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Usage of Compressed Air Storage Systems

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ABSTRACT

Right from the start in the 19th century (BRAMAH-Patent in 1812), the energy storage by pressurized gas had to fight against the supremacy of the High-Tech of the moment (generally against electrochemical solutions ranging from the lead-acid batteries to the recent developments in Vanadium Redox Flow systems) and could be used only in reduced fields of applications (the first mining locomotive in 1860, the MEKARSKY trams in Paris, Nantes, Berne etc from 1876 on...to the first stationary bulk storage in cavities in 1977 at Huntorf): this was no firm base for an uninterrupted development.
Recently pressure was put on storage technologies for grid connected renewable energies, for peak shaving/UPS applications and in order to avoid shedding and black-outs: it seems obvious, that compressed air is among the cheapest methods of energy storage but the converter system based on turbines with fossil fueled heat injection (CAES) raises environmental questions and doubts about efficiencies: this report tries to show that there may be another way to tackle the converter system by using positive displacement machines, as it is conceivable to integrate heat-exchangers in the piston workchambers to reach a near-isothermal process which would guarantee premium efficiencies; this integration is really simplified if the reciprocator is a liquid piston (BOP-B principle). A strong and fast development effort would be needed, as a high-tech wave is rolling again, trying to impose the hydrogen electrolysis-fuell cell-cycle as ultimate storage solution. But this time the compressed air holds most of the winning cards as we face a system which hardly will exceed the 40 % mark against an expected 70 % for pneumatics if substantial investment is made in R & D; it also must be stressed that storage filling with BOP is much easier anywhere – you just need air, whereas for the electrolyzer you need a lot of clean water: this may be difficult to find on islands or in desertic areas!

ZUSAMMENFASSUNG

Seit ihrer Entstehung im 19. Jahrhundert (BRAMAH-Patent 1812) hatte die Hochdruck-Luftdruckspeicherung immer mit der jeweils vorherrschenden HighTech zu kämpfen resp. zu konkurrenzieren (meistens mit der Elektrochemie, von den Bleibatterien bis neulich zu Vanadium-Redox-Flow) und konnte sich deswegen nur in spezifischen Anwendungen durchsetzen (erste Grubenlok 1860, MEKARSKY-Tram in Paris, Nantes, Bern usw. ab 1876, stationäre Grosspeicherung ab 1977 in Huntorf...). Dies schuf bis anhin keine ausreichende Basis für eine zusammenhängende technologische Entwicklung.

Der in der letzten Zeit formulierte Wunsch, erneuerbare Energien in dezentraler Anordnung zu nutzen und die bestehende Netze mit lokalen Speichern zu stützen (z.B. zur Vermeidung von Blackouts durch Bäume), führt unweigerlich zur Frage nach einer preiswerten Speichertechnologie: dass die Druckluft unter Berücksichtigung der Speicherkapazität preislich unschlagbar ist, scheint allgemein anerkannt zu sein. Zweifel bestehen lediglich bezüglich der Wandlereinheit, die z. Zt. nur durch brennerunterstützte Turbomaschinen realisiert wird (CAES-Konzept) und somit die Frage nach dem Wirkungsrad und der Umweltverträglichkeit aufwirft: dieser Bericht basiert denn auch auf der Überzeugung, dass der Weg über Verdrängermaschinen (volumetrische Maschinen) die Lösung bringen kann, zumal hier der Schritt zur verlustarmen Isothermie relativ einfach durch Wärmetauscher in den Arbeitsräumen vollzogen werden kann, insbesondere falls diese aus Flüssigkolben bestehen (BOP-B – Konzept). Hier sind grosse Anstrengungen gefordert, zumal – wie oft in der Geschichte der Druckluftspeicherung – wieder einmal eine HighTech-Welle angesagt ist, in Form des Wasserstoff-Kreislaufes mit Elektrolyse und Brennstoffzelle; diesmal hat aber die Druckluft einige gute Argumente in der Hand, denn hier gilt der „Konkurrenzkampf“ einem Konzept, das nur mit Mühe einen Zykluswirkungsgrad von 40 % überschreiten kann. Wogegen bei der Druckluftspeicherung nach dem BOP-B-Konzept (BOP = Batterie mit Oelhydraulik und Pneumatik) bei entsprechender Entwicklungsinvestition über 70 % Gesamtwirkungsgrad erwartet werden kann. Obschon beide Technologien nicht primär dem Energietransport dienen sollen, ist doch die Druckluftproduktion vor Ort direkt ab erneuerbarer Energie oder ab Netz viel einfacher als mit der Elektrolyse, da hier kein besonders aufbereitetes Wasser zugeführt werden muss.

