

How to transform innovative battery opportunities in field operational solutions for Telecom/IT

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Abstract—Orange has investigated for decades on innovative energy storage such as batteries aiming to replace the previous technologies by improved solution, but only few attempts have succeeded to reach the level of generalization on the operational field in Telecom core and network central offices, remote access sites and datacenters. This document reports part of the Orange long energy storage quest and ends by latest researches and tests resulting in potential partial replacement of the dominant lead-acid technology and in international ITU-T and ETSI standardization of a systematic approach method for identifying and selecting technologies adapted to operational Telecom application in a shorter time than in the past.

Keywords— *battery; lithium; BMS; energy storage; standard; method*

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I. INTRODUCTION

Orange has worked since years 1980 on energy power systems evolutions and new disruptive battery technologies. At that time, the sealed Valve Regulated Lead Acid (VRLA) technology was selected, developed and tested in partnership with industry and then introduced for replacing about 100% of the centralized vented lead-acid (VLA) technology in back-up applications coming from one century history. The main result was a universal and fully modular power system with very low maintenance and Hydrogen emission battery blocks, allowing easier O&M [1]. In the 1990s, R&D works were focused on battery technologies for mobile terminals i.e. Lithium battery (LiB) replacing NiCd and then NiMH and there was only few alternative technologies for replacing stationary lead acid batteries (LA) in network sites except the case of Zinc or Aluminum-air [2].

In the 2000's appear available industrial LiB systems,

SOOGREEN Celtic Plus European Project 2015-2018 part of Eureka network <https://www.celticplus.eu/project-soogreen/>

tested in lab and then after 2005 on site. Some were proposed with the new 400 VDC powering systems adapted to high density networks and datacenters equipment [3] in parallel with the development of part 11 of the advanced control monitoring ETSI standards series [4]. Other works were done to improve lifetime and better determine the State of Health (SoH) [5] of VRLA batteries now massively used in Orange networks.

A general investigation with “3C Projects” of existing and not mature battery and energy storage solutions was done and presented e.g. in ETSI EE Workshop of 2013 [6] answering to new interest for this e.g. with smart renewable energy.

The paper will shortly present these works done in Paris¹ and Lannion Orange Labs. In Paris, tests are done Lithium Iron Phosphate (LFP) prismatic cells and Battery Management System (BMS) optimized for Telecom O&M and contributed to the European project Soogreen [7] and some results are used for ITU-T SG5 and ETSI EE joint standardization [8] about an efficient method of battery selection and test adapted to ICT/Telecom applications such as Hybrid Genset Battery (HGB). Other works are on advanced Nickel-Zinc (NiZn) of a French research laboratory [9]. In Lannion tests are done on industrial Lithium-ion (Li-ion) 48 V packs and racks and on other advanced LA batteries to check if they are ready for the network. Finally, information and recommendation will be given to minimize battery environmental impact and enter in circular economy and energy and material sufficiency.

II. THE HISTORICAL REQUIREMENT OF ENERGY STORAGE FOR TELECOM NETWORK AND DATA CENTERS

A. Use of early battery and DC for Telecommunication

In 1850-1900, Telegraph and then phone and radio TSF services were locally powered by primary batteries e.g. made of Daniel 1 V cells (Zinc-Copper sulfate) offering high availability as explained by Emile Reynier [10].

The first efficient rechargeable battery was the 1.85 V Lead Acid invented by Gaston Planté in 1839 as a result of systematic trials in Voltameters of many metallic couples and selection of the best to retain electric charge. At end 1800 were erected DC and then AC grids and an obvious need of rechargeable batteries has risen to cover grid interruptions

¹ Issy les Moulineaux and then Chatillon Orange Labs close to Paris

and avoid primary batteries costs and pollution. Faure, Sellon and Volckmar combined process² was massively developed in Europe by Henry Tudor and also in USA around the 1880's for industrial facility, building lighting, telecom and tramway as reported by Mr Reynier in [10]. These industrial LA batteries were already offering energy density of 30 Wh/kg, the same as current LA batteries and in laboratory with thin plates up to 45 Wh/kg.

However LA solution was already recognized at that time as dangerous for health in manufacture and in end of life steps. Other ideas such as those based on zinc were already under test e.g. by masters (Reynier, Edison, etc.) but not mature enough or still too expensive to compete with LA. At least two major improvements of LA batteries have still increase their domination. The tubular design of Ironclad in 1950's has increased the cycling performance. Then has been introduced sealed battery technology with gel VRLA using silicone gel in 1957 (Sonnenschein) and electrolyte Absorbing Glass Material (AGM) VRLA in the 1970's resulting of 20 to 30 years of very patient design to reach efficient internal gas recombination.

On the portable device side, higher density technologies such as NiCd, and then less toxic and higher performance NiMH were followed by Dr Goodenough, Dr Yazami and Dr Yoshino discovering Li-ion insertion technologies in oxide of LiB cathode, and carbon anode features. LiB have brought new major improvement also for Electric cars, but their high initial cost was too high for stationary application in Telecom. This paper will not present the rich history of all the batteries such as those of portable device and electric vehicle, but will focus on similar chemistries candidate for LA replacement in Telecom/IT networks.

A common observation can be made in electrochemistry history based on LA, also true for other battery technologies. Progresses were done by slow changes at all levels (electrolyte, grids, active material pasting, ...) and adjusting electrical parameters (charge, discharge, floating modes). By analogy with Moore or Koomey laws type (twice more transistors on a microprocessor at industrial level, each 2 years with the same consumption [12]), it takes 15-25 years for doubling performances of industry scale batteries (example of European R&D roadmap in [11]). Now, renewable energy, smart green energy use and circular economy push us to re-open the files and find lower cost and greener batteries.

