Challenges of Low-Voltage Energy Storage for Lifts

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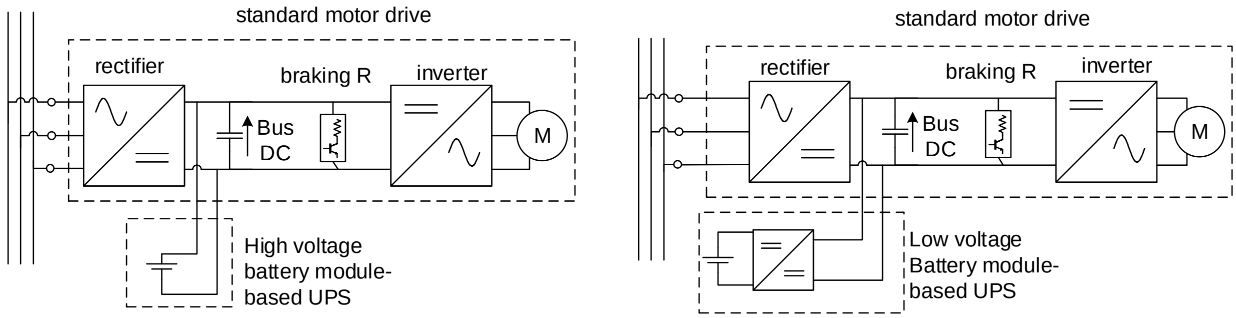
Abstract. Nowadays, the lift industry is moving towards finding new solutions for energy management. Examples of this are energy recovery systems based on local storage in ultracapacitors, battery-powered lifts for peak power consumption mitigation and improved UPS operation, solar and/or wind powered lifts, among others. Most of these new concepts include energy storage systems, so they require batteries and/or ultracapacitors, depending on the energy to be stored and the power cycling profile. As a matter of fact, both batteries and ultracapacitors are low voltage technologies, whereas lift traction systems are based on well-known three-phase industrial AC drives, operating at high voltage levels of around 600V at their DC bus. One of the possible solutions consists of the serialization of a large amount of basic cells until industrial voltage levels are reached. This solution, though apparently simple, is not practical because it is expensive and safety and reliability problems are multiplied. Thus, a practical energy storage system for lift applications should operate at around 48V, which is a safe, commercially standard and cost-effective voltage level.

Some modifications are required if a 48V energy source must be integrated in a lift traction system. There are two possible options. First, (bidirectional) DC-DC converters can be used interconnecting low-voltage 48V to conventional lift traction systems at 600V. Second, the entire traction system can be redesigned so as to operate at 48 V. This work shows the technical challenges of the integration of low-voltage energy storage systems in lift traction systems. Issues related to efficiency, cost, availability of required parts for production, flexibility of use and others are analysed. This way it is possible to identify the key challenges and the best suited solutions in each case.

1 INTRODUCTION

In recent times customers have been demanding products that turn around local energy storage ability and lift manufacturers are providing solutions [1-7]. Standard energy storage devices are primarily based on chemical batteries, and therefore lifts with electrical traction systems are the best suited ones for this type of adaptations. Ultracapacitor technology is relatively new but its advantages in terms of number of cycles and power density make them ideal for applications that require a high number of high power charging and discharging cycles [6],[8]. Next some application examples with batteries and ultracapacitors are shown:

