SKELETON TECHNOLOGIES

WHITE PAPER

SKELSTART ENGINE START MODULE 2.0: MORE POWER, LESS HASSLE

There are many different solutions on the market for starting an internal combustion (IC) engine – yet, lead-acid batteries are indisputably the most commonly used solution. Lately, ultracapacitor-based engine start modules (ESMs) have attracted attention, particularly due to ultracapacitors' unique properties. While batteries set limitations in terms of lifetime, power performance, and working environment, ultracapacitors do not - thus solving all of these problems. In fact, the three most important properties of ultracapacitors are: practically unlimited lifetime, remarkable power performance, and a wide operating temperature range, where performance is not greatly affected by extreme temperatures.

Ultracapacitors bring economic benefits

Due to the aforementioned properties of ultracapacitors, they can provide reliable engine starting even in the harshest conditions, together with the indirect benefits including less downtime, less maintenance procedures, less replacement costs, and lower fuel consumption.

Trucking

In the case of intra-city delivery truck, which stops after every few kilometers, an ultracapacitor-based ESM is the perfect solution to avoid excessive idling. For calculations, we assume that a truck with this kind of work profile idles 2 hours per day by average, and the fuel consumption idling is approximately 2.5 L/h. If the fuel costs 1.2 €/L, decreasing idling period by 2 hours would save 6 € per shift. Considering the cost of an ESM (SkelStart ESM 2.0 24V costs 1,390 €), break-even will be reached in 232 shifts. And would the truck be working 2 shifts per day and 7 days per week, it would take only about 17 weeks for the ESM to pay itself off.

Drivers who need to park their trucks overnight often choose a location shared by fellow truck drivers. When temperatures get lower, the probability for a need of a jumpstart rises. Thus, it's reasonable to have help nearby. When it's time for a jumpstart, however, it could waste about 1 hour of both parties' time – the trucker who needs a jumpstart, and the trucker who will help. One hour of downtime is assumed to cost about 150 €, or it will extend the day for the drivers. It could also mean some late delivery fees. Assuming about 10 jumpstarts per truck in cold season, the cost of associated downtime is up to 1500 € (also late delivery service, for example 200 € per delivery, may apply in some cases). Avoiding jumpstarts would cut the unintended costs.

One of the costs that could be avoided when using the ultracapacitor-based ESM is associated with batteries' short lifetime. Typical working profile of a long-haul truck is 5 days on the road and 2 days rest. The problem – batteries are far from fully charged in the end of the rest period. Starting the engine when batteries are not fully charged will damage the batteries and shorten their lifetime, especially in cold climates. Thus, in some cases, batteries must be replaced every 7-8 months. Ultracapacitor-based ESM can start the engine even when batteries are dead, and as an extra bonus, the lifetime of the batteries will increase as the ESM is used for engine cranking. Therefore, using the ESM will save you 700-900 € per year by eliminating the need for battery swaps (assuming 1.5 battery swaps/year).

Another problem worth noting is drivers holding their truck idle "just in case". In order to use the on-board loads, yet avoid possible starting problems, drivers choose to idle the engine. According to our client data, using the ESM for engine starting reduced the yearly idling fuel expenditure from 7% to 3%. Assuming a long-haul truck consumes about 30,000 L of fuel per year, the fuel consumed when idling is about 2,100 L. With the ESM, the idling time can be decreased, reducing the fuel consumption by approximately 900 L – down to 1,200 L. Total savings can be therefore up to 1,080 € per year if the "to be safe"-type of idling is avoided.

Last but not least – the ESM will also protect the truck's electrical system by isolating the starter load. In case of driver forgetting to switch off the hotel load inverter, the electrical system is protected. It's not as common as aforementioned problems, yet our clients report 1-2 such episodes per 100 trucks in a year. The biggest issue in terms of costs is the increased insurance premiums due to these incidents. In the end, the truck will be off the road for up to a week, and the insurance claim may be as high as 30,000 €.

Forestry

The high season for forestry is during the winter, when the daylight period is extremely short. Thus, every minute counts and some of the work is done in the dark. Even if the machinery needs only simple maintenance, e.g., cleaning chains of stuck branches, floodlights must be used when it's dark. For safety reasons, the engine must be shut down, increasing the risk of no-start, especially when working at low temperatures – batteries lose their power and capacity dramatically at temperatures below zero. If a jumpstart is necessary, the forest itself poses a problem – help may be far, further increasing the downtime. Using ultracapacitor-based ESM will provide reliable start of the engine regardless of temperature or batteries' state of charge, decreasing the risk of downtime and thus, saving money.