B. Evolution of battery need for Telecom networks and IT

The Telecom networks and Datacenters battery market's evolution can be understood based on:

- the evolution of network and services from voice to data and number of customers.
- the associated electricity supply availability (good grid quality in developed countries, bad grids with frequent long interruptions in emerging countries or even off-grid situation) and the raising renewable energy self- consumption pushing for local energy storage.

In Orange France, narrow band telecommunication services (electromechanical and then electronic switched voice and

data) offered by switches, access copper line interfaces and rented transmission lines were powered in 1970s in central offices by centralized AC rectifiers (e.g. by 1 to 5 heavy 48 VDC 1000 A thyristor units) with back-up based on vented LA batteries of 10 hours autonomy associated with two Diesel Engine Generator sets (Genset) in about 1000 big sites. About 15.000 small access sites were equipped with vented LA batteries of 12 to 36 hours autonomy. The vented LA batteries were creating a lot of work to check cells density, voltage and refill them in pure water.

In the 1980s BT, GEODE and ALFATEL collaborative projects were launched in Telecom National Research Center (CNET) with French industry and research to optimize power supply sizing, energy efficiency and maintenance. The result has been a reliable architecture with much less power redundancy thanks to full microprocessor smart management. It was proved that except for some strategic centers, all big sites connected to AC grid could be secured by a single Diesel Genset improved in reliability (e.g. for starting and cooling). The old centralized rectifiers units were replaced by distant 48 VDC modular cabinets close to Telecom equipment fed by secured 3 phases AC. This was possible in 1980s due to disruptive high frequency power width modulation (PWM) used in compact and efficient AC/48 VDC modular rectifiers and small VRLA AGM powerful battery modules technology with short autonomy of 15 min to 1 hour. With secured high voltage distribution rather than 48 VDC to Telco room in the center, the copper installation cost has been divided by about 10 (e.g. 500 kg copper for AC versus 5 tons before in 48 VDC for a 50 kW room). Cost of maintenance was also cut as all equipment was modular, interoperable between all vendors and VRLA batteries were maintenance free. At end 1990, before the massive ADSL and Mobile networks roll out, 90% of French sites were equipped with GEODE and ALFATEL. Now the GEODE systems are progressively replaced by new much higher power cabinets equipped with more compact and efficient rectifiers and architecture has come back to centralized 48 VDC power stations and batteries. This is reducing battery maintenance and weight issues on room raised floor but the high saving on copper distribution is lost.

Since 2000 Mobile network has been equipped with similar advanced 48VDC rectifiers and with VRLA AGM batteries technologies. But in about 4000 off-grid sites in Middle East or Africa, solar vented tubular LA of OPzS type are still used for powering mobile base stations (BS) as they have the best lifetime operation for cycling applications at hot temperature.

Since 2000, ETSI and ITU-T have standardized 400VDC solution to keep both advantages of DC and high voltage distribution in a unified up to 400 VDC power system and distribution [13] for Telecom equipment and servers³. Using only 400 VDC batteries simplifies a lot engineering and O&M compared to different batteries in 48 VDC systems and in AC Uninterrupted Power Supply (UPS). It enables also remote powering of access sites (e.g. FTTx cabinets or 5G microcells), avoiding distributed battery maintenance costs and delayed expensive AC grid local connection [13]. The migration to up to 400 VDC architecture will not change the

² Inventors such as Camille Faure have accelerated and optimized the battery energy density and the manufacturing process of the Planté solution as it was among the best for cell lifetime but very complex, long, inefficient and costly.

³ Servers become more distributed in Next Generation of Point of Presence (NGPoP [26]) in sites with FAN node concentration, cloud RAN, video service moved to the edge rather than in datacenters with flat IP CDN, virtualization (SDN or NFV) as seen on ETSI ITU-T TISPAN project (Telecom Internet converged Services and Protocols for advanced Network)

energy capacity of batteries used in fixed network and maybe not their technology.

Based on the previous description, the Telecom network battery stock in Orange can be roughly assessed in order of magnitude⁴ at 600 MWh in fixed networks, 1812 MWh in mobile networks and 60 MWh in datacenters giving a total of **2.5 GWh installed stationary LA batteries.**

A very rough extrapolation for worldwide Telecom and datacenters can be done based on 4.5 billion mobile users and 1.5 billion Fixed Network broadband users, if we suppose network back-up similar to Orange for 200 M customers, this gives $2.5 \times 6000 / 200$: **75 GWh installed LA batteries worldwide**

III. REVIEW OF PASSED AND PRESENT TESTS IN ORANGE

A. Metal-Air

Metal-air primary batteries are very old solutions, but in 1980's Orange has tested a regenerative solution provided by research laboratory SORAPEC France (SCPS now), with zinc layer on plastic pellets as fuel flow. It was working but solid zinc carbonates were rapidly blocking the fuel flow. The other tested solution was a 600 W regenerative aluminum-air battery [2] using improved anti-passivation negative electrode alloy. The issue was a lot of aluminum hydroxide gel everywhere making complex the regenerative process.

For both Zn and Al batteries the air electrodes were drying with carbonate crystallization blocking the operation. Thus a periodic flow of alkaline potassium electrolyte was applied but this creates a high self-discharge of zinc or aluminum by corrosion and inter-cell electric leakage at different potential as well-known for all flow batteries. Finally it was not possible to reduce or substitute Platinum by low cost catalyzer in the air membrane and so projects were abandoned.