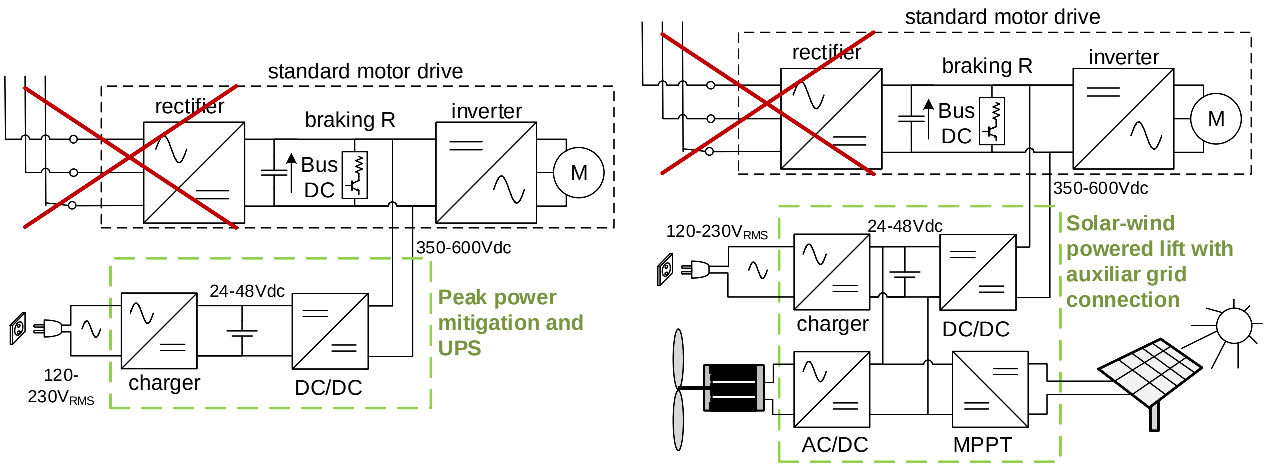
a) Extended UPS (Uninterruptible Power Supply) operation: some customers require to keep the operation of the lift even under long-term line black-outs. Among other solutions, an easy way out is to connect a battery module to the DC bus of the inverter, see Figure 1.a. Typical operating voltages are around 600V so a big amount of batteries must be serialized, which leads to an oversized energy storage capability. Moreover, special safety and battery management circuitry must be included, which makes this solution practical but expensive. In the same way, due to the fast ageing of batteries, operation costs are incremented. Another solution is just to interconnect a set of low voltage batteries with the high voltage DC bus through a DC/DC converter, see Figure 1.b.



a) b)

Figure 1 Different configurations for UPS function: a) with high voltage battery module, b) low voltage battery module plus DC/DC converter

b) Energy buffering and/or peak power mitigation for lifts: electrical consumption by lifts is characterized by cycles of high power peaks during acceleration or deceleration and (typically) half the peak power during steady travel. The peak power determines the installation and operation costs of the connection to the grid. The peak value could be one order of magnitude higher than the average power. This fact is particularly relevant for residential lifts where, due to the low number of travels, the total amount of required energy is very low. Installation and operation costs could be reduced if the lift is fed from a set of batteries that are permanently charged from the grid at a very low peak power rate, see Figure 2.a. Other benefits of this system are extended UPS functionalities and lower line-perturbations. This system can be complemented by an ultracapacitor-based storage system, thus minimizing high power demands from the battery and therefore increasing its life expectancy.



a) b)

Figure 2. a) Energy buffering and/or peak power mitigation system, b) Solar and/or wind powered lift with back-up grid connection

c) Solar and/or wind-powered lift: new trends related to energy efficiency and harvesting have pushed several manufacturers to offer systems that are powered by solar and/or wind energy sources. Typically batteries are used in order to store the generated energy and provide the demanded power to the lift. Both solar and wind powered sources are interfaced through power electronic devices so standard low-voltage battery modules at 48V can be used, see Figure 2.b. If a standard lift inverter must be used, a DC to DC power converter is required in order to connect the low-voltage battery storage system to the high-voltage (600V) DC bus at the inverter. If solar and/or wind energy resources are not enough to keep the elevator working, a back-up low-power grid connection can be added.

d) Energy recovery systems (ERS): lifts with gearless traction systems, high traffic and good levels of mechanical efficiency (around 80%) regenerate a considerable amount of energy that nowadays is lost at the braking resistor or transferred back to the grid. Thanks to ultracapacitor-based energy storage system (see Figure 3) it is possible to store this energy during braking phases and reuse it during demanding traction phases. Additionally, using the same hardware and without supplementary cost, it is possible to cover the peak power mitigation functionality.

