



Supercapacitors as part of a hybrid Engine starting system

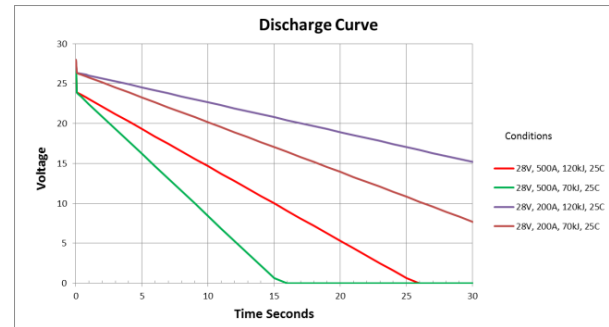
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8/27/15



Supercapacitors

- Supercapacitors or Electronic Double Layer Capacitors (EDLC) are considered pulse power devices
- Used in a wide range of application that require rapid discharging or charging with higher power
- Windmills, Electric and Hybrid vehicles. Current/power smoothing
- Ideal for engine starting
- Supercap is not a battery and normally not used for more than 10 seconds due to linear discharge curve
- Vehicle starting a pulse event, short term
 - > 2000 amps 1.5 sec
- Silent watch an energy requirement, long term
 - > 30 to 60 amps for 60 mins or more



Penn State - Advanced Research Lab (ARL) - Military

- Evaluated several Supercapacitor and battery technologies to determine best system to supply silent watch and engine starting
- **Concluded dual system is optimal**
- Supercapacitor for engine starting with low cost deep cycle lead acid for silent watch
 - Deep Cycle lead acid meets Silent Watch FTTS threshold 60A for > 4 hours
 - > Lower life cycle cost
 - Utilize Li-Ion for longer more demanding Silent watch requirements
 - > FTTS objective of >8 hours at 60A
- Saft's Nickel Supercapacitor has the power of several Hawker batteries, less effected by temperature with ability to quickly recharge from any source
 - Recharged from 24V manpack radio battery in <2 mins
- **Saft technology – safest, lowest self discharge, highest capacitance**

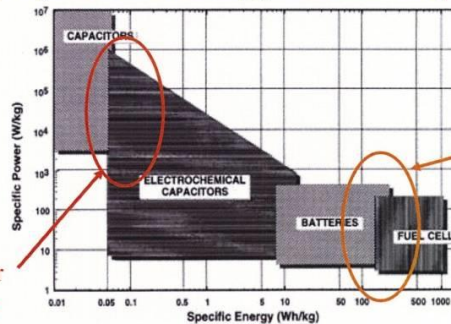
NDIA Joint project Army & Penn State (ARL)



Split Energy Storage System Design Benefits



- Separate the two different power requirements
 - High power for engine starting (more CCAs)
 - High energy for silent watch (deep cycle application)
- No battery exists that can be optimized for both functions
 - Use appropriate technology for each requirement



Operate here for engine starting

Operate here for silent watch

Allows for battery optimization and cost reduction

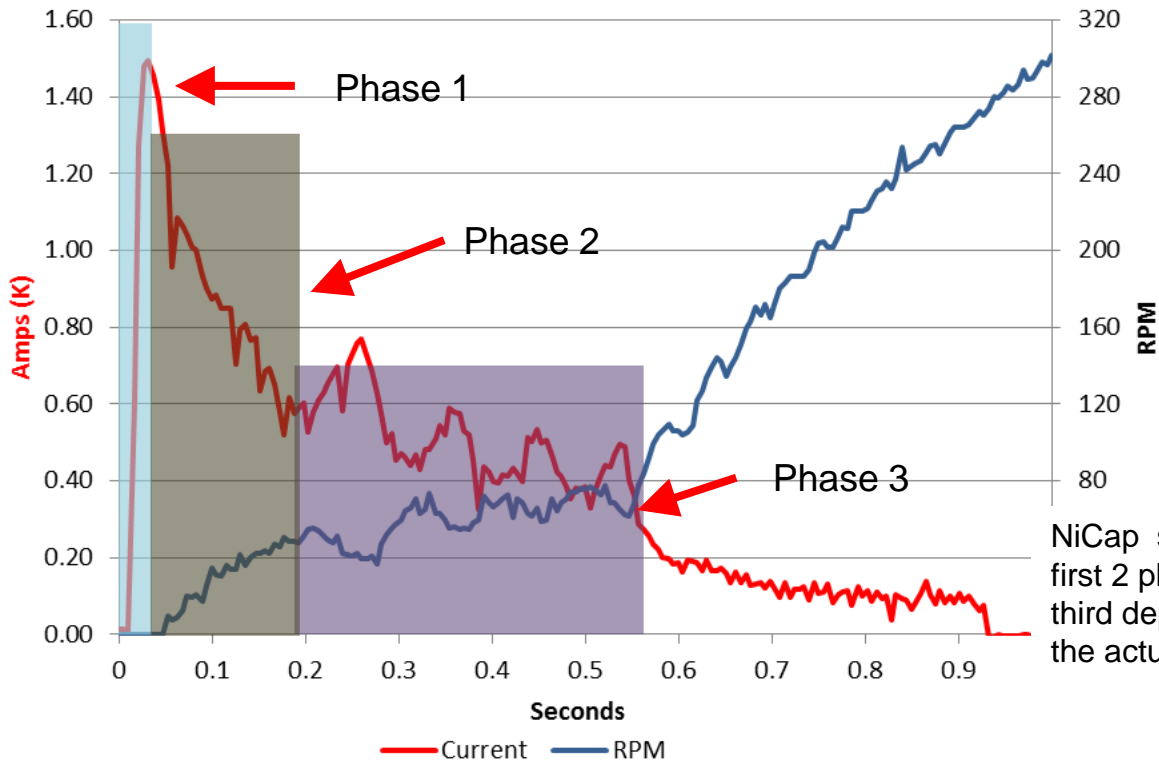
Part of a NDIA Joint project for vehicle energy management

