# REVIEW OF THE STATE OF-THE-ART OF TARGET BALIHT'S BATTERY COMPONENTS AND PATENTS

31 MAY 2020

WP1 DEFINITION OF REQUIREMENTS OF SELECTED BATTERY COMPONENTS TO BE USED IN WARM ENVIRONMENT APPLICATIONS AND REQUIREMENTS OF PROTOTYPE BATTERIES TO BE INSTALLED

DELIVERABLE D1.1

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# DELIVERABLE REPORT

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# TABLE OF CONTENTS

# LIST OF ABBREVIATIONS

| Abbreviation | Definition |
|---|---|
| BESS | Battery Energy Storage Systems |
| BMS | Battery Manager Systems |
| DERMS | Distributed Energy Resources Management System |
| DER | Distributed Energy Resource |
| DG | Distributed Generation |
| DMS | Data Management System |
| DSO | Distribution System Operator |
| ESS | Energy Storage System |
| EMS | Energy Management System |
| FRCS | flow rate control strategy |
| GUI | Graphical User Interface |
| HMI | Human Machine Interface |
| HVAC | Heating, Ventilation, and Air Conditioning |
| IC | Integrated Circuit |
| IP | Intellectual property |
| PPC | Power Plant Controller |
| PV | PhotoVoltaic |
| RES | Renewable energy sources |
| RFB | Redox flow battery |
| SCADA | Supervisory Control And Data Acquisition |
| SOA | Safe operation area |
| SOC | State of Charge |
| SOH | State of Health |
| VAR | Volt-Ampere Reactive |
| VRFB | Vanadium Redox flow battery |
| WP | Work package |

# Executive Summary

This report reflects the contributions for all partners involved in the review of technical literature, patents and company brochures updated since the proposal stage. This review updates the findings presented in the proposal text (section 1.4) for confirming that no competitive commercial technologies appeared.

A deep review was done for organic electrolytes, membranes and carbon electrodes within the proposal. This report extends this review to other components of the battery: frames, bipolar plates and the management systems.

# 1. Work Progress

The redox flow battery to be developed within the BALIHT project is based on the overall improvements achieved once all components are designed and tested for the high-temperature/high-cycling needs. This fact promotes that de different components are reviewed and analysed by the expert partners along the BALIHT's project consortium.

These elements are detailed as follow:

1. Organic electrolyte
2. Ionic membrane
3. Bipolar Electrodes, including bipolar plates and active electrodes
4. Polymeric Frames and Stack
5. Electrolyte tanks
6. Battery and Energy Management Systems

The partners with deep expertise on the development of each components, reviewed and provided information on each component of the organic redox flow battery, beyond what has been reviewed along the project proposal.

# 2. Results

This information is compiled here after all partners add their thoughts on other components of the battery.

## 2.1. Organic electrolytes for RFB

The development of organic electrolytes has accelerated within the last 12 months, as the general development of the literature in the field of redox flow batteries was exponential over the last few years. The main drivers for innovation are academic researchers with very little focus on subsequent commercial attractiveness of the technology, rather focusing on the development of new concepts than on selecting and optimizing promising technologies for scale-up ready for the market. Yet, many recent reviews summarize the current development in the academic field and show that the field of established electrolyte chemistries has not significantly expanded within the considered time period. , Main electrolyte classes of academic focus remain viologenes, nitroxide radicals, quinoid systems, ferrocene derivatives and very recently aza-aromatics. , All these electrolyte classes were qualified in small-scale lab environments and neither selected based on their potential for up-scaling due to the availability of raw materials (e.g. lignin) or commercial attractiveness of the required synthetic routes, nor fine-tuned in their chemical structure to fulfil the requirements of low cost and scale-ability.

Recent patents in the field of redox flow battery electrolytes are mainly filed by Chinese inventors (also filed exclusively in China) and focus on systems based on heavy metal ions and applications in salt caverns. Other prominent, recent inventors are the University of Southern California focusing on already established quinoid systems, ESS Tech, Inc. focusing on heavy metal based hybrid batteries and C-Tri Co., Ltd. (Korea) focusing on hybrid Li redox flow batteries employing established nitroxide radicals.

Therefore, the description of the state of the art in the initial proposal is still valid and no fundamental new developments were made in the meantime.

## 2.2. Membranes

Five types of cation exchange membranes and nanoporous membrane were screened for alkaline RFBs. The membrane preparation methods are as follows.

### 2.2.1. Polyvinylnorbornene (PVNB) membranes

The PVNB polymer was synthesized according to a previous study. A polymer solution with chloroform as solvent was prepared. Then, sodium 2-mercaptoethanesulfonate was added to react with the PVNB polymer to create sulfonic acid groups. Then the solution was poured into a flat-bottom petri dish and dried in the fume hood. After chloroform evaporation, a dense membrane formed.

Recent research focuses on the polymerization of monomers to form high molecular weight polymer. The content of initiator and the vinylnorbornene/norbornene ratio were tuned to achieve this target.

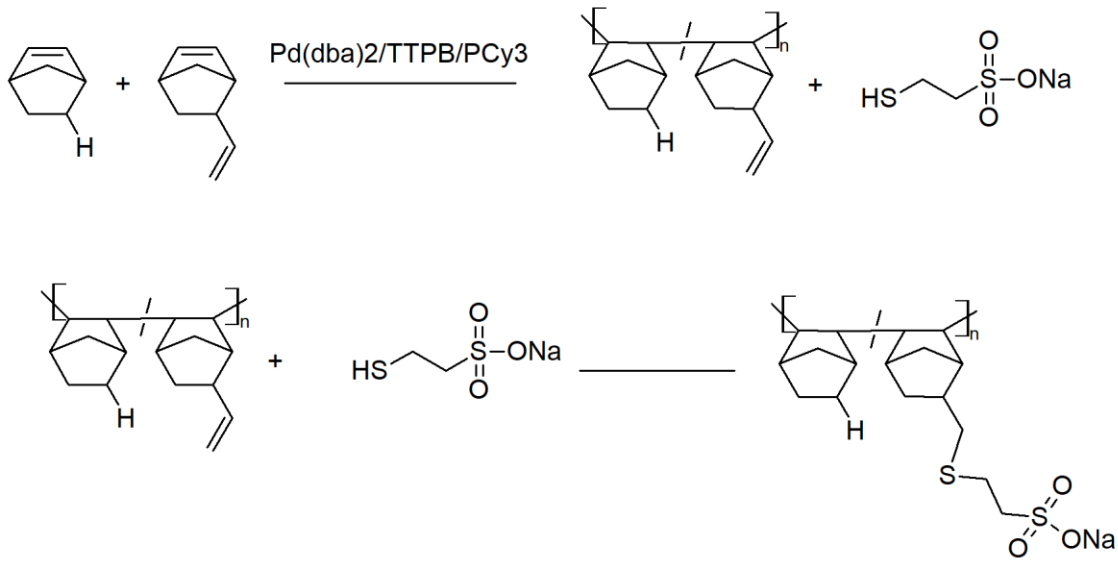


*Figure 1. PVNB synthesis route*

The poly(vinyl alcohol) (PVA) polymer was dissolved in DI water and heated to 90 °C to form a 5 wt.% solution. Meanwhile, aqueous 20 wt.% poly(styrene sulfonic acid-co-maleic acid) (PSSA_MA) solution was also prepared. Both solutions were mixed together and poured into a flat-bottom PTFE dish. The proportions of PVA and PSSA_MA varied to tune the ion exchange capacity and crosslinking degree. The dishes were put into the oven at 60 °C for the water evaporation. Then, the resulting dried membranes were peeled off after 24 h. To initiate the crosslinking reaction, the prepared membrane was annealed at 120 °C in an oven for 1 h. The thickness of the resulting membranes was in the range of 50~80 µm.

The membrane showed a good stability in 1M NaOH/ 1M KOH at 90 °C: the mechanical strength remained, and no damage was found visually after exposure in this alkaline solution for 7 days

### 2.2.2. Porous polybenzimidazole (PBI) membranes

The PBI polymer was a lab-made material with the dynamic viscosity of 304.8 Pa·s (measured with 17 wt.% in DMAc at 25 ± 1 °C). The PBI membrane was prepared by dissolving the PBI polymer in DMAc to form a 17 wt.% solution. The solution was cast onto a glass plate using a Braive instruments automatic film applicator at a casting thickness of 250 µm. Afterwards, the glass plate was immediately immersed into DI water (25 °C) to induce phase inversion and form the membrane with a porous structure. Afterwards, the membrane was peeled off from the glass plate. The prepared membrane was soaked in DI water for the next step.

### 2.2.3. Poly(vinylbenzyl chloride) (PVBC) membranes

A 10 wt.% PVBC solution was obtained by dissolving PVBC polymer into DMSO. A certain amount of sulfanilic acid was then added. The solution was stirred for 60 min at 60 °C. Subsequently, the solution was cooled down to room temperature, and 2 wt. % of crosslinking agent polyethylenimine (PEI, Mn~10,000, Sigma-Aldrich) was added. After several minutes, the solution became viscous. It was then poured into a flat-bottom glass dish, and dried at 40 °C under vacuum overnight. The membrane was peeled off subsequently and washed with water and stored for the next step. This thickness of the membrane was around 80 µm.

The membrane was found stable in 1.0 M NaOH at 80 ℃, but the area resistance and mechanical strength still need to be optimized.

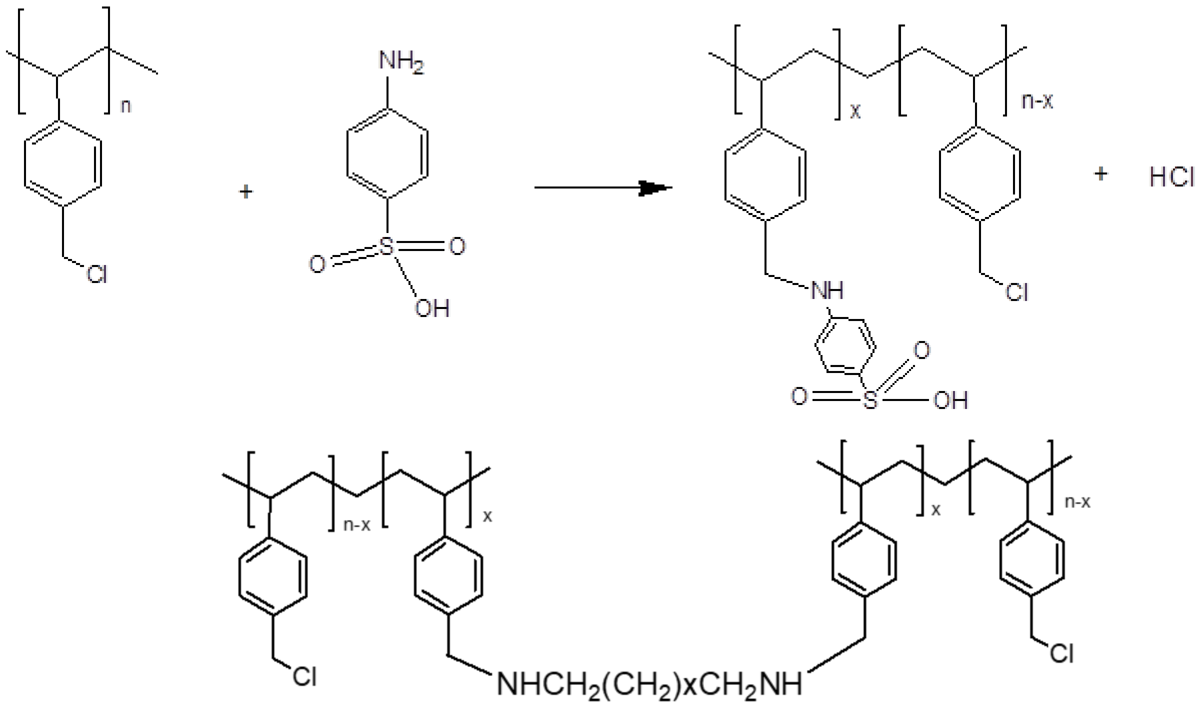


*Figure 2. PVBC synthesis route*

*Table 1. Summarised overview of project datasets*

| Membrane | PVBC / sulfanilic acid / PEI |
|---|---|
| M1 | 1 / 0.4 / 0.02 |
| M2 | 1 / 0.6 / 0.02 |
| M3 | 1 / 0.8 / 0.02 |

### 2.2.4. Poly(vinylbenzyl chloride) (PVBC) membranes

The pristine PVDF membrane was obtained via phase inversion. The casting solution was prepared by dissolving PVDF polymer in DMF (23 wt.%). The casting solutions were outgassed overnight by turning off the stirring and then cast on a glass plate using an automatic film applicator (Braive Instruments, Luik, Belgium). Hereafter, the cast films were immersed in a coagulation bath containing DI water at room temperature. The casting knife used, had an opening thickness of 200 µm and the casting speed was 0.021 ms-1. In this way, PVDF membranes with a thickness of around 100 µm were obtained.

The membranes were crosslinked in a 4.5 wt.% NaOH solution with 25 wt.% polyethylenimine (PEI, Mn~600, Sigma-Aldrich) for 24 h at room temperature. Afterwards, the membranes were washed many times and stored in water until further use.

## 2.3. Carbon electrodes for RFB

As described within the proposal, the aim of this development is to replace carbon fiber felts or fleeces from the redox-flow stack, because of cost reasons by a coating of an electrochemical active material on both sides of the bipolar plates instead. In that sense, a short review on active materials for electrodes is conducted here. The best way for its application onto both sides of the bipolar plate will depend on the active material selection for the electrode.

Taking the carbon-based electrodes as a reference, including metals within the formulation has been reported to enhance the conductivity[1, 2, 3]. However, these are based mainly on noble metals.

The use of graphite oxide[4] or graphene[5] was also proposed for these electrodes.

More recently[6,] metal (Ti, Zn, Mn, Ni, W) oxides and oxygen or nitrogen heteroatoms materials were also incorporated on the carbonaceous structure for enhancing electrodes performance.

## 2.4. Bipolar plates for RFB

The reviewed patent literature related to bipolar plates for fuel cells and redox cells on a regular basis, does not conduct to any direct or adversely affecting impact on the BALIHT project.

### 2.4.1. Project "Extrusions-Platte"

In 2019, the final report of the project "Extrusions-Platte" funded by the German Ministry for Economic Affairs and Energy under the No. 03ET6050A-E was published. The full text (in german) is available following the link in [7]:

From 01.11.2015 – 30.04.2019 a consortium consisting of the Hydrogen and Fuel Cell Center (ZBT) Duisburg, the Technical University Clausthal and the companies Eisenhuth, Centroplast Engineering Plastics and ThyssenKrupp Industrial Solutions were working on large scale bipolar plates for vanadium redox flow cells. Similar to the BALITH project the materials were based on graphite and polypropylene as the main raw materials and variable amounts of conductive black as an additive. However, the extruded plates had a thickness of 6 mm, were quite brittle and attempts to reduce the brittleness by the addition of thermoplastic elastomers failed.

In contrast the target of the BALIHT project is the extrusion of thin (approx. 1 mm), flexible bipolar plates with thermoplastic elastomers as the main binder material.

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[1] Kim, H.S. Electrochemical Properties of Graphite-based Electrodes for Redox Flow Batteries. Bull. Korean Chem. Soc. 2011. 32: p. 5, DOI: 10.5012/bkcs.2011.32.2.571.
[2] Wang, W.H. and Wang, X.D. Investigation of Ir-modified carbon felt as the positive electrode of an all-vanadium redox flow battery. Electrochimica Acta. 2007. 52(24): p. 6755-6762, DOI: http://dx.doi.org/10.1016/j.electacta.2007.04.121.
[3] Wei, Z.D. and Chan, S.H. Electrochemical deposition of PtRu on an uncatalyzed carbon electrode for methanol electrooxidation. Journal of Electroanalytical Chemistry. 2004. 569(1): p. 23-33, DOI: http://dx.doi.org/10.1016/j.jelechem.2004.01.034.
[4] Li, W., Liu, J., and Yan, C. Graphite–graphite oxide composite electrode for vanadium redox flow battery. Electrochimica Acta. 2011. 6(14): p. 5290-5294, DOI: http://dx.doi.org/10.1016/j.electacta.2011.02.083.
[5] Tsai, H.-M., Yang, S.-Y., Ma, C.-C.M., and Xie, X. Preparation and Electrochemical Properties of Graphene-Modified Electrodes for All-Vanadium Redox Flow Batteries. Electroanalysis. 2011. 23(9): p. 2139-2143, DOI: 10.1002/elan.201100181.
[6] Gencten, M, Sahin, Y. A critical review on progress of the electrode materials of vanadium redox flow battery. Int J Energy Res. 2020; 1– 21. https://doi.org/10.1002/er.5487
[7] https://www.tib.eu/suchen/?tx_tibsearch_search%5Bdocid%5D=TIBKAT%3A1678901008&tx_tibsearch_search%5Bcontroller%5D=Download&cHash=f922ec3c96866310d4b5f71b25c0776e#download-mark

### 2.4.2. Project "Re3dOx"

In September 2019 a subsequent Project Re3dOx with the partners of the previous project and Fumatech, also a funding of the German Ministry for Economic Affairs and Energy (No. 03ET6156F), was started. Details of the project can be consulted in [8]

The main focus of the project is the recycling of scrap material of e. g. bipolar plates and membranes, but according to a press release of ZBT Duisburg it is also an intention to imprint flowfield structures during the extrusion process already[9], which would be similar to SKTs planned activities in the BALIHT project.

## 2.5. Frames for RFB

There is not deep information on plastic frames beyond PVC or polyethylene materials. Some results come when the thermal stability of polypropylene is investigated. This is made by the addition of fibers and/or other nanosized fillers.