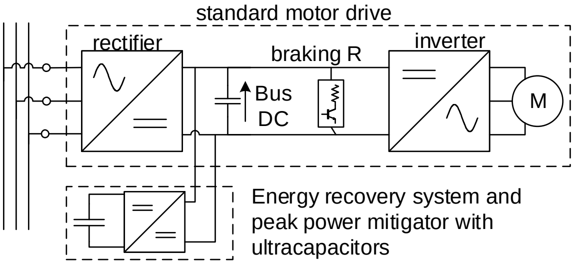


Figure 3 Energy recovery system with peak power mitigation functionality based on ultracapacitors

Previously listed applications require different energy and power ratings but their storage voltage levels and some components are common.

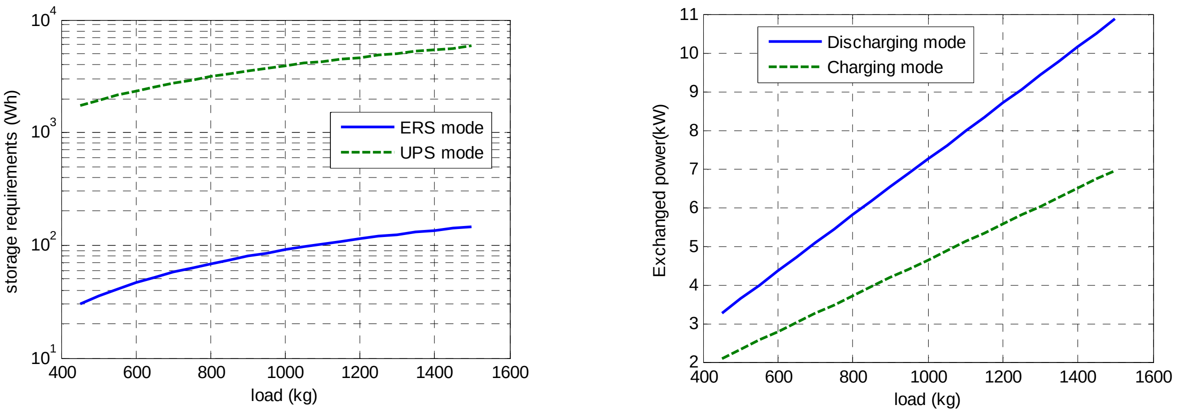
2 ENERGY STORAGE REQUIREMENTS

Basically there are two energy storage scenarios. First we have the long-term large-energy exchange case. This is the situation when extended UPS functionality or solar & wind energy is required and the lift must perform as much as 100 or more trips using its own stored energy. In this case the energy storage sizing is determined by the required energy and therefore the power exchange capability is much larger than the required one. The second case corresponds to short-term low-energy exchange. Energy buffering, peak power mitigation and energy recovery systems (ERS) require the exchange of short-term high power peaks. Thus, the total amount of energy is low and the required peak-power determines the size of the energy storage device. Anyway, some energy buffering applications under high traffic operation require the storage of a large amount of energy and therefore fall within the first scenario.

Figure 4.a shows the energy storage requirements for the above-mentioned cases and different car loads. A small lift (6 persons) 5 floor lift needs around 30Wh for ERS functionality. If a 100 travel autonomy is required on UPS operation mode, a small residential lift will need to store a little less than 2kWh. Figure 4.b shows the peak power exchange for different loads. Both absorbed (discharging) and regenerated (charging) powers are shown. These powers depend on the acceleration and speed profiles as well as on the overall lift efficiency, herein considered to be 80%. In the discharging case, the maximum absorbed power is related to low mechanical efficiencies, whereas when regenerating, the best mechanical efficiencies lead to the maximum charging power.