B. improved of AGM VRLA battery management

On the GEODE system [1] it was tried to reduce VRLA floating time and thus the grid corrosion that affects the lifetime. Each battery was alternatively put in rest for one week by keeping open the low voltage disconnection relay. Then it was recharged in boost mode to avoid undercharge and sulfating. But, failures of relay coils left open some battery circuit and when a grid interruption occurred, power was interrupted creating a major network failure. It was decided to stop the trial. Later, a trial was restarted in lab in the 2000s in a collaborative study with an important LA battery manufacturer to compare floating mode and intermittent recharge on brand new VRLA design. As the comparison can be very long, it was accelerated by temperature cycles. The trial has clearly shown through

⁴ Orange France network equipment consumes about 40 MW of permanent power. Half is in urban centers fed by Diesel and 3 hours battery back-up autonomy and half in rural centers with 12 hours battery autonomy. The battery capacity is about $20 \times 3 + 20 \times 12 = 300$ MWh, that can be roughly doubled for group i.e. 600 MWh.

Orange has about 120.000 mobile base stations (BS) in Europe and in Middle East Europe (MEA) consuming about 3 kW. About 50% are in Europe on good grids with autonomy between 0.5 and 8 hours (2 hours in average). 45% are in MEA on bad grid or on HGB systems with autonomy between 1 to 18 hours autonomy (6 hours in average). 4000 are powered by pure solar systems with 1 kW and 5 days autonomy. This leads to: $60.000 \times 3 \times 2 + 54.000 \times 3 \times 6 + 4000 \times 1 \times 24 \times 5 = 1812$ MWh

Datacenters adds about 60 MW with 1 hour autonomy i.e. 60 MWh

monthly capacity tests an increase of lifetime by intermittent charge versus floating, and also energy saving, but after 6 months the battery plastic envelopes have not survived to thermal cycle and the trial was stopped.

Other work on LA batteries better management was on state of health determination by impedance measurement and different testing as referred in [5], but at this time the best solution remains mid-point battery or 12 V block voltage measurement and discharge test of one of the redundant battery at a time to maintain system availability level. This work has resulted in a strong specification in each bid of Network Element that it shall avoid load transfer from one redundant power input say A when voltage is decreasing to the other say B. This was also verified for 400 VDC VRLA batteries as reported in [3], as well as possible test report using control monitoring standard [4].

C. Advanced LA batteries

Recently, the focus is on advanced batteries grids for high temperature floating and cycling such as in HGB system. Pure lead VRLA batteries can withstand some partial charge and can accept high current fast charge. Carbon add to Negative Active Material for LA batteries, first works were done in 2000's for start&go application as it can accept partial state of charge and fast recharge as LiB. It is used in electric grid for primary Energy Storage Reserve. Experimentations are done in Orange in hybrid PV system to replace tubular lead OPzV e.g. in Souge BS of Bordeaux. Lead-carbon may offer a high cycle performance and low cost but an issue may be water consumption due to carbon and calendar life. More is said in HGB example in this paper.

Cristal or Silicon battery is a LA battery type with electrolyte of lower density acid and specific alloy and active material. They may work in Partial State of Charge (PSoC), survive to full discharge and have very low self-discharge at high temperature. For now, only one limited test has been done in Orange but has not shown a clear benefit in cycling performance and cost maybe due to long and complex manufacturing.

Among many R&D based on lead, bipolar LA should show higher performances but they are not available even for Lab tests.

D. NiCd and NiMH

Manufacturers have proposed to Orange to replace LA batteries by Nickel based technologies. NiCd long experience return has proved its extreme performance at very cold climate and excellent reliability and lifetime advantage at hot temperature. But the much higher initial cost was not yet compensated by lifetime improvement as there was maintenance for still water refilling compared to VRLA in south of Europe. It may have been different with floating NiCd batteries that requires not more frequent water care than the period of replacement of VRLA, however, the cost advantage is not clear compared to new LiB solution.

In MEA, in general we need high temperature cycling operation on bad grid or HGB, and in that case cycling NiCd batteries are proposed but it requires water refilling every year or two years and in that case they are in competition with advanced LA or LiB or hot sodium. It is different for off-grid mobile network solar powering. Orange has a NiCd battery under test in a very hot part of Senegal on a 1 kW solar radio based station and it has been verified that NiCd has no issue even with more than 12 months delay of

installation compared to other technology as NiCd is not impacted by over discharge. In addition, the refilling period higher than 12 months is interesting compared to 3 months period for vented LA tubular solar batteries.

E. LiB investigation and tests

In 2000's, Orange Labs has received in the past from several LiB vendors prototypes of early Li-ion batteries but they were not operable because no BMS was provided, or it was not adapted. For some of them, cells are still working after 10 years of shelf storage at lab temperature without recharge which is quite noticeable.

A hot Lithium-metal was also tested, but the Canadian company has disappeared. It was in standby at 40°C and fully operated at 60-80°C, which means some no load consumption if ambient temperature is lower than 40°C and some minutes to reach full performance which is a problem for instant back-up use. A French company is now proposing a thin film hot Lithium-metal battery used in electric cars but it needs inefficient 60 °C preheating

Some LiB 48 V modules are tested since 3 years in Lannion Lab (Fig. 1) and on the field in Ivory Coast for back-up of curb telecom cabinet with high internal temperature and not sufficient volume for VRLA. The early supplier of 48 V 4 kWh Li-NCA modules shows only 3% capacity loss after 1000 cycles at 30% DoD cycles at 35 to 40°C.

Other tests have just started on LFP 19 inches 48 V racks of 50 to 200 Ah at 35 to 40°C.