There are developments on increasing the crystallinity of the polypropylene matrix, but other solutions have been porposed thoroughly:

- When fibres are used, they need for compatibilizers: MAH-elastomeric[10] enhance mechanical properties
- Nano clays seem to increase thermal stability but also enhances higher temperature degradation[11]
- Isotactic-PP and atactic-PP can be combined for both thermal and electrical properties control[12]
- Butylated lignin[13] can be added to enhance thermal stability (oxygen scavengers)
- Aluminium also helps to thermal stability of i-PP[14]: this is not assumed as aluminium particles could provide electrical conductivity, not desired for frames.
- Natural-based oxidants[15] (caffeic acid) allow better thermal stability (against UV-$O_2$)

On the other side, after analysing the patent for frames of redox flow batteries these are focussed on the design of flow channels better than on materials (see ANNEX for frames patents).

[8] https://www.german-energy-solutions.de/GES/Redaktion/EN/News/2019/20191017-re3dox.html
[9] https://www.zbt.de/en/news/news-anzeige-eng/news/projektstart-re3dox-recycling-und-ressourceneffizienz-bei-der-redox-flow-batterie/
[10] Niu, Pengfei & Liu, Baoying & Wei, Xiaoming & Wang, Xiaojun & Yang, Jinzhao. (2011). Study on mechanical properties and thermal stability of polypropylene/hemp fiber composites. Journal of Reinforced Plastics and Composites. 30. 36-44. 10.1177/0731684410383067.
[11] Fitaroni, Lays & De Lima, Juliana & Cruz, Sandra & Waldman, Walter. (2015). Thermal stability of polypropylene–montmorillonite clay nanocomposites: Limitation of the thermogravimetric analysis. Polymer Degradation and Stability. 111. 102-108. 10.1016/j.polymdegradstab.2014.10.016.
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[13] ye, Dezhan & Li, Shuai & Lu, Xiaomin & Zhang, Xi & Rojas, Orlando. (2016). Antioxidant and Thermal Stabilization of Polypropylene by Addition of Butylated-Lignin at Low Loadings. ACS Sustainable Chemistry & Engineering. 4. 10.1021/acssuschemeng.6b01241.
[14] Arranz-Andres, Javier & López, Félix & Benavente, Rosario. (2017). The Addition of Aluminum Nanoparticles to Polypropylene Increases Its Thermal Stability. International Journal of Engineering Research and Applications. 07. 05-12. 10.9790/9622-0702010512.
[15] Hernández-Fernández, J., Rayón, E., López, J., Arrieta, M. P., Enhancing the Thermal Stability of Polypropylene by Blending with Low Amounts of Natural Antioxidants. Macromol. Mater. Eng. 2019, 304, 1900379. https://doi.org/10.1002/mame.201900379

## 2.6. Tanks for RFB

As described, tanks for storing the electrolytes are mainly based on PVC or polyethylene[16]. These are rigid tanks aimed to resist strong acid media for conventional metal based RFB. However, the use of a flexible storage[17] tank made of rubber was proposed for using underground deposits for storing electrolytes of RFBs.

Further study of patents mainly showed configurations for enahncing the thermal dissipation and thermal management of the electrolyte temperature (see ANNEX for tanks patents). As the objective of the BALIHT project is to provide an advanced RFB for working at higher temperatures, this is not of application.

## 2.7. Battery Management System

The term Battery Management System (BMS) does neither have a universal or formal definition, nor does exist a unique summary with the tasks it should perform. The main reason is the strong dependence of its features and capabilities on the application: e.g. automotive, aerospace, stationary storage systems or consumer electronics applications, etc. There is no ideal solution for all the needs of battery management which derives from the diverse choices in terms of battery chemistry or geometry. Sporadically, it can be found that terms such as "voltage management systems" or "protection circuit module" are employed when referring to them.

In general, it is understood that a BMS is a system responsible for the supervision, control, and protection of battery cells – either individually or connected to form battery packs or stacks – and these are, in consequence, fundamental tasks for many aspects of the battery performance; from energy efficiency to safety, battery life and reliability. But for the sake of a formal definition a common understanding does not suffice[18].

As Redox flow batteries (RFB) make small percentage of batteries on today's market and organic based RFBs even less, there is little knowledge on organic RFBs' BMS which are usually custom made for each prototype of RFB or tailored Lithium-Ion BMS to meet RFB functions. Because of that, main focus of this deliverable will be on state of-the-art general BMS components and functions and vast variety of BMS that we could have found.

### 2.7.1. Designing of BMS – Requirements and functions[19, 18]

The complexity of a battery management system (BMS) strongly depends on the individual application. In simple cases, like single cell batteries in mobile phones, or e-book readers, a simple "fuel gauge" Integrated Circuit (IC) can be sufficient. These ICs usually are able to measure voltage, temperature and current and use simple methods to estimate the battery's current State of Charge (SOC). In more complex devices, like electric cars or big energy storage facilities, the BMS has to fulfill more sophisticated tasks. In addition, the basic parameters like cell voltage, cell temperature and current have to be measured. Nevertheless, advanced algorithms are needed, as e.g., the available energy has to be determined in order to reliably calculate needed energy to perform tasks this battery has been installed for.

[16] Shigematsu, T. Redox Flow Battery for Energy Storage. SEI Technical Review. 2011. 73: p. 4-13, DOI
[17] Tokuda, N., Kanno, T., Hara, T., Shigematsu, T., Tsutsui, Y., Ikeuchi, A., Itou, T., and Kumamoto, T. Development of a Redox Flow Battery System. SEI Technical Review. 2000. 50: p. 88-94, DOI.
[18] D6.1 – Analysis of the state of the art on BMS Author: Javier Muñoz Alvarez, Martin Sachenbacher, Daniel Ostermeier, Heinrich J. Stadlbauer, Uta Hummitzsch, Arkadiy Alexeev (LION SMART) - February 2017 EVERLASTING - Grant Agreement 71377 (Call: H2020-GV8-2015) Electric Vehicle Enhanced Range, Lifetime And Safety Through INGenious battery management
[19] Lelie, Markus & Braun, Thomas & Knips, Marcus & Nordmann, Hannes & Ringbeck, Florian & Zappen, Hendrik & Sauer, Dirk. (2018). Battery Management System Hardware Concepts: An Overview. Applied Sciences. 8. 534. 10.3390/app8040534

Designing a BMS is a complex task that requires considering the application's specific needs, the system context, as well as the characteristics of the adopted battery cells. From these considerations, a list of system requirements can be derived.

To protect individual battery cells and the entire battery pack from the afore-mentioned exothermic reactions, an electronic safety circuitry is required[18]. The most important task of the BMS is to fulfil safety functions in such a way that the cells in a battery system are not operated beyond their specified limits in terms of voltage, temperature, and current[20]. This set of specification limits for cells is often referred to as its safe operation area (SOA).

Generally, a BMS is an analogue and/or digital electronic device that fulfils the following essential requirements:

- Data acquisition.
- Data processing and data storage.
- Electrical management.
- Temperature management.
- Safety management.
- Communication.

In general, the following BMS component and functional requirements will usually be of relevance for most of BMS[19]:

- Acquisition of temperature,
- Acquisition of voltage (individual cells, stack or whole pack and Direct Current (DC)-link voltage as well),
- Acquisition of current (stack or whole pack),

As well as data communication between:

- BMS master module and BMS slave modules (that acquire above mentioned values),
- Battery pack and surrounding application (e.g., car, aeroplane).

And finally the requirements on:

- Robustness against Electromagnetic interference (EMI).
- Contactors and
- Redundancy of the system in terms of functional safety.
- Galvanic isolation of functional systems.
- Balancing
- Power consumption, size, weight, etc.
- Other (like flow rate for RFBs)

### 2.7.2. Topologies of BMS

In order to achieve the electrical specifications (e.g., stored amount of energy, power, voltage range, maximum current) necessary for an individual system, in many cases, multiple battery cells have to be combined to form a battery pack. In principle, different connection topologies are possible for these kinds of batteries. A schematic representation is shown in Figure 1 and Table 1. To realize a specific voltage range on the battery pack level, which reduces the current that is drawn for a given power value, cells have to be connected in series (Figure 1c), while parallel connections increase the capacity (Figure 1b). In today's systems, one possible variant is to use multiple cells

[20] D. Andrea, Battery management systems for large lithium-ion battery packs. Boston: Artech House, 2010

with small capacity in parallel to form modules with higher overall capacity, which are then connected in series to increase the voltage (Figure 1e). Another variant is the usage of battery cells with a high capacity, which are connected in series (Figure 1c). Both variants are the most reasonable ones in terms of BMS complexity. A parallel connection of multiple strings of battery cells (e.g., for special redundancy requirements) would increase the expenditure for cell voltage monitoring, balancing, etc., by a factor of the number of parallel strings, while this way only one voltage measurement channel per parallel connection of n cells is needed.

- Example: m cells in series are needed to reach the specified voltage, as well as n cells in parallel to provide the necessary capacity.
- Case 1: Using a series connection of m times n parallel cells, m voltage channels would be needed. (see Figure 3e)
- Case 2: Using a parallel connection of n strings of m cells in series, m _ n voltage measurement channels would be needed. (see Figure 3d)

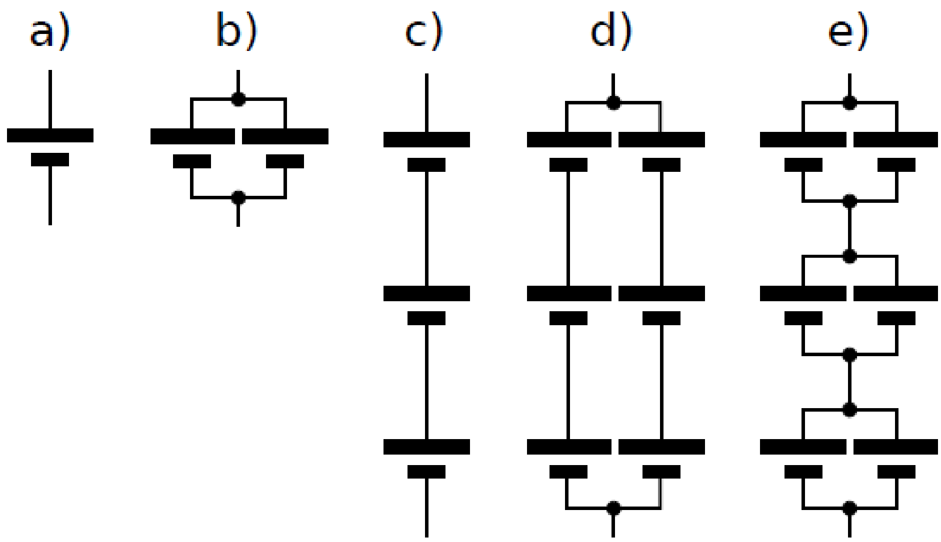


*Figure 3. Schematic representations of different battery pack topologies: (a) single cell; (b) parallel connection of two cells; (c) series connection of three cells; (d) parallel connection of two strings of three serially connected cells; (e) series connection of three modules consisting of two cells connected in parallel.*

| | (a) | (b) | (c) | (d) | (e) |
|---|---|---|---|---|---|
| Voltage | $V_{cell}$ | $V_{cell}$ | $3 \cdot V_{cell}$ | $3 \cdot V_{cell}$ | $3 \cdot V_{cell}$ |
| Capacity | $Q_{cell}$ | $2 \cdot Q_{cell}$ | $Q_{cell}$ | $2 \cdot Q_{cell}$ | $2 \cdot Q_{cell}$ |
| Voltage channels | 1 | 1 | 3 | 6 | 3 |

*Figure 4. Characteristics of the topology variants shown in Figure 3*

### 2.7.3. Modularization of BMS

For applications in need of higher power and/or with greater energy demand, the battery pack must consist of several cells. ICs are offered for these kinds of systems that provide monitoring for several cells at once and also provide means for balancing, which is not needed in one-cell-systems.

In these kinds of systems, usually more advanced functions are implemented in one central module or Electronic Control Unit (ECU), sometimes known as "BMS-Master". Figure 3 shows the structure of a typical system of this class. As examples for tasks the master cares about, sophisticated SOC

estimation, or power prediction algorithms, which need a certain amount of processing power, can be named. An overview can be found in [21]. The modules carrying the front-end ICs are then often referred to as "BMS-Slaves". They are used for basic functions like signal acquisition, filtering, etc., which are carried out by the monitoring ICs named above.

### 2.7.4. BMS Communication

The BMS usually has to communicate to the complete system (e.g., power electronics, energy management or Vehicle Control Unit (VCU) in a vehicle), in order to provide status information and receive instructions and parameters. For this, it must be considered which means of communication are provided or required by the system. In addition, the required communication speed, robustness and reliability need to be checked. Does the data have to be sent at a certain minimum speed to comply with safety relevant tasks or can there be a hierarchy based communication that is slow enough to save power, but still ensures the application's timing needs? Decisions regarding these aspects may very well already have been taken on the system level, requiring the BMS to adapt to this. One example would be the need to provide a Controller Area Network (CAN) interface to talk to the system, which inherently sets some boundary conditions regarding speed, robustness and reliability.

Apart from the system level, between the BMS components, communication is also necessary.

For modular systems that are spread over several Printed Circuit Boards (PCBs), e.g., it needs to be defined, if there is a "Master" module, how it talks to "Slave" modules that amongst others are responsible for data acquisition or control of actors. For this, basically the same aspects as for the system wide communication are relevant.

[21] C.-C. Liu, S. McArthur, S.-J. Lee "Smart grid handbook", 2016., page 146

### 2.7.5. Specifics of BMS for organic RFB

Battery management systems for organic redox flow batteries differs from those of solid-state batteries due to different structure and operating principle. In this specific case, with non-explosive lignin-based electrolyte, certain safety measures can be avoided but demand for control and data acquisition increases as the fluid dynamics plays important role in data management. This refers to flow pumps and frequency drives. Flow pumps with accompanying frequency drives can drastically increase the number of data to be collected as the frequency drives have built-in pump and drive protections. Only process significant data must be carried out to supervisory BMS software.

Apart from increased data acquisition, process control in redox flow batteries gets more complex with the need for PID control of the flow pumps. Pump power is regulated by BMS with PID regulator implemented in BMS's Programmable Logic Controller (PLC). Pump power and tank pressure are set points for PID regulator. PID controller implies changes of pump speed that cannot be too fast in order to prevent the hazard of damaging the stack. This applies to pump start and stop ramp times. All these parameters must be properly calibrated.

BMS components and functional requirements of relevance to RFB's BMS are the one mentioned above for the general BMS structure.

Data management is provided by means of SCADA functions. BMS software for redox flow batteries must provide full SCADA (Supervisory Control And Data Acquisition) functions installed on desktop computer (the need for industrial PC is yet to be considered). Apart from standard SCADA functions, BMS software must support communication protocol implemented in frequency drives for PID control and communication protocol implemented in Energy Management System (EMS) for power demand informations. These communication protocols are based on master-slave principle: master demands data from the slave device in real time environment (slave response time is less than 1 second and can be configurable).

All collected data must be appropriately archived for future analytics. Analysis can be carried out with graphical interpretation (charts, line graphs) or in table form. The media for data storage can be on the same desktop computer or on remote location.

### 2.7.6. State-of-charge of a Vanadium RFB[22]

The state-of-charge (SoC) indicates how much electric charge the battery currently stores, referred to its theoretical capacity. For an ideal battery, the SoC is the integration of the injected or released electric current with respect to the time divided by the theoretical battery capacity. An ideal battery does not lose any electric charge neither in the charging or the discharging process nor in times of standby. However, the theoretical capacity of a battery always differs from its nominal or useable capacity. This is mainly because the exploitation of the total SoC-range leads to several undesired effects such as accelerated aging or lower efficiencies. Thus, in regular operation, the SoC never reaches values of 0 % or 100 %.

### 2.7.7. Flow rate optimization for RFB – Current state of science[22]

The simplest flow rate control strategy (FRCS) of today's most spread version of RFB, Vanadium redox flow battery (VRFB), is deploying a constant flow rate for all SoCs and currents. Another simple approach is to adapt the flow rate according to the instantaneously derived stoichiometric requirements of the electrochemical reactions. These

[22] „Model-based Design and Optimization of Vanadium Redox Flow Batteries“, dissertation on Fakultät für Elektrotechnik und Informationstechnik des Karlsruher Instituts für Technologie , Sebastian König page 119-120

requirements are given by Faraday's first law of electrolysis. To compensate for imperfections and losses, the actual flow rate must be larger than the stoichiometric one. Hence, the instantaneous stoichiometric flow rate is multiplied by a constant factor, commonly referred to as the 'flow factor'[23]. The two approaches mentioned above have already been studied by NASA for the iron-chromium flow battery in 1982[24]. More than 30 years later, a similar comparison is presented for the VRFB[23]. In terms of discharge capacity and system efficiency, a variable flow rate using the scaled instantaneous stoichiometric flow rate is found to be advisable for the VRFB. One drawback of the presented study is the over-estimation of the pump efficiency where a constant pump efficiency of 80 % is assumed. This is more than twice as high as the best efficiency point of real pumps. In [25, 26] third FRCS representing a simple and straightforward optimization approach. If we charge the battery with a constant power, we have to adapt the flow rate depending on the SoC with the goal of maximizing the applied charging current. This is reasonable because the charging progress depends on the applied current, not on the applied power. Hence, the claim for a maximum current at a given power implies a low charging voltage, which benefits the efficiency. If we discharge the battery with a constant power, we adapt the flow rate depending on the SoC to minimize the absolute value of the discharging current. If we charge the battery with a constant current, the goal is to minimize the input power. If we discharge the battery with a constant current, the goal is to maximize the absolute value of the output power. This methodology is also used in[27]. Herein, the impact of temperature and pipe diameter on the efficiency is studied in addition. However, due to additionally considered loss mechanisms, namely shunt currents and vanadium crossover, the previously presented approach of minimizing and maximizing current and power, respectively, is no longer adequate. In addition to the presented model-based studies, some experimental studies have been published as well. By increasing the flow rate at pre-defined cell or stack voltage levels, a good compromise between system efficiency and discharge capacity can be yielded[28]. Herein, an experimental study is carried out with a kW-class VRFB. However, the values of the pre-set voltage limits and the values of the applied low and high flow rates are not varied. Hence, it can be assumed that this method represents a simple approach for finding an acceptable compromise between system efficiency and discharge capacity, but significant optimization potential remains unused. Another approach to reduce the average pump power demand is to apply a pulsating electrolyte flow[29]. Using a 20-$cm^2$ lab-scale flow cell, it is shown that significant energy savings are achievable with different on- and off-periods of the pumps. However, a pulsating flow rate exposes the stack to transient mechanical loads, which might reduce the lifetime and might increase the risk of leakages. Further, the method comprises a large number of variables, namely pump on- and off-times and applied flow rates for both, the charging and discharging process. Most likely, the optimal parameter set will additionally vary with SoC and applied charging and discharging current. Hence, an extensive optimization process is required to bring this method into practice.