3 ELECTRICAL ENERGY STORAGE TECHNOLOGIES

Among the possible electrical energy accumulating systems there are only two technologies that offer mature and commercial products: batteries and ultracapacitors. Both of them have been manufactured in large scale quantities for some years and therefore their performance, cost and reliability are optimized and they are somewhat standardized. Batteries are electrochemical devices that operate through chemical reactions, thus it becomes difficult to get an accurate knowledge of their internal state of operation. A battery is a complex device whose behaviour is mainly characterized by empirical models, its charging process is different from the discharging one and it is difficult to identify its state of charge (SOC) and state of health (SOH). Moreover, its ageing process depends on the depth of charging-discharging cycles, current, temperature, and other parameters.



a) b)

Figure 4. a) Energy storage requirements and b) power requirements for different loads and functionalities

Nowadays there are two main battery technologies in the market: Lead Acid Batteries and Lithium-Ion batteries. Figure 5 shows the main power-energy characteristics of both technologies and Table 1 summarizes the main features. The data in Table 1 is approximate and has been included only for comparative purposes. It is straightforward to identify Li-ion as the best choice in terms of functional features: it offers the best specific energy and power figures and the longest life span. However, on the other hand it requires the inclusion of battery management systems (BMS) and its cost is 10 to 20 times higher than the cost of Lead Acid technology.

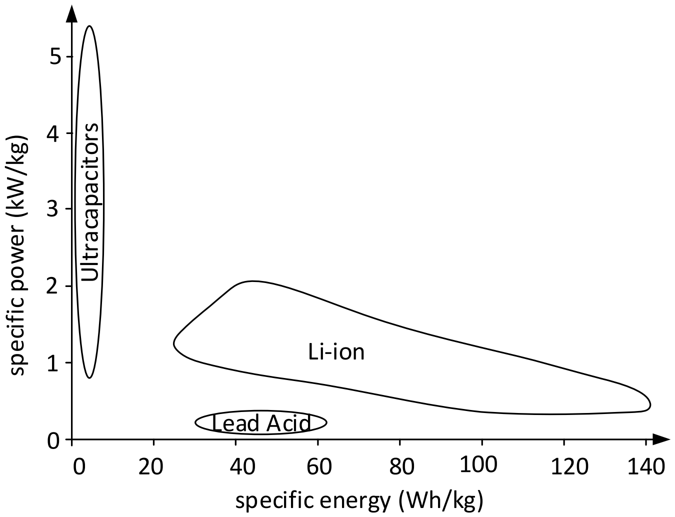


Figure 5. Power-energy properties of batteries and ultracapacitors

Considering the cost, ease of use and the habit gained from many years of successful installations, Lead Acid technology is the preferred choice for non-portable energy storage devices.

Contrary to batteries, ultracapacitor technology is based on pure capacitive phenomena. Thus, an ultracapacitor-based storage unit admits high charging and discharging powers, its state of charge is straightforwardly determined by the well-known equation (1) and it withstands up to 1.000.000 charging-discharging cycles, see Figure 5 and Table. 1. The main drawbacks are its low energy density and its very low nominal voltage, around 2.7V, which leads to the serialization of a big amount of cells and the inclusion of a voltage management system (VMS).

$$W = \frac{1}{2} C V^2 \tag{1}$$

Table 1 Comparative of battery and ultracapacitor technologies

Feature	**Lead Acid**	**LiOn**	**Ultracapacitor**
Number of cycles	300-2000	**>5000**	**>1000000**
Specific power (W/kg)	180	300-2000	**5000**
Specific energy (Wh/kg)	30-60	30-**140**	5
BMS/VMS	**no**	yes (BMS)	yes (VMS)
Cost (€/kWh)	**170**	1200	17000

It can be concluded that for UPS functionality a big amount of energy is required and therefore Lead Acid batteries must be installed, whereas in ERS or power mitigation applications ultracapacitors will be the favoured choice. Hybrid technologies are possible with additional electronics needed to make them truly compatible.