Fig. 1. Testbeds in Orange Lannion Lab on LiB racks or packs

F. Selection of Li-ion and test for Soogreen EU project

Soogreen EU project [7] target is to enable smart energy services from Telecom power system for smart grid or off-grid solutions and for that to select the best current stationary battery based on O&M, maturity and cost criteria. A benchmark review was done and LFP was selected as the best trade-off for hot cycling application considering the high safety of LFP cathode with Carbon anode, the good cycling performance at 35-45°C and tolerance of higher temperature as verified in tests of various suppliers of prismatic LFP cells of nominal capacity 8 Ah, 60 Ah and 90 Ah. In addition LFP does not use Cobalt as detailed in § V. As an interoperable solution as lead-acid is highly wished, prismatic LFP cells (Fig. 6) were chosen and a lab test bed was built. In addition, a fast commissioning is required due to high initial capacity dispersion shown on Fig. 2 even with low self-Discharge (2.5% to 2.7% after 2 years on shelves at 20 to 30°C in Paris Lab and a significant unbalance after some cycles in deep cycling mode is observed without BMS.

Thus, an efficient high current charge balancing BMS is required.

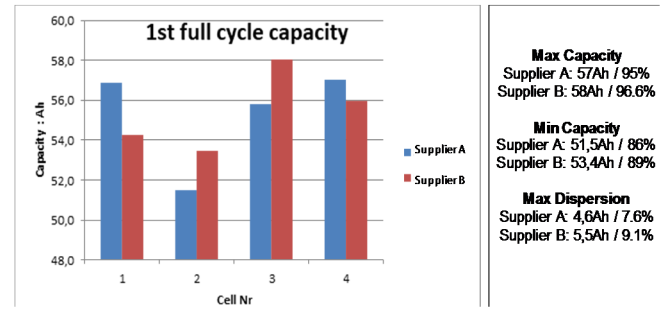


Fig. 2. Cell capacity at first full cycle after long storage

First tests were achieved on some 8 Ah cells from one vendor. The efficiency remains above 90% after 4300 cycles at 100% DoD at 0.4C rate as shown on Fig. 3.

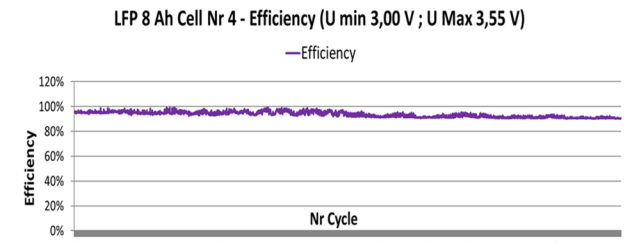


Fig. 3. Efficiency evolution with 100% DoC cycles of 8 Ah LFP cells.

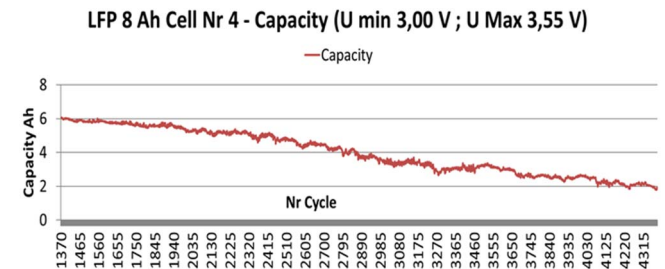


Fig. 4. Capacity degradation slope at 100% DoD cycles of 8 Ah LFP cells

The capacity degradation by cycling test is linear without sudden death till 30% residual nominal capacity (Fig. 4). Second tests were achieved on a batch of 60 Ah LFP cells from different vendors (Fig. 5).

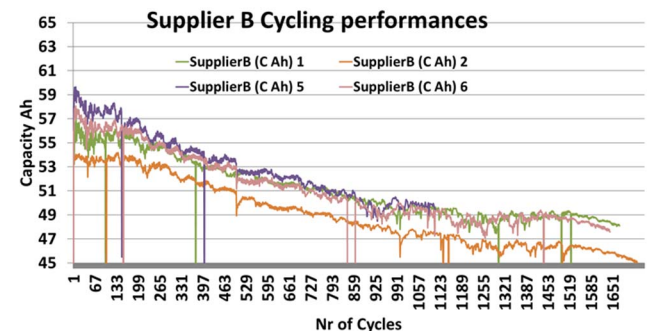


Fig. 5. Capacity evolution with 100% DoC cycles of 60 Ah LFP cells.

A capacity loss of about 16.5% is observed after 1500 cycles at 100% DoD at C/3 rate (3 cycles per day at 20 A charge and discharge current). The reduced slope at end of test is due to temperature increase.

The cells cycling test is achieved inside an outdoor plastic box (see Fig. 6). A difference between external temperature and battery cell of 10 to 15°C is measured from 0°C to 50°C which is the operating temperature range of LFP. It is observed that the temperature gap is higher at 20°C compared to 40°C. There has been no thermal runaway up to 50°C and without thermal management. It is possible to charge below 0°C at reduced current.

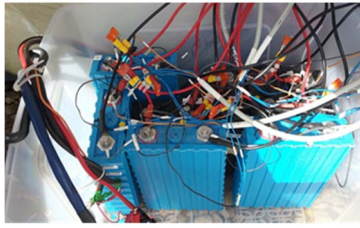


Fig. 6. Thermal box for hot cycling test of 60 Ah LFP cells.

At average temperature around 40°C, the cell capacity drops of 5% within 450 cycles while the capacity loss is 3% within the 1050 cycles at 23°C average temperature (capacity calculated at 25°C). The thermal sensitivity of capacity is quite obvious on Fig. 7. The capacity degradation slope is similar from 20°C to 35°C.