RESUME

Dès sa première apparition tout au début du XIXeme siècle (brevet de BRAMAH en 1812), le stockage d'énergie par air comprimé sous haute pression (accumulateur) eut à lutter contre la la technologie dominante du moment (donc en général contre les solutions électro-chimiques allant des batteries plomb-acide au dernier cri en redox-flow de vanadium), ce qui a toujours limité son champ d'applications (premières locomotives dans les mines en 1860, les tramways de MEKARSKY à Paris, Nantes, Berne etc à partir de 1876, pour aboutir au stockage en caverne de Huntorf en 1977) et n'a jamais permis une continuité dans le développement technologique.
Ce n'est que récemment que les exigences de stockage énergétique ont surgi pour connecter les énergies renouvelables au réseau, pour écrêter les pointes de consommation ou pour éviter les délestages. Or il apparaît clairement que l'air comprimé est une des méthodes les plus économiques pour le stockage, mais aussi que le principe du convertisseur sur la base du turbinage avec injection de chaleur générée par des brûleurs à combustibles fossiles (CAES) ne satisfait ni du point de vue écologique, ni du point de vue du rendement: le but de ce rapport est donc de démontrer qu'il peut exister une autre forme de conversion utilisant un principe volumétrique, car il est possible d'intégrer un système d'échangeur thermique dans les chambres de travail afin de s'approcher du fonctionnement isotherme qui est le garant de l'efficacité énergétique. Cette intégration est particulièrement simplifiée si le principe volumétrique est réalisé en utilisant des pistons liquides, ce qui est une des facettes du principe de la BOP-B. Un effort de développement fort et rapide est toutefois nécessaire pour faire face à la nouvelle vague d'une technologie qui se veut dominante basée sur le cycle de l'hydrogène par électrolyse et pile à combustible; certains semblent considérer cette technologie comme solution définitive pour le stockage, mais il apparaît que cette fois-ci l'air comprimé présente des atouts déterminants avec des rendements de cycle dépassant 70 % qui devraient être atteignables avec des efforts de R&D relativement modestes, à mettre en regard avec les 40% que l'hydrogène peine à dépasser avec un effort de de développement difficile à saisir en termes de temps et d'argent. Finalement soulignons que le fonctionnement de la BOP est pratiquement indépendant du site -- pourvu qu'il y ait de l'air -- alors que le cycle concurrent est tributaire d'une eau distillée de bonne qualité, denrée rare sur maintes îles, et ne parlons pas des zones désertiques

1. Procedure and initial situation

1.1 Scope of the project

Pneumatic storage ignores cycling limitations and the storage capacity economics (around 50 EUR/kWh in cavities up to 150 bar and approx. 70 EUR/kWh in industrial gas bottles up to 150 bar) features not only by far the lowest costs according to recent investigations, but also would reach full market acceptance in two main application fields: **THE SMOOTHING OF INTERMITTENT POWER IN GRID CONNECTIONS**, mainly for wind farms up to a power of 200 MW and a capacity of 1000 MWh, and the **GRID QUALITY MANAGEMENT** with peak shaving, spinning reserve etc for power up to 100 MW and capacities up to 20 MWh; in the lower part of this range, say up to 0,4 MW, the pneumatic storage could rapidly play its part in the new Distributed Generation grid concepts, as the hydrostatics (one of the main elements of the air-to-wire converter) is available off-the-shelf and can be integrated with little adapting effort. This market acceptability related to specific tasks and projects – e.g. for offshore wind farms – is of paramount importance, as it would be useless to have premium prices but no applications: here the storage is a condition for the application and vice versa.

