The Royal Academies for Science and the Arts of Belgium

Colloquium 2013:

Physics and the Energy Challenge

Energy Storage Techniques

Carlos Ziebert and Hans J. Seifert

Karlsruhe Institute of Technology, Institute for Applied Materials (IAM-AWP)
Herrmann-von-Helmholtz-Platz 1
76344 Eggenstein-Leopoldshafen
Germany

Stationary energy storage technologies support commercial breakthroughs of renewable energies by overcoming mismatches between energy output and demand and load leveling. Mobile energy storage enables electromobility and thereby fosters the development of environmental friendly transportation systems. Thermal energy storage is essential for heating, cooling and environmentally compatible industrial processing. On European level coordinated R&D on next generation energy storage technologies is required to support the strategic energy technology plan (SET-Plan) objectives and priorities in order to develop competitive low-carbon technologies and establish technological leadership in energy storage (Weblink to SET-Plan: http://ec.europa.eu/energy/technology/set_plan/set_plan_en.htm).

Having such aspects in mind, the European Energy Research Alliance (EERA; Weblink: http://www.eera-set.eu/) has launched the Joint Programme on Energy Storage (JPES) at the SET Plan Conference in Warsaw in November 2011. It is set up to increase the effectiveness and efficiency of R&D on the large field of energy storage through alignment and joint programming of R&D of its members, which are European leading research institutions and universities. It is coordinated by Karlsruhe Institute of Technology (KIT, IAM-AWP). By now 29 full and 6 associated participants from 15 European member states have joint the JPES and contribute a significant amount of 411 PY/Y (Weblink to homepage: http://www.eera-set.eu/index.php?index=13).

In the field of energy storage the JPES has introduced a coordination and programming effort at a level of ambition that did not exist before. Its key objective is elevating cooperation between national, public research organizations to a new level, from ad-hoc participation in projects to collectively planning and implementing joint strategic research by defining special research strengths of European member states and regions.

The JPES consists of the following six sub-programmes: SP 1 Electrochemical Energy Storage, SP 2 Chemical Energy Storage, SP 3 Thermal Energy Storage, SP 4 Mechanical Energy Storage, SP 5 Superconducting Magnetic Energy Storage and SP 6 Energy Storage Techno-Economics. The corresponding energy storage systems are of diverse nature in many respects (e.g. physical properties such as energy density, power density, efficiency, charge-discharge behavior) and all of them require technologies perfectly adjusted to their specific applications. Additionally, the development of hybrid energy storage systems is necessary e.g. for combination of long term and short term energy storage. The JPES integrates these different aspects by being active on all levels of the value chains: (1) materials, (2) process line, (3) component and system design, (4) system integration to specific application and (5) overall system integration (e.g. grid integration, vehicle integration).

An overview on the research and development activities of each sub-programme will be given with focus on physical aspects and the planned short, middle and long term activities. Outcomes will be described showing that the JPES is on a good way to be established as one of the most important European research networks on energy storage. The specific JPES sub-programmes described are:

Electrochemical Energy Storage (sub-programme 1)

The focus is mainly on R&D of lithium-based batteries and supercapacitors. Later attention and focus will be given to emerging electrochemical storage systems. This SP is mostly concentrated on materials issues, but also supports an interdisciplinary approach, including investigation of alternative storage methods, engineering, safety and application analysis (e.g., dedicated testing procedures for the various applications). The inventory of running projects and investigated materials as well as participating laboratories capabilities, the pre-normative research in support of specific standardization needs with the verification and joint clarification of dedicated test procedures with the share of a variety of measurement techniques and equipment assist the joint progress in the identified sector.

Chemical Energy Storage (sub-programme 2)

This sub-programme aims at giving a full overview of existing technologies, of their maturity, of the latest development and on-going research related to chemical energy storage. Based on this review main research axes to emphasize are identified and experimental work and methods are shared in order to pave the way to significant progresses towards industrialization of these technologies. This SP firstly focuses on hydrogen storage in gaseous, liquid and solid forms. However ammonia, chemical hydrides, methane, methanol and formic acid will be evaluated as well. As technical and safety challenges can be extremely different depending on the considered application, hydrogen and other chemicals for energy storage are evaluated for both stationary and transport applications.

Thermal Energy Storage (sub-programme 3)

This sub-programme aims to develop high performance thermal energy storage technologies for a variety of applications strategic to the EU member states to deliver both their short and long term visions related to energy, environment and well-being. This sub-programme covers materials, design concepts, storage integration and techno-economic assessment. It takes into account sensible heat storage, latent heat storage and thermochemical heat storage technologies.

Mechanical Energy Storage (sub-programme 4)

The main objective is to develop methods and equipment for mechanical storage of electric energy and, vice versa, to use the energy for supporting the grid when the consumption increases. As for now, three methods have been suggested for further analysis: hydro, compressed air and fly wheels. For these methods test facilities are created and simulation models are established for investigating the dynamic properties of the different methods and their grid connection.

Superconducting Magnetic Energy Storage (sub-programme 5)

Only the Superconducting Magnetic Energy Storage, SMES, stores electrical energy directly as electricity, and this allows a very fast delivery of high power at high efficiency. The central vision / mission of the SP-SMES is to enable highly efficient, reliable and cost effective fast superconducting magnetic energy storage solutions. The general objectives are to establish a joint European characterization and demonstration platform for SMES related superconducting materials with higher operating temperatures, to implement these materials in modular SMES approaches and the increase volumetric energy and power density thereby decreasing the system costs for becoming fully cost-competitive with alternative short term energy storage.

Energy Storage Techno-Economics (sub-programme 6)

Economic drivers will play an important part in the implementation of storage technologies. However, given the diverse geography of Europe and different energy policies, energy storage solutions in different member states are likely to pay differing roles and use different technologies. It is therefore important to develop a pan-European vision of energy storage. The techno economic sub programme seeks to clarify the benefits of energy storage on a pan-European level through the development of new models that will assist the introduction of new technologies. The standard model MARKAL is further developed to include energy storage and a soft-link to a storage time-shifting model will be established. Moreover national energy storage case studies are completed and compared and an assessment of the “externalities” of energy storage will be performed.

As an example for research on physical properties within the EERA JPES, calorimetric measurements using specific battery calorimeters combined with external electrochemical cyclers will be presented. Two Accelerating Rate Calorimeters (ARC) from Thermal Hazard Technology have been installed, one ES-ARC for coin and small cylindrical cells and one EV-ARC for pouch cells and different measurement routines have been elaborated. Isoperibolic investigations were performed at specific temperatures in the range from 23 to 60°C. In this range the applied environmental temperature did not largely influence the battery thermal behavior both for cylindrical and pouch cells. Tests under adiabatic conditions more accurately simulate the actual operating environment if several cells are put in a battery pack and the neighboring cells hinder or prevent the heat transfer. Cells were studied at starting temperatures between 20 and 40°C at 0.5 C rate. In this case, the temperature of cylindrical 18650 cells with $LiMn_2O_4$ cathode was largely increasing over 3 cycles by more than 40°C, emphasizing the danger of thermal runaway when cycling at higher temperatures. Moreover the heat capacities of different cells were measured and used to determine the heat generation and dissipation during electrochemical cycling. In addition the separation of reversible and irreversible parts of the heat was achieved by using potentiometric measurements and current interruption technique. Moreover for larger pouch cells with a $Li(Ni_{0.33}Mn_{0.33}Co_{0.33})O_2$ cathode it was possible to measure the surface temperature distribution during either isoperibolic or adiabatic cycling. All these data can be used as input data for thermal modeling and for adapting a thermal management system for batteries.