Energy Storage For Commercial EV

Extending Battery Life With Supercapacitors

There's a number of battery technologies available for electric vehicles. Different technologies have their advantages and disadvantages. There are the high performers, there are the safer ones, there are the longer lasting ones. OEMs have their preferred choices for passenger vehicles, but what about the ideal energy storage for commercial vehicles?

1. **Energy storage design and optimization in xEV design – a key to success**
   Batteries are always the hot topic around hybrid and electric vehicles. Everyone knows that batteries account for the main expense in xEVs and billions of dollars are spent annually for R&D activities to improve the cells, BMS, control strategies and protection. Battery pack designs can be tailored to specific drive cycles and charging sequences which is normally difficult to get for a passenger vehicle since every driver has it's own driving style, daily miles to cover in different routes that can be high speed highway drive all the way to crawling in a traffic jam. So far the best battery design strategy is to provide different capacity options for the customer to choose according to their expected driving profiles. By adding more battery capacity (kWh), both the performance and the driving distance can be improved for the EV. More capacity indeed comes with a cost and currently the options to choose are fairly limited.
2. **Hybrid and electric buses and delivery trucks – a heavy duty challenge**
   In general Lithium-Ion technologies offer excellent energy storage options for today's passenger vehicles. A reasonably sized battery provides the driving distance, performance and battery life required by the everyday driver. But what about commercial electric vehicles? With the increasing awareness of cities being polluted, bans are considered or already implemented (emission free buses only in The Netherlands from 2025) for diesel engines that affects delivery vehicles to large buses and everything in between. Can commercial vehicles be cost effectively electrified? Indeed they can be and it has a lot to do with sizing the battery pack according to the specific driving profiles.

Delivery trucks and especially buses have a more predictable driving profile which differs from passenger cars a bit. Normally for passenger cars, the primary consideration is driving distance then performance and charging time/flash charging option. These factors drive battery size larger than the daily drive cycle would require and the oversized battery easily takes care of the required power and energy density that is needed for frequent acceleration and brake energy regeneration which typically shorten battery life.

Commercial vehicles are different from this perspective as they are considered an investment so acceleration or top speed performance is not a key factor for buyers. However fully covering the daily driving distance and having a long life energy storage solution to drive the total cost of ownership (TCO) the lowest possible are critical parameters.

Buses and city delivery vehicles have a much more predictable drivecycle than cars which may be defined by the operator or there are examples for standard ones already, see an example of the EQ6100 city bus standard driving cycle below:

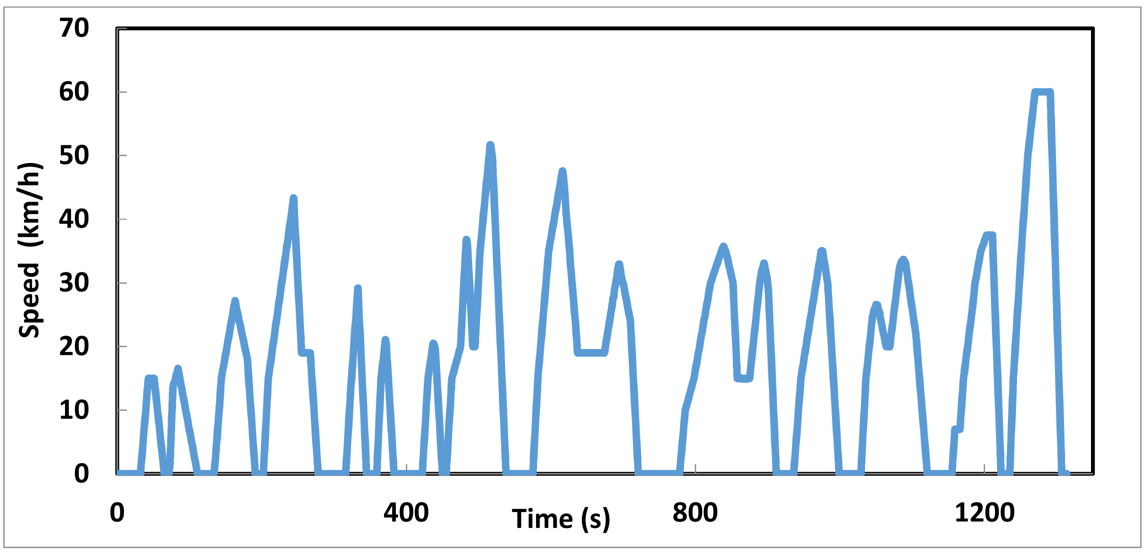

Figure 1. This cycle covers 6km between bus stops with max acceleration of 0.39m/s^2 and max breaking of 0.48m/s2. The daily distance to be covered by a bus considered to be 200km.