A third application is the substitution of lead-acid batteries in small **STAND-ALONE MINIGRIDS** (1 to 10 kW with capacities ranging from 10 to 100 kWh), which can be competitive only if high manufacturing volumes are anticipated, as the mere clustering of standard industrial components would not allow to enter such an established market, which needs custom designed low-priced products. Nevertheless, when storage capacity-to-converter power ratio is high (e.g. multiple-week-storages or long-range terminals for telecom carriers or scientific monitoring), throughbred designs may not be compulsory as anyway the price relation will be favourable, and even more if life expectancy, transportation and recycling are considered. Such applications could be a favourable testbench for this new technology.
Last but not least we must name the **MOBILE APPLICATIONS**, where the use of carbon fiber wound CNG 4 cylinders yields outstanding specific energies when compared to lead batteries, combined with ultra-fast filling and almost infinite cycling: a storage volume of 1m3 at 250 bar would tank 28 kWh in less than 30 s in a vessel compound of 300 kg when empty. This must be completed by a 20 kW-converter (50 kg, 200 liters) to be flanged directly on a 4-speed gearbox; thanks to the high conversion efficiencies such a system would have a range of 150 to 250 km based on a standard ECE speed profile, of course with premium regenerative braking.

1.2 Partners in the project

The general aspects of storage and the particular technology of the **B**atteries with **O**ilhydraulics and **P**neumatics (BOP) were compiled by the EPFL (Prof. Rufer, LEI Lausanne) and Brückmann Elektronik (Davos) under the coordinating activity of Cyphelly & Co (Les Brenets). The specific aspects of thermodynamics related with the chosen topological and kinetic lay-out were performed by Philoceram/Menhardt KG (Vienna) relying on former work for an EC project with subsequent updates and expansions.

1.3 The Targets

This report should give an exhaustive overview about the technical and economic potentials of pneumatic storages, particularly about the advantages and shortcomings of the BOP concept and the market structure into which this product would be inserted; this is to achieve by compiling investigative data aboute the state-of-the-art and competing systems (e.g. from the INVESTIRE[1]-Network about Storages for Intermittent Power Sources) down to potential customer demands from utilities, windfarmers and solar suppliers. We look for a clear statement about the need and how pressing the storage issue really is, in opinion of leading scientific and commercial authorities.

1.4 The followed way

The basic information was gathered in a first round by visiting outstanding players in research and operation in the industry and the universities related with storage activities or with essential sub-technologies (Prof. Backé at the IFAS in Aachen, Dr. Täubner at the flywheel plant Rosseta near Dessau, Prof. Barth at the T.U. Clausthal, P. Achten at INNAS in Breda, R. Althaus at Alstom in Baden etc). With all theses specialists, the Investire data and the reports about a former trip to the US visiting installations and manufacturers were thoroughly commented and checked against own experiences and knowledge, yielding thus a deep insight in a patchwork form which was later put in shape by a „road map" with subsequent tasks for the project participants. The final drafting was made by each partner and the editing took place at the EPFL in Lausanne.

