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Forklifts and Ultracapacitors

Since their invention in the early 1900's, forklifts have continued to grow in capacity and increase in performance to meet the continuous demand for higher productivity. Internal combustion engines, that power approximately one half of all trucks, have seen tremendous increases in power, efficiency and reliability, the lead acid batteries that power the other half of them have not changed nearly as much. Recently, the internal combustion engine powered trucks have come under great pressure to reduce emissions and further increase efficiency. All drivetrain architectures of lift trucks can benefit from hybridizing their current power source with an ultracapacitor based system.

Ultracapacitors are uniquely capable of providing "burst power" or "pulse energy", which is generally defined as peak power or high energy for up to one minute of operation. That is not to say they cannot be used for other longer duration applications. Forklifts run for many minutes to many hours between refueling/recharging, making it impractical to power a lift truck completely with ultracapacitors. However, most forklift duty cycles are fairly dynamic with several horizontal and vertical accelerations in every cycle, and the vast majority of those last only a few seconds with a few reaching into the minutes. To expand on that, while the individual duty cycle may last up to a few minutes, the dynamic portions only last a few seconds at a time with the most extreme portion being the lift cycles lasting up to 30 seconds regardless of the power/energy source employed. As a side note, the dynamic nature of forklift movements provides ample opportunity for the capture regenerative of energy, adding even greater value to the low resistance, high efficiency energy storage an ultracapacitor module can provide.

Battery Powered

It is common to design a much higher productivity new model truck to work with the same battery as the lower productivity model it replaces, or at least, maintain the maneuverability and minimum aisle width of its predecessor. The key requirement from the standards associations of manufacturers is that the truck meets stability requirements and to do that the battery provides the appropriate counterweight. In many cases the battery is not specifically prescribed or sold with the truck; however the economics of material handling are best served by low down-time from battery changes and long calendar lives of the batteries they purchase. In many cases the total battery purchases will equal or exceed the purchase price of the truck over its useful life.

The Rub

The size of a pallet drives many of the design details of a warehouse, especially the size of the racking. The aisle size is driven by the size and maneuverability of the trucks to be used. The larger the battery compartment, typically the less maneuverable a truck is (compared to an otherwise identical truck with a smaller battery compartment). To compound this, growth in new warehousing is very small (<0.5% of

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warehouses in North America are less than 2 years old) so manufacturers are not enthusiastic about designing and building radically different trucks to accommodate larger batteries.

Like nearly all repeatable chemical processes, heat is the enemy of a battery. An average temperature increase of 10C effectively reduces the life of a battery by half. A larger battery would live an exponentially longer life in the same application as a smaller one. Larger batteries have more surface area that allows for more cooling, lower resistance which means they heat up less and are more efficient. A warehouse must also have enough batteries to ensure appropriate charging and cooling time between uses. If there are not enough batteries to cover the demand for the battery to cool down it is prematurely returned to service and heated more, further shortening it's life.

The warrantied life of a battery is normalized to 25C and it is common in a high productivity warehouse to find batteries that exceed 50C, and depending on the exact environment it may take as long as 72 hours for that battery to return to 25C (or within 5C of whatever the ambient temperature is). Under this scenario the battery life optimum would require 8 hours for charging and 72 hours for cooling. If the battery lasted for 8 hours, a 3 shift operation would require as many as 10 batteries per truck (to optimize battery life). This is generally not logistically or financially feasible. In most 3 shift applications a truck has 3 batteries assigned to it. The battery used most is fairly new while the remaining 2 are in some state of reduced capacity. Because of the weaker condition of the other two batteries, the newer battery will likely get used a lot more and be returned to service before it is ready. In this scenario many more battery changes happen than is desirable and that is costly. Add this to the cost of replacing batteries early, and the cost of charging worn (high resistance) batteries.

To further complicate the matter, in cold or frozen storage warehouses battery chemistries become significantly de-rated. The energy and power capacity for most chemistry starts to drop off significantly as high as 0C and are really limited below –20C. These temperatures, which are ideally steady in refrigerated warehouses also exist naturally intermittently all over the world in unconditioned warehouses and in the outdoors, creating significant challenges in properly sizing, using and maintaining batteries.

