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INVESTIRE network—investigation of storage technologies for intermittent renewable energies in Europe

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Abstract

Most of the renewable energy systems require an energy storage system in order to match the demand. The storage function can be ensured through various systems such as secondary batteries, supercapacitors, flywheels, fuel cell system, compressed air systems, etc.), Each technology has specific characteristics, which are often compromises between many options (cost, overall efficiency, ability to withstand a wide range of cycling conditions, self-discharge rate, etc.), since they were designed for different applications with different requirements. The question to be answered is then: which storage technologies suit renewable energy systems better? The INVESTIRE network is going to answer this specific question and will propose R&D strategy in this field. Final results are expected for the end of 2003. In the meantime, the authors think this strategic approach should be given out to a large audience of scientific researchers in the field of energy storage technologies. An overview of the investigations are presented here, i.e. a categorisation of main existing renewable systems, an overview on storage technologies mentioned above, and a quick review of the objectives on economical aspects and environmental issues.

Keywords: Thematic network; Renewable energy systems; Storage technologies; Economics; Environmental issues

1. Introduction

Within the objective of increasing the penetration of renewable energies in Europe and worldwide, the storage issue is common to all countries. Most of the countries need or will need to have very short-term (for smoothing large and quick fluctuations of wind energy or increasing grid power quality) or mid-term storages (for electrification of off-grid applications). Only long-term storage (seasonal) is so far better adapted to the higher latitude countries. Therefore, scientific and technical problems encountered in the field to match the use of renewables and storage technologies are similar for most countries.

Moreover, any approach made at a national, regional or private level would be too restrictive, mainly due to the large number of storage technologies and possible applications. Even at a national level, there are few countries where actors are capable of developing to a significant level more than two storage technologies, when almost ten technologies are claimed to be potential candidates to the various renewable energy applications. The INVESTIRE European thematic network allows to exchange R&D information, disseminate experiences or increase the markets of the various energy storage systems from all European countries.

This networking action will thus increase the impact of scattered research efforts in this field, through the coordination and the bringing together of European-wide R&D expertise and resources.

Any application emphasises its own needs: the traditional car battery industry (lead–acid battery) was mainly concerned about cost and high current at low temperature. All recent developments in the field of advanced batteries are driven by portable applications (laptops and computers) or electric vehicles, for which specific power and energy and rate of recharge are the key criteria. These requirements are almost exactly at the opposite of what renewable energy systems care about: the main concerns usually are the cost, the lifetime in some cycling conditions, the efficiency, and for mid- and long-term storage the self-discharge.

Intermittent renewable energies include mainly solar photovoltaic and wind energy. These two types of generators supply dc or ac electricity in an intermittent manner, which then has to be stored to match the demand. For this purpose, such systems require electricity storage to obtain a permanent power supply and power quality. Until now, conventional lead–acid batteries are so far mostly used in the field

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of renewable energies [1] for economical reasons. Even if new lead–acid batteries designs [2,3] exist for photovoltaic applications, they remain the weakest part of such a PV system.

Nowadays, it is difficult to know if an alternative to lead–acid batteries is available and which storage technology will be the most promising one for specific applications in the context of intermittent renewable energies.

The storage function may be done through various ways: rechargeable secondary batteries, but also supercapacitors, flywheels, "electrolysers + hydrogen storage + fuel cell" systems, and compressed air storage with electromechanical systems.

The INVESTIRE network project most particularly addresses the objective of optimising power quality, by means of energy storage, for stand-alone and hybrid systems such as photovoltaic and wind generator. This key action is the core of the INVESTIRE network. The project will definitely contribute to this by sharing all experience from all partners overlooking all technologies in the field of energy storage and renewable energy.

1.1. *Scientific and technical approach*

The INVESTIRE network brings together for the first time a large range of existing energy storage technologies for renewable energy applications. Existing storage technologies are based on different principles. We tried to consider most of them and nine technologies have been addressed in the project: lead–acid, nickel and lithium batteries, supercapacitors, fuel cells, flywheels, redox batteries, compressed air and metal–air systems.

The INVESTIRE project brings together a large range of technologies and partners as different as manufacturers, laboratories, consultants, designers and suppliers. The almost equal breakdown between manufacturers and laboratories or between technology providers and technology users is to ensure that interesting RTD results are disseminated, exploited, and implemented.