The daily drive profile allows optimization to fit the right type and size of the battery to the vehicle that meets the operator's requirements from both performance and cost point of view. In this article, we focus on these aspects as the main contributors, though in terms of battery sizing the following main aspects are necessary to consider as well:

- auxiliary power requirements – commercial vehicles heating/air conditioning, lighting etc. which may draw additionally 5-30kW and puts battery in a challenging situation.

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- ambient temperature range – the battery pack may need to be heated or cooled which is effected by the self-heating too try to keep it in the range of 0-30°C. The selected type of Li-Ion technology may depend on this.
- charging time – the batteries suffer if 0.8C or higher charging speed applied and recommended to keep it below 0.5C to avoid high level of degradation for everyday charging. For commercial vehicles, daily 1-2x charging can be expected which needs to be aligned by the operations schedule.
- required lifetime – passenger vehicles normally need to cover 8 years of warranty for the battery. In terms of commercial vehicles normally a minimum of 4 years is expected before the battery pack is replaced.

3. Supercapacitors vs. batteries

In the above discussion, the "battery" is used generally to mean energy storage. To consider of types of energy storage, both supercaps and batteries are used for main energy storage, but in different use cases. Supercaps are more for high power density while batteries are for high energy density. The basic difference lies in the charge-discharge mechanism: supercaps charged and discharged as a form of an electrostatic process while batteries as an electrochemical process. Electrostatic charge movement allows a nearly infinite number of charge cycles even to zero volts and speed of charge/discharge in seconds.

Key Characteristic	Supercapacitor	Batteries
Voltage	2.5 – 5V	1.2 – 4.2V
Cold Operating Temp	**-40**°C	-20°C
Hot Temperature	**+70**°C **(+85 with derating)**	60°C
Cycle Life	**>500,000**	300 – 10,000
Calendar Life	**10-20yrs**	0.5 – 10yrs
Energy Density	1 – 10Wh/L	**100 – 350Wh/L**
Power Density	**1000 – 10,000W/L**	100 – 3,000W/L
Efficiency	**>98%**	70 – 95%
Charge Rate	**>1,500 C/x**	<40 C/x
Discharge Time	Sec / Minutes	**Hours**
Safety aspect	**Generally safe, no thermal runaway**	Thermal runaway may be considered
~Price per kWh	~ $10000	**$200-1000**

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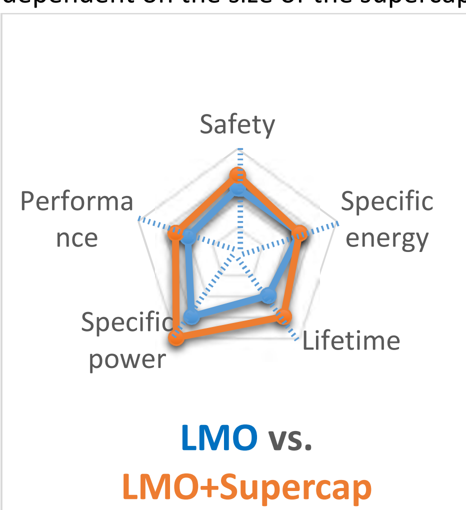
4. What about supercapacitors + batteries?