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[23] Tang, A., Bao, J., and Skyllas-Kazacos, M. 2014. Studies on pressure losses and flow rate optimization in vanadium redox flow battery. Journal of Power Sources 248, 154–162.

[24] Hagedorn, N. H., Hoberecht, M. A., and Thaller, L. H. 1982. NASA Redox Cell Stack Shunt Current, Pumping Power, and Cell Performance Tradeoffs. NASA

[25] Blanc, C. 2009. Modeling of Vanadium Redox Flow Battery Electricity Storage System, EPFL

[26] Blanc, C. and Rufer, A. Optimization of the operating point of a vanadium redox flow battery. 2009 IEEE Energy Conversion Congress and Exposition

[27] Xiong, B., Zhao, J., Tseng, K. J., Skyllas-Kazacos, M., Lim, T. M., and Zhang, Y. 2013. Thermal hydraulic behavior and efficiency analysis of an all-vanadium redox flow battery. Journal of Power Sources 242, 314–324.

[28] Ma, X., Zhang, H., Sun, C., Zou, Y., and Zhang, T. 2012. An optimal strategy of electrolyte flow rate for vanadium redox flow battery. Journal of Power Sources 203, 153–158

[29] Ling, C. Y., Cao, H., Chng, M. L., Han, M., and Birgersson, E. 2015. Pulsating electrolyte flow in a full vanadium redox battery. Journal of Power Sources 294, 305–311.

### 2.7.8. Overview of available BMS and their analysis

This section intends to give on overview of the battery management systems currently available on the market. Focus supposed to be on RFB BMS but there was not sufficient data for RFB specific BMS so we collected data for different kinds of BMS out of which few state that they also cover RFB operation.

It should be noted that obtaining an overview over the various BMS that are currently available for commercial or academic purposes is difficult due to several reasons. First: there are different applications for BMS, and thus the BMS available on the market are often highly adapted to their application purpose. In this study, the focus is put on the intended use of the BMS in stationary batteries applications; Second: few information is publicly available. Although these commercial systems have reached mass production levels and thus would be a very important part of the current BMS landscape, the respective companies currently keep most of the technical information about these systems – concerning topology, key specifications, software architecture, etc. – confidential, most likely because of fierce competition but also due to safety concerns.

In contrast, smaller manufacturers and engineering companies that focus on BMS for prototypes, small batch and pilot series production, often provide adequately detailed information concerning the technical specification and structure of their BMS.

In addition, there exist some BMS platforms – including the systems from Altera, Fraunhofer, and LION Smart – that use open-source development strategies and focus mainly on research and early prototyping purposes.

### 2.7.9. Energy Management Systems (EMS) for Battery Energy Storage Systems (BESS)[30]

The main objective of an Energy Manage System applied to a Battery Energy Storage System is to optimise the behaviour of the battery during short and long term operation considering the constrains and boundary conditions imposed by the energy system where the battery is embedded. In the short term, the energy management system allows the optimisation of the energy balance of the whole system considering energy generation profiles or forecast, market related indicators, and user related parameters. In the long term, the energy storage is optimise considering seasonal behaviours and degradation processes taking place in the battery.

In this section, it is presented the issues faced the integration of renewables in Distributed Generation (DG) grids and the growing necessity of energy storages, in addition to types of Energy Storage Systems (ESSs) and their applications.

Due to the increment of renewables sources as alternative energy resources to conventional fossil fuels, it was needed the conceptualization of DG, wherein the power generation takes place near the load centres by many small grid-connected power generating sources known as Distributed Energy Resources (DERs), being the major part of them renewables sources.

The integration of those renewable sources presents many challenges during operation and scheduling of DGs, as intermittency, power quality and prices of electricity generated. Because of this (and some other non-mentioned factors) EESSs can aid in the improvement of the operation and power delivery of the DG and can help eliminating uncertainties in the system. The most common power systems only depended on rotational generators for spinning

[30] A. H. F. a. K. Palanisamy, "Energy Storage Systems for Energy Management of Renewables in Distributed Generation Systems," in Energy Management of Distributed Generation Systems, 2016

reserves and ancillary services, but specially the renewable generation sources in a DG lack this facility and hence depend on external storage to fulfil these requirements. Some of the needs of ESS in DG are:

- Spinning reserve and short-term backup.
- Load levelling and peak shaving.
- Integration of renewable sources in DG.
- Power quality support.
- Ancillary services.

But firstly it has to be clarified that depending on the used technology, the different ESSs can be classified as shown in Figure 5.

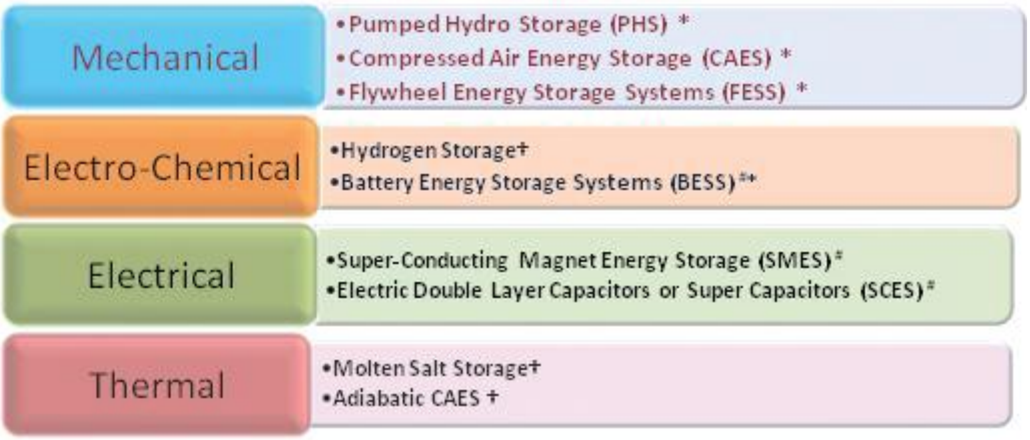


*Figure 5. Energy storage technologies*

Focusing on what we are interested on, the BESSs are the most extended implemented and commercially used storage systems in power system applications. They can also be classified in several ways, as depicted in Figure 6.

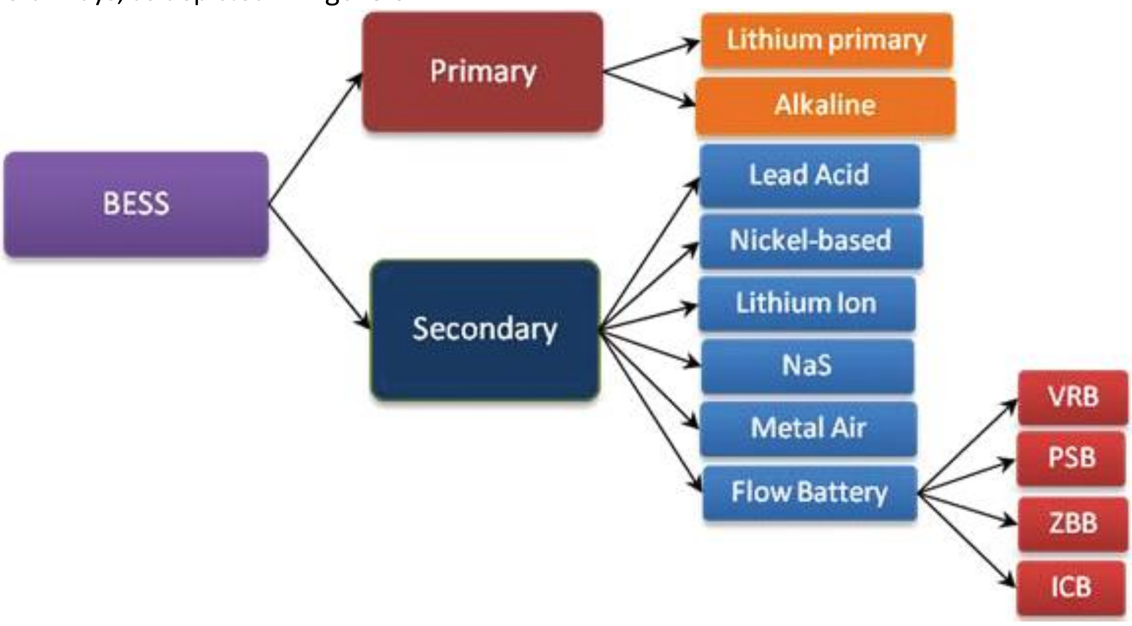


*Figure 6. Battery storage systems' hierarchy*

Taking into account that some applications, as it can be frequency regulation and power smoothing, require storage systems with the capability of charging/discharging high power in short duration, concrete type of storage needs to be selected and sized to be integrated with the DG. As storage systems are quite expensive, they should be managed effectively in order to ensure their duration and performance. An adequate management of both the storage and the generation units is mandatory to ensure an effective utilization of the DERs. So a general approach of this architecture can be seen on Figure 7.

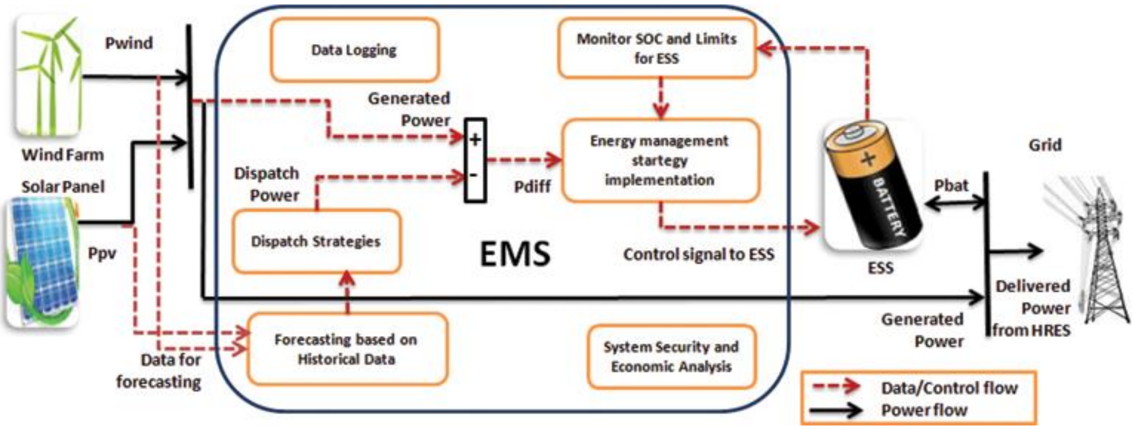


*Figure 7. Components of an EMS*

How this the energy is managed (strategy) on this kind of systems is a crucial part of planning of standalone and autonomous power systems incorporating renewable power. The storage system could be operated to address many different applications in a microgrid, so the management strategy will have to be proposed in view of attaining the predetermined objectives without affecting the system as well as the storage system. For example, from the point of view of a Distribution System Operator (DSO), the storage system's usage is to be mainly oriented towards peak shaving and renewable integration applications; on the other hand, a retailer would be interested on using the storage system for maximizing its benefits by arbitrage and ancillary services that would earn money.

As a conclusion, energy storages are becoming indispensable for operation of DGs integrating renewable energy sources. The constant evolution in technology now ensures power storage and delivery from few seconds to months. The key point here is to have an optimized selection, sizing and siting of ESS, and their effective implementation and usage in the distributed grid. This is the challenge here, to prioritize the objectives and evaluate a strategy most optimal for the considered application which can assure reliable power delivery without affecting system stability.

#### 2.7.9.1. A particular case: Leclanché EMS for BESS optimisation[31]

Leclanché S.A. is a company founded in 1909 manufacturing high quality energy storage solutions, mainly based on lithium-ion cell technologies.

The Battery Management Systems (BMS) developed by Leclanché follow either a master-slave architecture or single board architecture. Combining software and hardware, their BMS provide safety for: overcharge/deep discharge, over/under voltage, over current, over/under temperature, pre-charge, short circuit and other protection. They implement specific algorithms such as SOC, SOH, cell/module balancing and real time control over charge / discharge current, in addition with the capability of indicating performance and monitor control parameters. Also it includes a user-friendly Graphical User Interface which provides diagnostics for the system and system performance.

[31] Leclanché S.A., "Battery and energy management systems," 18 05 2020. [Online]. Available: https://www.leclanche.com/our-technologies/battery-and-energy-management-systems-2/.

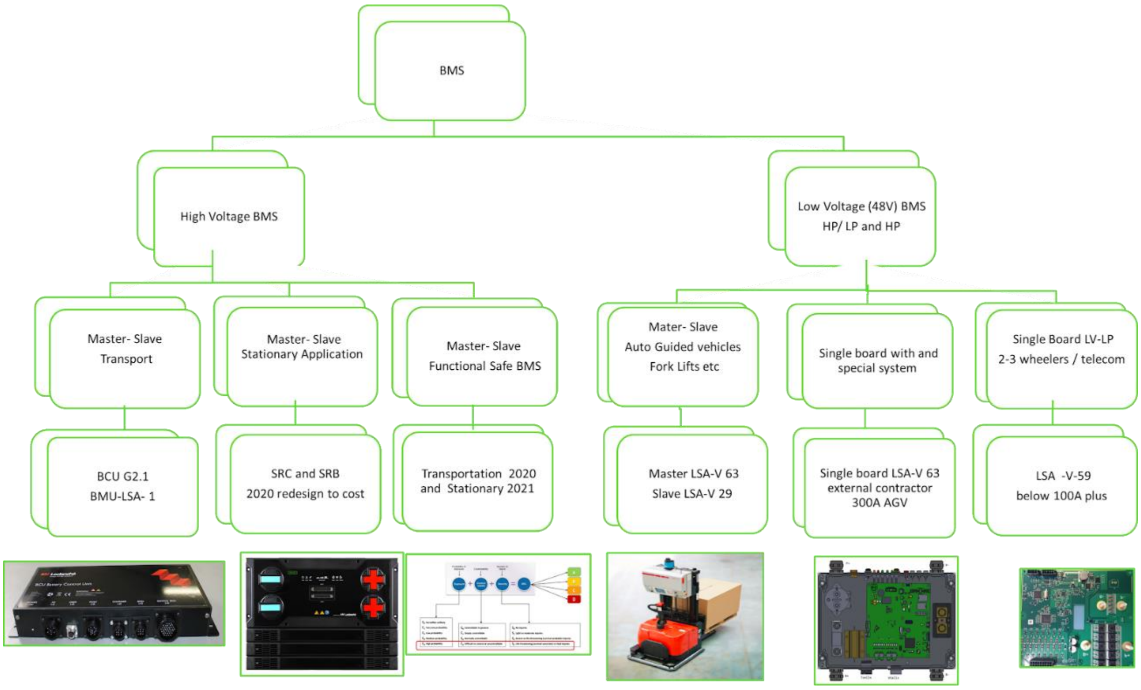


*Figure 8. Leclanché's BMS architecture*

On the other hand, their EMS software suite offers cutting-edge tools for managing large grid-connected Battery Energy Storage Systems (BESSS). This has been designed for integrating flexibility with multiple battery/inverter combinations. It has the following components:

- Power Plant Controller (PPC) for managing BESS operation
- Human Machine Interface (HMI) software for interacting remotely or locally with the PPC
- Cloud-based software for secure remote access
- Historical data logging and reporting

Their EMS is recognised in the industry as providing a very wide array of features and benefits which include:

- Seamless utility back-office integration (including SCADA, DMS, DERMS)
- ISO frequency regulation ancillary services
- Energy arbitrage
- Flexible fleet management
- Voltage support (Volt/VAR feedback)
- Power flow stability improvement
- Intermittency mitigation for wind and solar integration
- Real-time equipment monitoring

Balance of plant integration with HVAC, fire safety and security components

### 2.7.10. A real-time energy management system for smart grid integrated photovoltaic generation with battery storage[32,33]

This section proposes a real-time EMS suitable for rooftop PV installations with battery storage due to its particular interest in the project. The EMS is connected to a smart grid where the power output of the PV/battery system is indirectly controlled by price signals in response to the variation of demand of the electricity networks. The main goal of the EMS is to maximize the revenues over a given period of time while meeting the battery stored energy constraints.

Due to the intermittency of PV, this generation source cause reverse power flow in distribution networks, which leads to the problem of voltage rise. To operate as a dispatchable generator similar to the usual power energy sources, PV systems need energy storage for balancing the intermittency; this energy storage unit is used for balancing intermittent PV generation, storing the excess of PV power when solar irradiance is abundant or when load consumption is low, while on the other hand it discharges when the demand rises or PV ceases generation.

This proposed solution presents a real-time EMS which maximizes the total revenue for the PV/battery system that connects to a smart grid with time varying electricity prices. The proposed EMS uses a real-time reactive control mechanism to compensate for the PV generation forecast error. That mechanism only needs the average PV forecast during the optimization period.

The EMS algorithm steps that involve data communication between the EMS as the BMS can be summarized in the following steps:

1. Lagrange multiplier and average daily power are calculated at every interval of time
2. It is calculated the target battery power and written to the BMS
3. A times is used to proceed the loop at any time interval step size

After some simulations, a comparative analysis shows that the proposed EMS yields reasonable results in meeting the objective of maximizing the revenue under practical assumptions where the PV power is forecasted and the battery storage capacity is constrained.