From a technological point of view, the most represented technology is the lead–acid battery, with three important industrial groups, representing six national manufacturers. This technology represents more than 90% of the present storage market for renewables, and is therefore strongly involved. Then, lithium and nickel technologies have two and three manufacturers, respectively. Most of the six remaining storage technologies have one or two manufacturers involved. Fig. 1 shows the repartition of the partners (34 in total) for each storage technology. The consortium was designed in order to be the best appropriate to the selected objectives of the project: the present state-of-the-art and the roadmap for R&D.

More detailed objectives of the INVESTIRE project can be listed as follows:

- To review all possible storage technologies the most suited to renewable energy systems;

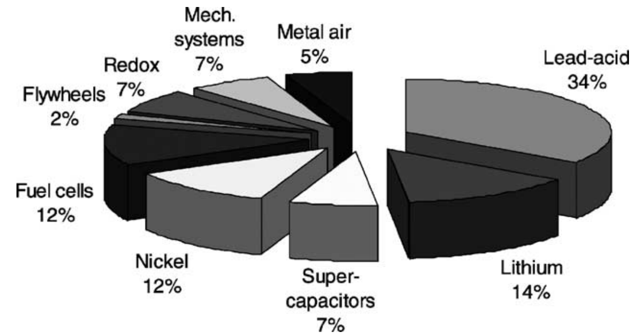

Fig. 1. Partnership of the INVESTIRE project according to the different energy storage technologies.

- To compare and assess the most relevant features and then to propose the best scope of application of each storage technology;
- To deliver the results of past and current research carried out on a national or international basis to potential users (laboratories, PV or wind systems suppliers, renewable energy project managers);
- To facilitate collaboration and exchange among EC-supported research projects in this field;
- To help identify research priorities and publish a 5–10 years RTD roadmap;
- To encourage the formation of new RTD partnerships;
- To foster cooperation between battery manufacturers and renewable energies system designers or suppliers.

This work has started with a brief review of the available storage technologies. Currently, the requirements of the main types of renewable energy systems are being listed. This will result in a list of technical criteria, which will form the basis to compare in a harmonized situation the performance of all the storage technologies.

2. Results and discussion

2.1. *Renewable energy systems*

The first investigation was to collect on information on the operating conditions of storages in autonomous power supply systems. The classification is strictly storage oriented and technology neutral. A characterisation of the different applications was prepared with respect to the demands on the storage unit. This investigation is mainly based on inputs and general experience gained by the partners on the classification of battery operating conditions [4] in PV powered autonomous power supply systems [5].

From this evaluation, a comprehensive overview on typical operating conditions for storage concerning currents, temperature range, number of cycles and typical applications has been prepared. This fairly comprehensive classification should serve as a basis especially for the classification of all

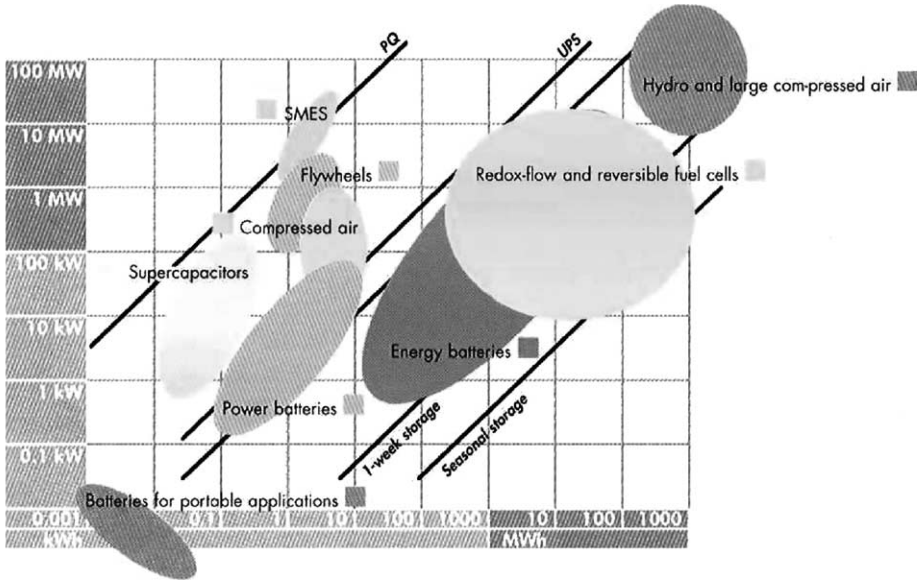

Fig. 2. Classification of the different storage technologies according to their specific power and energy.

existing data, economic characteristic and the final comparison of storage technologies.

