Introduction to Supercapacitors and Supercapacitor Assisted Engine Starting System

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Abstract- The presented work is a research done on one of the modern day energy storing devices i.e. supercapacitor, this encapsulates its structure, application, various components related and how supercapacitors can assist Engine Starting System. Moreover the paper also lists few future scopes of supercapacitors in various arenas of Power Systems and Power Storage Systems. A case study is also given to show how supercapacitor can over-weight conventional batteries and few other energy storage devices.

Index Terms- Supercapacitor, Internal Combustion Engine (ICE), Cold Cranking Ampere (CCA), Hybrid vehicle, Regenerative braking, Stop-Start Technology, Lead-acid battery, Effective Series Resistance(ESR).

1 Introduction

NOWDAYS every one of us is using vehicles, these vehicles no doubt have made our life easier. The very first step to use a vehicle is to start its engine, initially human powered techniques were used to start engine, but in present scenario starter motor is used. This starter motor is powered by batteries (generally lead acid battery are used) but batteries have certain limitations, such as large size which has to be increased further as demand increases, poor response to sudden power demand , needs maintenance and life is also very less.

There is significant rise in power demand in vehicles due to introduction of more electrical equipments to increase comfort and making vehicle operation easier, such as power steering, power window, air conditioning, heater, ESP, de-icer and etc., these all increase the current demand from battery.

During starting of an engine a sudden large current is drawn by starter motor from battery, which results in heating of battery and heating reduces life and capacity of battery. Current demand for starting of an Internal Combustion Engine increases with the size of an engine and decrease in temperature and also vary according to type of engine.

Generally voltage per cell in a battery is 2.35 volts which is practically not achieved, 6 cell (12 V) battery is used for starting the engine, if voltage drops below 10 volts a functional failure occurs and below 7.2 volts total failure occurs. In market, there are some power batteries available such as Li ion, Ni–Cd, Nickel metal hydride battery, but cost makes them out of option.

Application of supercapacitor in automobile industry provide maintenance free eco-friendly power source, increased life of existing energy sources, large environmental working range, efficient regenerative braking , increase scope of stop and start technology, power buffer in electrical drive train, reduced weight and volume of energy storing devices.

2 Supercapacitor Structure

Supercapacitor has emerged as new technology in energy storage. It has same fundamental equation as that of conventional capacitor. They are also known as Ultra capacitors and Electrochemical Dual Layer Capacitor (EDLC). The fundamental equation for a capacitor is

$$C = \varepsilon_O \varepsilon_r \frac{A}{D} \quad (1)$$

From the above equation (1) it is clear that capacitance is directly proportional to area of electrodes and inversely proportional to distance between electrodes. Supercapacitors have low energy density and high power density as compared to batteries, so supercapacitors can be used where there is a sudden power demand.

Supercapacitor is constructed from two carbon based electrodes, separator between electrodes and electrolyte.

