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Lead batteries for utility energy storage: A review

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ABSTRACT

Energy storage using batteries is accepted as one of the most important and efficient ways of stabilising electricity networks and there are a variety of different battery chemistries that may be used. Lead batteries are very well established both for automotive and industrial applications and have been successfully applied for utility energy storage but there are a range of competing technologies including Li-ion, sodium-sulfur and flow batteries that are used for energy storage. The technology for lead batteries and how they can be better adapted for energy storage applications is described. Lead batteries are capable of long cycle and calendar lives and have been developed in recent years to have much longer cycle lives compared to 20 years ago in conditions where the battery is not routinely returned to a fully charged condition. Li-ion batteries have advantages in terms of energy density and specific energy but this is less important for static installations. The other technical features of Li-ion and other types of battery are discussed in relation to lead batteries. A selection of larger lead battery energy storage installations are analysed and lessons learned identified. Lead is the most efficiently recycled commodity metal and lead batteries are the only battery energy storage system that is almost completely recycled, with over 99% of lead batteries being collected and recycled in Europe and USA. The sustainability of lead batteries is compared with other chemistries.

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1. Introduction

The need for energy storage in electricity networks is becoming increasingly important as more generating capacity uses renewable energy sources which are intrinsically intermittent. The spinning reserve of large networks is becoming less able to maintain power quality with increased renewable inputs and the strategies needed to optimise renewable input without curtailment or other measures are driving a move to energy storage. Electrochemical energy storage in batteries is attractive because it is compact, easy to deploy, economical and provides virtually instant response both to input from the battery and output from the network to the battery. There are a range of battery chemistries that can be used and lead batteries offer a reliable, cost-effective solution which can be adapted for different types of energy storage applications [1–6].

Lead–acid batteries are supplied by a large, well-established, worldwide supplier base and have the largest market share for rechargeable batteries both in terms of sales value and MWh of production. The largest market is for automotive batteries with a turnover of ~$25BN and the second market is for industrial batteries for standby and motive power with a turnover in 2015 of ~$10BN. The majority of industrial batteries are used for standby applications to provide secure power for telecommunications, data networks, national security, and a huge range of applications where continuity of the electricity supply is essential. Energy storage is an extension of standby or stationary service but the application requirements are quite different and as the market for energy storage grows, it needs to be recognised as a fully separate market sector [7].

In the very early days of the development of public electricity networks, low voltage DC power was distributed to local communities in large cities and lead–acid batteries were used to provide peak power and short term energy storage. DC distribution was soon displaced by AC systems and the ability to use transformers to step-up or step-down the voltage allowed large area networks to be developed. The use of battery energy storage systems (BESSs) rapidly diminished as networks grew in size. Stability is achieved by careful management of the network with generation being balanced with consumption. The AC frequency is permitted to vary within narrow limits as higher overall loads reduce the frequency and voltage settings may be changed to adjust demand slightly but the main method of control is spinning reserve where an unloaded generator that is synchronised with the grid can be brought into use very quickly. This could be hydro-electric generators. Rapid reserve differs from spinning reserve in so far as the energy source does not have to already be synchronised with the grid. BESSs fall into this category as the DC battery output can be converted to AC with solid-state power conversion equipment and systems brought on line almost instantaneously. Over time power quality in terms of reliability, frequency stability, voltage and volt-ampere reactive (VAR) control has become more critical. Large networks have installed pumped hydro-electric energy storage schemes to augment their spinning reserve but as renewable energy sources have become more important a higher level of rapid reserve is required. Batteries can provide this with lead batteries offering high efficiencies for short time reserve and their use for grid support, smart grids, local systems and home and small commercial energy systems will increase [8].

Advanced lead batteries have been used in many systems for utility and smaller scale domestic and commercial energy storage applications. The term advanced or carbon-enhanced (LC) lead batteries is used because in addition to standard lead–acid batteries, in the last two decades, devices with an integral supercapacitor function have been developed. These may have a