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The Bourner lecture — do standby batteries need to have a new chemistry?

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Abstract

The telecommunication and data communication businesses are experiencing strong growth and so is the demand for batteries for back-up power. The stationary lead-acid battery is the type that dominates these applications. This presentation will give some guidelines for battery scientists who want to apply their technology to back-up power. The opinion of the author is that the advanced batteries that are in the frontline today are poorly adapted to the needs of back-up power for networks. If developers of these advanced batteries are to stand a chance of achieving success in the network power market they must focus on reliability, volumetric energy density and cost.

Keywords: Standby power supplies; Telecommunications; Lead-acid batteries; Reliability; Cost effectiveness

1. The market

Data transmission and voice transmission are experiencing strong growth. This is fuelled by the popularity of the Internet and by mobile telephony. Soon Internet and mobile telephony will merge. Voice traffic over the mobile network will become packet-switched (data) instead of line-switched. The mobile network we have today is the so-called 2G (second generation) and will have enhanced data communication. New operators using 3G (third generation) networks will offer even more data transmission over the air interface. The mobile Internet will naturally create a need for more data transmission in the network. When the Internet is more accessible it will of course be used more, and hence, need more capacity. The increased band of 3G mobiles and also that of broadband Internet access will be used, together with new services eating up the bandwidth. Services like TV, video, still pictures and music are popular and they are demanding on the bandwidth.

There is a strong motivation for high availability on the networks. This is for several reasons. A very important one is that of loss of revenue. At transmission centres where traffic is concentrated, loss of service becomes very costly. Today, there are network centres where there are several operators sharing a common installation. These centres are sometimes called Internet hotels and also sometimes referred to as telehousing. In these premises the company responsible for the infrastructure normally is obligated strictly to provide safe, reliable, electric power. Even on the access side, both at the fixed site and at the radio base station, back-up power is necessary. The traffic at a radio base in a densely populated area is generating revenue, and therefore, back-up power is necessary.

2. Reliability

There are several options for back-up power. These options can be ranked in a diagram showing the reliability and volumetric energy density (Fig. 1).

The reliability scale is an important factor for the selection of back-up power. At the lower end of reliability we have motor generator combinations while we have batteries at the higher end of reliability. During my years in telecommunications, I have begun to realise that these two factors are the most important factors for back-up power in the infrastructure of telecom. The batteries we use today are highly reliable. This reliability is not inherent in batteries. It has long been fought for.

Accumulated experience in the production and design of lead-acid batteries has led to the level of reliability that we have at present. A battery consists of a set of cells in series. Every cell has to be highly reliable in order for the battery to have a high reliability. Even with such a mature technology

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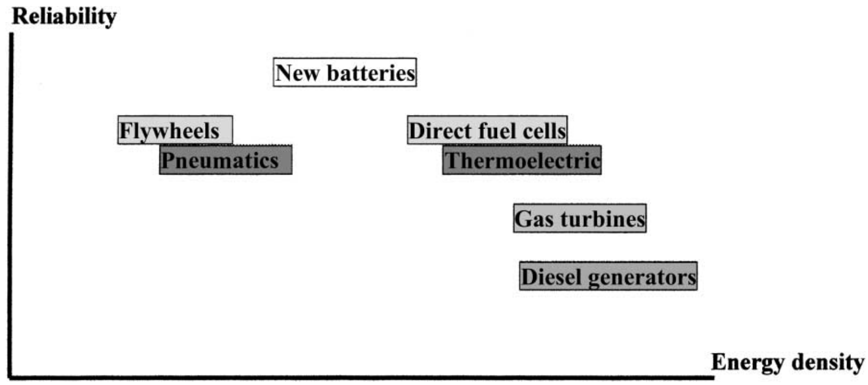

Fig. 1. A ranking of reliability against energy density.

as the lead-acid battery, minor new design features have presented reliability problems. At introduction, the low maintenance flooded and the valve regulated battery designs were plagued by reliabilities lower than the previous, older, technology.

The valve regulated lead-acid battery, which is the most common battery for industrial back-up purposes, has been plagued by problems; some of these failure modes can be found in Table 1.

It has been stated that valve regulated batteries become unreliable very early in life [1,2]. Our experience is that this technology has matured and reliable performance is now achieved. Improvements will continue to be made both in terms of energy density, longevity and production costs. If standardisation can be increased and production more centralised, cost could come down even further.

3. Primary versus secondary

Among candidates for back-up power, there are two groups from a systems point of view — electrically refuellable and those that cannot be refuelled electrically. Using terms common among battery scientist the groups are akin to primary and secondary batteries (Table 2).

