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Battery packs of the fastest electromobiles

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This article discusses the problem of a power supply in modern electromobiles, using different technologies, like lithium-ion cells. Present situation in automotive industry focuses attention of the engineering community on a search for potential energy sources and supplies. Battery cells are one of the many options available. For this early stage of development they are fairy sufficient.

In one part this article discuss a battery pack design process, followed by a comparison of two of many different options currently available on the market. Final choice of the suitable battery pack depends on the required parameters of a designed electromobile.

1. Introduction – Electromobiles

Watching present events in automotive industry it is starting to be quite obvious even for an amateur how future automobiles are going to look like and even more important question is getting clear – what would their energy source be. Currently numerous car manufacturers indicate their great interest in electro-mobility by presenting their first concepts, and in some cases even finished models ready for their owners to cruise the roads. Today you could buy an electro-mobile ready for roads like well-known Tesla (Roadster) or Nisan (Leaf).

Tesla Roadster

Nisan Leaf

Fig. 1.1 Current fully driveable EVs

BMW (Active E, Mini E), Ford (Focus EV), Audi (A1 E-tron), Nisan (Townpod), Kia (Pop) and several other companies have presented their latest concepts that might cruise the city roads in near future (fig. 1-2).

Audi A1 E-tron

BMW ActiveE

Nisan Townpod

Ford Focus EV

Fig. 1.2 Current most popular EV concepts

Apart from the serially manufactured models, there is a great number of cars being converted form ICE drive-train to electric one. These conversions can be in some cases quite seriously done and worth of notice.

2. Vehicle energy demand

Imagine yourselves driving a sports car on a race track. You expect your vehicle to accelerate quickly at the beginning as well as to drive continuously at the top limits of its capabilities. For this purpose you need enough power at your disposal. What does enough power mean? The power that drives your car comes from traction propulsion represented by an electric motor in our case. The power of the electric propulsion unit comes from electro-magnetic field generated in a stator and a rotor.

This electro-magnetic field is being created by an electric current flowing through the induction coils of the rotor and stator. The electrical current can be supplied by a fuel cell, a supercapacitor, or a battery cell (pack). So the answer is: enough power for the drive means enough kW-s in the battery as well as few other parameter of the battery pack ("BP"). These important parameters of a BP are:

- capacity (Ah)
- power (kW)
- energetic capacity (kWh)
- C-rate (-)
- nominal voltage (V)
- weight (kg)

The parameters of the BP mentioned above influence directly, or indirectly dynamics of a drive and a drive range. Dynamics of a drive represent acceleration in the first place, which is delimited mostly with maximal current that can a BP supply. This maximal current is expressed by C-rate characteristic of a BP. Drive range is defined by energetic capacity (kWh) divided by a energy consumption (Wh/km). Drive range is stated in kilometers.

3. Solution: Lithium-ion battery cells

In present there are several technologies used to store or generate electrical energy. There are fuel cells (FC) generating electrical current combining oxygen and hydrogen. Then a number of battery cell technologies, and supercapacitors. A battery cell technology called lithium-ion is discussed in this article. It has its advantages as well as disadvantages over other technologies like: NiCd, NiMh, Lead Acid, etc. (see Fig.3-1)

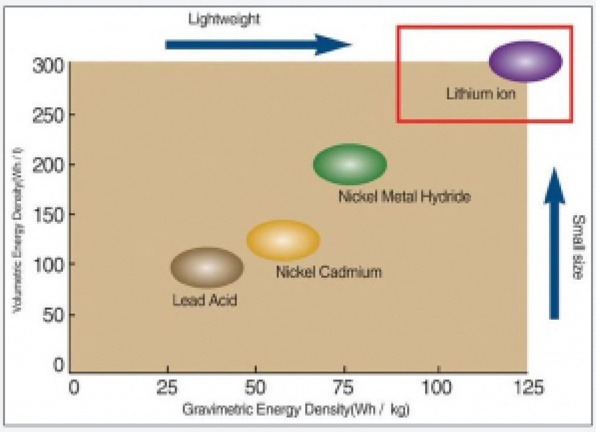

Fig. 3.1 Battery cell technologies comparison

The only relevant disadvantage of lithium-ion technology of battery cells is their price. Lithium-ion battery cells are more expensive than the NiCd or Lead Acid cells. [1]

4. Battery pack design

When designing a battery pack the first decision would be what technology to use. BP must not be composed of different technologies, like NiCd with Lithium-ion, or any other combination. The combination is not convenient because there are several great differences in these technologies, like their nominal voltage per cell. Nominal voltage for NiCd is 1.2V/cell where as for Lithium-ion nominal voltage is around 3.2V/cell (3.7). Another big difference is in their discharge characteristics. One technology discharges faster than the other, which is also referred as different “life cycle”. Based on a figure 3-1 it is most convenient to use Lithium-ion technology for BP in an electromobile. It has much higher energy density than other available technologies.

Fig. 4.1 Battery cell used in BP – model: AHR32113

There are several battery manufacturers which offer Lithium-ion battery cells of different nominal capacities, but the energy density does vary also between the manufacturers.