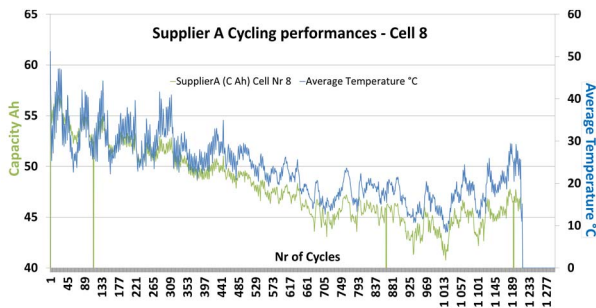


Fig. 7. Thermal sensitivity of capacity of 60 Ah LFP cells

The charge was found endothermic at 0.3C rate as the cell temperature decreases of 1°C to 5°C according to the supplier.

At about 1000 cycles on the 8 tested cells a rest time of 15 min after charge and discharge step has been added to the initial 10 seconds rest time and capacity degradation has stopped to decrease. But as temperature increases and capacity increases with temperature, the rest time effect is not clearly quantified. It would require long tests at different constant temperatures.

BMS (Battery Management System) design.

In LA batteries, the cells charge equalization is obtained by a slight battery overcharge by increasing the charger voltage, that it is not possible for LiB as some cells will see an overvoltage and be destroyed or become unsafe. Thus, a complex electronic BMS managing each cell voltage is required. But it was found that existing BMS do not fit because:

- “passive” BMS cannot compensate the charge dispersion in cycling use as high current cell discharge in resistance would create lot of heat dissipation.
- handling of short circuit or battery paralleling impose costly additional electronic and training.

Consequently, Orange Labs has implemented a BMS simulator for better analyzing and tuning an “active” (non-dissipative) high current balancing solution in charge and

discharge modes on LFP cells. The BMS simulator can manage a 12.8 V battery made of 4 LFP cells of 3.2 V and 90Ah nominal capacity (C_n) in series. Based on microcontroller and power electronic (Fig. 8), it can safely control charge, discharge and balancing in voltage and current at battery and cell levels (C1, C2, C3 and C4).



Fig. 8. BMS simulator installed on the battery

Balancing is achieved by a unidirectional step-down converter during charge and discharge based on cell voltage difference. The Fig. 9 shows the results of test 1 that, after tuning the algorithm the capacity is stabilized at 81 Ah i.e. 90% of C_n with a partial charge without a Constant Voltage (CV) charge.

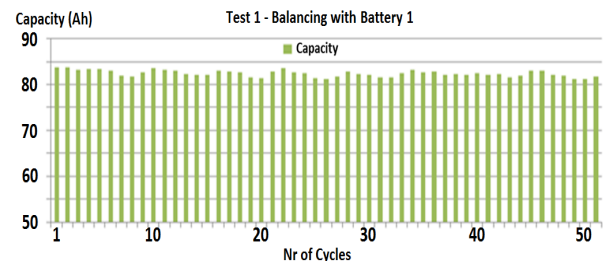


Fig. 9. Capacity evolution over 8 days cycling (about 50 cycles)

Test 2: the previous test is completed by full charge (CC + CV current and voltage charge modes). A balancing DC/DC converter ends the charge of each cell in CV mode at 3.55 V for a defined time. The Fig. 10 shows capacity improvement to 86 Ah i.e. up to 10% more than in test 1 and 97.7% of C_n .

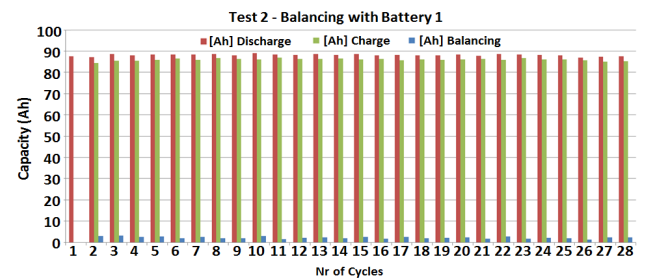


Fig. 10. Battery 1 capacity evolution over cycles

Test 3: the test 2 procedure is applied to a second battery with cells having different SoH: 3 with 87 to 88Ah / 3.2 V and one weak cell with 63 Ah / 3.2 V. The Fig. 11 shows that the battery 2 capacity can be stabilized at a minimum of 72 Ah (i.e 80% SoH) with an important balancing contribution. With a legacy BMS, the battery capacity would have been limited to 63 Ah (more than 10% less capacity available).

→ The high current balancing maintains performance and gives time to predict failure and repair.

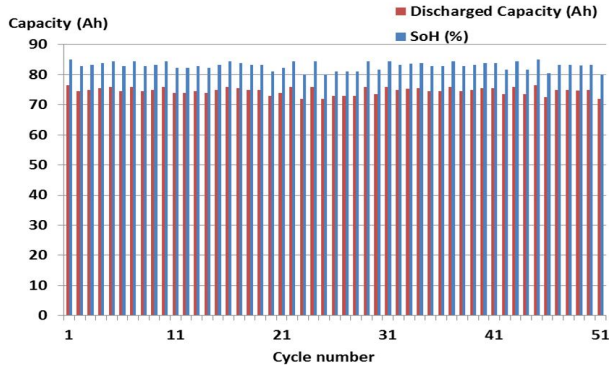


Fig. 11. Battery capacity evolution over cycles

In addition a previous lab test on a small 8 Ah 4 cells LFP battery has shown that a bi-directional balancing would improve even more the battery SoH, the global energy efficiency and reduce the charging time. This approach was not tested on 90 Ah batteries as the bi-directional balancing circuit was not available.

Short-circuit and paralleling management should be also taken into account when this will be applied to 48 V LFP batteries

G. NiZn investigation and tests of SCPS samples in Orange

Initially launched by Edison from earlier patents in early 1900's, the issue of NiZn has been short circuits by zinc dendrites until 1980 and 2010 patents by US company and essentially the French SCPS [9] provide solutions. The NiZn have power, efficiency and thermal performance of NiCd and energy density of NiMH due to cell voltage as high as 1.65 V compared to 1.25 V of other Nickel batteries. Orange has made in 2015 and 2016 tests of 10Ah cells and 12 V blocks samples with SCPS:

- daily cycling at 35°C and 80% DoD on 12 V block for solar application : 20% capacity loss after 500 cycles.
- ultrafast cycling cell test at 35°C (12 cycles per day at 100% DoD): 30% capacity loss after 1000 cycles

The life on shelf and floating have not been tested.