One size does NOT fit all

Engine starting sequence – Three Phases

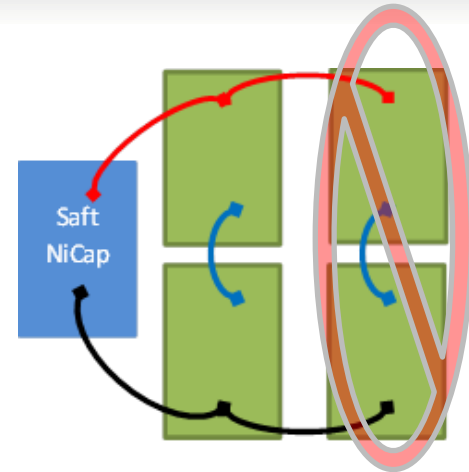
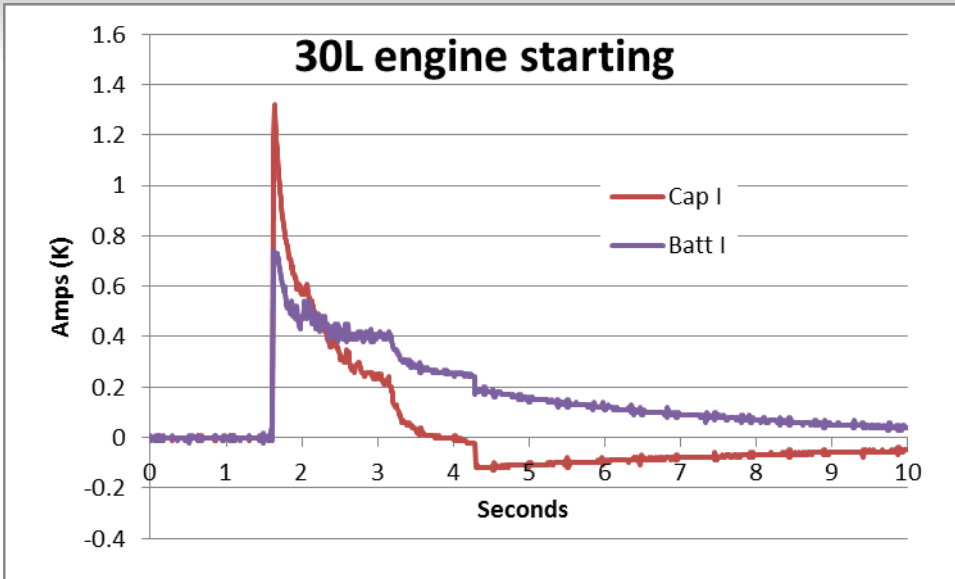
1. There initially is very high current demand with a duration of ~ 0.050 seconds (**locked rotor**). This is associated with the starter pinion gear being driven to the flywheel gear.
 - The engine has not started to move
2. After that initial spike, current drops abruptly to a value less than one-half its initial value while engine static friction and rotational inertial resistance is overcome and crankshaft movement begins (**break-away current**). This occurs over the next ~ 0.10 second period depending on engine size.
 - The engine is starting to rotate
3. Then beginning at approximately 0.15 second, current drawn by the starter begins to reach a constant value as the engine rotational speed increases continuously to a peak value (**rolling current**), $\frac{1}{2}$ break-away.
 - The engine is beginning to accelerate and reach a constant velocity