Supercap-battery hybrid energy storage systems are in use for a long time in the industrial world to improve the lifetime of primary and rechargeable batteries. Applications like smart metering devices can expect up to 4x extension of the primary battery life if a properly sized supercapacitor is connected in parallel to handle the high peak pulse currents during the meter reading communication sequence.
The same approach can be used for electric vehicles to improve either battery lifetime or power density. The improvement depends on the type of battery used. One of the potential choices for commercial vehicles is the Lithium Manganese (LMO) type, which is part of the Nissan Leaf and BMW EVs' battery solution. Supercaps could mainly improve lifetime due to the sensitivity of batteries to the depth of discharge (DoD). Depending on the size of supercap added, it can improve the power density and performance during acceleration as well. The other potential battery type which provides a reliable long-lasting solution but lacks the power density is molten sodium ceramic. The sodium, or often referred as ZEBRA batteries, needs to be heated to 250-350^{o}C to get activated but once activated they are ideal choice for applications with continuous charge and discharge. The ideal discharge time is 4-8hrs that matches the requirements of something like a delivery truck or a city bus daily drive with an overnight charge. Since sodium batteries have excellent lifetime and cycling capability, supercaps are needed to improve the power density and overall performance of the EV. The supercap portion is sized in this case to deliver the majority of the power and energy during the acceleration and absorb all the breaking energy which can be regenerated by the powertrain. The battery is mainly used to recharge the supercap module and maintain the speed (max 80-100km/h).

The below graphs show the expected improvement of the LMO and the sodium batteries with supercaps connected in parallel. The improvement are highly dependent on the size of the supercap portion.



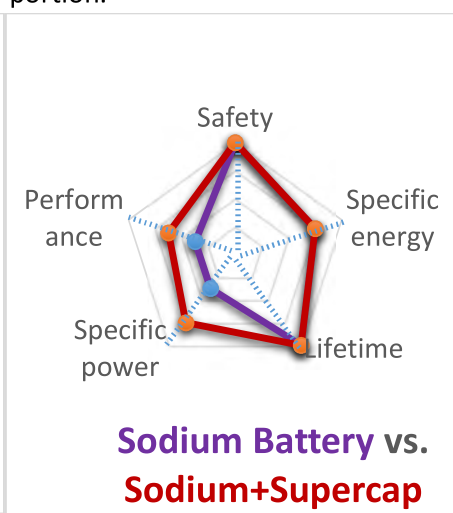


Figure 2. Relative characteristics of energy storage systems: batteries only and batteries with supercapacitors.

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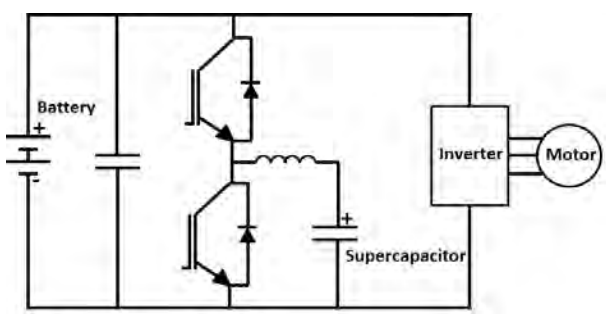
5. Electric bus case study with supercap-battery hybrid

Eaton has developed a battery supercap hybrid evaluation model which can be used to evaluate the expected lifespan of any type of battery exposed to a specific drive cycle. The model can simulate the improvements when supercapacitors are connected to the battery in a passive (directly parallel) or active (through a DCDC converter) way.   .

The following simulation was taking into consideration the EQ6100 city bus standard drive cycle with a bus having a hybrid energy storage system consisting of a 530V, 105Ah rated LMO battery pack and a 210V, 71F rated supercap module (2x parallel and 84x series connected Eaton XL60-2R7308T-R supercapacitors with a total weight of ~120kg and volume ~150L considering housing and cables). The supercap module is connected to the DC link through a bidirectional DC-DC converter. The converter is controlled by current sense mode to decide when to start charging and discharging the supercaps. The supercap bank works as a quasi low pass filter which allows steady current to pass, but absorbs current when there is a rapid increase (regenerative breaking) and releases current when there is a rapid decrease (acceleration).



Hybrid Energy Storage System (H-ESS)

XL60-2R7308W-R supercap cell

Battery lifetime depends mainly on the depth of discharge (DoD), cells charge voltage and cell temperature. In our simulation, we excluded the effect of the temperature assuming that it's well controlled. However by implementing supercaps to handle the high peak currents, the battery self-temperature rise is expected to lower which is an additional positive effect to extend the battery life.

Based on the battery manufacturer's input we develop the discharge profiles and the cycles to failure as a function of the DoD.