The Current Alternatives

Many things have been tried to improve the overall efficiency of the material handling systems but only a few have even had a glimmer of success in forklifts. AC traction and lift systems have made major strides in improving the reliability and reducing the maintenance of trucks around the world. They also have improved the performance of trucks over the battery discharge cycle. However their ability to manipulate the power output of a battery into consistent power for their motors means batteries are being discharged deeper with more heating. Both of these things we know to shorten the life of batteries. Fuel cell hybrids have also replaced batteries in as many as 5000 trucks globally. These systems, in their application infancy, were often undersized and the maintenance of the fuel cell was

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generally more expensive than the truck itself. Although most would consider fuel cells in forklifts to be moving out of their infancy, these systems are very complex and have not achieved the volume requirements to justify investment in the purpose built parts that would reduce cost and increase reliability. Where fuel cells have been most successful is in showing the operational and financial benefits of not having to wait for battery recharging and not having to swap the battery to do so. These devices also ultimately reduce the physical footprint of forklift fleets and their support infrastructure; as well improve the performance of the truck over the shift.

What do Ultra-caps Offer?

Electric forklift applications are typically high power and high energy applications. Most battery chemistries are energy dense, however they are not typically power dense. Ultracapacitors are power dense but not energy dense, making a combination of the two, in many ways, the perfect energy/power solution for electric forklifts. Ultra-caps hybridized with many different battery chemistries can provide significant gains in run time, truck performance, reliability, battery life and, lower energy costs.

These benefits manifest themselves visually and immediately as fewer battery changes, and more work completed at a faster rate per battery. This potentially can reduce the battery fleet size significantly, in some cases even limiting the required number of batteries to one per truck, reaping the benefits of fuel cells at much lower price points and orders of magnitude higher reliability. Ultra-caps can provide these benefits by increasing truck output in single-shift single battery operations or by using opportunity or rapid charging in multiple shift applications, often without the need for purchasing special rapid charge batteries or special charging equipment.

For facilities already engaged in rapid or opportunity charging, ultracapacitors offer benefits not only in performance but in potentially lower charge rates possibly lowering peak power costs, and lower operating temperature increasing the batteries life. In fact the opportunity exists to pair ultracapacitors with more energy oriented battery architectures, maximizing the benefits to customers and suppliers.

The best results are typically seen on the more dynamic, “high performance” cycles, however significant improvements can be seen even in long distance horizontal transport. Certainly the primary demographic for ultracapacitors on lift trucks would be high performance users in refrigerated warehouses, but anywhere productivity and performance are a priority would be a solid target for hybrid ultracapacitor/battery systems.

Common integration schemes

Capacitors can be integrated in several ways. Here are a few generalized schematics on the most common methods. These are arranged in order based on an increasing amount of engineering work required to complete.

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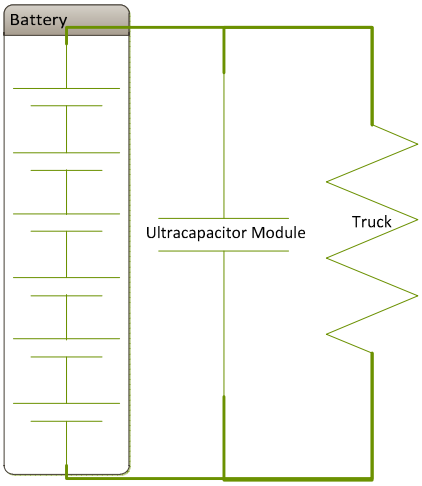

Figure 1: Basic Integration (built in battery)

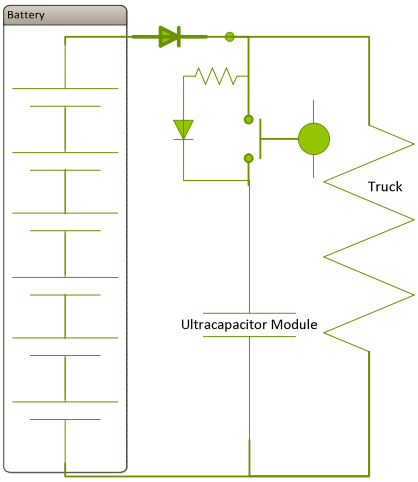

Figure 3: Improved Regen Capture (w/controls)

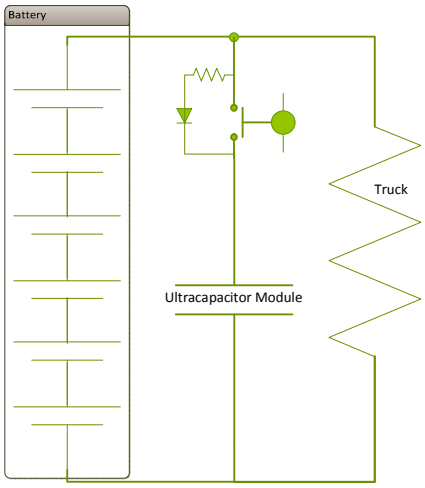

Figure 2: Controlled Integration (removable battery)