A worldwide manufacturer has bought patents and made pre-industrial cells with improved performances.

IV. NEW ITU-T & ETSI STANDARDS ON ENERGY STORAGE

A. Battery test method standards for stationary ICT use

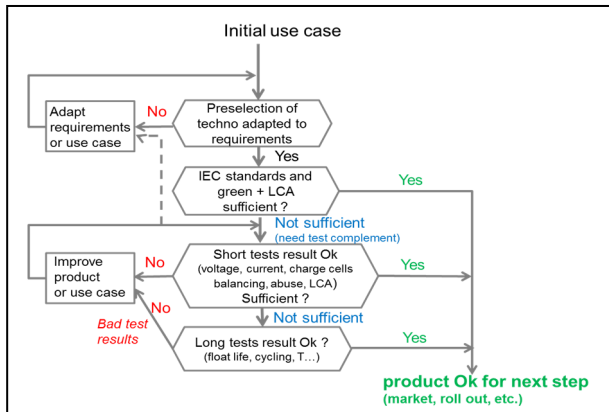


Fig. 12. ETSI and ITU-T selection and test flowchart method

ITU-T SG5 and ETSI EE have joint work on standards documents series helping to make the right energy storage technology selection for stationary use in a defined Telecom/ICT application use case. It is based on systematic review of technologies and on an evaluation and test method defined in [8] and summarized by the flowchart of Fig. 12 for accelerating selection of a stationary battery adapted to ICT use case application.

B. Example of application of the standard on HGB use case

The standard will be better understood on example. e.g. HGB. HGB is a difficult application in terms of battery performance and lifetime requirements as major use is in hot thermal environment in a criteria table. Then a matching work is done to determine which technologies can match the application requirements as reported in TABLE I. example based on the discussion that follows. Candidate technologies such as advanced LA, hot NaNiCl, LiB types and as challenging advanced Nickel based batteries are seen as the most promising solutions not all at the same maturity level.

TABLE I. ITU-T AND ETSI MATCHING TABLE FOR APPLICATION

HGB application		Considered Technologies results ^a				Need more check
Criteria	Level	pure LA or carbon LA	NaNiCl	LFP	NiZn	
IEC standards	E	Ok	?	Ok	?	test NaNiCl NiZn
Efficiency	T+ E	>80%	>70%	>90%	>80%	test NiNaCl
35-40°C cycling life	E+ T	2000 to 5000 cycles at 50%	3000 cycles at 80%	2000 to 5000 at 90%	2000 at 100% in Lab	test for sure value
PSoC acceptance	T	How much?	full	full	full	test LA
Self-discharge & restart	T	sulfation risk	20% /day 24h restart	under voltages tress?	passivation?	test or review spec
O&M as VRLA	T	full	no	unclear	yes in Lab	test LFP
stress tolerance	E+ T	full	?	unclear	full	test NiNaCl, LFP
operation with 1 fault	T	yes	unclear	unclear	yes	test NiNaCl, LFP
CAPEX /TCO	E	ok	unclear	maybe	?	test all except LA

Advanced LA batteries: Pure lead thin plate AGM VRLA are well-known for their high recharge rate and operation at 45°C are adapted to HGB application but cycling performance is lower than tubular LA with 2000 cycles at 50% DoD. Lead-Carbon batteries offer a better acceptance of PSoC and claims over 5000 cycles at 50% DoD at 25°C but they have relatively high self-discharge and consumption of water that can reduce cycling lifetime above 35°C and the return of field experience is still pending.

Another major issue of LA technology is theft as lead is easy to melt and resell, or blocks are easy to reuse. It needs to solve this e.g. by GPS trackers. If not, this will highly increase the mean TCO.

Hot battery NaNiCl (melting electrolyte salts at about 300°C inside ceramic cells) was developed within the

ZEBRA program (Zero Emissions Batteries Research Activity) for Electric vehicles (EV) but is today only used in some buses. The new marketing goal is stationary cycling application as life is as high as 5000 cycles at 60% DoD at 55 °C in addition to good PSoC, high energy density (80 Wh/kg and 80 Wh/l) giving a reduced footprint, and full recycling of material while not easy for thieves.

However capacity and cells balance are strongly impacted by discharge power. The 3 hours discharge gives only 60% capacity of the 10 hours one. The charge is also slow: 30 to 80% in 3 hours and 20 to 100% in 8 hours.

About efficiency, let's consider the case of HGB powering a common 3 kW BS with a genset of 16 to 20 kVA and 12 hours cycling (2 cycles per day) of 4 hours partial charge at 60% capacity and 8 hours discharge at 3 kW i.e. 24 kWh. The battery capacity is then $24/60\% = 40$ kWh e.g. 3 batteries of 15 kWh in parallel.

The electrochemical energy efficiency is 85%, thus, the charged energy per cycle is $24/85\% = 28.2$ kWh. The heat loss to ambient air of a 15 kWh battery is given as 120 W i.e. 2.9 kWh per day (19% of battery capacity). This heat will come from chemistry charge/discharge losses or from the heater and is of $3 \times 2.9/2 = 4.35$ kWh⁵. The system efficiency is $24/(28.2+4.35) = 74\%$ which is correct. The lifetime would be 5000 cycles / (2×365 cycles/year) = 6.8 years.