Because of operational convenience an electrically refuellable battery is always preferred over a back-up power source which needs to be mechanically refuelled. The storage of fuel on site is normally associated with some risk. Storage of fuels is regulated and in some locations a permit is required. This is a concern both for fuel cells and for motor generators. Also the waste product from mechanically refuelled devices can be a problem. For instance, ducting from a diesel generator and from a fuel cell is required.

You need to remove waste heat and moisture. The mechanically refuellable metal/air batteries which have been suggested and promoted as back-up power, create a problem on the waste side rather than the fuel side. The aluminium/air battery has been promoted recently, as a clean back-up source. When end-customers became aware of the waste electrolyte problem the interest in this device soon faded.

4. Batteries versus the alternatives

The flywheel has recently caught much attention as a clean back-up power source [3]. The proponents of this technology have stressed its virtues; environmental friendliness, high power density and longevity. Put into a back-up power source perspective reveals that it is less reliable than a battery. This comes from the fact that is uses an electronic power conversion stage for its electrical output. An electric power converter decreases overall reliability. Another drawback of the flywheel is the lack of long term experience. The flywheel is similar to a superconducting coil in many aspects. Both devices are dependent on power electronics for their output of electric power.

The flywheel's measure of performance for gravimetric energy density is ultimate strength divided by density. For those materials with the best index of performance this translates into an ultimate energy density close to that of the lead-acid battery. So the battery fares well in this comparison versus another back-up power source.

Table 1
Problems with valve regulated lead-acid batteries

Problem	Comment	Cure
Corrosion	The ultimate failure mode	Better alloys, new grid making methods
Top-lead corrosion	An unnecessary failure mode	Proper alloys
PCL	Occurs even for very few cycles	Higher compression, more dense active material, addition of tin
Negative self-discharge	Appears over a 2–4 year span	More lead surface area to positive grid, high overpotential negative

Table 2
Primary and secondary standby devices

Primary	Secondary
Motor generators	Rechargeable batteries
Thermoelectric generators	SMES
Fuel cells	Flywheels
Metal/air batteries	Reversible fuel cells
Other primary batteries	Pneumatic storage

If we omit metal/air, batteries can be almost completely sealed and be without moving parts — which are very attractive attributes from a reliability point of view. The most desirable features for new batteries are:

1. Higher volumetric energy density.
2. Higher gravimetric energy density.
3. Better endurance at high temperatures.
4. Components that are more environmentally acceptable.

Most of the research for new chemistries has focused on portable batteries and batteries for electric traction. The research on portable batteries is driven by the market and is, to a substantial part, financed by the battery companies. For electric vehicle batteries research is funded mainly by the State. At the present time there is very little research into batteries for stationary applications except for the continuing development of existing lead-acid technology.

5. New battery chemistries

We put together last year a diagram showing new battery chemistries (Fig. 2). We found the highest volumetric energy densities in flooded nickel/metal hydride batteries. We found that the longest working calendar life for full scale batteries was from sodium/nickel chloride batteries. We are aware that most research is spent on lithium batteries in various forms, both in terms of chemistries and in mechanical design.

However, little research has been done so far on calendar life float studies for secondary lithium batteries. The Canadian research into PEO-solid electrolyte batteries proved that this battery did indeed have a long life. The company ARGO-TECH, which uses technology that partly comes from this research is, at present time, the only company that is researches into lithium batteries with the stationary application as main interest.

Each year, a forum for energy related research for telecom is arranged by IEEE: the INTELEC Conference. One of its topics is batteries. There are few presentations about alternate chemistries. In the year 2000, there were the following numbers on various battery systems: lead-acid 29, Ni/Cd 1, Ni/MH 2, Li-ion 1, Li-polymer 2; and this was the year with the most papers on alternate battery chemistries.

6. Relations between cost and performance

It is the authors opinion that new chemistries can get substantial market penetration into stationary standby batteries when their cost is in the range of two to four times that of lead-acid batteries. This is the approximate relationship today between industrial nickel/cadmium and lead-acid batteries. The nickel/cadmium battery has the advantage of long life at elevated temperatures. Some customers have been attracted by this feature. The better high temperature endurance enables them to increase the intervals of battery replacement. The alternate solutions, to use compressor