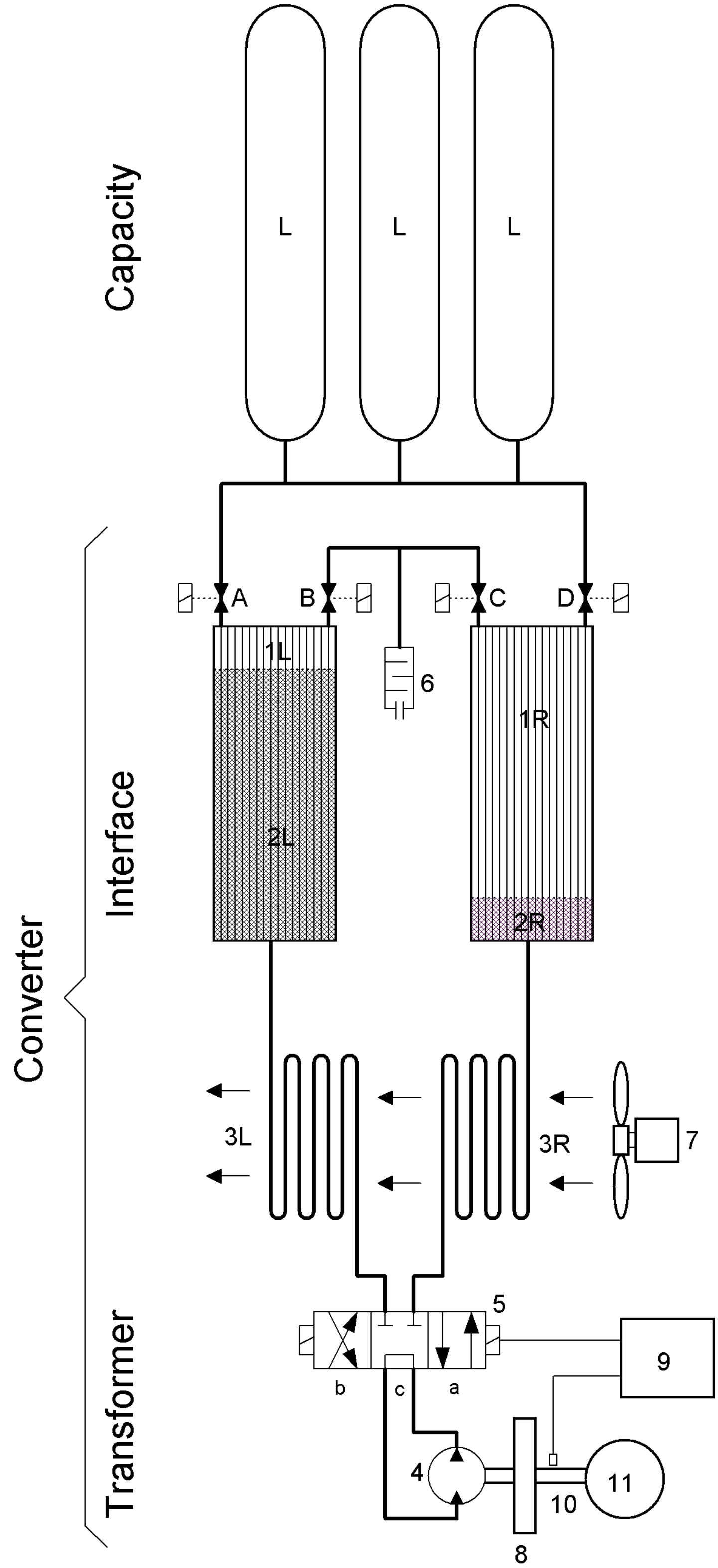
2. Technology (Working principle of the BOP-B concept)

In order to exploit all the promising features of pneumatic storages we need a converter (power package) which would compress or expand the air with high efficiency, acting as interface to standard forms of energy like electricity or rotating shafts. The key to high conversion efficiencies is to maintain almost constant temperatures during compression or expansion (a swerve of 30 ºC induces an efficiency drop of 5 %). So far, only positive displacement machines can be fitted with <u>heat exchanging systems in the workchambers</u> which would allow for such an isothermal behaviour; if the reciprocator is a liquid piston, the provisions for good and simple heat exchange are quite easy and reliable and efficiency grows as no seal friction is involved.

The working principle of the converter is shown in Fig. 1 in a strongly simplified manner in order to explain the sequences of a cycle: when the storage works as motor (expansion = discharge) the compressed air enters through the opened valve <u>**D**</u> in the workchamber <u>**1R**</u> of the right cylinder comprising the liquid piston <u>**2R**</u>, the said valve <u>**D**</u> being controled so as to admit exactly the portion of compressed air which – once expanded – will reach atmospheric pressure. The pressure established in the right cylinder is transmitted through the exchanger coil <u>**3R**</u> to the hydrostatics <u>**4**</u>, passing the 4-Way-Valve <u>**5**</u> which rests in the position <u>**b**</u> and thus activates the motor port. This leads to an expelling of the air in the workchamber <u>**1L**</u> by the return flow of <u>**4**</u>, which joins the muffler <u>**6**</u> through the opened valve <u>**B**</u>. We put emphasis on the fact, that the air in the righthanded workchamber <u>**1R**</u> is squeezed between metal plates when expanding: these metal plates just emerge from the thermally stabilized liquid, so the cooling down of the air will be seriously hampered (the same would

[1] INVESTIRE is an european Program, which checks all forms of energy storage, includes 35 partners and lasts from 2001 until 2004.