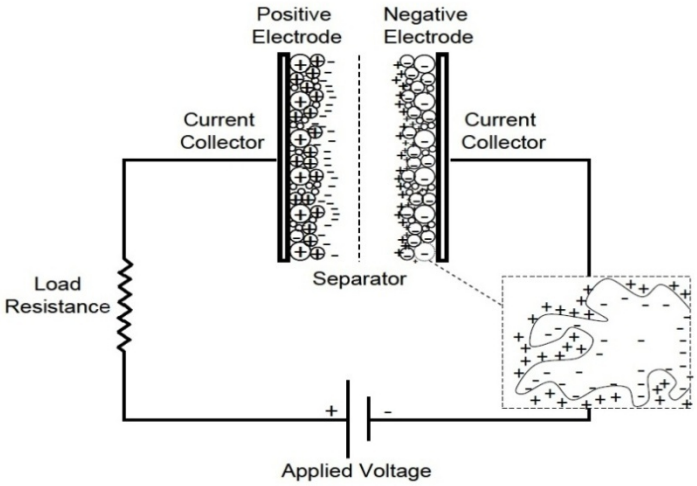


Fig. 2.1. Supercapacitor Structure

Supercapacitor stores electrostatic energy. As voltage is applied across system unlike charges attract each other. Ions in electrolyte diffuses across separator into the pores of electrodes, but electrodes are so designed that they prevent recombination of ions. These double layer coupled with an increase in area and decrease in distance between electrodes and achieves high energy density than conventional capacitor, as during whole process there is no transfer of electrical charge or chemical change, these charges are associated with non-faradic process. As the process is non faradic super capacitor possess properties such as large number of charging and discharging cycles, highly reversible stored charge. Super capacitor can have aqueous or organic electrolyte. Aqueous electrolyte includes H_2SO_4 and KOH. These have generally low ESR and low minimum pore size requirement as compare to organic electrolyte. Area of electrode is increased by using activated carbon and carbon nano tube as electrode. As activated carbon is cheap it is widely used. Activated carbon has different size micropores, mesopores and macropores to achieve high surface area. Large pore size correlate with high power density and low pore size correlate with high energy density. Recent researches suggest carbon nanotubes as super capacitor electrode material. Nanotubes are grown as entangled mat of carbon nanotubes with an accessible network of mesopores. These mesopores are interconnected allowing continuous charge distribution, that uses almost all of available surface area. As electrolyte ion can more easily diffuse into mesopore network. Carbon nanotubes have low ESR than activated carbon.

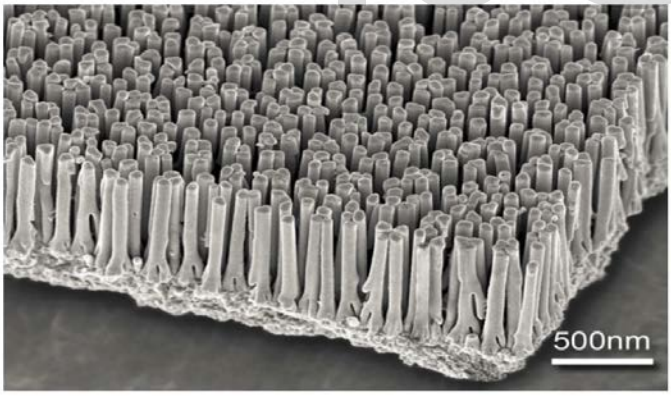


Fig 2.2 . Carbon Nanotubes

Supercapacitor stores charge at interface between high surface electrode and liquid electrolyte. Charge separation is created nearly at each solid, liquid interference. It is observed in supercapacitor that distance between electrodes is angstroms and area is thousands of square meters per gram of electrode.

Conventional capacitor has low energy and power density than supercapacitor but supercapacitor has higher power density and lower energy density than battery. So supercapacitor holds properties of both conventional capacitor and battery. Figure below shows energy and power density of different energy storing devices.

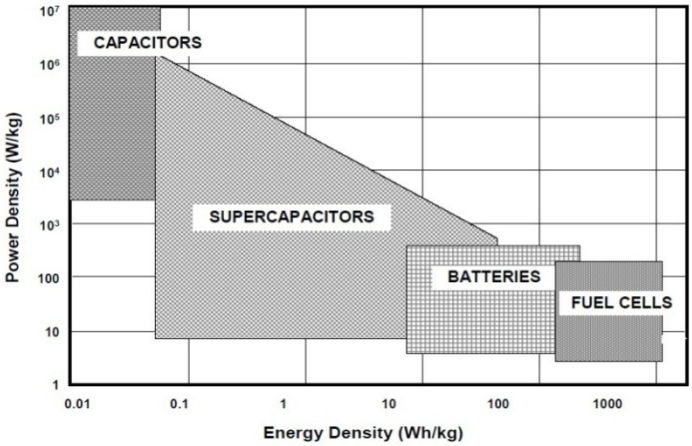


Fig. 2.3. Power Density of different energy storing devices

Effective series resistance (ESR)

This is very important parameter to be taken care while constructing a supercapacitor. It should be as minimum as possible.