Engine starting sequence 12L engine



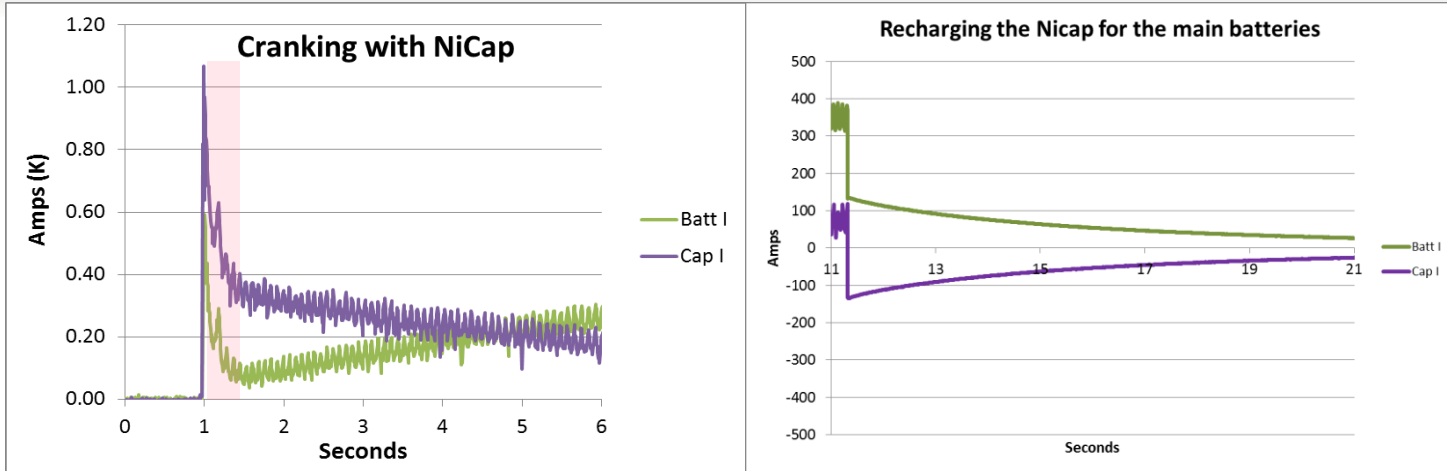
NiCap supports most of the first 2 phases and part of the third depending on how long the actual cranking is

NiCap engine starting



Even on larger engines the NiCap can provide a bulk of the starting current. We removed 2 of the 4 6D lead acid batteries and replaced them with 1 24V 500F NiCap. The NiCap is providing most of the current for the first .75 seconds on a 1.5 second start. You'll also note the recharge of 10 seconds starting a 4 seconds

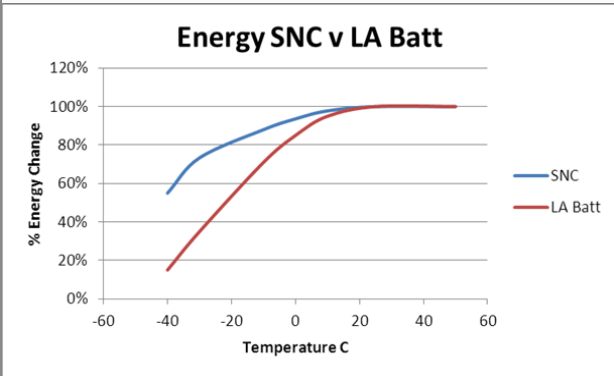
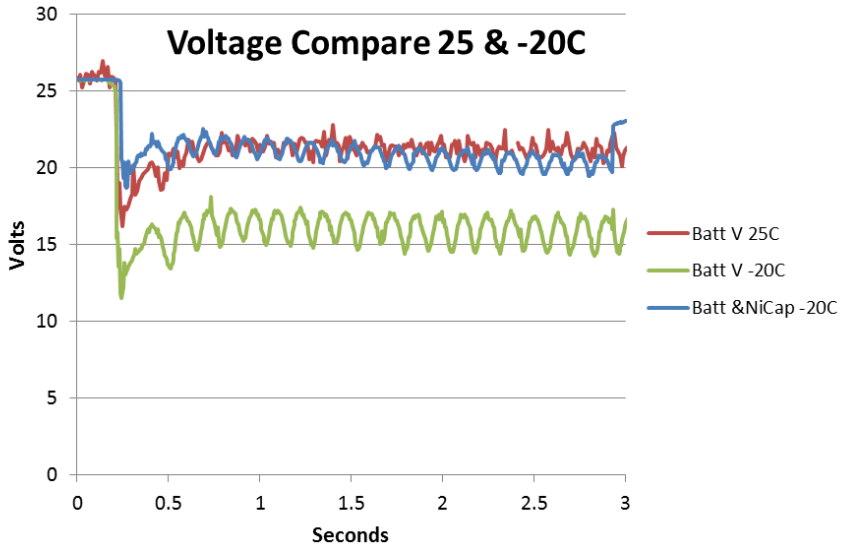
Supercap with Lead acid battery