However, commissioning or restart time from cold state is long (10 to 24 h)⁶, so the MTTR (meantime to repair) to avoid internal freezing after a discharge should be limited to 2 days due to fast self-discharge in the heater. Finally the battery Capex about 4 times higher than Lead-acid raises a financial risk issue.

Li-Ion batteries have the advantage of high cycling performance and PSoC acceptance for all the different variants Nickel Cobalt Aluminum (NCA), Nickel, Manganese Cobalt (NMC), Lithium Manganese Oxide (LMO) or LFP. Carbon negative can offer up 5000 cycles at 90% at module level. Future Lithium Titanate Oxide LTO should offer up to 10000 cycles. Efficiency is as high as 90% and reduced self-discharge allows long shelf period. The major observed choices are LFP or NMC, but the increasing cost of cobalt could push LMO forward. However LiB depends on electronic reliability for safety and performance (see BMS discussion in §III.F) and BMS communication protocol with the charging system can be an issue. In addition acute technician training is requested for O&M and TCO is not always optimal compared to LA batteries due to high initial costs of LiB. The fast moving technology could also afraid decision makers.

Nickel technologies could be also an option. NiCd is reliable and doesn't need frequent water refilling at high temperature but it suffers from Cadmium management at end of life in MEA. NiMH is also very performing though less robust than NiCd and more expensive. Recent metal hydride alloys may change this in near future. NiFe has a low efficiency as it needs frequent water refill. SCPS NiZn [9] is under pre-industrialization by a major manufacturer

and could compete in near future as it is equivalent to NiCd (more than 1000 cycles at 100% at 45°C) with PSoC acceptance, high discharge power and fast charge of 1 hour at high efficiency of 85%. It has the same O&M as LA or NiCd and the cost perspective should be less than twice the LA cost if confirmed.

I. ENVIRONMENTAL IMPACT AND CIRCULAR ECONOMY

Regarding batteries environmental footprint, the potential issue is on raw material supply. For main elements, Obased on [24] presents the situation.

Main battery element availability

Material	Mt / year (mines/total)	reserve (Mt)	Used in batteries	Year
Lead	4.8/11.6	88 to 100	71%	2016
Lithium	0.035	8 to 14	39%	2016
Graphite	1.2	215 to 250	8%	2016
Nickel	2.25	78 to 100	7%	2016

As presented in [14] compounds used for some LiB contain cobalt (e.g. in LiCoO₂), phosphate (in LiFePO₄) or vanadium (in LiVPO₄F), this one being also used in Vanadium redox flow battery). These materials are identified as critical in the 2017 European Commission Critical Raw Materials list [15] (EU CRML) because their production is concentrated in a handful of countries and their end-of-life recycling input rate is about null.

For Cobalt, in 2010-2014 period, 64% of 123.000 metric tons (t) of annual world production came from Democratic Republic of Congo [15] at cost as high as 95.000 \$/t in 2018 (London Metal Exchange). However, for these three materials the world reserves, estimated in [16], can supply the global demand for about 65 years for cobalt and 250 for vanadium and no issue is seen for phosphate in batteries compared to agriculture over-consumption of 150 Mt/year at 120 \$/t in 2018.

Likewise, for Li-ion batteries anodes graphite and germanium as substitute of silicon are cited in [14] as commonly studied materials. Both are listed in EU CRML but it is not so critical in the case of Germanium⁷ and graphite might be produced artificially from carbon.

NiMH batteries use two additives (Na₂WO₄ and Yb(NO₃)₃ x 5H₂O) cited in [17] containing materials registered in the EU CRML list: tungsten and ytterbium. The first additive is used to enhance high-temperature performance, whereas the second one increases the specific capacity. Ytterbium is also used in LFP batteries and is classified as a heavy rare earth element coming mainly from Minerals such as xenotime mined in the southeast Guangdong province in China [19]. In 2011 only 50 t of ytterbium was produced worldwide and reserves were estimated to about 1 Mt.

Vented LA batteries of higher end of cycling batteries range used in hotter climates [21] use antimony, another material in EU CRML, to stabilize the active material of the positive

⁵ The power required from the genset and rectifiers in 4 hours charge is $(28.2 + 4.35 + 3 \times 4 \text{ kWh})/4/85\% = 13$ kVA which is acceptable for a 16 or 20 kVA Diesel generator.

⁶ The ceramic alumina container of liquid sodium and in particular its sealed top only accepts very few and slow thermal cycles

⁷ Germanium extraction from coal ash and flue dust is not considered. From 2010 to 2014 China's germanium production accounted for 67% of the global supply with only 2% recycled. Germanium proven reserves in the USGS mineral commodity summary [16] are only estimated for USA and from zinc ore as low as 2500 t. For China it is 3500 t. With a 2017 world refinery production quoted at 134 t. The supply would be sufficient for about 45 years. However, global resources of germanium are estimated at 11000 t in zinc ores and 24600 t in coal ash and flue dust.[17]

electrode by adding 1.6 to 2.5% antimony in lead alloys. As for Li-ion and NiMH critical materials the issue with antimony is first of all production concentration (China supplied 87% of antimony at global scale from 2010 to 2014 [15]), and secondly low recycling rate (28% according to [15]) and finally based on [22], limited reserves (162 500 t produced in 2012 for 3.4 Mt estimated reserves).

In LA tin is also used for the positive electrodes in lead-tin-calcium alloy. Tin is not part of the EU CRML but is in the new 2018 critical mineral list of USGS [23] because it is identified as a key material for soldering alloys.