4 MATCHING OF REQUIREMENTS

An appropriate battery or ultracapacitor module for a given application must be selected. The fact is that considering safety issues and available complementary technologies (battery chargers, inverters and so on), 48V has become the highest standard nominal voltage for commercial battery modules and one of the most widely used voltage levels for ultracapacitors. Figure 6 summarizes both the energy and power requirements of Figures 4 and 5. Two storage design examples are also shown in the same figure.

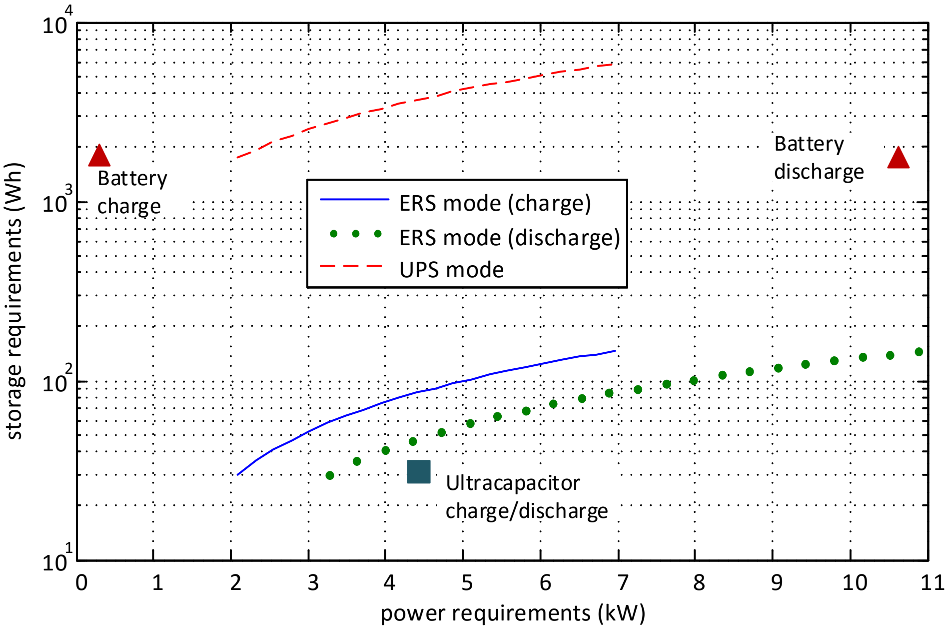


Figure 6. Energy-power diagram of requirements and technologies

First, a battery module has been selected for a small lift UPS functionality. It comprises 4 commercial cells of 12V/40Ah, leading to an overall energy of 1920Wh, with a discharging power of 11kW and a charging power of 400W. The volume is only 22 litres so it can be easily fit in any lift installation. Both the charging and discharging powers are shown by triangles at Figure 6. This battery module will be denoted as the basic battery module (BBM). It is obvious that energy requirement leads to a set of batteries that are clearly oversized in terms of power. In this type of functionality fast charging is not a requisite so the charging power can be significantly lower than the discharging one. Anyway, it has to be pointed out that in order to avoid fast battery ageing, it is recommended to operate far below the nominal power of batteries and assuring low energy discharge cycles. Therefore, the rated discharging power of the battery at Figure 6 cannot be fully exploited and the actual power capability will be closer to the required one.

Next, an ultracapacitor module has been designed for ERS functionality intended for small lifts. It usable energy is 35Wh and offers an equal charging or discharging power of 4.5kW. It takes a volume of no more than 10 litres. This ultracapacitor module will be denoted as the basic ultracapacitor module (BUM) and it is indicated by a square at Figure 6. As can be observed, energy and power requirements are relatively close to that offered by the selected module.

Looking at Figure 6, it is straightforward to determine that using 1 to 3 parallelized BBMs it is possible to cover all the considered UPS requirements and, in the same way, using 1 to 3 BUMs in parallel meets ERS requirements. Therefore, it can be concluded that 48V battery modules and 48V ultracapacitor modules could play the role of basic building blocks covering the considered energy storage needs for lift applications.