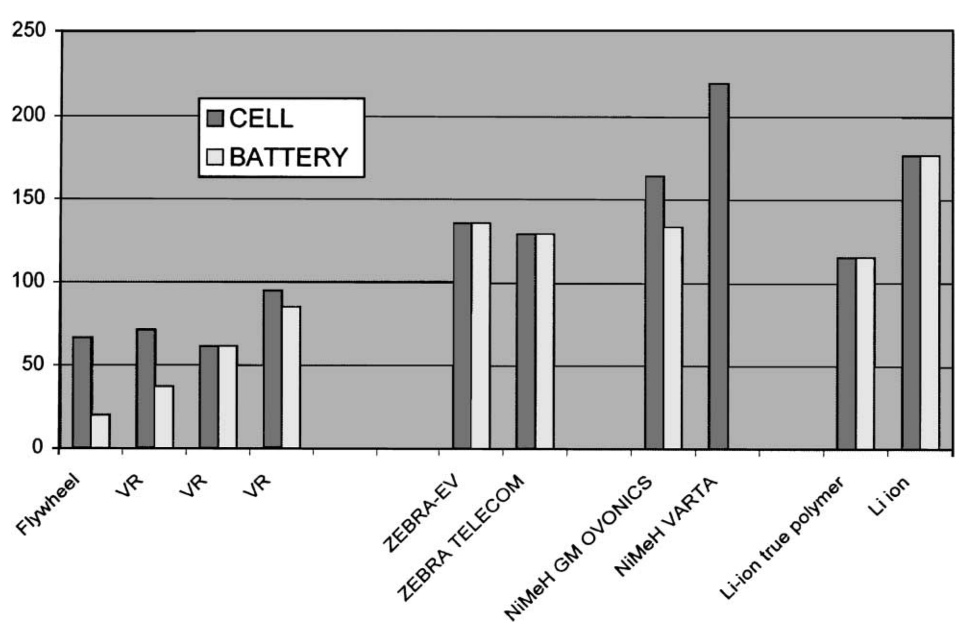

Fig. 2. Volumetric energy densities of a flywheel and of some new chemistries.

driven refrigeration or to use high temperature lead-acid batteries, are less attractive in many applications. Nickel/cadmium batteries will continue to be used in niche applications in telecom where the main advantage is that high temperature endurance is required. However, improved lead-acid batteries, specialised for high temperature, will counteract this. As mentioned previously, the most desirable feature of a new battery is volumetric energy density. In this aspect, the difference is not that great between nickel/cadmium and lead-acid.

To really make a difference, a new chemistry battery has to have a substantial advantage over the best lead-acid battery designs, which have a volumetric energy density of 100 Wh dm^{-3}.

7. Some basic costs

It is the author's opinion that the cost of battery basically is composed of raw materials cost factor and a necessary surface area factor. The raw materials cost is composed of a cost per ampere-hour of the compound and its relation to the other materials. When using nickel in an aqueous battery with a 1.2 cell voltage and one electron per mole exchange, the unit cost is higher than for a sodium/nickel chloride battery where we get two electrons per mole and 2.5 V. The necessary surface area is not such a definite factor because industrial development can influence this strongly. Battery chemistries which use poorly conducting electrolytes and have low cell voltages need to produce more electrode surfaces for the same performance. The very high power density figure of merit of the lead-acid battery is one of the factors that has contributed to the success of this battery.

Lithium batteries, which have high energy densities, have the draw back that the most efficient materials for the positive electrodes are costly. The really affordable materials that can be used in lithium batteries, such as sulphur polymers and manganese oxides are, as yet, less developed.

8. Float charge requirement

Another factor that is very important for a successful battery is the ability to be operated in the float charge mode. Today, back-up power is provided by fully floating configurations. The batteries are connected in parallel with the load and the rectifiers. There is no power electronics between the battery and the load. This is considered as necessary for high reliability. The various advanced sealed nickel batteries have a disadvantage in this respect, as they do not lend themselves to be operated safely in the float charge mode. The nickel battery which has recently been most successful commercially is a flooded version, which can safely be charged in the float mode. Nickel/metal hydride batteries seem attractive from the volumetric energy density point of view.

9. Author's speculation

Nickel metal/hydride batteries have the virtues of high energy density. Their inability to operate safely in float charge mode and in a high temperature environment are problems at present time. If it could be shown that the hydride alloy could survive for a substantial time at elevated temperature, nickel/metal hydride could gain a substantial market share. It might be that flooded design with separate head space for recombination could do the job.

Batteries operating at high and elevated temperatures have been proposed for electric vehicles, but the high temperature is a definite disadvantage for this application. For stationary applications, where the back-up energy is in the range >5–10 kWh, the drawbacks of high temperature is not so large as in the electric vehicle application. Also the more moderate demand on power density makes batteries based on beta-alumina and on polymers more viable for standby applications.

For lithium batteries, one must keep an eye on the development of production technologies and on the development of non-cobalt positives. If the manufacturing costs for the large amounts of electrode surfaces that are required and their assembly into working units can be brought down substantially, then lithium batteries might have a success in the area of standby power for telecomunications.

For further reading see [4].

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