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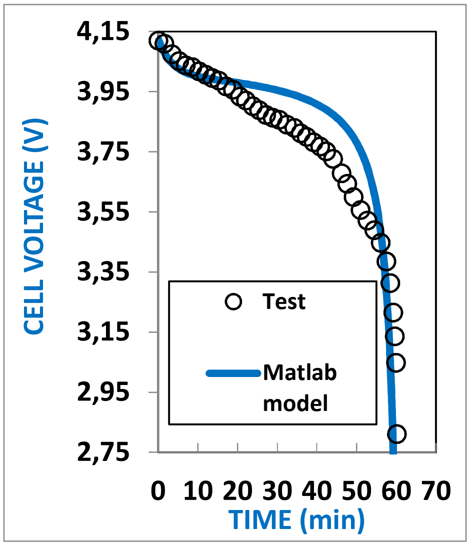

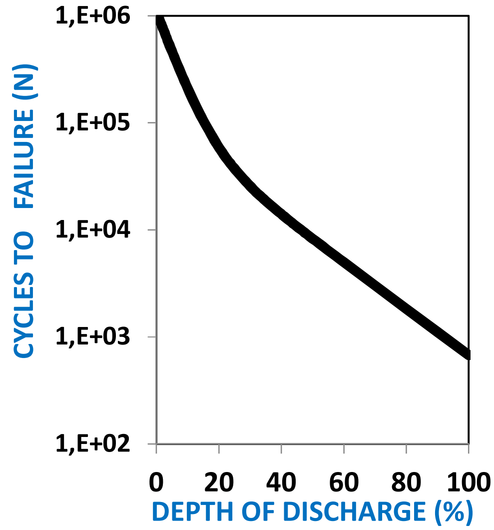

Based on the drive cycle, the actual transmission power can be computed to get the actual battery current profile. Based on the current profile, the actual battery discharge can be computed. The comparison of the model to test data shows good correlation of the model to actual performance thus validating the model.

3 different battery pack confrigurations were evaluated resulting different SOC during the actual drive cycle. These simulations are made without supercaps connected.

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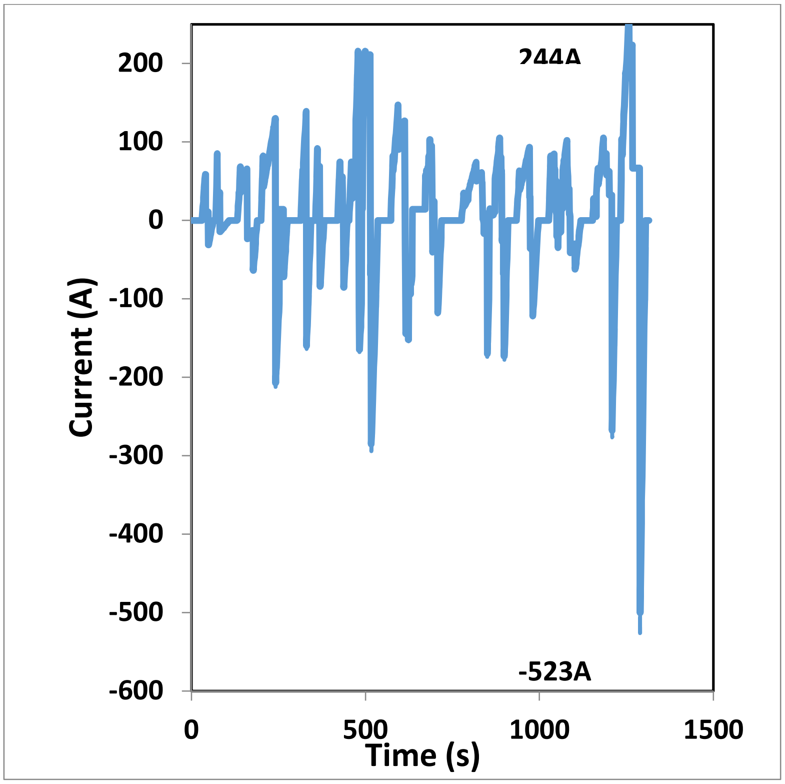

Figure 3. Drive cycle current vs time for the E6100 drive cycle.