It is algebraic sum of resistance of internal component of capacitors such as electrodes, current collector, dielectric material etc. these components are considered to have small resistance connected series.

Pmax = V^2/4ESR (2)

This relationship in equation (2) shows how the ESR can limit the maximum power of a capacitor.

ESR of conventional capacitor is greater than supercapacitor. ESR increases its quality of electrolyte and electrode material is degraded.

Some properties of super capacitor such as: High power density, Moderate energy density, Low ESR, Large number of charging and discharging cycles and wide range of working temperature makes it suitable for assisting battery for engine starting.

3 METHODOLOGY

Till now discussion was focused on how electrical load is increased in vehicles, problem associate with battery, structure of super capacitor and how they are different from battery and what makes them future energy storage devices.

Now the point of interest is how supercapacitors are installed with batteries to provide power in transient state and study all other factors related to whole setup. For this we will first know parameter of conventional engine starting system.

During starting of any engine a high inrush current is drawn by starter motor from battery. Starter motor provides cranking torque to fly wheel and crankshaft, rotating crank shaft provide reciprocating motion to piston which ultimately result in firing of engine. For starting an

engine the fly wheel must be revolve between 80 to 200 rpm. It takes about 1.5 to 2 seconds to start an engine. During this transient period large current drawn is from the battery. Current and time required during the start of engine changes in accordance to the size, temperature and type of engine.
The sudden starting current will drain out battery which will decrease life of battery and increase other battery associated problems. This problem can be solved by adding a bank of supercapacitor, in this bank all supercapacitors are connected in series and bank is connected to battery in parallel. Power requirement at peak load is provided by supercapacitors as their internal resistance (ESR) is very low. Small and constant load are powered by battery.

3.1 Advantages

There are many advantages of using supercapacitor assisted engine starting. These are listed below:
1. By using supercapacitor bank load on battery is distributed addition to this out of order batteries or old batteries can be used which don't have sufficient cranking power but has sufficient energy to provide power to constant load such as headlamp and tail lamp etc.

2. Addition of supercapacitor bank will increase the life of battery connected in parallel with bank. Battery life is increased about 2.5 to 3 times. Secondly battery with same voltage but lower ampere hour rating can be used which will save both money and space. This will also reduce overall weight of vehicle.

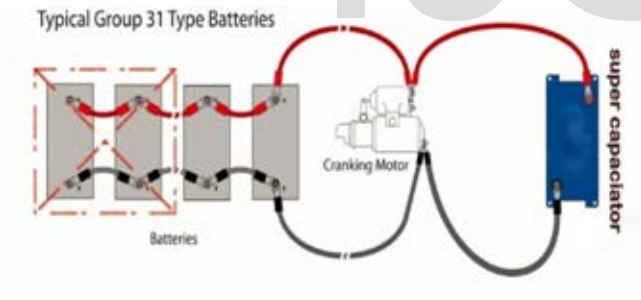


Fig. 3.1. Using Supercapacitors for engine starting

Figure 3.1 shows how initially four batteries were used to start engine but by using supercapacitor only two batteries are to be used.

3. Almost every vehicle is having a constant load of 45 Amperes. For air-conditioning, GPS, radio, lights, power break, power steering, power window etc.
Figure 3.2 shows how electrical load is distributed in vehicle. Supercapacitor assisted Starting system will provide more number of starting, experiment at room temperature shows that battery alone fails after 40,000 starts but battery plus supercapacitor can provide 1,20,000 starts before functional failure. For this experiment capacitor bank is of 150 F capacitors at 14 V and with an ESR of 4.5mΩ is used. Market is available with capacitors of 3000F each and capacitor bank of 500F at 16V with an ESR of 2.1mΩ.