### 2.7.11. Future development of BMS and EMS

Currently, the standards of structure, communication, measuring, testing and safety criteria have only been established for some mature battery technologies and the general standard system is incomplete. Thus, to establish a standard system for batteries and their application is a major task in the future for increasing compatibility and interoperability. On the other hand, when an energy storage system relates to an external grid, the requirements for the battery storage system are different owing to different applications. For example, load leveling usually needs only local signals, but remote, dynamic and time varying signals are needed for batter energy storage systems to smooth wind or solar power output. Therefore, developing a corresponding and special BMS is needed. Developing an advanced, well-adapted BMS is one of the directions in the future as well as a need for a cooperation and coordination among various devices, BMS, renewable energy systems and energy management system.

[32] I. U. R. O.-M. M. L. N. Chee Lim Nge, "Elsevier," 21 06 2018. [Online]. Available: https://fardapaper.ir/mohavaha/uploads/2018/12/Fardapaper-A-real-time-energy-management-system-for-smart-grid-integrated-photovoltaic-generation-with-battery-storage.pdf. [Accessed 18 05 2020]

[33] All the details and equations mentioned on this section are detailed on the referenced paper. They have been omitted for not adding too much overhead, understandable only for experts, on this section.

# 3. ANNEX: List of the available BMS to be analyzed

Overall, from the research of the current state of the BMS market, the following list of 37 BMS has been compiled – in alphabetical order:

#1. Ashwoods Energy's BMS (Vayon)
#2. AVL's BMS
#3: BMS PowerSafe's BMS
#4. Calsonic Kansei's Nissan Leaf-BMS
#5. Delphi Automotive PLC Battery Management Controller
#6. DENSO's Toyota Prius PlugIn-BMS
#7. E22 Battery management system
#8. Elite Power Solutions' Energy Management System
#9. Elithion's Lithiumate Pro
#10. Electric Vehicle Power System Technology Co., Ltd's (EVPST) BMS-1
#11. Ford Fusion Hybrid's BMS
#12. Hitachi's Chevrolet Malibu Eco-BMS
#13. I + ME ACTIA's BMS
#14. JTT Electronics LTD's S-line
#15. JTT Electronics LTD's X-line
#16: Leclanché Energy storage solutions BMS
#17. LG Chem's Chevrolet Volt-BMS
#18. Lian Innovative's BMS
#19. Lithium Balance's S-BMS
#20. Lithium Balance's S-BMS 9-16
#21. Manzanita Micro's Mk3x-line
#22. Mitsubishi iMiEV's BMS
#23. Navitas Solutions' Wireless BMS (WiBMS)
#24. Orion BMS - Extended Size
#25. Orion BMS - Junior
#26. Preh GmbH's BMW i3-BMS
#27. REAPsystems' BMS
#28. Sensor Technik Wiedemann's (STW) mBMS
#29: SBS Storage battery systems, LLC EquaLink BMS
#30. Tesla Motors' Model S-BMS
#31. Tritium's IQ BMS
#32. Valence U-BMS
#33. Ventec SAS iBMS 8-18S
#34. Victron energySmart BMS Cl 12/100

Open research and prototyping platforms:
#35. Altera's BMS
#36. Fraunhofer's foxBMS
#37. LION Smart's Li-BMS V4

In the following, an overview of the key features of each of the 37 considered BMS is provided.

## 3.1. AshWoods Energy's BMS - now Vayon

The BMS from Ashwoods Energy is a modular system with multiple Battery Management Modules (BMM), a System Interface Module (SIM), and a CAN Current Sensor (CCS). The BMM combines properties of the PMU – SOC estimation, MMU – balancing – and CMU – voltage and temperature measurement – layer, whereas the SIM only shows PMU characteristics. It is needed for the communication with exterior controllers and enables charge and discharge mode. The CCS is used to measure the pack current and drive contactors of batteries with up to 1000 V. The application domain of this BMS are all possible variants of electric vehicles.

## 3.2. AVL's BMS

AVL's modular Battery Management System consists of two layers called Battery Control Unit (BCU) as well as Module Control Unit (MCU) and is used for all automotive applications. While the MCUs measure cell voltages and temperatures, the BCU is meant to control those and perform all PMU functions. The maximum system voltage level is 800 V.

## 3.3. BMS PowerSafe's BMS

BMS PowerSafe now has off-the-shelf solutions for stationary energy storage.
These solutions have been manufactured in volume for our customers, and are totally reliable and proven for your applications: Smart-grid, Autonomous energy storage unit, UPS (inverter + battery) of medium and high power. Their BMS solutions are serializable (for high voltages) or parallelizable (for large energy capacities). Parallel 48 V BMS solutions have been developed: they are adaptable to all electrochemicals. They make it possible to make energy modules and to adjust the number of them to the necessary energy capacity of your application, or of your customer.

## 3.4. Calsonic Kansei's Nissan Leaf-BMS

The BMS mounted in the Nissan Leaf has a centralized architecture. All CMU-, MMU- and PMU-requirements are fulfilled by one board that controls the 360 V system, which is quite uncommon for a battery of an all-electric vehicle.

## 3.5. Delphi Automotive PLC Battery Management Controller

Delphi's modular Battery Management Systems are structured in a Hybrid and EV Controller and several Battery Management Controllers. The Hybrid and EV Controller acts as gateway between the battery and exterior vehicle controllers, whereas the Battery Management Controller provides all vital functions of a BMS for up to 450 V systems.

## 3.6. DENSO's Toyota Prius Plug-In BMS

Toyota uses Denso's modular master-/slave-BMS for its PlugIn Prius. With four slaves, monitoring 56 serial cells, the battery works at a total pack-voltage of 207 V. One particularity of this BMS is, in contrast to all the other systems, the active balancing performed in the Toyota Prius Plug-In.

## 3.7. E22 BMS

E22's Battery Management System (BMS) has been designed to manage E22's VRFBs systems. This control system has the flexibility to maximize the battery performance, adapting the Auxiliary Power consumption to the minimum level to maximize the Battery System Efficiency. Also, E22's BMS can adequate the E22's VRFBs electrochemical behavior to any energy and power application. One distinctive feature of the E22's BMS is the ability to analyze and diagnose the component's State of Health and immediately send an internal info to LEMS and EMS to activate a preventive maintenance. This type of alarm info so generated by the BMS prevents that the identified event raises to an Emergency Stop System event. This state-of-the-art control system comes along fully integrated with the E22's VRFBs systems and it's not commercialized separately.

## 3.8. Elite Power Solutions' Energy Management System

The company provides a BMS that shows a typical master/slave-topology. The master, called EMS-CPU, contains all PMU functions and controls a multitude of 4SB-V7, 4SB20-V2, or 4SB200-V7 Sense Boards. These are slave-boards which fulfills MMU and CMU features. With a total voltage of up to 500 V it is able to manage BEV, PHEV and HEV batteries.

## 3.9. Elithion's Lithiumate Pro

Elithion divides the tasks of the BMS between a controller called Lithium Pro Master – PMU functions – and either several cell-boards – CMU+MMU functions – for a single battery cell, or multiple cell-boards – CMU+MMU functions – that handle up to 16 cells in series. The maximum pack-voltage is restricted to 840 V and all EV uses are claimed to be possible.

## 3.10. Electric Vehicle Power System Technology Co., Ltd. – EVPST – BMS-1

The BMS-1 contains a controlling module (CM) with PMU properties and up to four testing Modules (TM) with MMU and CMU qualities. The only advertised purpose of this 240 V system is the application in BEVs.

## 3.11. Ford Fusion Hybrid's BMS

Ford uses a single centralized board, which satisfies all battery related tasks for the Fusion Hybrid. 76 serial cells in the battery add up to a total system voltage of 275 V.

## 3.12. Hitachi's Chevrolet Malibu Eco-BMS

The combination of 32 serial cells create a pack-voltage of 115 V in Malibu Eco's battery pack. This system is supervised by a single, centralized battery management board.

## 3.13. I + ME ACTIA

The BMS of I + ME ACTIA consists of a master 4.5 board and a set of slave 6 boards. The topology is clearly a modular master-/slave architecture and intended to be used in different EV applications.

## 3.14. JTT Electronics Ltd. S-line

JTT Electronics provides two different systems for automotive applications: the S-series of BMS consists of 4 different centralized, stand-alone modules for different battery sizes (S1, S2, S3, S4). The S-line provides solutions for 55, 110, 165 and 200 volts, small EV exercises.

## 3.15. JTT Electronics Ltd. X-line

For bigger vehicles, or in general applications that demand higher voltage levels, JTT supplies the X-line. This system combines an X-BCU – master – with several X-MCUP controllers – slave – to achieve all necessary functions of a BMS.

## 3.16. Leclanché Energy storage solutions BMS

Leclanché develops its own in-house BMS, in partnership with a hardware company. All BMS are either master-slave or single board architecture. BMS commonly provide software and hardware safety for overcharge/ deep discharge, over/under voltage, over current, over/under temperature, pre-charge, short circuit and other protection. They have built-in technology and specific algorithms such as SOC, SOH, cell/ module balancing and real time control over charge/ discharge current. They also have the capability to indicate performance and monitor control parameters. A user-friendly Graphical User Interface (GUI) provides system performance and diagnostics for the system. BMS provide CAN and RS485 communication ports to connect to the host/ higher layer system. It has High voltage BMS, BMS for e-Transport solutions, BMS for stationary solutions and low volateg BMS.

## 3.17. LG Chem's Chevrolet Volt-BMS

LG Chem's modular BMS, consisting of one master and four slave boards, provides supervisory control for Chevrolet's Volt electric vehicle, where 90 serial cells sum up to 360 V at the pack level.

## 3.18. Lian Innovative's BMS

Lian uses a modular architecture to form their BMS. It consists of a Power Control Unit (PCU), a Central Controller Unit (CCU) and Cell Boards (CB), either InnoCab, InnoLess, or InnoTeg. The Power Control Unit measures the pack voltage and current and connects/disconnects the battery to the load/charger, the Central Control Unit manages the remaining PMU tasks for all traction applications and up to 900 V. InnoLess are wireless cell-boards, each card is connected to one single cell. The InnoCab does the same, but wired and the InnoTeg board is a wired solution that senses five cells per card.

## 3.19. Lithium Balance's S-BMS

The S-BMS is composed of a master board – Battery Management Control Unit – and monitoring boards – Local Monitoring Unit. S-BMS and S-BMS 9-16 show a conventional master-/slave-architecture with MMU+CMU- and PMU-functions on different boards. However, the S-BMS is capable to achieve pack-voltages of up to 1000 V for any automotive application.

## 3.20. Lithium Balance's S-BMS 9-16

The modular S-BMS 9-16 in contrast is limited to 48 V packages. The supervision is achieved by two local monitoring unit and one battery management control unit.

## 3.21. Manzanita Micro's Mk3x-line

Manzanita offers three different centralized systems of varying size – Mk3 Lithium BMS. Multiple boards of each system can be arranged in a row to increase the maximum pack-voltage – distributed system. Altogether, the boards can manage 120 (Mk3x4smt), 240 (Mk3x8), or 254 (Mk3x12) serial cells for any automotive application.

## 3.22. Mitsubishi iMiEV's BMS

Mitsubishi's BMS makes use of a modular architecture with one master and 11 slave units. Each slave is able to monitor 8 serial cells, which results in a total pack-voltage of 330 V for the Mitsubishi iMiEV.

## 3.23. Navitas Solutions' Wireless BMS (WiBMS)

Navitas offers a modular BMS for all automotive applications, which consists of a Battery Managing Module (MM) – master – and several Battery Sensing Modules (SM) – slave. Peculiar features of this BMS are the communication of Sensing Modules and Managing Module via wireless protocol –Wireless Local Area Network – as well as the possibility to reach pack-voltages of more than 1000 V.

## 3.24. Orion BMS – Extended Size

The Orion BMS is a centralized system with the option to connect several boards in series – distributed topology – to achieve a larger system with voltages as high as 2000 V. All electric traction applications can be managed with this system.

## 3.25. Orion BMS – Junior

Orion Jr BMS is a smaller version on the same basis without the possibility to form a distributed architecture. The designed use includes 48 V applications for light mobile traction devices.

## 3.26. Preh GmbH's BMW i3-BMS

Preh supplies BMW's i3 with a modular BMS consisting of a master and 8 control boards – slave – boards. Every slave can monitor 12 serial cells, resulting in 96 serial cells and a total pack voltage of 360 V.

## 3.27. REAP Systems' BMS

REAP Systems produces a centralized Li-Ion BMS that is able to form a system in distributed topology for every automotive application. All single boards are able to handle 14 serial battery cells.

## 3.28. Sensortechnik Wiedemann’s – STW – mBMS

STW's mBMS is a modular, tripartite system. Its components comprise a Battery Main Supervisor with PMU functions – SOC/SOH estimation and voltage/temperature/current control – a Power Measurement Board (PMB), which also fulfills some PMU tasks – disconnect switch, current monitoring – and several Cell Sensor Circuits (CSC). With a maximum pack-size of 800 V, this BMS is capable of addressing all electric traction applications.

## 3.29. SBS Storage battery systems, LLC EquaLink BMS

EquaLink is an Ethernet-based battery management system that monitors the voltage, internal resistance and temperature of each battery in a stationary, telecom or UPS battery system. Through a patented balancing process, EquaLink actively regulates the float charging current of each battery, ensuring all batteries charge at their optimal voltage. EquaLink Battery Management System actively manages batteries to increase reliability and extend the service life, Other battery monitoring systems simply monitor batteries as they deteriorate. EquaLink can monitor current, ambient/room temperature, humidity, hydrogen gas and electrolyte levels. Through available Form C contacts/relays, EquaLink can also monitor electrical equipment such as UPSs, inverters, transfer switches, generators and air conditioning systems. EquaLink is designed for many battery applications including: lead acid (flooded/wet, VRLA, gel, AGM, etc.) as well as nickel cadmium (NiCd) and nickel metal hydride (NiMH).

## 3.30. Tesla Motors’ Model S-BMS

Another example for a typical modular, master/slave-architecture is the BMS of the Model S from Tesla Motors. All 16 slaves are able to measure values of 6 serial cells, resulting in a 400 V system with 96 cells in a row.

## 3.31. #31: Tritium’s IQ BMS

Tritium's IQ BMS also represents a typical master/slave-architecture with a Battery pack Management Unit (BMU), which acts as master, and several Cell Management Units (CMU), which function as slaves. Up to 256 cells can be combined in series in order to form a 1000 V battery-pack.

## 3.32. Valence U-BMS

Valence offers four centralized system variants for different battery sizes: U-BMS-LV, U-BMS-LVM, U-BMS-HV and U-BMS-SHV. The U-BMS-LVM allows multiple units to be connected to a distributed system up to 1000 V. The others are used for 150 V (-LV), 450 V (-HV), or 450 V (-HV) automotive applications.

## 3.33. Ventec SAS i-BMS 8-18S

The iBMS 8-18s is Ventec’s only System for automotive applications – small electric vehicles. It has a centralized, distributed structure. Every single module handles 18 cells, the total pack-voltage is limited to 1000 V.

## 3.34. Victron energy Smart BMS CL 12/100

The Smart BMS CL 12/100 is a Battery Management system for Victron lithium-iron-phosphate ($LiFePO4$) Smart Batteries. It has been specifically designed for 12V systems with a 12V alternator. The BMS CL 12/100 monitors and protects each individual battery cell within the battery (or battery bank) and will disconnect the alternator, charge sources or DC loads in case of low battery voltage, high battery voltage or over temperature. The dedicated alternator input provides current limiting and one-way traffic from the alternator into the battery, this so any size alternator (and start battery) can be safely connected to the Smart Lithium battery or batteries. The BMS is also equipped with a remote on off connector, to turn the BMS (and the system) off via a remote switch, and a pre-alarm contact, to give a warning signal before the BMS will disconnect the batteries from the system.

## 3.35. Altera's BMS

Altera offers a flexible FPGA-based control platform that can be configured by the customer, resulting in improved performance and efficiency. It is able to estimate the SOC, SOH with a Kalman filter for 96 serial cells.

## 3.36. Fraunhofer's fox BMS

Fraunhofer's foxBMS is a flexible, also FPGA-supported BMS platform, which normally works with fox BMS master and fox BMS slaves. However, it is also possible to leave out the slaves and thereby get to a system with centralized architecture, where CMU and MMU properties are also covered by the master module.

## 3.37. LION Smart's Li-BMS V4

The BMS of LION Smart consists of a master – Lion Control Module – and several slaves – Lion Measure Module – and follows the typical structure of a modular system with a combined CMU/MMU-unit and a separate PMU-unit. It is technical possible to connect 16 slaves, 12 serial cells apiece, to form a battery with up to 800 V for EV applications. The Li-BMS V4 offers an open source code based for software adjustment by customers.