For LiB materials additional supply risk indicators such as future technology demand or substitutability are presented in [25]. All in all 11 indicators are considered to rank each material's supply risk. After normalization the main issue for a material like Cobalt is not about the available reserves but by-product dependency (Cobalt is mainly extracted as a by-product of Copper or Nickel [16]) and political risk (Cobalt is mainly produced in a country with very poor Worldwide Governance Indicator, Policy Perception Index and Human Development Index [25]).

II. CONCLUSION AND NEXT STEPS

Battery use in Telecom networks and datacenters is increasing with the spread of networks. LA technology is still largely dominant after more than 1 century due to low cost and acceptable electric and lifetime performance for back-up and cycling use applications. Hot climate and cycling use should bring opportunity for LiB to replace LA batteries in hot climate on bad electric grids, HGB or hybrid solar application. They may have more chances of success than existing NiCd with recycling issue in MEA. Among Lithium-ion LFP is safer and has a better LCA as it avoids using critical materials such as cobalt and nickel to be preserved for high energy density batteries for portable device and EV. Soogreen EU project has now defined conditions for massive adoption of LFP i.e. reaching same easy O&M as lead with cell replacement ability and a high current BMS. There may be also new challengers among advanced lead batteries if lifetime benefit is proved in the field. New industry level NiZn when available for test may be the green cycling battery with good TCO as NiMH is more expensive and as hot sodium batteries have less power acceptance and resilience. Metal-air or redox batteries are still at research level and rather complex. Research on energy storage is intensive with smart renewable energy and the list is open. The new ITU-T and ETSI standard of selection and test method should simplify and accelerate the decision process.

REFERENCES

- [1] J.P. Leblanc, D. Marquet – (PTT/CNET Issy les Moulineaux, France); G. Gatine (Merlin Gerin France), "The decentralized power DC unit in the energy system (Geode) for telecommunications equipments" IEEE/Intelec 1987
- [2] T. A. Dougherty ; A. P. Karpinski ; S. P. Lapp ; R. N. Kallok ; S. V. Natale ALUPOWER, "Aluminum-air reserve power unit for use in a 6 kW standby power system" IEEE/intelec 1995
- [3] D. Marquet, O. Foucault, J. Acheen, J.F. Turc (Orange), M. Szpek (Emerson network power), J. Brunarie (SAFT) "Pre roll-out field test of 400 VDC power supply: the new alliance of Edison and Tesla towards energy efficiency" IEEE/intelec 2011
- [4] ETSI EE standard "ES 202 336-1 to 12 Environmental Engineering (EE); Monitoring and control interface for infrastructure equipment; Power cooling, building of Telecom/ICT equipment;
- [5] O. Foucault, D. Marquet, (Orange Labs), "Testing battery state of health with portable metering devices", IEEE/intelec 2007
- [6] C. Campion 3C Projects, "Energy Storage Solutions Panorama for Telecom Stand-By applications", 3rd ETSI EE Workshop June 2015,
- [7] Rocha, H. et al., "SooGREEN: Service-oriented optimization of Green mobile networks", International workshop 2017. <http://dl.ifip.org/db/conf/wiopt/wiopt2017/1570349026.pdf>
- [8] ITU-T L.1220 series Recommendation (equivalent to ETSI standard TS 103 553 series) « Innovative energy storage technology for stationary use – Part 1: Overview" (published), Part 2: Battery and Part 3: Supercapacitor (unpublished)"
- [9] R. Rouget SCPS "Nickel- zinc battery znergy storage for stationary and mobile applications", 3rd ETSI EE Workshop June 2015
- [10] Emile Reygnier « Piles électriques et accumulateurs », Librairie Polytechnique Baudry & Co, Paris, June 1888, http://jubilotheque.upmc.fr/fonds-physchim/PC_000325_001/
- [11] E-mobility roadmap for the EU battery industry, The European Association for Advanced Rechargeable Batteries 2013
- [12] Moore laws https://en.wikipedia.org/wiki/Moore%27s_law
- [13] Marquet D, Foucault O, Pichon JM., Hirose K, Bianco C, Hockley R, "Telecom operators to accelerate the migration towards 400 volt direct current" IEEE Intelec 2017, Queensland.
- [14] N. Nitta, F. Wu, J.T. Lee, G. Yushin, "Li-ion battery materials: present and future" Materials Today, 2015
- [15] European Commission, "Communication on 2017 list of Critical Raw Materials for the EU", 2017
- [16] USGS, "Mineral Commodity Summary 2018", part Cobalt, Phosphate, Vanadium, Germanium, 2018
- [17] European Commission, "Report on critical raw materials", 2015
- [18] J.K. Fink, "Additives for High Performance Applications: Chemistry and Applications", 2017
- [19] USGS, "Advance release Rare Earths in 2015", 2015
- [20] F. Duncan, "Ytterbium", 2011, Royal Australian Chemical Institute
- [21] ITRI , "Lead-Acid Batteries Impact on future tin use - Technical Report 2017", 2017
- [22] BRGM, "Material criticality note – antimony – april 2015" (« Fiche de synthèse sur la criticité des métaux – l'antimoine – avril 2015 »), 2015
- [23] Fortier, S.M., Nassar et alii, E.A., 2018, "Draft critical mineral list— Summary of methodology and background information—U.S. Geological Survey No. 3359: U.S. Open-File Report 2018–1021", 15 p., <https://doi.org/10.3133/ofr20181021>
- [24] USGS Mineral Commodity Summaries 2017 <https://minerals.usgs.gov/minerals/pubs/mcs/2017/mcs2017.pdf>
- [25] C. Helbig, "Supply risks associated with lithium-ion battery materials" Journal of Cleaner Production 172 (2018) 274-286
- [26] IETF DMM Call#5, 2014, Next Generation Point of Presence (NG PoP) Driver for Digital MultiMedia (DMM) http://yegin.org/NGmobility/NGPOP_DMM.pdf