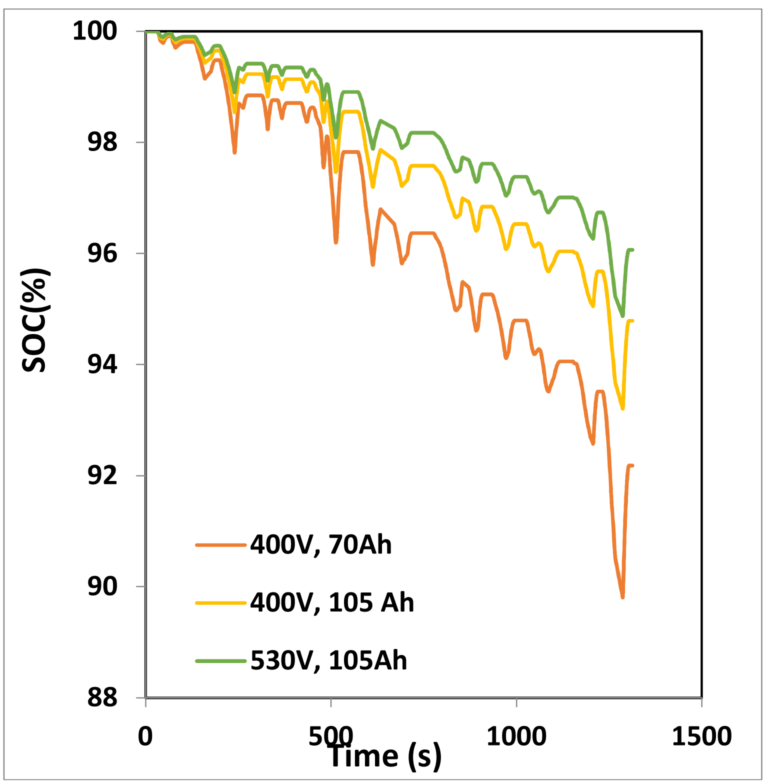

Figure 4. Depth of discharge of 3 battery configurations for the E6100 drive cycle.

What is noticeable based on the SOC curves is the number of small charge-discharge cycles by every regenerative breaking and acceleration. These relatively small but frequent events accounts for a considerable level of degradation of the battery in addition to the planned daily recharge. Supercapacitors as part of the ESS can absorb and release part of the high current pulses and this way contribute to a much smoother battery discharge curve.

How the ESS DC-DC converter's control is to be set to get the right result?

The fast Fourier transform analysis of the actual drive cycle allows us to see the range of time constant to be considered for the evaluation. Based on the FFT, we considered 6-100s time constant to evaluate our „low pass filter" consisting an adequately-sized supercap module. The size of the module will depend on the actual time constant selected and the DC-DC converter parameters. Using a larger supercap module helps to gain efficiency and driving range and the currently simulated bus model can still be optimized by considering different converters and supercap setup. For the sake of showing an unbiased effect on battery life using different time constants for the controller circuit, we considered the same supercap module and converter combination.

