and economic analysis should decide.

LITERATURE

1. K. Stańczyk, M. Bieniecki, "Opportunities to reduce CO2 emissions and its impact on the efficiency and cost of power generation from coal", Journal of Mining and Geoengineering vol. 2/2007, Krakow 2007, pp.575—586.
2. Krawczyk, G, "Assessment of effectiveness of the application of energy storage devices in the underground supply system", The doctoral dissertation. Technical University of Radom 2012.
3. A. Cenian, T. Noch - editors, " Eco-Energetics - technology issues, the environment and economics", First edition, Publisher GWSA, Gdansk 2010, pp. 282-291.
4. Internet, http://www.cire.pl/pliki/2/magazyn_energ_elektryczn.pdf
5. A. Evans, V. Strezov, T. J. Evans, "Assessment of utility energy storage options for increased renewable energy penetration", Renewable and Sustainable Energy Reviews 16 (2012), pp. 4141– 414.
6. Internet, http://naukawpolsce.pap.pl/aktualnosci/news,381950,polak-opracowal-akumulatory-wydajniejsze-o-50-proc-niz-tradycyjne.html (09.10.2015)
7. A. Poullikkas, "A comparative overview of large-scale battery systems for electricity storage", Renewable and Sustainable Energy Reviews 27 (2013), pp. 778–788.
8. A. Z. Weber, M. M. Mench, J. P. Meyers, P. N. Ross, J. T. Gostick, Q. Liu, "Redox flow batteries: a review", Journal of Applied Electrochemistry, Volume 41 (10), September 2011, pp.1165-1166,
9. Czerwiński A., "Accumulators, batteries and cells", Transport and Communication Publishers, Warsaw 2005.
10. http://www.dacpol.eu/pl/dane-techniczne-superkondensatorow-175/product/superkondensatory-961 (09.10.2015)
11. http://www.tecategroup.com/capacitors/datasheets/powerburst/TPLE.pdf (09.10.2015)
12. C. Liu, Z. Yu, D. Neff, A. Zhamu and B.Z. Jang, "Graphene-Based Supercapacitor with an Ultrahigh Energy Density", Nano Letters, 10, pp. 4863–4868.
13. A. Rabiee, H. Khorramdel, and J. Aghaei, "A review of energy storage systems in microgrids with wind turbines", Renewable and Sustainable Energy Reviews 18 (2013) 316–326.
14. F. S. Barnes, J. G. Levine, "Large Energy Storage Systems. Handbook", CRC Press Taylor & Francis Group. USA 2011, pp. 112-147.
15. A. Baranecki, "Energy Storage Devices", Przegląd Elektrotechniczny, LXXII nr 7-8 2004, pp. 25-29.
16. G. Błaszczyk, "Aternative Energy Storage Methods", Elektroenergetyka 1/2005 (52), Publisher - PSE.
17. EG&G Services Parsons, "Fuel Cell Handbook (five edition)", Morgantown, West Virginia, October 2000.
18. Internet, http://new.abb.com/docs/librariesprovider28/dzisiaj/dzisiaj-2013_3.pdf?sfvrsn=4 (09.10.2015)
19. H. Majchrzak, G. Tomasik and M. Kwiatkowski, "Application of energy storage technology for integration of wind farms with an electric power system", Electric Power & Economy, October 2012, pp. 579-588.
20. Internet, http://www.ien.gda.pl/download_attachment.php?f=pl.attachment_1670951b707f655796.pdf (09.10.2015)

TECHNOLOGIE MAGAZYNOWANIA ENERGII SZANSĄ DLA ENERGETYKI ZAWODOWEJ NA EFEKTYWNE WYKORZYSTANIE ENERGII ZE ŹRÓDEŁ ODNAWIALNYCH.

Streszczenie

Rosnące zapotrzebowanie na niezawodność dostaw energii elektrycznej i wzrost udziału energii produkowanej z odnawialnych źródeł, które charakteryzują się dużą zmiennością produkcji sprawiają, że sieci przystosowywane są do współpracy z różnymi zasobnikami energii. Są one stosowane w celu uniknięcia nieciągłości zasilania oraz poprawy parametrów jakości energii. W artykule przedstawiono podstawowe typy urządzeń magazynujących energię.

Autorzy:
dr inż. **Grzegorz Krawczyk** – Uniwersytet Technologiczno-Humanistyczny im. Kazimierza Pułaskiego w Radomiu, Wydział Transportu i Elektrotechniki, Instytut Systemów Transportowych i Elektrotechniki, Zakład Elektrotechniki i Energetyki, mail: g. krawczyk@uthrad.pl