# 4. ANNEX: Relation of BMS, cells and battery packs manufacturers identified through the study (alphabetical order)

| Company Name | URL |
|---|---|
| 123 Electric | http://www.123electric.eu/ |
| A123 Systems | http://www.a123systems.com/lithium-battery.htm |
| AA Portable Power | http://www.aaportablepower.com/ |
| AC Propulsion System | http://www.greencarcongress.com/2008/11/ac-propulsion-s.html |
| Adverc | http://www.adverc.co.uk/ |
| AllCell Technologies | https://www.allcelltech.com/index.php/products/battery-packs |
| Amperex Technology | http://www.atlbattery.com/about/en/about-1.htm |
| Ashwoods Energy Limited (Vayon) | http://www.ashwoodsenergy.org |
| AVL | https://www.avl.com/battery-management-system-bms-development |
| BatteryMan | http://www.sdle.co.il/allsites/810/assets/batteryman_herzelia.pdf |
| Beckett Energy | http://beckettenergy.com/beckett-energy-systems-products/ |
| Beijing Pride New Energy Battery Technology Co., Ltd. | http://www.pride-power.com/ |
| Belktronix | http://www.belktronix.com/batmon.html |
| BMS PowerSafe | https://bmspowersafe.com/en/stationary-solutions/ |
| Bosh Battery Systems GmbH | http://www.bosch.de/de/de/our_company_1/business_sectors_and_divisions_1/battery_systems/battery_systems.html |
| Boston power | http://www.boston-power.com/products |
| Btech | http://www.btechinc.com/ |
| C&C Power | http://www.ccpower.com/products/batt-safe-battery-monitoring/ |
| CALB lithium battery | http://en.calb.cn/product/show/?id-633 |
| Calsonic Kansei (Nissan) | https://www.calsonickansei.co.jp/english/products/electronic/lbc.html |
| Chargery | http://www.chargery.com/ |
| China Aviation Lithium Battery Co., Ltd. | http://en.calb.cn/product/show/?id-626 |
| Clayton Power | http://www.claytonpower.com/products/bms/ |
| Clean Power Auto LLC | http://cleanpowerauto.com/product-support/ |
| Contemporary Amperex Technology Co. CATL | http://www.catlbattery.com/index.php/solution-typeid-16.html# |
| Continental | http://www.continental-corporation.com/www/pressportal_com_en/themes/press_releases/3_automotive_group/powertrain/press_releases/pr_2008_09_24_liion_batteries_en.html |
| CorvusEnergy | https://corvusenergy.com/technology-specifications/ |
| Daimler (Accumotive) | http://www.accumotive.de/de/produkte.html |
| Delphi Automotive PLC | http://delphi.com/manufacturers/auto/hevevproducts/controllers/bmc/ |
| Denso | http://denso-europe.com/wp-content/uploads/2011/08/batteryECU.jpg |
| DOW KOKAM (Xalt Energy) | http://kokam.com/cell/ |

| Company Name | URL |
|---|---|
| E22 | https://energystoragesolutions.com/vanadium-redox-flow-batteries/ |
| EaglePicher Technologies, LLC | http://www.eaglepicher.com/r-n-d/new-product-development/battery-management-systems |
| Elektromotus | https://www.elektromotus.lt/product-category/emus-bms/ |
| Elite Power Solutions | http://elitepowersolutions.com/packages.html |
| Elithion | http://elithion.com/products.php#Off-the-shelf_BMSs |
| EnerDel | http://www.enerdel.com/packs/ |
| Epower Electronics | http://www.hzepower.com/Home/Index#1 |
| EV power | http://www.ev-power.com.au/-Thundersky-Battery-Balancing-System-.html |
| Evaira | http://emsys-design.com/index.php |
| EVLithium | http://webshop.evlithium.net/index.php?cPath=26_25 |
| EVPST | http://www.evpst.com/Product.asp?bid=29&BigClassName=EV%20BMS |
| Fedco Batteries | http://www.fedcobatteries.com/ |
| Flux Power Inc. | http://www.fluxpwr.com/products/technology/ |
| Fraunhofer IIS | https://www.foxbms.org/typo3/index.php?id=foxbms |
| G4 Synergetics | http://www.g4synergetics.com/index.php/products-main |
| Gold Up New Energy | |
| GuanTuo Power | http://guantuopower.en.made-in-china.com/product/eqJQnMxglUpw/China-Lithium-Battery-BMS-GTBMS005A-MC16-.html |
| Guoxuan High-tech Power Energy | http://www.bloomberg.com/research/stocks/private/snapshot.asp?privcapId=312416846 |
| Hangzhou Jieneng Power Co., Ltd. | |
| High Tech Systems | http://hightechsystems.weebly.com/bms.html |
| Hitachi Automotive Systems | http://www.hitachi.com/New/cnews/month/2016/04/160420.pdf |
| Hyundai Kefico | https://www.hyundai-kefico.com/en/business/evms_electric.do |
| I + ME ACTIA | http://www.ime-actia.de/index.php/en/solutions-for-vehicle-manufacturers/solutions-for-cars/battery-management-systems |
| Jiangsu Highstar Battery Manufacturing | http://www.highstarbattery.com/gsjj/ |
| Johnson Matthey Battery Systems | http://www.jmbatterysystems.com/technology/battery-management-systems-(bms) |
| Jon Elis | http://www.diyelectriccar.com/forums/showthread.php/new-bms-offerings-jon-elis-low-84280.html |
| JTT Electronics LTD. | http://www.jttelectronics.com/products/cat/battery-management-systems |
| Just Power | http://eentsv2.ee.nsysu.edu.tw/eehome/seminar/docbank/Seminar00028.pdf |
| K2 Energy | http://www.k2battery.com/systems.html |
| Kopf | http://www.kopfweb.de/index.php/en/Entwicklung/component/content/article/8-entwicklung/50-development-batterie-management-systeme-bms-for-hybrid-and-electrical-vehicles |
| L&T Technology Services | http://www.lnttechservices.com/solutions/power-electronics/battery-management/ |
| Leclanché Energy storage solutions | https://www.leclanche.com/our-technologies/battery-and-energy-management-systems-2/ |

| Company Name | URL |
|---|---|
| Leoyun New Energy | http://www.qqdcw.com/product/mbr111213024130531517/pro111213024354968585.xhtml |
| LG Chem/ LG CPI (LG) | http://www.lgchem.com/global/vehicle-battery/car-batteries-Different/product-detail-PDEB0002 |
| Lian | http://lianinno.com/battery-management-systems/ |
| LIGOO New Energy Technology | http://www.ligoo.cn/en/products.asp?class_id=20021001 |
| LiPoTech | http://www.lipotech.net/industria/index.php?option=com_content&view=article&id=1&Itemid=94 |
| Lithium Balance Corporation | http://www.lithiumbalance.com/en/component/product/categories/19 |
| Manzanita Micro | http://www.manzanitamicro.com/products?page=shop.browse&category_id=36 |
| Merlin Equipment Ltd. | http://www.merlinequipment.com/markets/group.asp?groupid=59 |
| Microvast Inc. | http://www.microvast.com/index.php/solution/solution_cell |
| Midtronics | http://www.midtronics.com/shop/products-1/integrated-solutions/midtronics-ing-100-battery-monitor |
| Narada Power Source | http://en.naradapower.com/index.php/technologies?ctype=57 |
| Navitas solutions | http://www.navitasone.com/ |
| Navitas System, LLC | http://www.navitassys.com/products-systems/battery-management-systems-bms/ |
| NEC | https://www.neces.com/products-services/battery-systems/battery-components-and-accessories/ |
| Ningbo Bate Technology Co., Ltd. | https://www.bloomberg.com/profiles/companies/NBBTTZ:CH-ningbo-bate-technology-co-ltd |
| Ningbo Longway Electrical Co., Ltd. | http://www.yangming.com.cn/english/ProductsView.asp?ID=18&SortID=10 |
| Nuvation Engineering | http://www.nuvation.com/battery-management-system |
| Octillon Power Systems | http://www.octillion.us/energy-storage-products |
| Orion BMS | http://www.orionbms.com/resources/ |
| Panasonic | http://www.semicon.panasonic.co.jp/en/applications/automotive/ev_hev/bms/#t1 |
| Peter Perkins | http://batteryvehiclesociety.org.uk/forums/viewtopic.php?t=1245 |
| PowerShield | https://www.powershield.com/ |
| Preh | http://www.preh.com/produkte/e-mobility/ |
| REAP Systems | http://cgi.ddoerffel.force9.co.uk/_products/products_BMS.html |
| REC BMS | http://www.rec-bms.com/ |
| Redarc Electronics | https://www.redarc.com.au/battery-chargers/battery-management-systems |
| Rimac Automobili | http://storage.rimac-automobili.com/b2b-materials/docs/battery-management-system-and-battery-packs/RA_BMS_Detailed.pdf |
| Rotronics | http://www.rotronicsbms.com/our-products/ |
| Rozwiazania dla EV | http://rs232.elektroda.eu/?page_id=385 |
| Saftbatteries | http://www.saftbatteries.de/market-solutions/mobility |
| Samsung SDI | http://www.samsungsdi.com/automotive-battery/index.html |
| SBS Storage battery systems, LLC | https://www.sbsbattery.com/sbs-equalink-battery-monitoring-system-bms.html |

| Company Name | URL |
|---|---|
| Sensor Technik Wiedemann (STW) | https://www.sensor-technik.de/en/products.html?view=product&stwpid=14 |
| Setec Pty Ltd. | http://www.setec.com.au/portfolio/genius-battery-management-system/ |
| Shenzhen Antega Technology Co., Ltd. | http://ccne.mofcom.gov.cn/1282430 |
| Shenzhen Battsiter Tech Co., Ltd. | |
| Shenzhen Klclear Technology | http://www.klclear.com/productslist.asp?sortid=49&l=en |
| Shenzhen OptimumNano Energy | http://www.optimumnanoenergy.com/index.php?c=product&cid=54 |
| SINOEV Technologies | http://www.sinoev.com/traction-battery-pack/ |
| SK Innovation | https://cleantechnica.com/2016/09/22/sk-innovation-raises-battery-production-25/ |
| Sony | http://www.sony.net/SonyInfo/News/Press/201104/11-053E/ |
| Sunwoda Electronic | |
| TESVOLT | http://www.tesvolt.com/bidirectional-battery-management-system.html |
| Torqeedo | http://www.torqeedo.com/en/products/batteries/power-26-104/2103-00.html |
| Toshiba Corporation | https://www.toshiba.co.jp/about/press/2011_11/pr1701.htm |
| Tritium | http://tritium.com.au/products/iq-battery-management-system/ |
| TWS (Technology with Spirit) | http://www.tws.com/web/index.php/technology/bms/ |
| Valence Technology | https://www.valence.com/products/battery-management-systems/ |
| Vecture Inc. | http://www.eberspaecher-vecture.com/bms/technology/designing-the-optimal-bms.html |
| Ventec Inc. | http://ventec-ibms.com/en/embedded-bms-solutions/ventec-ibms-8-18s-packs-in-series/ |
| Victron energy | https://www.victronenergy.com/battery-management-systems |
| Voltabox | http://www.voltabox.com/products/modular-system/battery-management-system-bms/ |
| Winston Battery | http://en.winston-battery.com/ |
| Wuhu Tianyuan Automobile Electric Co., Ltd. | |
| Zanthic | http://www.zanthic.com/project31.htm |

# 5. ANNEX: patents for electrolyte tanks

**1. CN208889777U - 05/21/2019**

[en] THE UTILITY MODEL DISCLOSES A FLOW BATTERY ELECTROLYTE STORAGE TANK

Inventor(s):ZHOU YU (--); YANG LINLIN (--); YU SHUYUAN (--); LIN YOUBIN (--); SU XIULI (--)

Applicant(s):SHANGHAI ELECTRIC GROUP CO LTD (--)

Priority Number:CN201821316539U  (20180815)

Abstract [en]:

The utility model provides a flow battery electrolyte storage tank which comprises a negative electrode liquid storage tank, an electrolyte outlet and an electrolyte inlet, the electrolyte outlet andthe electrolyte inlet are formed in the negative electrode liquid storage tank, a liposuction cotton layer is arranged in the negative electrode liquid storage tank, and the liposuction cotton layer is arranged at the position of the electrolyte outlet. According to the flow battery electrolyte storage tank, organic matters in electrolyte are adsorbed through physical adsorption, organic matter molecules are prevented from entering a pipeline and a galvanic pile system, and the structural design does not affect the overall design of the storage tank; And only one liposuction cotton layer is additionally arranged inside, so that the defects in the prior art are overcome, the operation is simple and convenient, and the service life of the electric pile can be effectively prolonged.

**2. CN208655798U - 03/26/2019**

[en] A HEAT TRANSFER STORAGE TANK FOR VANADIUM REDOX FLOW BATTERY SYSTEM

Inventor(s):WANG SHUTING (--); ZHANG HUAMIN (--); NI YE (--); RONG MINGLIN (--); SONG YUBO (--); ZHANG TAO (--); ZOU YI (--)

Applicant(s):DALIAN RONGKE POWER CO LTD (--)

Priority Number:CN201821297562U  (20180813)

Abstract [en]:

A heat transfer storage tank for vanadium redox flow battery system belongs to vanadium redox flow battery heat transfer field, and in order to solve the problem that reduces indirect heating equipment occupation space and cost, main points are: press from both sides bucket wall within the jacket layer, outer bucket wall, barrel head wall, apron formations with the enclosure space of isolated inside and outside bucket, press from both sides the jacket layer and kept off class board subregion and be the relatively independent fender stream subregion of a plurality of to leave on keeping off thestream board and make the heat transferring medium keep off the mesopore that flows the by stages and flow in the difference, at least two mesopores that keep off to flow on the boards be not locatedsame height, the effect reduces the heat transfer cost, reduces to take up an area of the space.

**3. CN107946617A - 04/20/2018**

[en] FOUR-STORAGE TANK REDOX FLOW BATTERY STRUCTURE AND METHOD FOR IMPROVING ELECTROLYTE UTILIZATION RATIO

Inventor(s):LIU BAICHEN (--); ZHENG MENGLIAN (--); SUN JIE (--); ZHAO JUNXIONG (--); TIAN SHUAIQI (--); WANG TAO (--); ZHANG LIANG (--); FAN LIWU (--); YU ZITAO (--)

Applicant(s):UNIV ZHEJIANG (--)

Priority Number:CN201711105480A (20171110)

Abstract [en]:

The invention discloses a four-storage tank redox flow battery structure and method for improving electrolyte utilization ratio, and belongs to the field of new energy storage. Compared with a traditional redox flow battery, the four-storage tank redox flow battery structure has the advantages that each of a positive electrolyte inlet, a negative electrolyte inlet, a positive electrolyte outlet and a negative electrolyte outlet is connected with an independent liquid storage tank, so that liquid inlet and liquid outlet are not circulated. In the redox flow battery structure, the utilization ratio of a positive electrolyte and a negative electrolyte is remarkably improved, the difference of electrolyte charge state between a battery stack and the liquid storage tank can be substantially reduced, and the concentration polarization between the stack and the liquid storage tank is reduced; moreover, long-term charging and discharging of the battery still can be maintained under the condition of low flowing speed, the redox flow battery structure can be applied to an occasion with larger current density, and normal working of the battery is maintained; and under the condition of relatively large volume of the liquid storage tank, favorable uniformity of the electrolyte in the liquid storage tank can be enabled to be maintained, and the influence to the battery brought by non-uniformelectrolyte mixing of a traditional two-storage tank structure is prevented.

**4. CN207426026U - 05/29/2018**

[en] IMPROVE FOUR STORAGE TANK REDOX FLOW BATTERY STRUCTURES OF ELECTROLYTE UTILIZATION RATIO

Inventor(s):LIU BAICHEN (--); ZHENG MENGLIAN (--); SUN JIE (--); ZHAO JUNXIONG (--); TIAN SHUAIQI (--); WANG TAO (--); ZHANG LIANG (--); FAN LIWU (--); YU ZITAO (--)

Applicant(s):UNIV ZHEJIANG (--)

Priority Number:CN201721496998U (20171110)

Abstract [en]:

The utility model discloses an improve four storage tank redox flow battery structures of electrolyte utilization ratio belongs to new forms of energy energy storage field. The utility model disclosescompare with traditional redox flow battery, connect an independent liquid storage pot respectively at positive electrolyte inlet, cathode electrolyte inlet, positive electrolyte liquid outlet and cathode electrolyte liquid outlet, make the feed liquor and go out liquid do not forming the circulation. The utility model discloses an in the structure of electricity liquid stream pond, positive cathode electrolyte's utilization ratio is showing to be increased, can reduce electrolyte state of charge's between battery pile and the liquid storage pot difference by a wide margin, reduces the concentration polarization between pile and the liquid storage pot. And still can keep the long -time charge -discharge of battery under the condition of the low velocity of flow, and can be applied to thebigger occasion of current density, keep the battery in proper working order. Under the great condition of the volume of liquid storage pot, can guarantee the liquid storage pot in electrolyte can keep good homogeneity, avoid that electrolyte mixes the inhomogeneous influence that brings the battery among traditional two storage tank structure.

**5. CN206849952U - 01/05/2018**

[en] ELECTROLYTE STORAGE TANK AND HAVE THIS ELECTROLYTE STORAGE TANK'S REDOX FLOW BATTERY SYSTEM

Inventor(s):WANG SHUTING (--); ZHANG HUAMIN (--); HAN LECONG (--); ZHANG TAO (--); ZOU YI (--)

Applicant(s):DALIAN RONGKE POWER CO LTD (--)

Priority Number:CN201720834802U (20170711)

Abstract [en]:

Electrolyte storage tank and have this electrolyte storage tank's redox flow battery system belongs to the redox flow battery field, and for original electrolyte in solving the storage tank mixes inhomogeneous problem with time liquid, the technical essential is: including the cylindrical coil pipe of reducing, reducing cylindricality coil pipe sets up in the internal portion of jar, and reducingcylindricality coil pipe is connected and is formed in the pipe and by a plurality of rings of coil pipe screwed connection, and the diameter of each ring coil pipe is on to end circle direction by the first circle and reduces trend, and the lateral wall of each ring coil pipe has a plurality of trompils, and the effect is: the cylindrical coil pipe of reducing of this kind of shape and structurehas driven motion of former electrolyte and the effect of fluid viscidity, has carried out the energy transfer exchange, finally reachs the mixed liquid of homogeneous concentration ratio, has solvedthe current inhomogeneous problem of liquid mixing.