Simplified BOP-B layout



L	Pressure Vessels
A,B,C,D	Control Valves
1L, 1R	Workchambers
2L, 2R	Liquid Pistons
3L, 3R	External Heat Exchangers
4	Hydrostatic Pump / Motor
5	4-Way Distributor Valve
6	Suction-Exhaus Muffler
7	Exchanger Fan
8	Flywheel
9	Speed Control
10	Shaft
11	Motgen

Fig. 1

happen during compression, where a temperature rise would be limited, as the external exchanger **3R-3L** always tends towards the surrounding temperature of the fan air flow.
As the stroke ends, the 4-Way-Valve **5** inverts the interface flow by switching to the position **a** without changing the rotational sense of the hydrostatics, the inertia of the liquid pistons being negligible. This allows to place a flywheel **8** on the shaft **10** to avoid speed pulsation due to the succession of expansion or compression curves whose speed can be regulated modulating the rest in the idling center position **c** of the 4-Way-Valve in accordance to the speed sensor control **9**, generating in this way a genuine power control at the shaft **10** or at the motgen **11**. The same valve **5** can change the flux sense of power from charge to discharge with a switching delay of 20 to 30 ms, which is really small when compared to the rhythm of the interface (one stroke in 2-3 s, modulating pulses every 5 to 60 s).
The converter chain between air and wire consits of 3 steps: Air-Oil (called the interface, a) Oil-Shaft (hydrostatics, b) and Shaft-Wire (motgen, c), apart of small loss generators like the flywheel and the fan. In the kW range, efficiencies of 90 % for a, 95 % for b and 90 % for c are attainable without excessive R&D efforts, which would yield a two-way efficiency of 60 %. In the MW range, 92 % for a, 96 % for b and 95 % for c are reachable targets, but with strong development efforts: this would yield a two-way efficiency slightly over 70 %.
These efficiencies are also linked to the power control range and to the interface volume, so a vehicle with a 4 gear transmission would probably reach one-way efficiencies close to 90 % as the power control range is small and one conversion step is missing (the motgen).
For further details and the differences between BOP-A and BOP-B refer to the corresponding annex of the German version of the report.

3. Advantages, Matchings, Developments

Although the compound shown in Fig. 1 leaves out essential parts of the concept (the uninterrupted power transfer is only possible with at least two reciprocating stages, the piston fluid is not the hydraulic oil etc), this drawing is good enough to lay stress on the advantages according to the applications and to count all the development tasks involved:
The most obvious advantages of BOP storages are:

- only two stages are needed to reach highest pressures (in standard multistage piston compressors the stage number is determined by the heat-up in every piston (max. 150 ºC), which leads to 4-5 stages for 250 bar with the corresponding losses: even if the stage efficiency reaches 90 %, a 5-stage compressor will hence stay globally under 60 %).
- The power matching mechanism is inherently integrated in the mechanism and offers easy adaptions for many applications.
- The power package is separated from the storage capacity, and is thus an independent design parameter: big power can be combined with small storages.
- For the accurate energy monitoring a simple pressure gauge will do.
- Most constitutive elements of the BOP are well-known designs which will not surprise in terms of reliability or costs: high pressure gas steel bottles are produced since more than 100 years and hydrostatics as efficiency-setting

component is really mature, thoroughly understandable and analysed both theoretically and statisticallly in many applications (the efficiencies reach currently 95 % in a broad speed and pressure range, the latter can even be expanded by specific designs).