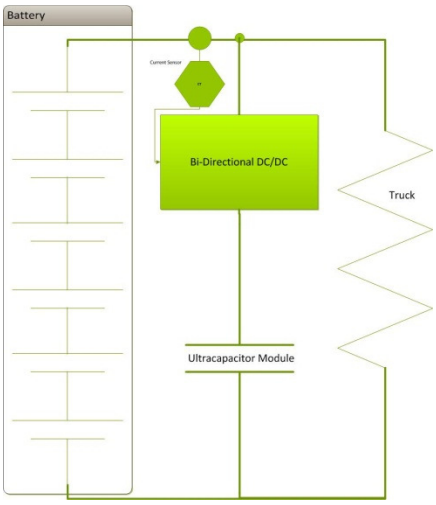

Figure 4: Optimized Performance and Cost

System Sizing and Application

Optimal sizing of the battery and ultracapacitor module is highly dependent on the method of hybridization selected and the specific goals of the system and the actual duty cycle performed by the forklift. Hybridization choices can be as simple as a parallel system. Options can include diode isolation of the battery to improve efficiency of regenerative energy reuse or a cost optimized current injecting system that allows either the battery or the capacitor system to determine the truck voltage range and the remaining system to be sized ideally for energy content and cost. The Ioxus Engineered Solutions group can help you size and determine how best to incorporate ultracapacitors into your truck as well as can offer complete turnkey systems manufactured to be installed on your assembly line to offer the greatest benefit to your customers.

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Internal Combustion Trucks

With the increase in awareness of the effects of carbon footprint as well as the restrictions/benefits of cap and trade/carbon credits systems, many manufacturers have pursued fuel economy improvements for their forklift offerings. Also, several countries have begun lead reduction initiatives as well as clean air initiatives from government bodies and unions. Ultracapacitors can be the solution for simple improvements like eliminating lead starting batteries and instituting stop/start hybrids to much more complex ones like full parallel, serial or combination hybrids. One approach that seems to be gaining momentum is to use fully hybridized systems on lift trucks, similar in concept to hybrid automobiles. Toyota and other manufacturers have demonstrated forklifts that are built on automotive power train platforms including fuel cell systems as well as internal combustion/ electric drive hybrids like the Prius. Forklifts however, have much different duty cycles and demands than cars.

Starting Batteries

With the addition of start/stop (micro hybrid), idling emissions and fuel consumption will be nearly eliminated, a very simple change that generates substantial benefits. However, starting batteries will be used much harder than they are currently, and in many automotive tests for this application, standard starting batteries have not fared well. A quick look at the applications suggests a larger or alternative battery is in order to support this change. However, room for a larger battery is hard to come by in the tight packaging of a fork lift, and batteries really are not well suited to the task to begin with. Ultracapacitors are ideal power sources for starting engines, being able to deliver the large instantaneous power required for cranking and will happily do this hundreds of thousands of times in even the coldest of conditions. Exact applications should be discussed with your Ioxus representative to determine the appropriate sizing.

Full Hybrids

While cars need large energy storage systems for their hybrids to work, as we have previously discussed, the duty cycles for forklifts are different, in most cases very short by comparison. This means that large energy storage systems are not as vital and that more power dense energy storage is preferred for forklifts. Current forklifts using internal combustion engines (ICEs) are sized for peak power demand. Much like the fuel cell hybrid currently being sold into electric lift trucks, the power plant for a hybrid using an internal combustion engine can be drastically reduced relative to the current power plant, because the ultracapacitor storage system can provide the peak power demand and be quickly recharged to handle the next event. Typically the ratio between peak power and average power is substantial for forklifts, in some applications as high as 10:1. Hybridizing allows you to design your system around a power plant to deliver 100%-200% of average power. This means your power source can be much smaller. In some dynamic applications, because the amount of potential regenerative energy, the new power plant power requirement could be as small as 10% of the current power plant.

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Conclusion

Ultracapacitors can provide the key ingredient in your forklift to allow it to achieve the greatest ROI for your customers. Ultracapacitors help with maximizing the performance and run time of your current fleet through battery parallel or start/stop systems, thereby providing the long life, reliable, efficient energy storage system that allows you to cost optimize your next generation hybrid forklift. If you have additional questions about integrating ultracapacitors into your forklift application, the Ioxus engineering team has extensive experience and can provide assistance.

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