5 INTEGRATION OF A 48V SOURCE IN LIFT TRACTION SYSTEMS

The “standard motor drive” block depicted in Figures 1 to 3 represents the common topology used in lift drives. When a given electrical power has to be exchanged a current-voltage pair must be selected, see equation (2)

$$P = VI \tag{2}$$

Considering that the current is responsible for the main part of power losses, a high voltage-low current set of parameters is preferred. Thus, the industry has been adopting standard voltage levels that are related to the power to be exchanged. When dealing with powers from some kW up to several tens of kW, three-phase $400V_{RMS}$ is the electric distribution standard. Electrical lift traction systems are modified versions of well-known industrial drivers, which are fed from a $400V_{RMS}$ three-phase grid and, therefore, after being rectified, a 500-600V DC bus is obtained. This standard drive technology has been used during more than 30 years in industry, so it is extremely robust, reliable and, due to the large manufacturing scale, cost effective.

The problem arises when a 48V or even a lower voltage energy source is feeding part or the entire energy requirements of a lift. There are two possible scenarios. The first attempt consists of trying to keep the already developed and well-known lift drives by interfacing the 48V energy source and the 600V bus by a DC/DC power converter. The second approach is simply to redesign the entire traction system and build a 48Vdc compatible drive. Next, these two scenarios will be explained.

5.1 Integration of 48V source in a standard lift traction system

This is the case of Figures 1.b, 2.a, 2.b and 3, where a DC/DC converter is in charge of the energy exchange from the low-voltage storage system to the high-voltage DC bus. First of all it is important to point out that neither the low voltage level not the high voltage side operate at a constant voltage. In the low-voltage side, batteries or ultracapacitors can be installed. If a 48V battery module is considered, its voltage can evolve from 42V to 53V, depending on the SOC. If ultracapacitors are considered, the situation is even more variable: its voltage can evolve from 24V to 48V, depending also on the state of charge.

Looking at the high voltage side, the situation is not better. If the drive is motoring, energy is removed from the DC bus and, thereafter, its voltage decreases. In the same way, if the drive is regenerating, energy is delivered to the DC bus and its voltage increases. The lower voltage limit is determined by the dynamics of the DC/DC converter (i.e. the time it requires until a satisfactory voltage regulation is achieved), whereas the higher voltage limit depends on the same regulation dynamics (if a bidirectional DC/DC converter is used) but also on the voltage value at which the braking resistor switches on. Most of the commercially available drive manufacturers establish a non-error voltage range from low 400V to 700V or 800V.

A cost effective solution is made possible by a large manufacturing scale, so it is desirable to get a DC/DC converter that can operate with a broad range or almost all the existing commercial drives. For doing so, it must include a plug & play functionality, that is: just plug in the power wires, switch on the device, and the system must operate, without producing any disturbance in its regular operation and without any need for modifications in the existing equipment. Thus, if a low-voltage energy source must be integrated on a standard lift traction system, a DC/DC converter with the next features is required:

- Rated power: 4kW to 15kW (depending on the lift)
- Input voltage: 42V to 53V or 24V to 48V
- Output voltage: 400V to 800V
- High dynamic response
- Bidirectional energy transfer ability (if ERS functionality)
- Plug & play capability
- High efficiency (>90%) along all voltage-range

By now there is only one commercially available DC/DC converter compatible with these features [7]. It has to be pointed out that a DC/DC power converter limits the power exchange ability, but not the usable energy amount, which depends only on the installed batteries or ultracapacitors.

5.2 Redesign of the entire traction system at 48V

In applications where the three-phase 400V_{RMS} line is not connected (Figures 2.a and 2.b) there is no need to keep high voltage DC bus levels, so it is possible to build the entire traction system considering a 48V DC bus, see Figure 7. This DC bus voltage limits to 34V_{RMS} the available line-voltage at the inverter output and the current is multiplied by a factor of 10 or more. So a new motor and inverter must be carefully designed and installed.