**6. CN107195930A - 09/22/2017**

[en] GAS ONLINE CONTROL DEVICE AND METHOD OF LIQUID STORAGE TANK OF ENERGY STORAGE POWER STATION OF ALL-VANADIUM REDOX FLOW BATTERY

Inventor(s):LI AIKUI (--); WANG QIAN (--); LIU YATING (--); WANG WEI (--); YUAN XIAODONG (--); FENG WANXING (--); ZHOU SHENG (--); MA YUEJIANG (--); CAI WEI (--)

Applicant(s):WUHAN NARI LTD LIABILITY CO OF STATE GRID ELECTRIC POWER RES INST (--); STATE GRID JIANGSU ELECTRIC POWER CO RES INST (--)

Priority Number:CN201710421540A (20170607)

Abstract [en]:

The invention relates to the technical field of battery energy storage, and particularly to a gas online control device and method of a liquid storage tank of an energy storage power station of an all-vanadium redox flow battery. A gas detection device used for detecting gas content in the liquid storage tank, converting a collected signal into an electric signal, transmitting the electric signal to a control system, and comparing the electric signal with a set gas content threshold value is configured in the liquid storage tank; when the gas content is beyond the preset threshold value, the control system opens an air inlet valve and an air outlet valve, and then inert gas is inflated in the liquid storage tank for protection; and the air inlet valve and the air outlet valve are closed until the gas content in the liquid storage tank collected by the control system is lower than the set threshold value. The energy efficiency and safety of the all-vanadium redox flow battery are improved, the service life is prolonged, automatic control of the air inlet valve and the air outlet valve and accurate control of the usage of the inert gas can be realized through the online control system, gas waste is avoided, the running and maintaining cost of the power station of the all-vanadium redox flow battery is accordingly reduced and the economical efficiency of the energy storage power station is increased.

**7. US2018342753A1 - 11/29/2018**

[en] ELECTROLYTE SOLUTION TANK FOR REDOX FLOW BATTERY AND REDOX FLOW BATTERY SYSTEM

Inventor(s):NAKAJIMA ATSUSHI (JP)

Applicant(s):DENSO CORP (JP)

Priority Number:JP2017103077A  (20170524)

Abstract [en]:

An electrolyte solution tank has a tank body, an electrolyte solution supply part, and electrolyte solution drain part and a flow guide mechanism. The electrolyte solution supply part supplies the electrolyte solution into an interior chamber in the tank body. The electrolyte solution is drained from the tank body to the outside of the tank through the electrolyte solution drain part. The flow guide mechanism is arranged in the interior chamber of the tank body. The flow guide mechanism guides the flow of the electrolyte solution in the interior chamber to the electrolyte solution drain part along a vertically downward direction.

**8. WO2018183289A1 - 10/04/2018**

[en] TANKS EMBODIMENT FOR A FLOW BATTERY

Inventor(s):D'ANZI ANGELO (US); BROVERO CARLO ALBERTO (IT); PIRACCINI GIANLUCA (IT); TAPPI MAURIZIO (IT)

Applicant(s):DANZI ANGELO (US); BROVERO CARLO ALBERTO (IT); PIRACCINI GIANLUCA (IT); TAPPI MAURIZIO (IT)

Priority Number:US201762476920P  (20170327)

Abstract [en]:

A flow battery of the type comprising at least one stack of planar cells (17), at least one negative electrolyte tank (3), at least one positive electrolyte tank (4), at least two pumps (5 and 6), for supplying electrolytes to at least one stack of planar cells (17). Either or both of the first tank (3) and the second tank (4), a primary cabinet (19), an underground tanks container (20), having a thermal insulation (18) between said tanks container (20) and the tanks (3 and 4), at least one secondary heat exchanger (21), at least one primary heat exchanger (22), at least one coolant pump (23), wherein said container (20) is buried below ground level.

**9. CN106784953A - 05/31/2017**

[en] FOUR-TANK LIFTING FLOW BATTERY ENERGY STORAGE DEVICE

Inventor(s):LI ZHAOMING (--)

Applicant(s):SHANGHAI JIUNENG ENERGY TECH DEV CO LTD (--)

Priority Number:CN201710019320A (20170111)

Abstract [en]:

A four-tank lifting flow battery energy storage device is formed by connecting two anode storage tanks with lifting devices and two cathode storage tanks with lifting devices to a flow battery pile via flexible connecting pipelines. According to the device, an electrolyte flows from the electrolyte storage tanks at high liquid levels to the flow battery pile at a low liquid level to achieve a circulating loop of the electrolyte due to a liquid level difference principle formed by lifting systems; compared with the prior art, the device avoids the use of a liquid circulation pump; power consumption and noise pollution caused by the circulating pump are reduced; and the energy storage battery device is simpler in structure.

**10. CN106248879A - 12/21/2016**

[en] ONLINE GAS DETECTION METHOD USED FOR ALL VANADIUM FLOW BATTERY LIQUID STORAGE TANK

Inventor(s):LI AIKUI (--); WANG QIAN (--); WANG WEI (--); MA JUN (--); LI GUANGLEI (--)

Applicant(s):WUHAN NARI LTD LIABILITY CO OF STATE GRID ELECTRIC POWER RES INST (--); ELECTRIC POWER RES INST OF STATE GRID SHANDONG ELECTRIC POWER CO (--)

Priority Number:CN201610639555A (20160805)

Abstract [en]:

The invention provides an online gas detection method used for an all vanadium flow battery liquid storage tank. The liquid storage tank is provided with an online detection system, and a gas in the tank is detected and analyzed when an inert gas is introduced to dispel air in the liquid storage tank to obtain component information of the gas in the liquid storage tank in order to accurately control the use amount of a protection gas; and the state of the gas in the liquid storage tank is detected in real time in the battery running process, and the inert gas is timely introduced when oxygen and other electrolyte ion-sensitive gas components are detected in order to protect and keep comprehensive valence balance of ions in the electrolyte. The gas in the all vanadium flow battery liquid storage tank is detected and analyzed in an online manner through adopting the online gas detection system, so the use amount of the protection gas is accurately controlled, and waste of the production gas is avoided, thereby the building cost of all vanadium flow battery energy storage power stations is reduced, the vanadium battery is well protected, the running efficiency of the battery is improved, the service life of the battery is prolonged, the running cost is reduced, and the running economy of the energy storage power stations is improved.

**11. CN107195942A - 09/22/2017**

[en] ELECTROLYTE STORAGE TANK, REDOX FLOW BATTERY, BOX-TYPE REDOX FLOW BATTERY SYSTEM AND CHARGE-DISCHARGE CONTROL METHOD OF REDOX FLOW BATTERY

Inventor(s):WU JINGBO (--); ZHANG HUAMIN (--); MA XIANGKUN (--); WANG HONGBO (--); QUAN YING (--); WANG YOU (--); HAN XI (--); LI JUN (--)

Applicant(s):DALIAN RONGKE POWER CO LTD (--)

Priority Number:CN201610144504A (20160314)

Abstract [en]:

The invention discloses an electrolyte storage tank, a redox flow battery, a box-type redox flow battery system and a charge-discharge control method of redox flow battery. A ring tube I and a ring tube II are arranged in the electrolyte storage tank, wherein the ring tube II communicates with an electrolyte return hole, the ring tube I communicates with an electrolyte output, the annular perimeter of the ring tube I is not equal to the annular perimeter of the ring tube II, and a plurality of liquid holes are formed in tube walls of both of the annular tube I and the annular tube II. By a multi-layer ring tube structure in the storage tank, an electrolyte flowing dead zone of an electrolyte in the storage tank is greatly reduced, the flowing of the electrolyte is more uniform, and the utilization of the electrolyte is effectively improved; and moreover, since the longitudinal distance between the electrolyte output and the electrolyte return hole is reduced, the problem of SOC lag is effectively solved, and the SOC monitoring accuracy of the redox flow battery is improved.

**12. KR20170077720A - 07/06/2017**

[en] ELECTROLYTE STORAGE TANK USING CONTAINER AND REDOX FLOW BATTERY SYSTEM HAVING THE SAME

Inventor(s):HA TAE JUNG (KR); KIM BYUNG CHUL (KR)

Applicant(s):OCI CO LTD (KR)

Priority Number:KR20150187929A (20151228)

Abstract [ko]:

N/A

**13. WO2017062936A1 - 04/13/2017**

[en] SEALED AQUEOUS FLOW BATTERY SYSTEMS WITH IN-TANK ELECTROLYTE REBALANCING

Inventor(s):SELVERSTON STEVEN (US); WAINRIGHT JESSE S (US); SAVINELL ROBERT (US)

Applicant(s):UNIV CASE WESTERN RESERVE (US)

Priority Number:US201562239469P (20151009)

Abstract [en]:

A battery system comprising a sealed aqueous flow battery that employs a passive, in-tank electrolyte recombination system. The recombination system allows for electrolyte stabilization in batteries where hydrogen evolution may occur as a side reaction without the need to use any externally-supplied rebalancing reactants. The system is a passive system that does not require a control system, additional pumps, or pumping energy.

**14. KR20170030252A - 03/17/2017**

[en] ELECTROLYTE TANK FOR REDOX FLOW BATTERY

Inventor(s):LEE JI YOUNG (KR); KIM JAE MIN (KR); YE HEE CHANG (KR); KIM SOO HWAN (KR)

Applicant(s):OCI CO LTD (KR)

Priority Number:KR20150127558A (20150909)

Abstract [en]:

The present invention relates to an electrolyte tank for a redox flow battery. More specifically, according to the present invention, disclosed is the electrolyte tank for a redox flow battery, capable of accurately detecting a change in capacity of an electrolyte. The present invention comprises: a main electrolyte tank for circulating and storing the electrolyte supplied to a stack; an electrolyte supply port for supplying the electrolyte to the stack from the main electrolyte tank; an electrolyte recovery port for recovering the electrolyte discharged from the stack; an auxiliary tank for measuring the liquid surface, which communicates with the main electrolyte tank; and a water level sensor for measuring the level of the electrolyte, which is stored in the auxiliary tank for measuring the liquid surface.

# 6. ANNEX: patents for frames

**1. CN110048141A - 07/23/2019**

[en] REDOX FLOW BATTERY ELECTRODE PLATE FRAME RUNNER AND REDOX FLOW BATTERY RUNNER

Inventor(s):WANG ZHISHENG (--); WANG BINGFU (--)

Applicant(s):GAO YAN (--); ZENG JIANHUA (--); SHI LEI (--); WANG CHAO (--)

Priority Number:CN201910321341A (20190422)

Abstract [en]:

The invention discloses a redox flow battery electrode plate frame runner. The redox flow battery electrode plate frame runner comprises an electrode plate frame body, a lower-part electrolyte flowingsharing passage and a flowing limiting runner and also comprises at least one flowing dispersing runner and a flow sharing flowing runner, wherein the lower-part electrolyte flowing sharing passage is arranged at the electrode plate frame body in a penetrating way, the flowing limiting runner communicates with the lower-part electrolyte flowing sharing passage, the sharing flowing runner is connected with a plurality of flowing allocation runners, one end of each of the plurality of flowing allocation runners is connected with the flowing dispersing runner, and the other ends of the pluralityof flowing allocation runners communicate with an electrode cavity. In the redox flow battery electrode plate frame runner proposed by the invention, gradual dispersing flowing to the electrode cavity is employed, an electrolyte simultaneously enters the electrode cavity from the plurality of flowing allocation runners and acts with a porous electrode material, the redox flow speed is reduced, the uniformity of redox flow in the electrode material is improved, full contact of the electrolyte and the electrode material is improved, the surface utilization ratio of the electrode material is improved, the surface reaction polarization of the electrode is reduced, the internal current loss of the battery is reduced, the average power of a battery unit comprising the redox flow battery electrode plate frame runner can reach 300W or above, and the corresponding battery stack power can exceed 30kW.

**2. CN109786783A - 05/21/2019**

[en] ELECTRODE FRAME FOR REDOX FLOW BATTERY WITH MULTI-CAVITY STRUCTURE AND BATTERY ELECTRIC STACK

Inventor(s):WANG YU (--); XIONG RENHAI (--); LYU YUKANG (--); WANG YUPAN (--)

Applicant(s):HANGZHOU DEHAI AIKE ENERGY TECH CO LTD (--)

Priority Number:CN201910075967A (20190126)

Abstract [en]:

The invention relates to an electrode frame for a redox flow battery with a multi-cavity structure and a battery electric stack comprising the electrode frame. The electrode frame comprises a positiveliquid inlet, a positive liquid outlet, a negative liquid inlet, a negative liquid outlet and an electrode cavity, wherein the liquid inlet and the liquid outlet are arranged at diagonal positions ofthe electrode frame, the liquid inlet and the liquid outlet both are provided with liquid inlet/outlet runners, sealing structures are arranged on a front surface and a rear surface of the electrodeframe, at least two electrode cavities are formed in the electrode frame, each electrode cavity is partitioned by an isolation strip, a sealing groove is arranged in the isolation strip and is used for sealing, each electrode cavity is hermetically arranged, each electrode cavity is a single battery reaction region, and the independent positive liquid inlet, the positive liquid outlet, the negative liquid inlet, the negative liquid outlet and the electrolyte inlet/outlet runner are arranged in each electrode cavity. The invention provides the electrode frame for partitioning the reaction region by the isolation strip, the complexity of a liquid pipeline is substantially reduced, and the assembly efficiency and the system integration are improved.

**3. CN209447939U - 09/27/2019**

[en] TANDEM FLOW BATTERY ELECTRODE FRAME AND BATTERY STACK THEREOF

Inventor(s):WANG YU (--); XIONG RENHAI (--); LYU YUKANG (--); WANG YUPAN (--)

Applicant(s):HANGZHOU DEHAIAIKE ENERGY TECH CO LTD (--)

Priority Number:CN201920133773U (20190126)

Abstract [en]:

The utility model discloses a tandem flow battery electrode frame and a battery stack thereof. The electrode frame comprises a positive electrode liquid inlet, a positive electrode liquid outlet, a negative electrode liquid inlet, a negative electrode liquid outlet and an electrode cavity; the liquid inlet and the liquid outlet are distributed at the diagonal positions of the electrode frame; both the liquid inlet and the liquid outlet are provided with liquid inlet and outlet runners; sealing structures are arranged on the front and back surfaces of the electrode frame; the electrode frame is provided with at least two electrode cavities; each electrode cavity is independently sealed; wherein each electrode cavity is a single battery reaction area, each electrode cavity is provided with an independent positive electrode liquid inlet, an independent positive electrode liquid outlet, an independent negative electrode liquid inlet, an independent negative electrode liquid outlet and an electrolyte inlet and outlet flow channel, and the positive electrode liquid inlets, the positive electrode liquid outlets, the negative electrode liquid inlets and the negative electrode liquid outlets of the adjacent single battery reaction areas are opposite in position. According to the utility model, the electrode cavity is divided into a plurality of single-battery reaction areas, and the electrolyte of the adjacent single-battery reaction areas is respectively positive and negative electrolyte, so that an internal series structure is formed, the complexity of a liquid pipeline is greatly reduced, and the assembly efficiency and the system integration degree are improved.

**4. CN209200075U - 08/02/2019**

[en] PARALLEL FLOW BATTERY ELECTRODE FRAME

Inventor(s):WANG YU (--); XIONG RENHAI (--); LYU YUKANG (--); WANG YUPAN (--)

Applicant(s):HANGZHOU DEHAIAIKE ENERGY TECH CO LTD (--)

Priority Number:CN201920138242U (20190126)

Abstract [en]:

The utility model discloses a parallel flow battery electrode frame. The electrode frame comprises a positive electrode liquid inlet, a positive electrode liquid outlet, a negative electrode liquid inlet, a negative electrode liquid outlet and an electrode cavity; the liquid inlet and the liquid outlet are distributed at the diagonal positions of the electrode frame; both the liquid inlet and theliquid outlet are provided with liquid inlet and outlet runners; sealing structures are arranged on the front and back surfaces of the electrode frame; the electrode frame is provided with at least two electrode cavities; each electrode cavity is sealed; wherein each electrode cavity is a single battery reaction area, each electrode cavity is provided with an independent positive electrode liquidinlet, an independent positive electrode liquid outlet, an independent negative electrode liquid inlet, an independent negative electrode liquid outlet and an electrolyte inlet and outlet flow channel, and the positive electrode liquid inlets, the positive electrode liquid outlets, the negative electrode liquid inlets and the negative electrode liquid outlets of the adjacent single battery reaction areas are the same in position. The utility model provides the electrode frame for dividing the reaction area by utilizing the isolation belt, so that the complexity of a liquid pipeline is greatlyreduced, the distribution uniformity of electrolyte in the reaction area is improved, the assembly efficiency is improved, and the system integration degree is improved.

**5. CN109411782A - 03/01/2019**

[en] LIQUID FLOW FRAME OF ALL-VANADIUM REDOX FLOW BATTERY

Inventor(s):YUAN XIUGUI (--); YUAN WEIXIONG (--); YUAN HAO (--); LIU SUQIN (--)

Applicant(s):UNIV CENTRAL SOUTH (--)

Priority Number:CN201811524318A (20181213)

Abstract [en]:

The invention discloses a liquid flow frame of an all-vanadium redox flow battery. The liquid flow frame comprises a hollow frame body, the frame body is symmetrically provided with a liquid inlet flow channel and a liquid outlet flow channel, and the liquid inlet flow channel comprises a liquid inlet main flow channel body, a liquid inlet first-grade buffer flow channel body, a liquid inlet first-grade branch flow channel body, a liquid inlet second-grade branch flow channel body and a liquid inlet second-grade branch flow channel body which are communicated in sequence; the liquid outlet flow channel comprises a liquid outlet main flow channel body, a liquid outlet first-grade buffer flow channel body, a liquid outlet first-grade branch flow channel body, a liquid outlet second-grade branch flow channel body and a liquid outlet second-grade branch flow channel body which are communicated in sequence; the liquid inlet first-grade branch flow channel body and the liquid outlet first-grade branch flow channel body are both evenly provided with multiple parallelogram protrusions for forming inclined electrolyte flow channels, and the liquid inlet second-grade branch flow channel bodyand the liquid outlet second-grade branch flow channel body are both evenly provided with rectangular protrusions for forming electrolyte flow channels. An electrolyte can be more evenly and uniformly distributed in the middle of the liquid flow frame, which helps to improve the energy efficiency of the vanadium battery and the current efficiency.