The only non-standard part of the BOP-B is the Interface, which will CONCENTRATE MOST OF THE DEVELOPING EFFORT:
The tasks can be classified as follows:

- iterative approach to the various workchamber heat-exchanger concepts, designing all the details under consideration of liquid and gas behaviour.
- Optimizing the materials under both the physical an chemical aspects, considering gas diffusion in the liquid, capillarity phenomena, foaming, pollution, ageing in function of the material choices etc
- Development of the airside valving and of its electronic management, avoiding dynamic back-lashes on the transformer part of the converter.
- Creation of the control concept and dosage algorithm for the high pressure intake air valve for the expanding phase.
- Conception of a topologically optimized lay-out of the interface components
- Programs for detailed behaviour prediction and modelling of the global dynamic response of the converter.

The whole converter is certainly not so intricate as say a diesel engine, moreover its constituents are not so imbricated as for an ICE, which allows for a quite independent development work on each element and offers a certain choice possibility of the integration concept in harmony with the applications. Anyway, a strong development work must be performed on all elements of the converter chain: the motor/generator (motgen) with its electronic commutator, the hydrostatics (with a possible integration of the valving and clutching effects with reduction of the idling losses, combined with a thrust compensation on the bearings to enhance life figures), the fan and its control and last but not least on the flywheel, whose helium enclosure and forming already have generated impressive improvements at the preliminary development stage

4. Markets and Players

Analysing the 4 identified storage markets (grid injection of renewable energies, grid quality/UPS, stand alone and mobile) it is obvious that only two of them have established markets:
The stand alone minigrids use almost exclusively lead-acid batteries with known shortcomings like fast ageing (reduced cyclability), unreliable state-of-charge monitoring and unsatisfactory environmental impact (the manufacturing of the batteries swallows more or less the same energy as the storage capacity multiplied by the attainable life cycle number), which disqualifies this technology for sustainable operations in warmer countries. These shortcomings appear even more crudely in the mobile applications, leading to the electric vehicle market collapse before real growth started; only the new hybrid solutions may bring a revival which would exceed the standard fork lift/traction/AGV turnover.
The manufacturers are the big automotive SLI suppliers, which offer somewhat modified standards for the stationary market with really competitive prices (except for top class applications like UPS, where tubular batteries form the expensive top of this technology – without really living up to the expectations: a chance for BOP?).

According to this fuzzy situation, it is dificult to separate these fields from the big automotive turnover, but the guess is that 10 % is a maximum, which means a mere 300 MEUR.

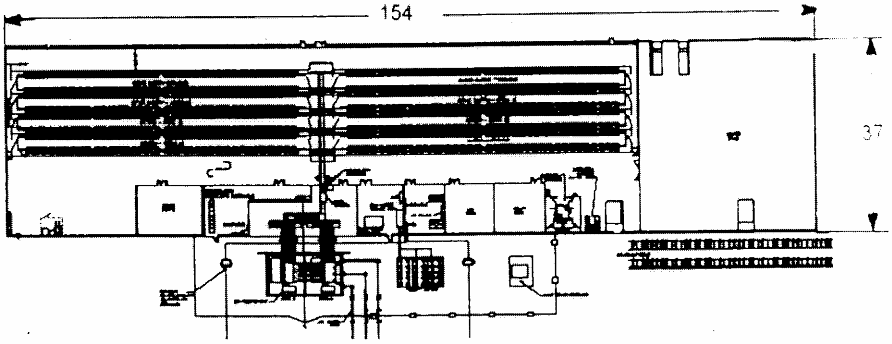
In the realm of big storage plants the review is really simple, as the situation can be qualified as pre-emerging: only two elder large-scale CAES plants (the 290 MW Huntorf 1978 and the110 MW McIntosh 1991) based on fossil fuel booster would be able to tackle the offshore farm challenge thanks to their power range; for grid quality management – which is basically a big UPS for utilities – only less than 20 installations are known with more than 1 MW transfer power, the newest being also by far the strongest with 40 MW for Alaska‘s Golden Valley BESS (end of 2003). For the big majority of these storages lead-acid was the initial bet, but since 1997 only NaS systems are commissionned with the exception of some Vanadium-Redox-Flow plants (like at Sumitimo SEI) and the NiCd stack at Golden Valley.