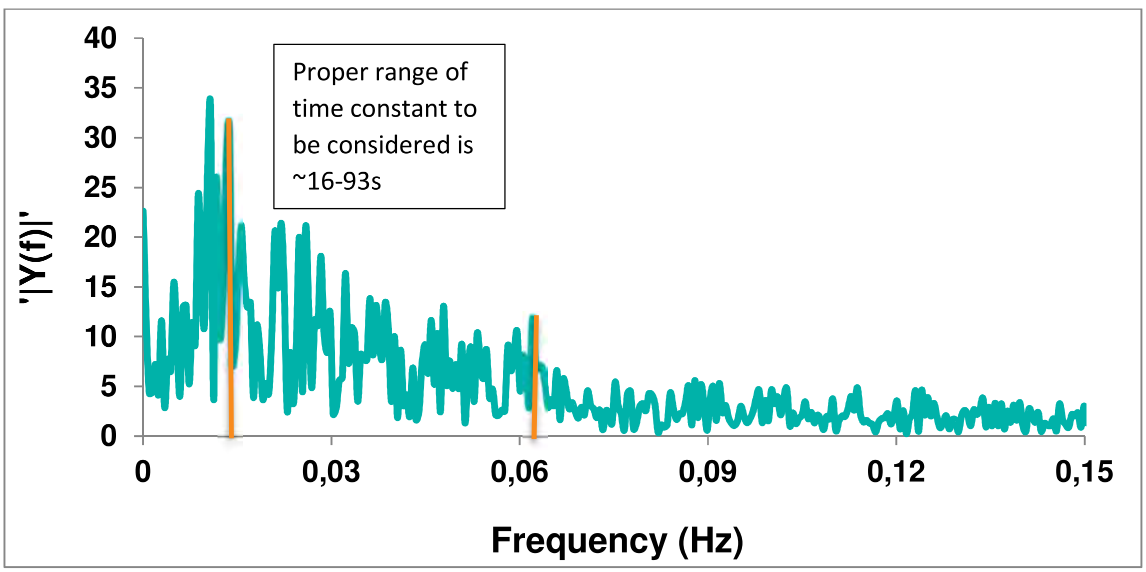

Figure 5. FFT of drive cycle current.

The result of the simulation taking the different low pass control strategies in place shows a great deal of reduction of the battery current transients. The higher the time constant for the control circuit the larger the effect of the peak current shaving.

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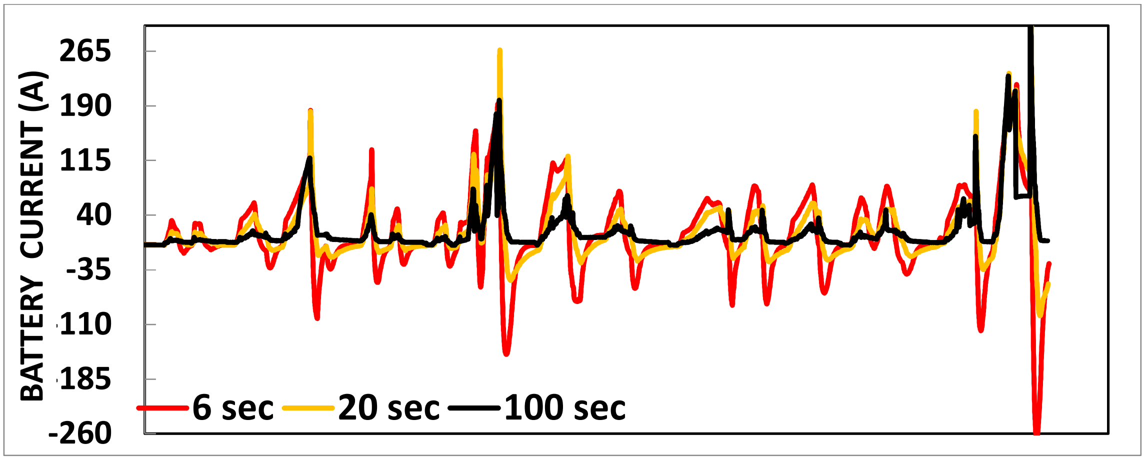

Figure 6. Battery current during the driveprofile using different control strategies of the supercap charge-discharge

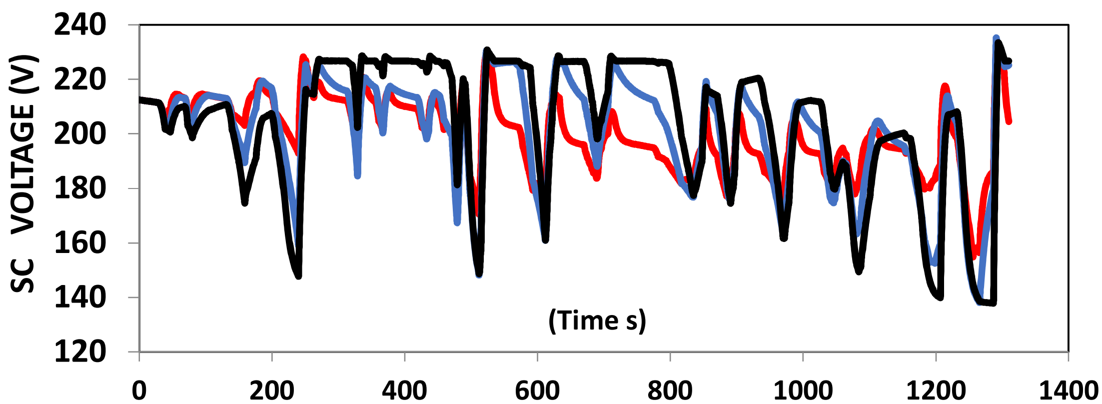

Figure 7. Supercap voltage fluctuation during the drivecycle. This is an important parameter to optimize the DCDC converter