NiCap due to its lower ESR generally supplies more of the initial starting power than the batteries. Much of this depends on the cable impedance and location between NiCap and starter motor

Since they are low energy devices the recharge is quick and takes about 10 seconds and take only .2Ah from the battery

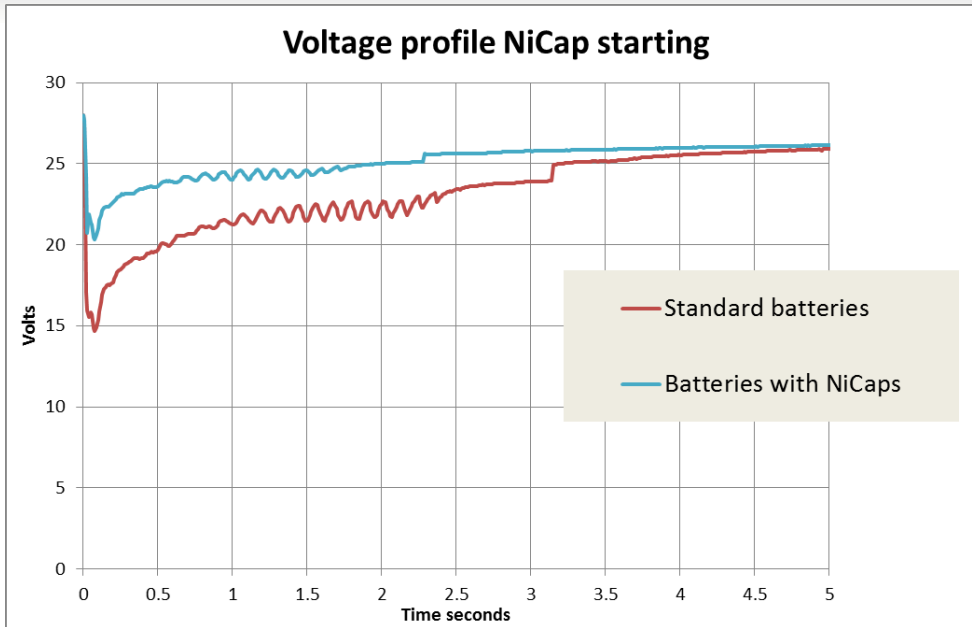
Cold Starting with NiCap (-20C, -4F)



Adding a NiCap allows the voltage and therefor the RPM to be the same as if it was cranking at room temp even as very cold temperatures. Higher RPM = faster starting

Testing in Williston ND in Feb 2013 @ -25C
Supercap got engine to starting speed

Improved starting speed with Lead Acid



69L Engine
2 starter motors

Typically a 10 to 15% increase in starting speed at room

Supercap No Idle

- NiCap is an ideal starting device dedicated to pulse power
- 1M engine starting cycles
- Recharge in seconds

- Many people looking to no-idle and or start stop for cost saving
- Turning off engine as often as possible
- **7 seconds of idle fuel to start a mid size diesel engine**
- Depending on use 5 to 15% fuel saving can be see which is comparable to many hybrid vehicles

- Utilizing higher energy batteries can complement a system with a NiCap
- Look for more reserve power vs CCA

Introducing Xcelion 6T™

- Saft's industrialized Lithium-ion 6T product for military vehicles
- Drop-in replacement for lead-acid (Pb-acid) batteries
- 60Ah 1,100 amps CCA
- Meeting mission objectives for military vehicles
 - Reduces life cycle cost over the current solution
 - > High cycle capability – 14x the life of Pb-acid
 - Great power density and energy efficiency
 - > Complex vehicles require higher power and more energy than Pb-acid chemistry can provide
 - Reduces logistics burdens to store, transport, distribute and retrograde materials
 - > Longer life = fewer replacements