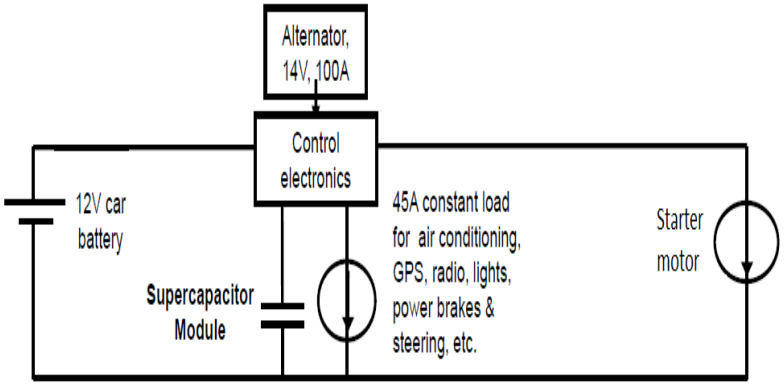


Fig. 3.2. Distribution of electrical load in vehicle

4. In cold regions engine starting is a main problem. It is observed that when temperature falls from 40°C to 0°C internal resistance of battery increases 10 times and engine viscous force becomes thrice. So cranking torque to engine crankshaft is increased and due to increased internal resistance of battery its capability to discharge current to crank cold engine is reduced. Supercapacitors can provide large power at subzero temperature. As there is no faradic reaction they are not affected when temperature is reduced. Supercapacitors can work efficiently between +65°C to -40°C, so Supercapacitors support battery during cold starting. Cold cranking ampere according to SAE standards of north America is defined as current that a new, fully charged battery at -18°C can deliver for 30 seconds while maintaining voltage at 1.2V per cell or higher. This amounts to 7.2V for 12V nominal battery. Table below shows how much CCA is required to start engine of different size.

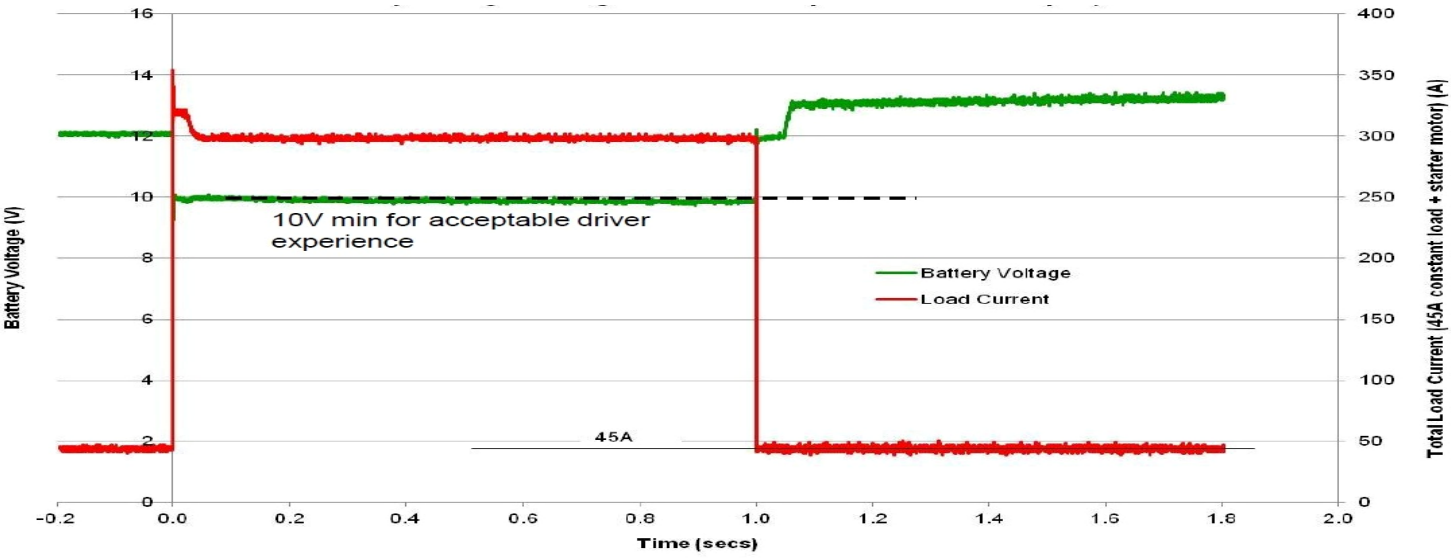
Truck Class	Engine Displacement (liter)	Cold Cranking Current(A)
6	6 to 7	800-900
6	8 to 10	1000-1200
7	12	1600
8	15-16	2400

Table 3.1 shows seriousness of the cold starting problem .