The SOC and DOD curves during the cycle are smoothed pretty well according to the expectation. The SOC of the battery with more utilization of the supercap bank may show a lower rate at the end of the cycle which mainly has to do with the positive balance of the energy stored in the capacitors which stored the large breaking energy at the cycle's end. See the supercap bank's voltage increase. Normally using supercap hybrids extends the drive range -according to other studies as much as 8% - due to the more efficient breaking energy absorption (>98%). In a passive hybrid connection this effect is more obvious while in the active setup this mainly depends on the converter's efficiency.

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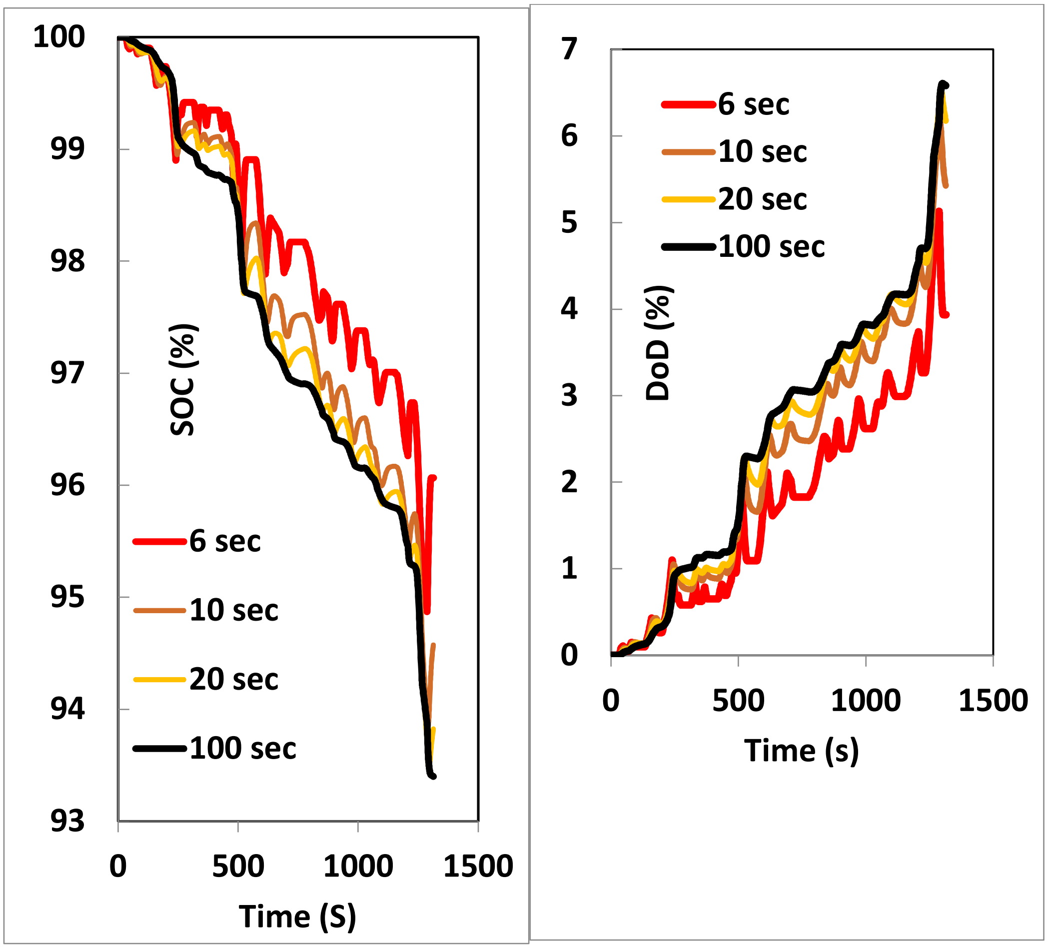

Figure 8-9. Battery SOC and DoD during one drive cycle with using different control strategies of the supercap charge discharge .

The final question remains: how much lifetime improvement we can gain with the hybrid solution vs. the battery only solution?