Saft Xcelion 6T™ battery

**One Xcelion 6T™ Li-ion
replaces 2 Pb-acid
batteries for a quarter
of the weight and half
the volume.**



Flooded Pb-acid 12V batteries

Comparison 6T to standard PbA 6T

Main features	PB Acid 6T (2-12V in series)	Xcelion 6T™ (1-24V)
Cell Type	Absorbed Glass Mat (AGM)	SLFP (VL30AFe)
Voltage	24 V	24V
Capacity (Ah)	120 (C/20 Rate) 83 (C-Rate)	60 (C-Rate)
Cycle Life (40% DoD)	360	5,000
Cycle Life (100% DoD)	120	3,000
Number of Silent Watch Missions	120	3,000
Temperature range	- 40°C to + 55°C	- 40°C to + 60°C
Weight (kg)	52	22.7
Dimensions (mm)	2 x (H: 240, L: 330, W: 173)	H: 230, L: 269, W: 254
BMS w/Comms CANBUS	N/A	Yes
Internal Heaters (Artic Heat)	N/A	Yes
Recharge Rate	2 hours	2C Rate (20 mins @ 200A)

Part of the reason PbA do not last as long as advertised



AGM requires 14.7V to charge and 13.7V for float
Higher or lower temps affect that value

Advantage to using NiCap with Li-Ion

- Li-Ion has the highest energy density on any battery technology
- Concerns over controlling the charge and discharge to maintain a safe battery a major focus for many manufactures of Li-Ion systems
- Saft's focuses on systems and matching the chemistry with the application
- Saft's x6T currently uses Li-FePO for high power and safety
- The battery is design for long silent watch and engine starting
- Battery's control system employ low state of charge cut off – reserve protect.
- Set to insure battery still maintains enough power to start if drained below a specific limit.
- Using Saft's NiCap with our Li-Ion battery allow you to se a lower state of charge since the NiCap well do all the starting therefore increasing silent watch time
- This system employs the highest starting reliability with the longest silent watch time – THE BEST OF BOTH WORLDS
- **Guaranteed cranking even at low SoC cut off**

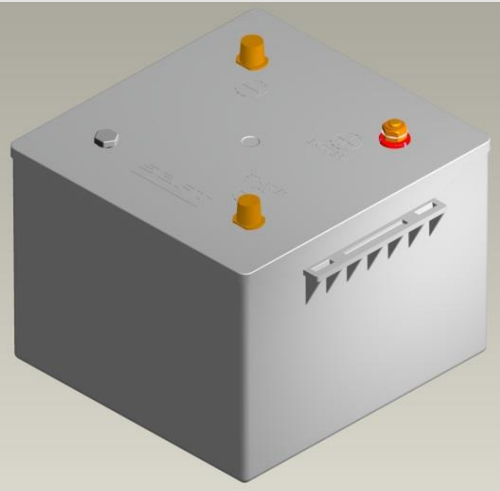
Review energy choices

- Assuming use of Supercap for engine starting
- Optimization of silent watch battery can be done
- Without Supercap lowest DoD allowed and still be able to start engine is 70%
- With Supercap a lower DoD can be used 90%
- Reducing the number of batteries
- Replacing 1 x6T with one NiCap 6T
- Same total Ah rating better cold starting guaranteed cranking even at Low SOC cut off

Battery Configuration	Three Saft x6T 3P	Four Saft x6T 4P
Total Ah available	180	240
Allowed DoD	90%	70%
Usable Ah		
	162 Ah	168 Ah

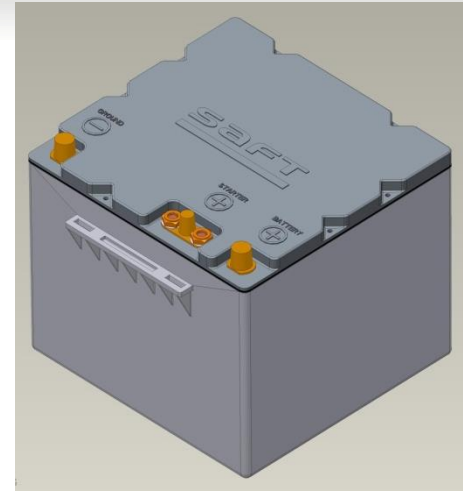
Saft developing a 80Ah version for even longer silent watch if using a Saft NiCap