Deep and long-haul operating experience exist only for lead-acid battery systems (which obviously were a big struggle against cell failures, see # 8 on Fig. 3); this is the reason why no reliable data about operating and maintenance costs can be found and hence no clearly defined competitior has emerged; perhaps the *true contenders are the electronic power control inverters against the synchronous motgens,* as all solutions facing the BOP rotating shaft challenge are based on electrochemical low voltage storage which must be electronically transformed for grid connection. But the cost ratio between electronics and electromechanics lies somewhere around 4: combining this with the low prices of the volume capacity we can see that *thanks to the BOP-B pneumatic storage the conquest of this market can be unleashed,* as until now the technologies offered solutions lying miles away from the needs of the utilities or the wind farmers. This can be seen on Fig 2, where we compare the Golden Valley lay-out to BOP-A and BOP-B installations based on the same specifications.

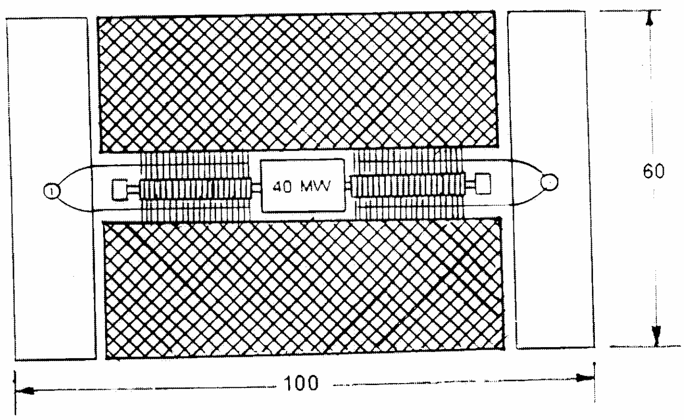
Finally, let‘s mention the Vanadium-Redox-Flow technology, whose published features at least partially move towards the good BOP-B characteristics (power package separated from the storage volume, high cyclability, acceptable energy monitoring etc) and could be a competitor. But this technology stumbles over contradictory data reporting, which induced the project team to investigate this matter thoroughly (see the corresponding Annex of the German version of the report). The resulting comparison between the main storage technologies can be found in Fig. 3.

STORAGE SYSTEM COMPARISON based on the Golden Valley project 40 MW / 13,3 MWh (last update 29-01-2004)

NiCd Golden Valley: ***30 MEUR***, including 13'760 units of SAFT SBH 920 Ah, *5698 m²*



BOP A with steel bottles: ***17,84 MEUR***, outline shown for a 2m height: *6000 m²*
5320 m³ of bottle capacity @ 2 EUR/ℓ for 250 bar max = 10,64 MEUR
40 MW sync. motgen with ancillaries = 2 MEUR
80 fixed displacement 0,8 ℓ/rev clutchable reversible hydrostatics = 1,2 MEUR
2500 m³ of oil = 2 MEUR
ancillaries, controls, piping, flexible reservoirs = 2 MEUR



BOP B with steel bottles: ***9,91 MEUR***, outline shown for a 2m height: *2496 m²*
475 m³ of bottle capacity @ 2 EUR/ℓ at 250 bar max = 0,95 MEUR
40 MW sync. motgen with ancillaries = 2 MEUR
56 fixed displacement 0,8 ℓ/rev clutchable reversible hydrostatics = 0,825 MEUR
56 reciprocating multipliers/separators = 0,385 MEUR
56 interfaces with controls and ancillaries = 2,75 MEUR
piping, valving etc = 3 MEUR