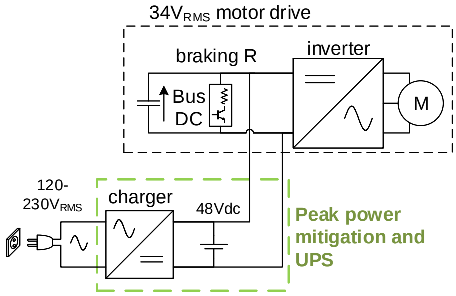


Figure 7. A 48V DC bus traction system with a $34V_{RMS}$ motor

The new voltage level leads to high currents and therefore, in order to avoid high power losses and bulky wires, the storage device, driver and motor must be located close from each other, which sometimes becomes difficult to achieve. The main drawback of this approach is that the seller and/installer must offer and master two different traction systems for the same range of lifts.

It is possible to conclude that the inclusion of a DC/DC power converter makes it possible to get any of the required functionality by exploiting well known standard drives, simplifies the portfolio of the sellers/installers and provides a big amount of flexibility. In the other hand, the all-in 48V drive covers only part of the functionalities, does not work with ultracapacitors and, somehow, complicates the portfolio. Next, a deeper analysis of the required DC/DC power converter is shown.

6 BIDIRECTIONAL DC/DC CONVERTER

The required DC/DC converter must solve several design challenges:

- Large input to output voltage relation: the input-to-output voltage ratio is larger than 10 and could be, in some cases, above 20. This ratio makes it difficult to achieve high efficiencies.

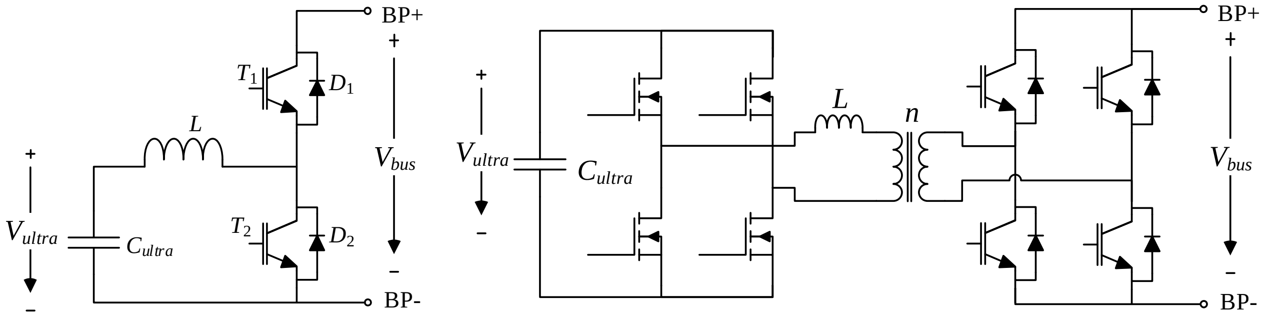
- Variable input and output voltage: when the input and output voltages are kept constant it becomes quite simple to design an optimized high efficiency converter. But it is difficult to get high efficiency values along all the operating conditions if input and/or output voltages evolve significantly. Moreover, the required power exchange is not constant so the highly variable design conditions make it difficult to achieve the design goals.

- High control dynamics: in cases where the lift is fed exclusively through the DC/DC converter (topologies of Figures 1.b, 2.a and 2.b), the same converter is the sole responsible agent of keeping the DC-bus voltage level within acceptable values. This DC-bus is randomly perturbed by input-output powers that are permanently exchanged with the motor inverter and, therefore, it is crucial to achieve very fast control dynamics capable of rejecting these perturbations.

- Plug & play functionality: the control must achieve the above mentioned dynamics without any complicated link with existing drivers. Only power wires must be connected and the device must operate in an autonomous way.