**6. CN209298249U - 08/23/2019**

[en] FLOW FRAME OF ALL-VANADIUM FLOW BATTERY

Inventor(s):YUAN XIUGUI (--); YUAN WEIXIONG (--); YUAN HAO (--); LIU SUQIN (--)

Applicant(s):UNIV CENTRAL SOUTH (--)

Priority Number:CN201822092802U (20181213)

Abstract [en]:

The utility model discloses a flow frame of an all-vanadium flow battery. Hollow frame body, a liquid inlet flow channel and a liquid outlet flow channel are symmetrically formed in the frame body; the liquid inlet flow channel comprises a liquid inlet main flow channel, a liquid inlet first-stage buffer flow channel, a liquid inlet first-stage sub-flow channel, a liquid inlet second-stage bufferflow channel and a liquid inlet second-stage sub-flow channel which are communicated in sequence; the liquid outlet flow channel comprises a liquid outlet main flow channel, a liquid outlet first-stage buffer flow channel, a liquid outlet first-stage sub-flow channel, a liquid outlet second-stage buffer flow channel and a liquid outlet second-stage sub-flow channel which are communicated in sequence; a plurality of parallelogram bulges used for forming inclined electrolyte flow channels are uniformly arranged in the liquid inlet first-stage branch flow channel and the liquid outlet first-stagebranch flow channel; and a plurality of rectangular bulges used for forming electrolyte flow channels are uniformly arranged in the liquid inlet second-stage branch flow channel and the liquid outletsecond-stage branch flow channel. According to the flow frame disclosed by the utility model, electrolyte can be more uniformly and consistently distributed in the middle of the flow frame, so that the energy efficiency of the vanadium battery is favorably improved, and the current efficiency is improved.

**7. CN109575479A - 04/05/2019**

[en] PVC MATERIAL AND APPLICATION THEREOF IN POSITIVE AND NEGATIVE ELECTRODE FRAME OF ZINC-BROMINE FLOW BATTERY

Inventor(s):QIN PENG (--); XIE MINGXING (--); YIN GUOJIE (--); HUANG XIANBO (--); YE NANBIAO (--); YANG XIAOYUN (--)

Applicant(s):KINGFA SCIENCE & TECHNOLOGY CO (--)

Priority Number:CN201811492504A (20181207)

Abstract [en]:

The invention relates to the field of PVC materials, in particular to a PVC material applied to a positive and negative electrode frame of a zinc-bromine flow battery. The PVC material comprises the following components by weight percentage: 75-85% of PVC resin, 0.1-0.5% of synthetic PE wax and 0.2-1.5% of phosphite ester. The selected synthetic PE wax can migrate to the outer surface of the product to form a protective layer, so that the basal body resin is not eroded by the solution, and the addition of completely phenol-free liquid phosphite ester is beneficial to improving the transparency, thermal stability and aging resistance of the product; and specific PE synthetic wax and phosphite ester are selected to be used together, so that the positive and negative electrode shell materialcan be protected from corrosion, cracking and peeling at high temperature, and has excellent thermal stability, excellent aging resistance and good transparency.

**8. CN209133610U - 07/19/2019**

[en] FLOW FRAME FOR FLOW BATTERY

Inventor(s):ZHENG QIONG (--); LI XIANFENG (--); YUAN CHENGUANG (--); ZHANG HUAMIN (--); YUE MENG (--); LYU ZHIQIANG (--)

Applicant(s):DALIAN INST CHEM & PHYSICS CAS (--)

Priority Number:CN201821954419U (20181126)

Abstract [en]:

The utility model relates to a redox flow battery. The flow frame for the flow battery is a flow battery assembled by a flow frame structure with single-side full-circumferential inflow, on one hand,full-circumferential inflow and outflow can increase the flow of an electrolyte entering the battery, strengthen internal mass transfer of the battery and reduce internal polarization of the battery,so that the internal resistance of the battery is reduced, and the performance of the battery is improved; on the other hand, the flow guide baffles and the flow guide groove distances for liquid inlet and outlet are arranged according to arithmetic progression, the distribution uniformity of inlet and outlet electrolyte in an electrode area inlet and outlet can be improved, and the battery operation reliability is improved.

**9. WO2020080278A1 - 04/23/2020**

[en] CELL FRAME AND REDOX FLOW BATTERY

Inventor(s):NAKAO TAKATO (JP); THEEDA UMA JAYA RAVALI (JP)

Applicant(s):TOYO ENGINEERING CORP (JP)

Priority Number:JP2018196652A (20181018)

Abstract [en]:

A cell frame 20, having: a frame body 21 provided with an opening 22, the frame body 21 having a through hole 31, which penetrates the frame body 21 from one surface to the other surface in the periphery of the opening 22 and which channels a fluid containing an active material, and a groove-shaped slit 35, which is formed on the one surface or the other surface and which connects the through hole 31 and the opening 22; and a rotating body 40, which is made of an insulating material, accommodated in the slit 35, and made to rotate by a fluid flowing in the slit 35 between the through hole 31 and the opening 22.

**10. CN208889773U - 05/21/2019**

[en] DISCLOSED IS AN ELECTRODE FRAME STRUCTURE FOR A FLOW BATTERY

Inventor(s):YUAN CHENGUANG (--); LI XIANFENG (--); ZHENG QIONG (--); ZHANG HUAMIN (--)

Applicant(s):DALIAN INST CHEM & PHYSICS CAS (--)

Priority Number:CN201821601421U (20180929)

Abstract [en]:

The utility model relates to the technical field of flow battery energy storage, in particular to an electrode frame structure for a flow battery. A through hole for accommodating the porous electrodeis formed in the middle; Liquid distribution grooves are respectively formed in the surface of one side of the electrode frame and two opposite sides of the middle through hole; The electrolyte outlet is located above the left of the flat plate, the number of the outlet main runner grooves is two, the number of the outlet main runner grooves is two, the number of the outlet main runner grooves istwo, the upper outlet main runner groove is communicated with the upper half part of the electrolyte outlet, and the lower outlet main runner groove is communicated with the lower half part of the electrolyte outlet; The right end of the upper outlet main runner groove is communicated with the left end of the right outlet liquid distribution groove, and the right end of the lower outlet main runner groove is communicated with the left end of the left outlet liquid distribution groove; And the electrolyte inlet and the electrolyte outlet are symmetrical. According to the utility model, the electrolyte flowing area is increased; Reducing flow resistance.

**11. CN209389139U - 09/13/2019**

[en] INTEGRATED END FRAME PLATE OF REDOX FLOW BATTERY

Inventor(s):MA DONGLIANG (--); GU YU (--)

Applicant(s):FOSHAN ZHONGLIANG XINNENG TECH CO LTD (--)

Priority Number:CN201821545857U (20180921)

Abstract [en]:

An integrated end frame plate of a redox flow battery comprises a collector plate, a conductive plastic plate, an electrode, a perfluorinated ionic membrane and a liquid flow end frame plate which aresequentially combined, and the collector plate, the conductive plastic plate and the liquid flow end frame plate are formed through one-time injection molding; solution tanks are arranged on the leftside and the right side of the liquid flow end frame plate, and are provided with liquid inlet long straight U-shaped solution circuitous tanks and liquid outlet long straight U-shaped solution circuitous tanks; one-time injection molding, the peripheries of the conductive plastic plate and the collector plate are wrapped into a whole by injection molding plastics, so that the internal leakage phenomenon of positive and negative electrolyte in sealed corner areas of the end frame plate, the conductive plastic plate and the collector plate of the flow battery is solved, the production processand the production cost can be greatly reduced compared with the prior art, and the flow battery is suitable for large-scale specialized production and manufacturing.

**12. CN208589496U - 03/08/2019**

[en] FLOW FRAME AND REDOX FLOW BATTERY THEREOF

Inventor(s):YU SHUYUAN (--); YANG LINLIN (--); LIN YOUBIN (--); ZHOU YU (--); SU XIULI (--)

Applicant(s):SHANGHAI ELECTRIC GROUP CO LTD (--)

Priority Number:CN201821283739U (20180809)

Abstract [en]:

The utility model provides a flow frame, include that positive pole liquid flows frame and negative pole flow frame, positive pole liquid stream frame and negative pole flow frame include respectivelythat the access opening is shareed in the import of being connected with outside electrolyte storage tank and the access opening is shareed in the export, and the import is shareed the access openingand is looped through imported current -limiting passageway, is imported first order splitter box and import second level splitter box intercommunication, import current -limiting passageway is Z style of calligraphy, its lateral surface that is located flow frame, import first order splitter box has a plurality ofly, its medial surface and intercommunication import current -limiting passageway that lies in flow frame, second level splitter box intercommunication electrode groove, its medial surface that is located flow frame, electrode groove loops through export second level splitter box, export first order splitter box, export current -limiting passageway and export sharing access opening intercommunication. The utility model discloses a flow frame and redox flow battery thereof can realize that even reposition of redundant personnel of electrolyte and battery are sealed, ensures the stability of redox flow battery system operation, improves battery power efficiency, extension battery life. The utility model provides an adopt above -mentioned flow frame's redox flow battery.

**13. CN208368633U - 01/11/2019**

[en] ELECTRODE FRAME FOR VANADIUM REDOX FLOW BATTERY

Inventor(s):WANG YU (--); XIONG RENHAI (--); LYU YUKANG (--); WANG YUPAN (--)

Applicant(s):HANGZHOU DEHAI AIKE ENERGY TECH CO LTD (--)

Priority Number:CN201820991637U (20180626)

Abstract [en]:

The utility model mainly discloses an electrode frame for vanadium redox flow battery, its technical scheme: set up the electrode chamber in the middle of the electrode frame main part, electrode frame main part four corners is equipped with anodal inlet, anodal liquid outlet, negative pole inlet and negative pole liquid outlet respectively, anodal inlet has connected gradually anodal feed liquorsprue, the first subchannel of anodal feed liquor and anodal feed liquor intermediate layer runner, and anodal liquid outlet has connected gradually and has anodally gone out the liquid sprue, has anodally gone out the first subchannel of liquid and anodal and go out liquid intermediate layer runner, electrode frame main part reverse side is equipped with amberplex, anodal inlet, anodal liquid outlet, electrode chamber and amberplex edge all around all are equipped with the seal groove, seal groove department is equipped with the sealing strip, amberplex is fixed through the sealing strip allaround. Can improve the spray deposition uniformity of electrolyte, improve battery reaction efficiency, the sealed design of separated reduces leakage current, pile thickness, reduces the equipment process, reduces the equipment degree of difficulty, reduces the pile cost.

**14. WO2019234869A1 - 12/12/2019**

[en] BIPOLAR PLATE, CELL FRAME, CELL STACK, AND REDOX FLOW BATTERY

Inventor(s):HANAFUSA KEI (JP); IDA SHOMA (JP); OKUMURA SOUICHIROU (JP); TSUSHIMA SHOHJI (JP); FUJITA KIKUO (JP); YAMASAKI SHINTARO (JP); YAJI KENTARO (JP); SUZUKI TAKAHIRO (JP)

Applicant(s):SUMITOMO ELECTRIC INDUSTRIES (JP); UNIV OSAKA (JP)

Priority Number:JP2018021778W (20180606)

Abstract [en]:

A bipolar plate comprising an effective electrode region in which an electrode of a redox flow battery is positioned on at least one surface, wherein the effective electrode region comprises a closed groove section and a protruding section, said closed groove section being a groove section through which an electrolytic solution flows, and not opening to one of a supply edge that is positioned on an electrolytic solution supply side of the effective electrode region and a discharge edge that is positioned on an electrolytic solution discharge side, or not opening to either, and said protruding section having a peripheral edge that is independent from and does not duplicate a peripheral edge of the closed groove section, and protruding from a bottom surface of the closed groove section within a range that is less than or equal to the groove depth of the closed groove section.

**15. WO2019234868A1 - 12/12/2019**

[en] BIPOLAR PLATE, CELL FRAME, CELL STACK, AND REDOX FLOW BATTERY

Inventor(s):HANAFUSA KEI (JP); IDA SHOMA (JP); OKUMURA SOUICHIROU (JP); TSUSHIMA SHOHJI (JP); FUJITA KIKUO (JP); YAMASAKI SHINTARO (JP); YAJI KENTARO (JP); SUZUKI TAKAHIRO (JP)

Applicant(s):SUMITOMO ELECTRIC INDUSTRIES (JP); UNIV OSAKA (JP)

Priority Number:JP2018021777W (20180606)

Abstract [en]:

A bipolar plate that has a facing surface facing an electrode of a redox flow battery, and an electrolytic solution introduction section and discharge section positioned on the facing surface, said bipolar plate comprising: an introduction path that has a groove section CI0 connecting to the introduction section and a groove section CIn branching off from the groove section CI0, neither of said grooves connecting to the discharge section; and a discharge path that has a groove section CO0 connecting to the discharge section and a groove section COm branching off from the groove section CO0, neither of said grooves connecting to the introduction section, wherein the groove section CIn branches off from a groove section CIn-1 in a direction intersecting the direction of extension of the groove section CIn-1, the groove section COm branches off from a groove section COm-1 in a direction intersecting the direction of extension of the groove section COm-1, and when the bipolar plate is in planar view, tip end sections of all of the grooves are tapered. Here, n and m are arbitrary natural numbers greater than or equal to 1.

**16. WO2019234867A1 - 12/12/2019**

[en] BIPOLAR PLATE, CELL FRAME, CELL STACK, AND REDOX FLOW BATTERY

Inventor(s):HANAFUSA KEI (JP); IDA SHOMA (JP); OKUMURA SOUICHIROU (JP); TSUSHIMA SHOHJI (JP); FUJITA KIKUO (JP); YAMASAKI SHINTARO (JP); YAJI KENTARO (JP); SUZUKI TAKAHIRO (JP)

Applicant(s):SUMITOMO ELECTRIC INDUSTRIES (JP); UNIV OSAKA (JP)

Priority Number:JP2018021776W (20180606)

Abstract [en]:

A bipolar plate having an electrode of a redox flow battery positioned thereon and comprising: a facing surface that faces said electrode; and at least one groove that forms, in the facing surface, a flow path through which an electrolytic solution flows, wherein when the bipolar plate is in planar view, at least one of the grooves has a curved section.

**17. WO2019206119A1 - 10/31/2019**

[en] STACK FRAME FOR FLOW BATTERY

Espacenet = http://worldwide.espacenet.com/searchResults?ST=singleline&locale=en_EP&submitted=true&DB=worldwide.espacenet.com&query=WO2019206119A1

Inventor(s):ZU GE (CN); WANG JIN (CN); ZHENG XIAOHAO (CN)

Applicant(s):JIANGSU TRANSUNIVERSE POWER CO LTD (CN)

Priority Number:CN201810391609A (20180427)

Abstract [en]:

The present invention relates to a stack frame for a flow battery characterized in that the stack frame is made of a polymer material and has a hollow structure, and the outer shape thereof has a horizontally and/or vertically symmetrical structure. The stack frame has a front portion and a back portion. A surface of the front portion has an electrolyte inlet, an electrolyte outlet, an electrolyte guiding recess, and a gasket recess. The electrolyte guiding recess and the gasket recess do not communicate with each other. The electrolyte guiding recess is at least partially exposed to the surface of the front portion of the stack frame. The electrolyte guiding recess allows an electrolyte to flow in or out of graphite felts at two sides of a bipolar plate or two sides of a separator of a flow battery.

**18. WO2019206117A1 - 10/31/2019**

[en] STACK FRAME FOR FLOW BATTERY

Inventor(s):ZU GE (CN); WANG JIN (CN); ZHENG XIAOHAO (CN)

Applicant(s):JIANGSU TRANSUNIVERSE POWER CO LTD (CN)

Priority Number:CN201810391600A (20180427)

Abstract [en]:

The present invention relates to a stack frame for a flow battery. The stack frame is made of a polymer material and is a hollow structure. The stack frame has an electrolyte inlet, an electrolyte outlet, an electrolyte guiding recess, and a gasket recess. The electrolyte guiding recess respectively and independently communicates with the electrolyte inlet and the electrolyte outlet, and allows an electrolyte to pass therethrough and flow in or out of graphite felts at two sides of a bipolar plate or two sides of a separator. The electrolyte guiding recess and the gasket recess do not communicate with each other.

**19. WO2019167143A1 - 09/06/2019**

[en] FRAME BODY, CELL FRAME, CELL STACK, AND REDOX FLOW BATTERY

Inventor(s):YAMAGUCHI HIDEYUKI (JP); MOTOI KENJI (JP); YAMANA TAKESHI (JP)

Applicant(s):SUMITOMO ELECTRIC INDUSTRIES (JP)

Priority Number:JP2018007343W (20180227)

Abstract [en]:

This frame body is used for a redox flow battery. The frame body has outer periphery end portions, the outer periphery end portions have notches, and the depth of each notch is 5-60 mm.

**20. WO2019150570A1 - 08/08/2019**

[en] CELL FRAME, BATTERY CELL, CELL STACK, AND REDOX FLOW BATTERY

Inventor(s):ITO TAKEFUMI (JP); KUWABARA MASAHIRO (JP)

Applicant(s):SUMITOMO ELECTRIC INDUSTRIES (JP)

Priority Number:JP2018003736W (20180205)

Abstract [en]:

Provided is a cell frame that is provided with a bipolar plate and a frame body provided on the outer periphery of the bipolar plate, wherein: a groove through which an electrolyte supplied from the outside of the cell frame flows is provided on one surface of the bipolar plate; the groove is provided with liquid retention parts for retaining the electrolyte when the supply of the electrolyte from the outside is stopped; the planar area of an opening in the frame body is 250 cm2 or greater; and a total volume for the volume of a recess created by the bipolar plate and an inside wall of the frame body and the total volume of the liquid retention parts is 5 cm3 or greater.