Marine

On the sea, the situation is even more complicated. If there is no spare battery to replace the dead battery with, a jumpstart or a tugboat service is necessary as not having a running engine can lead to maneuvering issues when entering the harbor. Tugboat service can be a remarkable cost. One of our clients needed the tugboat service when returning from a regatta, as they could not operate the keel without a running engine (Cookson 50 yacht). They had three batteries, including a spare, which were all drained. As a solution, the starter battery was replaced with an ESM. As a result the total weight of yacht was reduced by 15 kg and there is now a solution for using energy left in „dead" batteries to generate high starting power in a few minutes with no extra assistance.

Comparing ultracapacitor and battery-based technology

Batteries and ultracapacitors are so fundamentally different, that there's a very little point in comparing the exact same parameters for the devices. For batteries, one of the key standards set for starting, lighting, or ignition batteries is Cold Cranking Amps (CCA). CCA is a measure of

battery's ability to start the engine in cold temperatures. It is defined as the current that a fully charged battery can deliver for 30 seconds at –18°C (0°F), maintaining voltage at 7.2 V or higher (for nominal 12V battery). On the other hand, the whole point of using ultracapacitors for engine starting is to crank it within the first two seconds instead of 30.

Clearly, for ultracapacitor-based ESMs (or other capacitor-based systems), standards other than CCA are necessary to evaluate their engine cranking performance. KiloFarad International (KFI) Standards Committee proposed the following standards[1]:

+ Rated Voltage (RV) - the nominal voltage of the whole ESM instead of an individual ultracapacitor cell. Thus, it's easy to compare with a battery. For an engine that has a 12V battery, an ESM with nominal voltage of 12V would be compatible.
+ Peak Power (PP) - the maximum instantaneous power that the ESM can deliver at –18°C (0°F) or 0°C (32°F). In fact, the maximum power at –18°C (0°F) is named Cold Peak Power (CPP) and the value at 0°C (32°F) just Peak Power (PP). These parameters can be used to evaluate the ESM capability of breaking the engine loose before starting to rotate.
+ Cranking Power (CP), together with Cold Cranking Power (CCP), are the measures of average power an ESM can deliver during the first 1.5 seconds at 0°C (32°F) or –18°C (0°F), respectively. An IC engine RPM reaches near maximum value within the first 1.5 seconds, characterizing the ESM performance in terms of spinning up the engine.

While directly comparing batteries with ultracapacitor-based modules is complicated, it is still something that the industry is interested in. Thus, the CCA parameter is also calculated for ESMs, yet it's not exactly the same as for batteries. For ultracapacitor-based ESMs, CCA is commonly calculated as a current delivered for 3 seconds at –18°C (0°F). However, using the set standards for ultracapacitor-based systems makes it easy to compare the modules to each other. The table below compares the new generation SkelStart ESM 2.0 with one of its competitors on market – the Maxwell 24 V ESM Ultra 31/1100/24V ESM. It is clear that SkelStart ESM 2.0 outperforms Maxwell's ESM in every parameter and provides significantly more power.

Measurement			Description	SkelStart ESM 2.0 24V	Maxwell Ultra 31/1100/24V ESM
Cold Cranking Amps	CCA	[A]	Current delivered for 3 seconds at –18°C	1198 A	1100 A
Peak Power	PP	[kW]	At 0°C	92.9 kW	51 kW
Cranking power	CP	[kW]	1.5 second average power at 0°C	51 kW	33 kW *
Cold cranking power	CCP	[kW]	1.5 second average power at -18°C	45 kW	29 kW *

* estimated value

1 John R. Miller, "Standards for Engine-Starting Capacitors," in Proceedings of the 15th International Seminar on Double Layer Capacitors and Hybrid Energy Storage Devices, Deerfield Beach, FL, 2005.