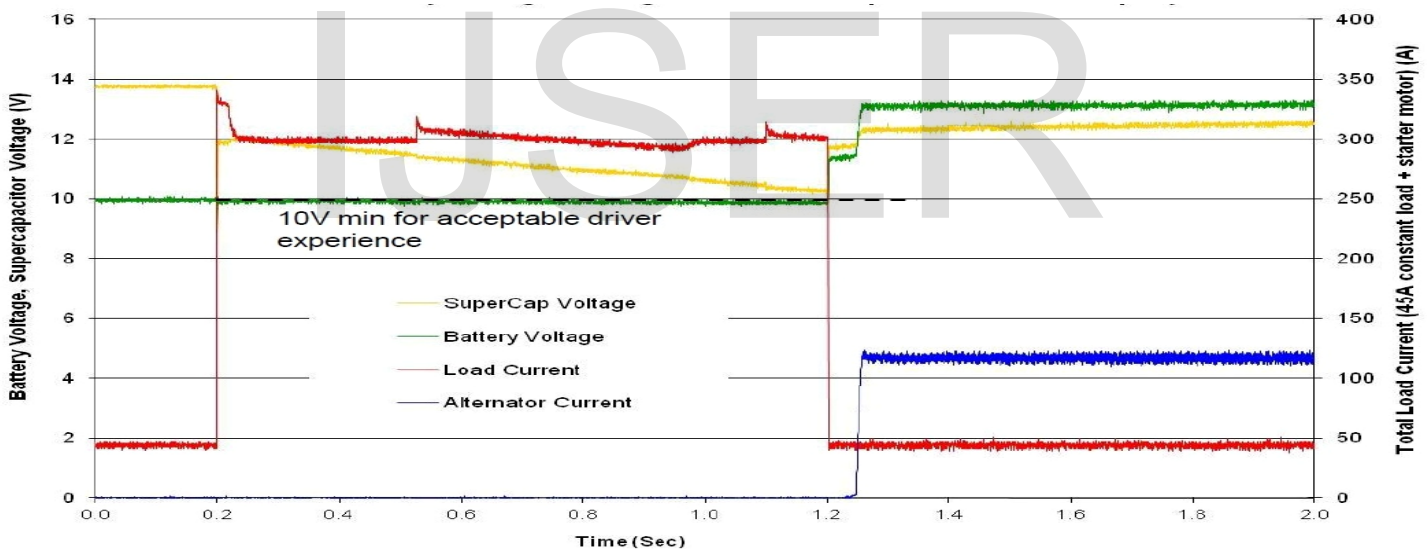
5. Lastly as the supercapacitors are maintenance free and don't require service so they are much better than conventional batteries and no time check is required. Even they are eco friendly as compared to Lead Acid Batteries as they don't produce any acidic fumes.

3.2 Graphs

The following graph shows how alone battery and supercapacitor assisted starting are different.



Graph 3.1



Graph 3.2

From Graph 3.1 It can be clearly observed how voltage falls when high current is drawn whereas in Graph 3.2 battery with lower voltage(nearly functionally failure) can start engine.

Starting current is provided by supercapacitors, after starting supercapacitors and battery get charged again. While constant load current of 45 Amperes is provided by either alternator or battery.

4 Future Scope

Research on energy storage devices has been increased in last decade, nowadays there is demand of lighter size and compact devices with potential energy storage. Particularly in auto sector there is great focus on hybrid vehicles, stop-start technology, supercapacitors and their scope.

Drive train support in Hybrid Vehicles

Bank of supercapacitors added with battery pack in hybrid vehicles (HV) & (HEV) to support electrical drive train. Hybrid vehicle use bank of Li-ion battery bank. These batteries are costly but far better than lead-acid batteries but during peak loads pack is under stress. By use of supercapacitors the power at peak load is provided by

supercapacitors, such as during acceleration, while when vehicle is running at constant speed it is powered by battery pack. The switching of power as above is controlled by Electronic Power Control Unit. Supercapacitors are also used to support drive train in fuel cell or hydrogen powered vehicles.