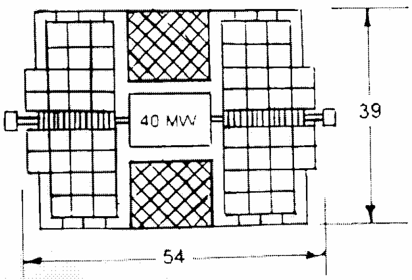


Bild 2

Fig.3 : COMPARISON OF STORAGE TECHNOLOGIES

PARAMETER	BOP A	BOP B	TUBULAR PLATE	VANADIUM FLOW
Specific energy per volume (with ancillaries)	1,6[1] Wh/ℓ	24[1] Wh/ℓ	13[2] Wh/ℓ	5,6[3] –20[9] Wh/ℓ
Specific energy per weight (with ancillaries)	1,75[1] Wh/kg* 3,3[1] Wh/kg**	23,2[1] Wh/kg* 50,0[1] Wh/kg**	6,5[2] Wh/kg	5,45[3] - 9[9] Wh/kg
Efficiency (two ways): Wire-to-Wire / Shaft-to-shaft	0,68[1] 0,84[1] with conversion	0,6[1] 0,68[1] with conversion	0,8new – 0,6old 0,65new – 0,5old without conversion	0,63[3] - 0,7[5] with conversion
Cost per Storage Capacity	920[6] € /kWh	50[10] -71[6] € /kWh	200[7] € /kWh	200 -360[7] € /kWh
Converter Cost (> 20 MW into Grid)	130[10] € /kW Motgen+Hydr.	284[10] € /kW Motgen+Interf. Hydr.	€291[6] /kW Inverter	1000[5] € /kW Stacks+Inverter.
Operating Liquid Needs Sump Tank	Oil 50%Vol. YES	Oil some ℓ NO	Acid 54% of Vol. YES	Electrolyte 90%Vol. YES
Cyclability	over 15'000º over 100'000ºº	over 15'000º over 100'000ºº	3000[2] yields cited Wh/ ℓ - figures	>>2000[7]
Discharge and Forget	YES	YES	NO	YES
Fast Filling of smaller Storages	NO	YES	NO	YES
Accurate SOC Monitoring	YES	YES	NO	ACCEPTABLE
Extension of Storage with added Elements	Any Age Same Height	Any Age Any Size	No Mixing of Ages And Sizes	Any Age and Volume
Temperature Range	- 20°C → 50°C[1]	- 10°C → 50°C[1]	- 10°C → 40°C[9]	- 10°C → 40°C[9]

We compare here both BOP systems to tubular plate lead-acid batteries and Vanadium-Redox-Flow systems, as all other technologies either are too expensive or lie too far away from mainstream specs (this concerns the electrolysis-fuel cell cycle with its bad efficiency and uncertain life figure, the Li-Ion with its safety electronics, the Lithium-Metal-Polymer with its astronomic pricing etc).

These comparison charts must be handled with extreme caution, as many authors mingle OEM pricing with retail sales and manufacturing costs; very often the figures result from copying in an undiscriminating way, so we decided to indicate the source for every number; here the reference key:

1) Basic physics, computed by Dr. Menhardt, a member of the team
2) Hoppecke brochure for OpzS Solar 350 at 3000 cycles with I5 and 40 ºC (DOD 28 %)
3) *A. Buonarota* Traditional & Advanced Energy Storage, CIRED Barcelona, 12-15 May 2003
4) *M.Skyllas-Kazacos* Rec. Progress w. UNSW VRB www.ceic.unsw.edu.au/centers/vrb/vanart2a.htm
5) *J.H.R. Enslin* In Store for the Future? Renewable Energy World Jan.-Feb. 2004, Vol 7, # 1
6) Commercial offer for Standard Gas Steel Bottles from *Vítkovice Láhvarna,* 14-05-2002, see º)
7) *M. Villoz* BfE-report about the INVESTIRE Network progress, Nov. 2003
8) *SAND 99-2232* Lessons learned from the Puerto Rico BESS
9) *C.J.Rydh* Environmental assessment of VRB and lead batteries, J. Power Source 80 (1999)21 29
10) ABB & Alstom Baden, data about sync. Motgens and Storage Cavity Pricing by e-mail 2004-05-11

º) Standard Steel Gas Bottles according to BS EN 1964-1:2000 or CNG 1 Cylinders ISO 11 439

ºº) CNG 4 Carbon Fiber Wound Cylinder ISO 11 439

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