2.2. Storage technologies

The thematic network studies and compares nine storage technologies existing in the present or near future for renewable energies such as photovoltaic or wind generator. Even if the main criteria about renewable energy systems are not the specific energy (Wh/kg) or power (W/kg), Fig. 2 gathers very well the technologies studied within the INVESTIRE project.

The advantages and drawbacks of each technology will therefore be underlined, and the gap between the conventional lead batteries and new candidates will be evaluated. Data already existing in the field, or within the manufacturers and the laboratories will be used to ascertain the results.

Of course, the storage technologies will also be assessed from an economic standpoint, analysing both the present situation and the prospects, and considering their environmental impact.

The project will finally include the writing of a strategy document for future R&D, and the dissemination of all the information made available.

2.3. Economic aspects

The objective of the economic study is to express a uniform methodology to be able to compare different storage systems concerning costs. The costs of stored or discharged energy in a storage device will be calculated as extra costs involved in using a storage device. Since advantages of using electricity storage can have multiple dimensions (savings on electricity supply from the grid, advantage of having uninterrupted supply, etc.) it will require a considerable research effort to assess these advantages and to financially incorporate them into the usage costs of storage. Since this is beyond the scope of this project, only costs of (dis)charged electricity will be calculated (€/kWh).

2.4. Environmental issues

In order to obtain relevant data for an assessment of environmental aspects of the storage technologies, environmental indicators were established on the basis of data provided by the experts, and on the basis of literature research.

2.5. Quantitative indicators

- Energy requirements over life cycle (energy input for manufacturing, use, disposal, excluding stored energy);
- Greenhouse gas emissions (in CO_2 equivalents);
- Resource depletion (use of scarce abiotic resources, e.g. scarce metals).

All the above indicators will be expressed per watt hour of storage capacity. These three quantitative indicators will be calculated according to standard evaluation methods used in life cycle assessments (CML method [6], extended to include primary energy requirements).

2.6. Qualitative indicators

- Use of toxic or dangerous materials;
- Emissions of environmentally harmful substances based on the list of reportable emissions in the IPPC directive of the EU [7];

- Occupational or public safety risks;
- Ecosystem and land-use aspects;
- Recyclability and waste aspects.

3. Conclusion

The review of all the requirements and expectations for the storage function within the various type of renewable energy systems (useable capacity, efficiency, lifetime, costs, . . .) will lead to an evaluation of the promising emerging technologies for intermittent renewable energy applications and to a proposal for a mid- and long-term RTD strategy in this field (the present and expected technical performance, the cost of prospect and the environmental considerations) covering the R&D needs in technological improvements and in standardization.

The main deliverables of the INVESTIRE network are scheduled for October 2003. They include:

- A summary of the actors and the state-of-the-art of the existing storage technologies;
- The requirements of the storage function within the various types of renewable energy systems;
- An evaluation report on the promising emerging technologies for intermittent renewable energy applications, based on a database of selected examples and case studies;
- A proposal for a mid- and long-term RTD strategy, based on:
  - The renewable energy requirements;
  - The present and expected technical performance;
  - The cost prospects and the environmental considerations.

Comparisons between all storage technologies will be the subject of another paper. This article will be issued at the end of the INVESTIRE project. At last this comparison will allow to define which technology better suits the field of renewable energy and which ones are attractive alternatives or not to lead–acid batteries.

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References

[1] R.M. Dell, D.A.J. Rand, J. Power Sources 100 (2001) 2–17.
[2] J. Garche, Phys. Chem. Chem. Phys. 3 (2001) 356–367.
[3] D.U. Sauer, J. Garche, J. Power Sources 95 (2001) 130–134.
[4] D.U. Sauer, G. Bopp, M. Bächler, W. Höhe, A. Jossen, P. Sprau, B. Willer, M. Wollny, in: Proceedings of the 14th European Photovoltaic Solar Energy Conference, Barcelona, Spain, 1997, What happens to Batteries in PV Systems or do we Need one Special Battery for Solar Applications?
[5] A more detailed analysis of the battery operating conditions is planned in the project BENCHMARKING, an accompanying measure project started on 1 January 2002 (NNE5-2001-00198), A classification of operating conditions is in the centre of this projects, results will be available by summer 2003.
[6] J.B. Guinée, M. Gorrée, R. Heijungs, et al., Life cycle assessment—an operational guide to the ISO standards, Final Report, Centrum Milieukunde Leiden, Leiden, 2001.
[7] Commission Decision of 17 July 2000 on the implementation of a European pollutant emission register (EPER) according to Article 15 of Council directive 96/61/EC concerning integrated prevention and control (IPPC), Official Journal of the European Communities, C(2000), 2004.