Stop and Start System

As we all stuck in traffic jams daily or stop at traffic signals, during this we let our car "ON" which result in wastage of fuel and money both. In stop start system as soon as we stop the vehicle it automatically stops engine and as soon as we press clutch paddle to engage engine with gear box engine starts automatically. Stop start system has 5-8% saving in fuel and vehicle emission but require the engine to be started many more times over its life supercapacitors can provide larger numbers of staring.

Regenerative Energy Capture

During braking lots of energy is wasted and dissipated into the atmosphere in the form of heat but in Regenerative Braking Systems during braking it restores some part of energy dissipated during braking. It is of two types, one for hybrid vehicles and other for conventional vehicles. In hybrid vehicles motor or engine provides power to vehicle, when vehicle is powered by motor and brakes are applied motor acts as generator now rotational energy from wheel acts as mechanical input for generator and produces stopping torque, it is done by use of electronic power units by change in mode of working of motor from forward motoring to forward braking leading to recover of braking energy, but in case of sudden braking car stops by conventional braking system.

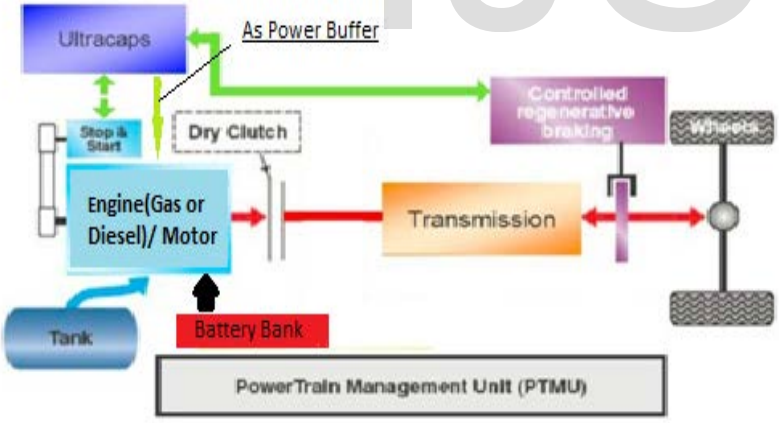


Fig. 4.1. Different Applications in vehicles

While in case of non-hybrid/conventional braking system, energy is recovered by smart alternators which produces energy when engine is running ideally and but when engine is providing power to vehicle, alternator is idle which reduces load on engine and provide better response during acceleration hence increases efficiency by 5%. The below case study will make us to understand the significance of supercapacitor.

Figure 4.1 shows all the applications of supercapacitors as mentioned in future scope.

Case Study:

This study shows how supercapacitors are used to recover braking energy

If a 1000 Kg car travelling at 50 km/hr and stopping in 10 seconds then;

Kinetic Energy of vehicle = 96.45 KJ (It is maximum amount of energy that can be recovered by regenerative braking at 100% efficiency)

Average power during braking= 9.64 Kilowatts

At 14 V charging voltage, charging current will be= 689 Amperes

This charging current is too large for a battery to accept but not for a supercapacitor. So we can conclude that without supercapacitor maximum regenerative energy is wasted.

5 Conclusion

Supercapacitors had resolved the limitations of Lead Acid Batteries and provided excellent power performance. Continuously researches are going on to increase energy density and voltage of supercapacitor. Fuel cells are only solution for long range zero emission driving, energy density of H_2 is equal to petrol but fuel cell perform poorly for rapid change in power such as acceleration, regenerative braking and also no satisfactory results are seen at low temperature. The all above problems can be easily resolved by use of supercapacitor. Supercapacitor undoubtedly has exceptional power performance with large number of charging and discharging cycles which makes it suitable for assisting battery for starting ICE and other vehicle applications.

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