**21. CN109841867A - 06/04/2019**

[en] LIQUID FLOW FRAME SUITABLE FOR TRAPEZOIDAL FLOW BATTERY STACK

Inventor(s):ZHENG QIONG (--); ZHANG HUAMIN (--); YUE MENG (--); LI XIANFENG (--)

Applicant(s):DALIAN INST CHEM & PHYSICS CAS (--); DALIAN RONGKE POWER CO LTD (--)

Priority Number:CN201711213539A (20171128)

Abstract [en]:

The invention relates to a liquid flow frame suitable for a trapezoidal flow battery stack. The liquid flow frame is a plate-shaped structure with through holes in the middle, the through holes are electrode regions, the cross sections of the through holes parallel to a plate body plane are an isosceles trapezoids, one side surface or two side surfaces of a plate are provided with grooves for freeflow areas of electrolyte close to edges of upper and lower bottom sides of the through holes, a groove at an edge of the lower bottom side is an inlet free flow area, a groove at an edge of the upper bottom side is an outlet free flow area, and more than two grooves for secondary flow guiding channels are set between each free flow area and the through holes. The liquid flow frame has the advantages of simple structure

and convenient processing, the uniformity of electrolyte distribution can be effectively improved, the local overheating inside a reactor is suppressed, the polarization is reduced, and the electrolyte utilization is improved.

**22. CN109841866A - 06/04/2019**

[en] LIQUID FLOW FRAME SUITABLE FOR TRAPEZOIDAL FLOW BATTERY

Inventor(s):ZHENG QIONG (--); ZHANG HUAMIN (--); YUE MENG (--); LI XIANFENG (--)

Applicant(s):DALIAN INST CHEM & PHYSICS CAS (--); DALIAN RONGKE POWER CO LTD (--)

Priority Number:CN201711212809A (20171128)

Abstract [en]:

The invention relates to a liquid flow frame suitable for a trapezoidal flow battery. The liquid flow frame is a plate-shaped structure with through holes in the middle, the cross sections of the through holes parallel to a plate body plane is isosceles trapezoids, one side surface or two side surfaces of a plate are provided with grooves for free flow areas close to edges of upper and lower bottom sides of the trapezoidal through holes, and more than two trapezoidal grooves for secondary flow guiding channels are set between each free flow area and the trapezoidal through holes. The liquid flow frame has the advantages of simple structure and convenient processing, the uniformity of electrolyte distribution is effectively improved by promoting the radial flow of an electrolyte along a fanshape where the trapezoid is located, therefore, the local effect is alleviated, and the battery performance is improved.

**23. CN109841873A - 06/04/2019**

[en] LIQUID FLOW FRAME SUITABLE FOR FLOW BATTERY STACK

Inventor(s):ZHENG QIONG (--); ZHANG HUAMIN (--); YUE MENG (--); LI XIANFENG (--)

Applicant(s):DALIAN INST CHEM & PHYSICS CAS (--); DALIAN RONGKE POWER CO LTD (--)

Priority Number:CN201711213096A (20171128)

Abstract [en]:

The invention relates to a liquid flow frame suitable for a flow battery stack or a flow battery. The liquid flow frame is a plate-shaped structure with through holes in the middle, the through holesare electrode regions, the cross sections of the through holes parallel to a plate body plane are rectangles or isosceles trapezoids, one side surface or two side surfaces of a plate are provided withgrooves for free flow areas of electrolyte close to edges of upper and lower bottom sides of the through holes, a groove at an edge of one side of the rectangle or a lower bottom side of the trapezoid is an inlet free flow area, an opposite side of the side of the rectangle or an upper bottom side of the trapezoid is an outlet free flow area, and more than two grooves for secondary flow guiding channels are set between each free flow area and the through holes. The liquid flow frame has the advantages of simple structure and convenient processing, the uniformity of electrolyte distribution can be effectively improved, the local overheating inside a reactor is suppressed, the polarization is reduced, and the electrolyte utilization is improved.

**24. WO2019046724A8 - 03/12/2020**

[en] SEGMENTED FRAMES FOR REDOX FLOW BATTERIES

Inventor(s):KATO GARRETT (US)

Applicant(s):ITN ENERGY SYSTEMS INC (US)

Priority Number:US201762553631P (20170901)

Abstract [en]:

A segmented frame plate is provided, which may be used in a frame plate assembly of a redox flow battery cell stack. A plurality of segmented frame plates may couple together around a perimeter of a cell plate. Each segmented frame plate may provide fluidic communication from/to a redox flow reservoir and/or another frame plate assembly to a cell plate of the frame plate assembly.

**25. WO2019021441A1 - 01/31/2019**

[en] CELL FRAME, CELL STACK, AND REDOX FLOW BATTERY

Inventor(s):FUJITA HAYATO (JP); TOYODA HARUHISA (JP)

Applicant(s):SUMITOMO ELECTRIC INDUSTRIES (JP)

Priority Number:JP2017027328W (20170727)

Abstract [en]:

Provided is a cell frame comprising a bipolar plate and a frame body, the cell frame further comprising: an introduction-side flow control groove connected to an inlet slit and extending in the width direction of the cell frame; a discharge-side flow control groove connected to an outlet slit and extending in the width direction; and a diffusion groove unit causing the introduction-side flow control groove and the discharge-side flow control groove to communicate with each other. The diffusion groove unit includes: an introduction-side longitudinal groove which branches from the introduction-side flow control groove, extends toward the discharge-side flow control groove and does not directly communicate with the discharge-side flow control groove; a discharge-side longitudinal groove which branches from the discharge-side flow control groove, extends toward the introduction-side flow control groove and does not directly communicate with the introduction-side flow control groove; and one or more lateral grooves communicating with the introduction-side longitudinal groove and the discharge-side longitudinal groove.

**26. WO2019021440A1 - 01/31/2019**

[en] BIPOLAR PLATE, CELL FRAME, CELL STACK, AND REDOX FLOW BATTERY

Inventor(s):KUWABARA MASAHIRO (JP); KANNO TAKASHI (JP)

Applicant(s):SUMITOMO ELECTRIC INDUSTRIES (JP)

Priority Number:JP2017027327W (20170727)

Abstract [en]:

This bipolar plate has a flow path wherethrough an electrolyte flows. The flow path comprises an electrolyte inlet port on the lower side of the bipolar plate, an electrolyte outlet port on the upper side of the bipolar plate, an inlet groove part leading to the inlet port, and an outlet groove part leading to the outlet port. The inlet groove part and outlet groove part comprise either a communicating part placing the inlet port and outlet port in communication and having localities of reduced cross sectional area, or a closed end part separating the inlet groove part and outlet groove part from one another. Partway from the inlet port to the leading end of the inlet groove part in the longitudinal direction, the inlet groove part is provided with: a lower convolution part which bends toward the lower end of the bipolar plate, and an inlet solution accumulation part for accumulating the electrolyte which is nearer to the leading end of the inlet groove part than to the lower convolution part.

**27. WO2019012984A1 - 01/17/2019**

[en] BIPOLAR PLATE, CELL FRAME, BATTERY CELL, CELL STACK, AND REDOX FLOW BATTERY

Inventor(s):DONG YONGRONG (JP); MIYAWAKI HIDEKI (JP)

Applicant(s):SUMITOMO ELECTRIC INDUSTRIES (JP)

Priority Number:JP2017137469A (20170713)

Abstract [en]:

This bipolar plate is disposed so as to face an electrode that conducts battery reactions by receiving a supply of an electrolytic solution, and comprises: a plurality of groove portions which allow the electrolytic solution to flow to the front and/or rear surface of the bipolar plate; and ridge portions separating the adjacent groove portions. The ridge portions include a specific ridge portion provided with: a contact surface which is in contact with the electrode; and one or more recessed portions which are open in the contact surface.

**28. WO2018134956A1 - 07/26/2018**

[en] BIPOLAR PLATE, CELL FRAME, CELL STACK AND REDOX FLOW BATTERY

Inventor(s):FUJITA HAYATO (JP); MOTOI KENJI (JP)

Applicant(s):SUMITOMO ELECTRIC INDUSTRIES (JP)

Priority Number:JP2017001826W (20170119)

Abstract [en]:

This bipolar plate, arranged between a positive electrode and a negative electrode of a redox flow battery, comprises, on a surface of the bipolar plate facing at least one of the positive electrode and the negative electrode, multiple grooves through which an electrolyte solution flows, and a ridge positioned between neighboring grooves. In at least a portion of the groove inner surfaces configuring the grooves, the surface roughness is greater than or equal to 0.1 µm by arithmetic average thickness Ra.

**29. WO2018134928A1 - 07/26/2018**

[en] BIPOLAR PLATE, CELL FRAME, CELL STACK, AND REDOX FLOW CELL

Inventor(s):YAMAGUCHI HIDEYUKI (JP); MOTOI KENJI (JP)

Applicant(s):SUMITOMO ELECTRIC INDUSTRIES (JP)

Priority Number:JP2017001615W (20170118)

Abstract [en]:

In this bipolar plate in which electrodes of a redox flow cell are arranged, the curvature radii of corners of an outer peripheral edge, when viewed in a cross section orthogonal to the planar surface of the bipolar plate, are in the range of 0.1-4.0 mm inclusive.

**30. WO2018116467A1 - 06/28/2018**

[en] CELL FRAME, CELL STACK, AND REDOX FLOW BATTERY

Inventor(s):KUWABARA MASAHIRO (JP); MOTOI KENJI (JP)

Applicant(s):SUMITOMO ELECTRIC INDUSTRIES (JP)

Priority Number:JP2016088518W (20161222)

Abstract [en]:

This cell frame comprises, on each of a surface facing a positive pole electrode and a surface facing a negative pole electrode, an introduction flow path for introducing an electrolytic solution into each of the electrodes, and an discharge flow path provided independently from the introduction flow path and having no communication therewith, and discharging the electrolytic solution from each electrode. The introduction flow path comprises an introduction side rectification groove, and a plurality of introduction side branching grooves spaced from one another and communicating with the introduction side rectification groove. The discharge flow path comprises a discharge side rectification groove, and a plurality of discharge side branching grooves spaced from one another and communicating with the discharge side rectification groove. Each of the introduction side branching grooves extends toward the discharge side rectification groove, and each of the discharge side branching grooves extends toward the introduction side rectification groove. Both the spacing distance X, between the introduction side rectification groove and each of the discharge side branching grooves, and the spacing distance Y, between the discharge side rectification groove and each of the introduction side branching grooves, are between 1 mm and 30 mm inclusive.

**31. WO2018105092A1 - 06/14/2018**

[en] FRAME BODY, CELL FRAME, CELL STACK, AND REDOX FLOW BATTERY

Inventor(s):KUWABARA MASAHIRO (JP)

Applicant(s):SUMITOMO ELECTRIC INDUSTRIES (JP)

Priority Number:JP2016086644W (20161208)

Abstract [en]:

This frame body is to be installed in the surrounding of a bipolar plate disposed between a positive pole electrode and a negative pole electrode of a redox flow battery. The frame body comprises: a positive electrode solution supply slit and a positive electrode solution discharge slit provided on one surface side of the frame body, and supply/evacuating the positive pole electrolytic solution to/from the positive pole electrode; and a negative electrode solution supply slit and a negative electrode solution discharge slit provided on the other surface side of the frame body, and supplying/evacuating a negative pole electrolytic solution to/from the negative pole electrode. Among the set of respective inlet portions from the positive electrode solution supply slit and the negative electrode solution supply slit, and the set of respective outlet portions from the positive electrode solution discharge slit and the negative electrode solution discharge slit, at least one set is provided in such a manner that the portions partially overlap with one another in the thickness direction of the frame body.

**32. WO2018092215A1 - 05/24/2018**

[en] CELL FRAME, CELL STACK, AND REDOX FLOW BATTERY

Inventor(s):KANNO TAKASHI (JP)

Applicant(s):SUMITOMO ELECTRIC INDUSTRIES (JP)

Priority Number:JP2016083981W  (20161116)

Abstract [en]:

Provided is a cell frame comprising: a bipolar plate that is connected with electrodes constituting a battery cell; and a frame surrounding the periphery of the bipolar plate. The frame is provided with a liquid supply manifold for supplying an electrolyte solution to the interior of the battery cell. The bipolar plate is provided with a plurality of main grooves that are arranged on the electrode-side surfaces thereof and through which the electrolyte solution flows. At least one of the frame and the bipolar plate is provided with a liquid supply rectifying section that diffuses electrolyte solution from the liquid supply manifold in the direction of arrangement of the grooves and supplies the electrolyte solution to each of the main grooves. The width ratio Wr/Wi of the width Wi of inlets for the electrolyte solution in the main grooves and the width Wr of the liquid supply rectifying section in a direction orthogonal to the direction of arrangement of the main grooves is 1.5-10.

**33. WO2018092216A1 - 05/24/2018**

[en] CELL FRAME, CELL STACK, AND REDOX FLOW BATTERY

Inventor(s):KANNO TAKASHI (JP)

Applicant(s):SUMITOMO ELECTRIC INDUSTRIES (JP)

Priority Number:JP2016083982W  (20161116)

Abstract [en]:

Provided is a cell frame comprising: a bipolar plate that is connected with electrodes constituting a battery cell; and a frame surrounding the periphery of the bipolar plate. The frame is provided with a drainage manifold for discharging an electrolyte solution to the exterior of the battery cell. The bipolar plate is provided with a plurality of main grooves that are arranged on the electrode-side surfaces thereof and through which the electrolyte solution flows. At least one of the frame and the bipolar plate is provided with a drainage rectifying section that collects electrolyte solution discharged from each of the main grooves and guides the electrolyte solution to the drainage manifold. When the width of the main grooves is denoted by Wc, the total width Wctotal of the plurality of main grooves is larger than the width Wd of the drainage rectifying section in a direction orthogonal to the direction of arrangement of the main grooves.

**34. WO2018069996A1 - 04/19/2018**

[en] BIPOLAR PLATE, CELL FRAME, CELL STACK, AND REDOX FLOW CELL

Inventor(s):KANNO TAKASHI (JP); MOTOI KENJI (JP)

Applicant(s):SUMITOMO ELECTRIC INDUSTRIES (JP)

Priority Number:JP2016080270W (20161012)

Abstract [en]:

Provided is a bipolar plate that is disposed between a positive electrode and a negative electrode of a redox flow cell, wherein the bipolar plate has, on a surface that faces at least one of the positive electrode and the negative electrode of the bipolar plate, at least one groove for circulating an electrolyte, wherein the groove has a pair of side walls that face each other in a cross-section thereof orthogonal to the direction in which the electrolyte is circulated, and wherein a narrow-width section in which the spacing between the side walls is decreased in the depth direction is provided in at least a portion of the groove in the depth direction.

**35. WO2018066095A1 - 04/12/2018**

[en] FRAME BODY, CELL FRAME, CELL STACK, AND REDOX FLOW BATTERY

Inventor(s):FUJITA HAYATO (JP); KANNO TAKASHI (JP); MOTOI KENJI (JP); YAMANA TAKESHI (JP)

Applicant(s):SUMITOMO ELECTRIC INDUSTRIES (JP)

Priority Number:JP2016079680W (20161005)

Abstract [en]:

This frame body is part of a planar cell frame used in the cell stack of a redox flow battery, and supports, from an outer peripheral side, a bipolar plate provided in the cell frame. The frame body is provided with a frame-facing surface which, when a plurality of the cell frames are stacked, is face-to-face with the frame body of another cell frame that is adjacent thereto in the stacking direction, the surface roughness Ra of the frame-facing surface being between 0.03 µm and 3.2 µm inclusive.

**36. WO2018066094A1 - 04/12/2018**

[en] FRAME BODY, CELL FRAME, CELL STACK, AND REDOX FLOW BATTERY

Inventor(s):YAMAGUCHI HIDEYUKI (JP); KANNO TAKASHI (JP); MOTOI KENJI (JP); YAMANA TAKESHI (JP)

Applicant(s):SUMITOMO ELECTRIC INDUSTRIES (JP)

Priority Number:JP2016079679W (20161005)

Abstract [en]:

Disclosed is a frame body to be used in a cell frame of a redox flow battery. The frame body has an outer peripheral section, and the outer peripheral section has a thin region the thickness of which is gradually reduced toward the outer periphery of the frame body from the center of the frame body.

**37. US2020112044A2 - 04/09/2020**

[en] CELL FRAME AND REDOX FLOW BATTERY

Inventor(s):KANNO TAKASHI (JP); YAMANISHI KATSUYA (JP); ITO TAKEFUMI (JP); KUWABARA MASAHIRO (JP); MORIUCHI KIYOAKI (JP); YAMAGUCHI HIDEYUKI (JP); FUJITA HAYATO (JP); SHIRAKI KOUSUKE (JP); HAYASHI KIYOAKI (JP)

Applicant(s):KANNO TAKASHI (JP); YAMANISHI KATSUYA (JP); ITO TAKEFUMI (JP); KUWABARA MASAHIRO (JP); MORIUCHI KIYOAKI (JP); YAMAGUCHI HIDEYUKI (JP); FUJITA HAYATO (JP); SHIRAKI KOUSUKE (JP); HAYASHI KIYOAKI (JP); SUMITOMO ELECTRIC INDUSTRIES (JP)

Priority Number:US201916250682A (20190117); JP2014226269A (20141106); US201715501502A (20170203); JP2015078209W (20151005)

Abstract [en]:

The battery cell for a flow battery includes a cell frame including a frame including a through-window and a manifold serving as an electrolyte flow path, and a bipolar plate blocking the through-window; a positive electrode disposed on one surface side of the bipolar plate; and a negative electrode disposed on another surface side of the bipolar plate. In this battery cell, in the frame, a thickness of a portion in which the manifold is formed is defined as Ft; in the bipolar plate, a thickness of a portion blocking the through-window is defined as Bt; in the positive electrode, a thickness of a portion facing the bipolar plate is defined as Pt; in the negative electrode, a thickness of a portion facing the bipolar plate is defined as Nt; and these thicknesses satisfy Ft=4 mm, Bt=Ft-3.0 mm, Pt=1.5 mm, and Nt=1.5 mm.