	Cell parameters:			
Battery details:	**AHR32113 Cylindrical Cell**			
Capacity (Ah):	**4,4**	Ah		
Maximal cur. Rate (C):	**48**	C		
Maximal voltage (V):	4	V		
Minimal voltage (V):	2,8	V		
Nominal voltage (V):	**3,3**	V		
Enegetical cap. (Wh):	14,5	Wh		
Current_max (A):	211	A		
Current_impulse (A):	0	A		
Power_max (W):	697	W		
Power_impulse (W):	0	W		
Power (W/kg):	56,3	Wh/kg	2701	W/kg
Power (W/L):	125,5	Wh/l	6023	W/l
Cell weight (kg):	**0,258**	kg		
Cell dimensions:				
Length (cm):	**11,3**	cm		
Width (cm):	**3,2**	cm		
Hight (cm):	**3,2**	cm		
Velocity (cm^3):	115,7	cm^3		
Velocity (l):	0,116	l		
Charging info:				
Voltage_max (V):	3,6	V		
Current_max (A):	10	A		
Power_max (W):	36	W		

Fig. 4.2 Detailed parameters of a cell AHR32113

One of the best battery manufacturers is a company called A123 Systems. It offers cells of capacity 1.1, 2.3, 4.4 and 20Ah. Energy density of A123 cells is one of the best, lies around 2700W/kg, and around 6000W/liter. Based on it's convenient parameters A123 4.4Ah cell (fig. 4-1, 4-2) will be used to build the battery pack. [2]

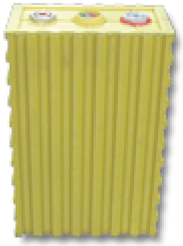

Fig. 4.3 Battery cell – model: TS-LFP90AHA

Just for comparison manufacturer ThunderSky offers cells of capacities 40, 60, 90, 100, 120, ..., 700 Ah (fig. 4-3) and their energy density is poor, only around 275W/kg and 400W/liter. (fig. 4-4) [3]

	Cell characteristics		
Battery details:	**TS-LFP90AHA**		
Capacity (Ah):	**90**	Ah	
Maximal cur. Rate (C):	**3**	C	
Maximal voltage (V):	4	V	
Minimal voltage (V):	2,8	V	
Nominal voltage (V):	**3,2**	V	
Enegetical cap. (Wh):	288,0	Wh	
Current_max (A):	270	A	
Current_impulse (A):	0	A	
Power_max (W):	864	W	
Power_impulse (W):	0	W	
Power (W/kg):	96,0	Wh/kg	288 W/kg
Power (W/L):	132,8	Wh/l	398 W/l
Cell weight (kg):	**3**	kg	
Cell dimensions:			
Length (cm):	**14,5**	cm	
Width (cm):	**6,8**	cm	
Hight (cm):	**22**	cm	
Velocity (cm^3):	2169,2	cm^3	
Velocity (l):	2,169	l	
Charging info:			
Voltage_max (V):	4	V	
Current_max (A):	30	A	
Power_max (W):	120	W	

Fig. 4.4 Parameters of a cell TS-LFP90AHA

4.1 “A123 Systems” battery pack

Further selection process is based on required parameters set by chosen electromotor (its inverter), optionally by a DC/DC converter – nominal voltage of the BP, and finally by required drive range and dynamics – energetic capacity of the BP and maximal discharge current.

Tab. 4.1 EVO 240 specifications

MOTOR	
Dimensions	L 222 D 400 mm
Maximal peak torque	800 Nm
Maximal peak power	335 kW
Maximal nominal torque	440 Nm
Maximal nominal power	150 kW
Maximal RPMs	5000 ot/min
Weight	80 kg
Maximal efficiency	96,5%
INVERTOR	
Dimensions	643x340x166 mm
Voltage range	300-720 V
Maximal current	343 A
Weight	30 kg

Fig. 4.5 Image of EVO 240 electric motor

EVO AFM-240 (fig. 4-5) had been chosen for the traction propulsion with following parameters (see table 4-1) [4] According to chosen motor and inverter a need of a DC/DC converter is obvious from operating voltage range of the inverter: 300-720V. Battery pack will be designed for a nominal voltage of 400V. A 150kW DC/DC converter will throw this static voltage of the BP into the range of inverter’s 300-720V. By choosing the propulsion system the following parameter of the BP are set (fig. 4-6):

- nominal voltage: 400V
- number of cells in series: 121

To gain required acceleration motor will demand a great portion of electrical current (up to 1000A) from the power supply. This means the BP must be designed to be able to deliver this portion of power when demanded. Parameter called “C-rate” gives the information about the battery cell maximal discharge current (eq. 4-1).

$$I_{MAX} = Nominal\,capacity(Ah) * C - rate(-) \quad (4\text{-}1)$$

Maximal discharge current for the whole BP is then calculated using the eq. 4-2:

$$I_{MAX} = Nom.\,cap.(Ah) * C - rate(-) * \#of\,parallel \quad (4\text{-}2)$$

Driving rage is calculated dividing en. capacity (Wh) of the BP with energy demand (Wh/km):

$$D - range = En.\,cap.(Wh)/En.\,demand(Wh/km) \quad (4\text{-}3)$$

This implies next parameters of the BP (fig. 4-6):