Increasing reliability

Usually, engine starts after it has been cranked beyond the threshold rotation speed, e.g., 100 RPM, and the fuel pressure reaches the nominal value. Typically, this will take about two rotations of the engine, and the engine starting time falls in between 1 to 2 seconds. This may not be the case after a longer stationary period. In most modern rail injection diesels, the required pressure for starting is 100 – 200 bar, which may take up to 10 engine revolutions (3-5 sec) to reach nominal pressure.

Even if ultracapacitor-based technology is used for engine cranking, this may cause a non-start event at first try - the ESM may not have enough energy left to crank the engine at the required minimum speed for longer than 5 seconds. It is important to note, that with the fuel pressure up, the ESM will start the engine on the second attempt. The ESM will be ready for a second attempt after a 3-minute charge. If the nominal required fuel pressure is reached, the engine will start in less than 2 seconds.

Even if after a prolonged stationary period the batteries are "dead", ultracapacitors can charge themselves from the so-called dead batteries. Ultracapacitor-based ESM will lose about 50% of its energy when the engine is cranked or attempted to do so. A bit of calculating shows, that for the SkelStart ESM 2.0, which stores 35 Wh of energy in total, it's about 17.5 Wh. As batteries store much more energy, the so-called dead battery, which is unable to start the engine, may have just enough left to charge the ESM. In fact, about 5% of the energy stored in a typical battery is needed for the process.

The ability to charge itself from seemingly empty batteries, gives ultracapacitor-based technology a huge advantage in terms of reliability – the probability of a non-start is remarkably lower.

SkelStart Engine Start Module 2.0 – new generation

Similarly to the previous SkelStart Engine Start Module, the ESM 2.0 comes in 12V as well as 24V version. Designed together with SkelStart Torque, the technology inside is developed keeping heavy industry in mind. This means it's more powerful and more reliable than before. SkelStart ESM 2.0 has been improved in terms of almost every parameter, e.g., improved CCA, peak power, CCP, but also higher maximum voltage, and lower equivalent series resistance (ESR).

Advantages of higher power

Improved Cold Cranking Power, Cranking Power and Peak Power values also further improve the SkelStart ESM reliability, especially at very low temperatures. Even though the maximum peak power of the ESM drops noticeably if the temperatures get colder (the drop is far more severe for batteries) – the more power to start with, the more power at the extremes. For example, SkelStart ESM 2.0 provides almost 50 kW of peak power at –40°C (–40°F) – nearly the same that Maxwell's

Ultra 31/1100/24V ESM at 0°C (32°F). Thus, the new generation's ESM will provide you more reliability working in cold temperatures. Also, more power means that the same job can be done with less modules. In case of larger engines, for which two SkelStart ESMs were required before, only one SkelStart ESM 2.0 will be necessary.

Advantages of higher voltage and lower ESR

The power profile of engine starting has a remarkably high power peak up to the point the engine is cranked over for the first time. The magnitude of this peak, i.e., the power necessary to crank the engine, is dependent on the ESR of the starter motor and battery/ESM. After the engine is cranked, the power drops sharply due to the counter electromotive force generated by the starter motor itself, decreasing the potential difference between the starter and the ESM. Therefore, the lower the ESR, the lower the power peak of engine starting. The ESM technology, compared to lead acid batteries, offers much lower ESR, thus cutting the total series resistance of the system almost in half. This allows the ultracapacitor-based ESM to crank the engine nearly instantaneously.