Saft 6T NiCap



SNC6T24-300 - 85kJ

2 units finishing development
24V, 300F, 85kJ
24V, 500F, 160kJ

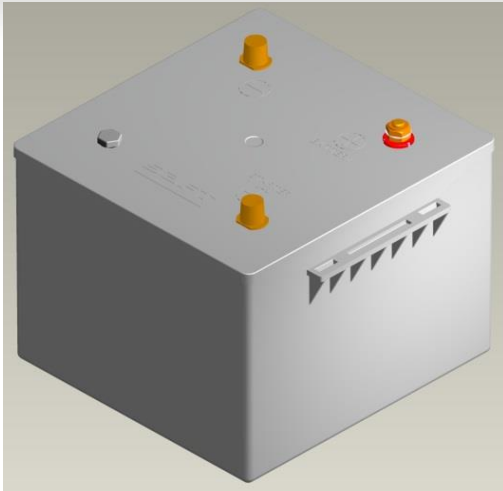


SNC6TA24-500 - 160kJ

Three terminal drop in with isolation to prevent NiCap for discharging into batteries. Submersible to 1M

- The 300F unit is a true 6T length width and height.
- The 500F has the same footprint however the main cover is ¼" taller battery terminals height matches standard 6T

Saft SNC6T24-300 installation PbA batteries



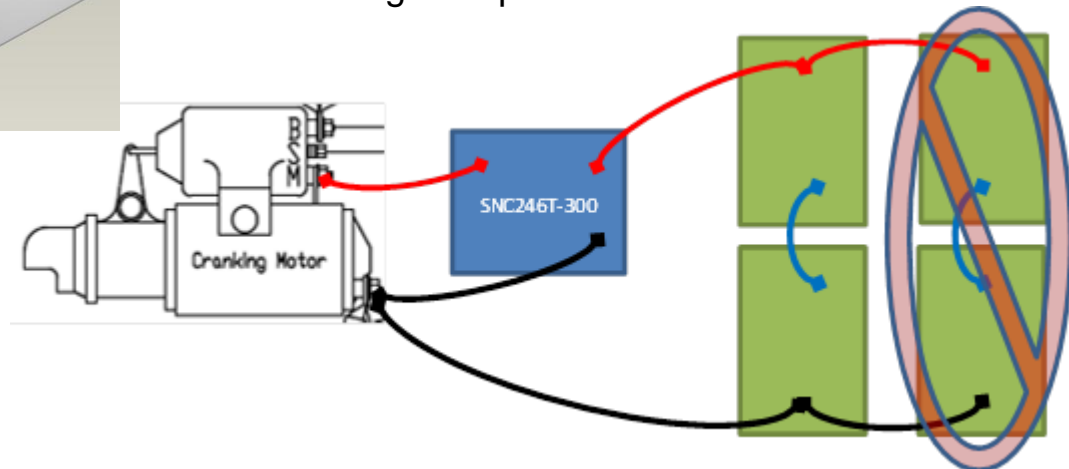
24V 300F 85kJ

Three terminal NiCap with isolation

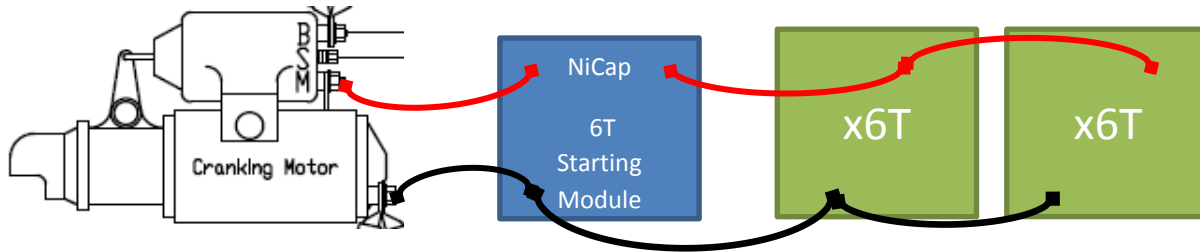
1500A for 2 seconds

- Recharged from battery or vehicle charging system in 10 seconds
- Patented system prevents batteries from draining NiCap

Submergible to 1M
for 30 minutes



Saft 6T with X6T



- Over 2000 Amps of cranking current
- Faster cold temperature cranking to -50C
- Dead battery starting
- 1M engine starts
- Long Silent watch with fast recovery
- 10 years of operation

Recommend replacing 4 PbA batteries with 1 SNC6T and 2 x6T