- number of cells in parallel: 12
- max. discharge current: 2534A
- power: 1012kW
- available en. capacity: 17kWh
- driving range: 80km

Since the whole number of cells is now known the rest of the BP's parameters are (fig. 4-6):

- weight: 375kg
- volume: 168liters
- price: 20400€

Battery pack calculator		
No. of bat. in series:	**121**	
No. of bat. in parallel:	**12**	
Cost per cell (€):	**14,00**	€
En. demand (Wh/km):	**212**	Wh/km
Pack voltage_max (V):	484	V
Pack voltage_min (V):	338,8	V
Pack voltage_nominal:	399,3	V
Pack current_max (A):	2534,4	A
Pack current_impulse:	0	A
Pack power_max (kW):	1012	kW
Pack power_impulse:	0,0	kW
Pack en. cap. 100% SOC:	21,1	kWh
Pack en. cap. 80% SOC:	16,9	kWh
Pack dimensions:		
Range (km):	79,6	km
Pack weight (kg):	374,6	kg
Pack volume (l):	168,0	l
Pack cost (€):	20328,00	€
Pack charging info:		
Voltage_max (V):	435,6	V
Current_max (A):	120	A
Power_max (kW):	52,3	kW

Fig. 4.6 A123 Systems battery pack calclations

4.2 "ThunderSky" battery pack

For battery pack comparison ThunderSky cell TS LFP90AHA was chosen. Battery pack was also designed to meet the required parameters set by the chosen propulsion system and required drive characteristics. Required parameters are the same as with A123 systems BP:

- nominal voltage: 400V
- max. discharge current: >700A
- driving range: >80km
- BP power: >300kW

BP was designed using the same equations as in the case of A123 Systems BP – detailed overview of the ThunderSky BP is displayed on a figure below.

Battery pack calculator		
No. of bat. in series:	**125**	
No. of bat. in parallel:	**3**	
Cost per cell (€):	**79,09 €**	$ 117,00
En. demand (Wh/km):	**212**	Wh/km
Pack voltage_max (V):	500	V
Pack voltage_min (V):	350	V
Pack voltage_nominal:	400	V
Pack current_max (A):	810	A
Pack current_impulse:	0	A
Pack power_max (kW):	324,0	kW
Pack power_impulse:	0,0	kW
Pack en. cap. 100% SOC:	108,0	kWh
Pack en. cap. 80% SOC:	86,4	kWh
Pack dimensions:		
Range (km):	407,5	km
Pack weight (kg):	1125,0	kg
Pack volume (l):	813,5	l
Pack cost (€):	29657,29	€
Pack charging info:		
Voltage_max (V):	500	V
Current_max (A):	90	A
Power_max (kW):	45,0	kW

Fig. 4.7 ThunderSky battery pack detailed overview

5. Conclusion

When compared side by side these two BPs, there are several great differences noticeable (fig. 4-6, 4-7, 5-1 and 5-2):

- driving range: 80km || 407km
- total BP weight: 375kg || 1125kg

- total BP volume: 168liters || 814litres
- BP cost: 20 400€ || 30 000€

PACK CHARACTERISTICS:	53 Ah
Cells type:	*AHR32113 Cylindrical Cell*
Number of cells:	1452 cells
Nominal voltage:	399 V
Maximal current:	2534 A
Available en. capacity:	16,9 kWh
Weight:	375 kg
Range:	80 km
Prise:	20328 €

Fig. 5.1 A brief overview of the A123 BP

PACK CHARACTERISTICS:	270 Ah
Cells type:	*TS-LFP90AHA*
Number of cells:	375 cells
Nominal voltage:	400,0 V
Maximal current:	810 A
Available en. capacity:	86,4 kWh
Weight:	1125 kg
Range:	408 km
Prise:	29657 €

Fig. 5.2 A brief overview of the ThunderSky BP

These differences are caused by different manufacturing technologies used in these two types of battery cells. As was mentioned earlier although both cells are Lithium-ion type, but A123 system uses more advanced technologies described as "Nanophosphate®" lithium ion battery technology" [5]

From presented comparison it is clear that BP build from battery cells offered by A123 Systems have better performance characteristics in many points of view. These advantages make the A123 battery pack more suitable for application in extra fast electromobiles. ThunderSky BP might also be suitable for an electromobile but only when the driving range is the criteria, not the vehicle acceleration.

6. Links and literature

1. Features of lithium-ion batteries – overview:
   http://www.compactpower.com/lithium.shtml
2. A123 Systems products overview:
   http://www.a123systems.com/products-cell-32113-cylindrical-cell.htm
3. Thunder Sky products overview:
   http://www.thunder-sky.com/products_en.asp
4. Electromotor EVO AFM-240 description page:
   http://www.evo-electric.com/products/electric-motors/
5. A123 Systems core technology description
   http://www.a123systems.com/technology-core.htm

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