Figure 8.a depicts the basic buck-boost topology that is commonly proposed when DC/DC conversion is required. Although simple and easy to control, this transformer-less topology is not well suited when high input-to-output voltage ratios are required and leads to very poor efficiency values (below 50% in some cases). Due to the high input-to-output voltage ratio, it is almost mandatory to include a transformer in the conversion chain and, therefore, an intermediate AC stage is required. The Dual Active Bridge (DAB) of Figure 8.b is a basic topology achieving DC/AC/DC conversion with an intermediate transformer. Though the number of switching semiconductors has

been multiplied by four, their individual voltage and current values match with the switched power so the power losses falls within logical values, thus obtaining acceptable efficiencies.



a) b)

Figure 8. DC/DC converters; a) buck-boost topology, b) Dual Active Bridge (DAB)

The preferred solution in terms of efficiency is the Series Resonant Dual Active Bridge (SRDAB), see Figure 9. Based on a DAB structure, it includes a series capacitor in the intermediate AC stage, thus, a resonant tank is obtained. By switching at frequencies above the resonant one, it is possible to get soft switching behaviour under some conditions, and therefore efficiencies of around 95% are obtained.

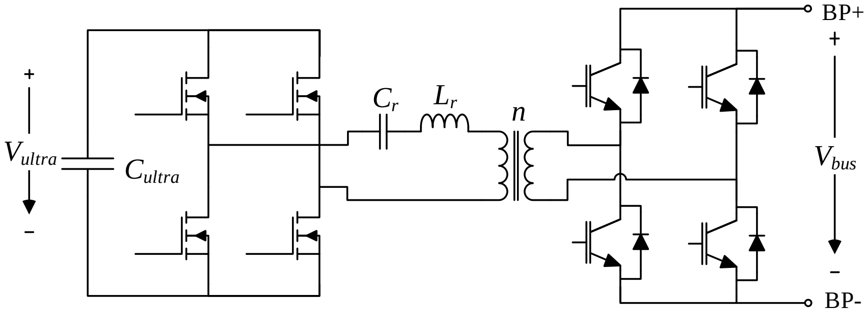


Figure 9. Series-Resonant Dual Active Bridge

Another benefit of the above mentioned soft switching behaviour of the SRDAB is the minimization of radiated and conduced interferences, thus making it easier to comply with EMC requirements. The already good efficiency of the SRDAB can be additionally improved by the use of new state-of-the art Silicon Carbide (SiC) semiconductors. So far, the only commercially available DC/DC converter compatible with this application is based on the SRDAB topology and includes SiC technology, thus providing the required flexibility of use and efficiency [7]. In addition to all the previous features, this converter can be easily parallelized and therefore, using basic storage modules and this basic DC/DC converter, a scalable portfolio can be built thus covering a large variety of energy-power requirements.

7 CONCLUSIONS

This paper analyses a variety of lift applications requiring energy storage. After this, storage requirements are classified in two groups: long term high-energy UPS type functionalities and short term low-energy ERS type functionalities. Among the available accumulation technologies, Lead-Acid batteries are the preferred choice if a big amount of energy is required whereas ultracapacitors offer the best performance for high-power low-energy applications with intensive cyclical operation. Due to commercial availability, cost and design requirements, the 48V standard is selected for energy storage modules. It is shown that basic battery modules and basic ultracapacitor modules can be used as building blocks in scalable systems thus covering the required energy-power range. This scalable system needs to be complemented by a high-gain DC/DC converter with particular features, which has become the main challenge of the proposed architectures. Nowadays, some power electronic manufacturers have understood the need and potential market of such a special converter and therefore they have included it as standard product in their portfolio. Thus, using the proposed flexible architecture, any small or medium size lift manufacturer can offer high-end solutions with minor investments, responding quickly to the market requirements for higher efficiency.

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BIOGRAPHICAL DETAILS

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