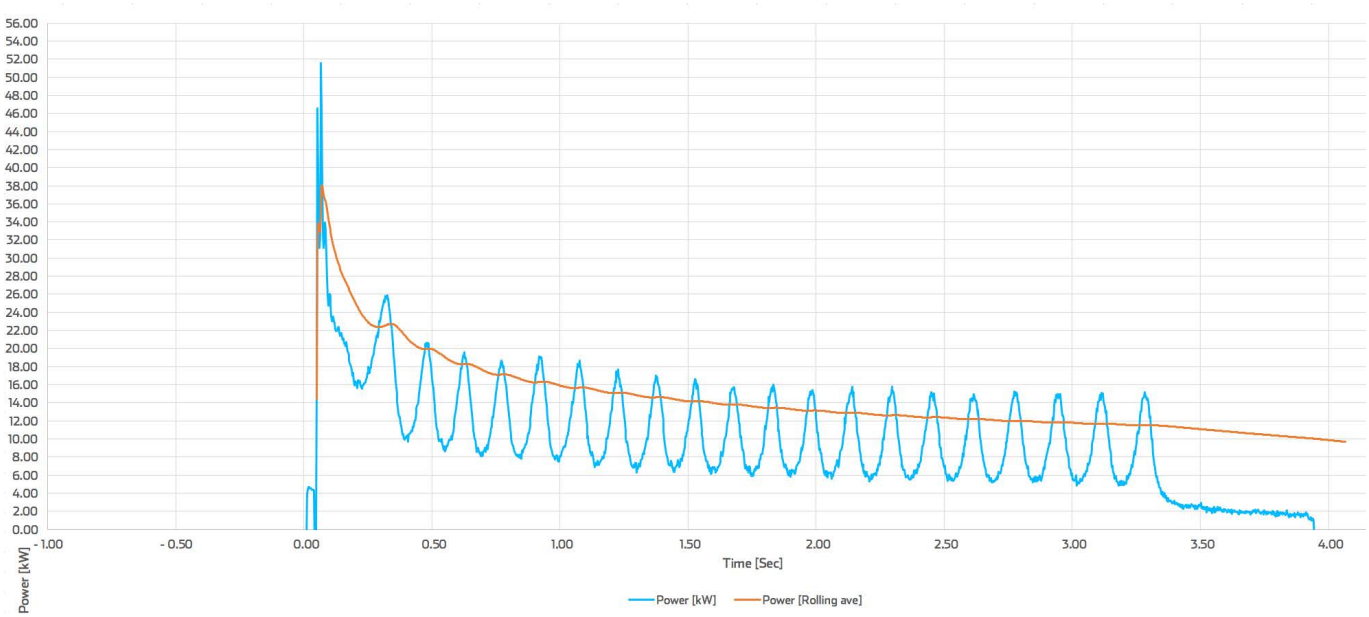

Figure 1. Power profile of engine starting.

The SkelStart ESM 2.0 24V module offers maximum voltage of 28.2V, higher than previous version and higher than batteries. In fact, 24V battery's maximum voltage is about 26 V if it's fully charged and even lower when it's not. Higher voltage helps to balance the counter electromotive force produced by the starter after the engine starts rotating.

Specifications

	12V	24V
Net mass	8 kg	
Dimensions	L 328 x W 171 x H 241 mm	
Working temperature	–40ºC to + 65ºC	
Cold Cranking Amps (CCA)	2342 A	1218 A
Maximum peak current (0,4sec duration)	7801 A	4460 A
Peak Power (PP)	87.5 kW	109.6 kW
Charged full voltage	14.1 V	28.2 V
Energy	35 Wh	35 Wh
Rated Capacitance	1280 F	320 F
Individual Cell Capacitance	3200 F	3200 F
Charging current	16 A (max)	16 A (max)
Continuous input voltage range	9-16 V	18-30 V
Continuous input voltage range with specified charge time	11.5-16 V	23-30 V
Recharge time (from 0 V)	19 min	8.5 min
ESR IEC	0.56 mOhm	1.79 mOhm
Standby current draw	<15 mA	<10 mA

Installation

Detailed installation guide is included with the product.
SkelStart ESM 2.0 can be installed to replace one of the batteries or in addition to the batteries. In general, the installation process of SkelStart ESM 2.0 includes some rewiring as follows:

1. The first cable connects battery plus terminal to the ESM. This cable can be connected to the battery plus terminal, or to a junction box with a suitable output access.
2. The second cable connects the ESM to ground. This cable can be connected to the battery minus terminal or to the vehicle frame.

3. The third cable connects the ESM to the starter. It must be noted that to the starter plus solenoid may be connected cables from battery plus terminal, the alternator, and other loads. These cables must be removed and connected together, leaving the starter out of the system. The new cable from the ESM must be the only cable connected to the starter.

Testing and certifications

The SkelStart Engine Start Modules have passed the tests for E-mark certification.
The SkelStart Engine Start Modules also meet the provisions of the 2014/30/EU Directive of the European Parliament and of the Council on electromagnetic compatibility, meaning that they are CE certified.

Skeleton Technologies has been granted to ISO 9001:2015 and ISO 14001:2015 certifications to recognize our compliance with the quality management system standards and environmental management systems standards respectively. In addition, all our ultracapacitor cells are RoHS (Restriction of Hazardous Substances) compliant (Directive 2002/95/EC).