According to the battery manufacturer the lifespan of the battery pack taken into consideration with these conditions is 4 years. The expected improvement is realistically with some optimization of the real conditions can be approximately 2x.

Please note that the 100s filter time constant may not be realistically implemented with the same converter and supercapacitor module as considered for the lower filter times so it's considered to be a theoretical solution only.

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Filter Time	SC Min V	Expected Battery Life
6	154.8	4.32 yrs
10	140.5	5.10 yrs
20	138.2	5.44 yrs
40	138.3	5.83 yrs
60	137.9	7.88 yrs
100	93.4	15.15 yrs

Batteries with lower power density then high performance Li-Ion may benefit from the supercap's load firming even more. The following graph shows a forklift 48V lead-acid battery's DoD improvement during a standard cycle with and without an Eaton XLR-48R6167-R supercap module (48.6V/166F/5mΩ/15kg) connected. The improvement is significant which not only allows the battery life to increase, but to actually decrease the size of the battery. According to our simulation the 920Ah lead-acid battery could be eventually reduced to 350Ah in case the daily runtime allows it.

System	Life Years	Factor
920Ah Battery only	2.7	--
920Ah Bat. + SC	6.9	2.52
680Ah Bat. + SC	5.4	2.0
610Ah Bat. + SC	5.0	1.85
350Ah Bat. + SC	3.2	1.18

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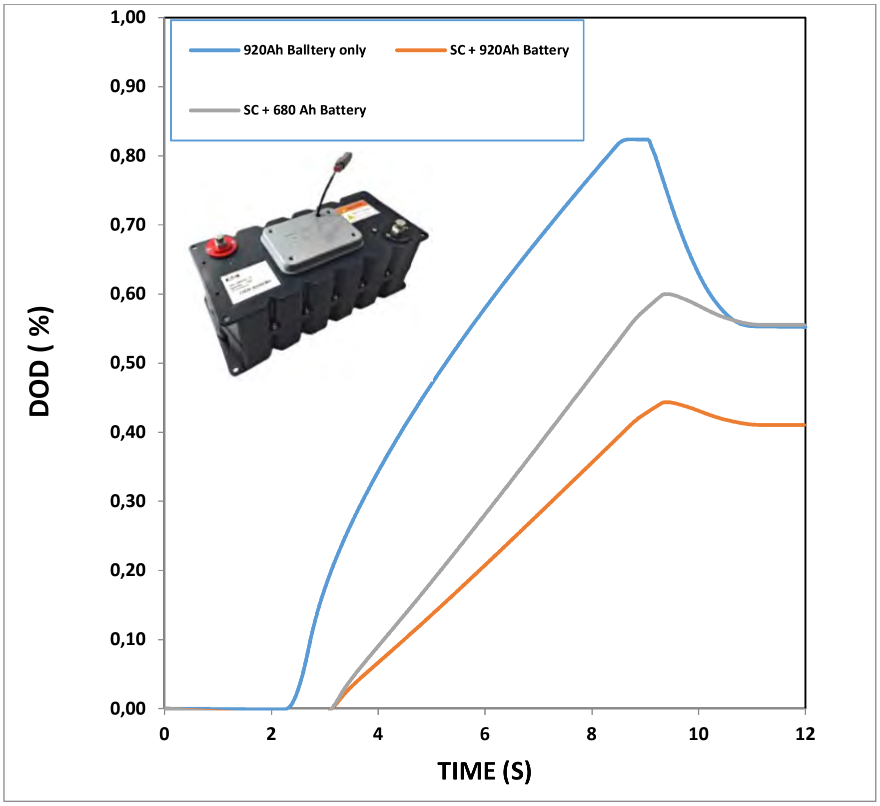

Figure 10. Forklift PbA battery DoD during one drive cycle with using different capacities and supercaps in direct parallel connection

6. Conclusion

Eaton, a committed power solutions provider and supercapacitor manufacturer developed a simulation method to evaluate battery-supercap hybrid solutions for electrically powered commercial vehicles (buses, delivery vans, forklifts, material handling equipments). Battery powered vehicles having heavy duty and tough load cycles can benefit if using a battery-supercap hybrid energy storage system. A properly sized hybrid system can double battery life and improve driving performance.

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+Información del producto

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