OPPORTUNITIES COMING BY USING AUTOMOTIVE COMPONENTS IN L CATEGORY EVS (LEVS)

SOLUTIONPLUS POLICY PAPER

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PICTURES

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EXECUTIVE SUMMARY

The wide diffusion of the Battery Electric Vehicles (BEVs) largely depends on one hand on their purchasing price and operational costs (Total Costs of Ownership - TCO) and on the other hand on their safety & reliability levels.

In the area of the LEVs (Light Electric Vehicles), the today limited production volumes have a double negative effect on their e-powertrain components: the prices are high and in general the reliability is poor (not in line with the automotive standards).

Aim of this technical policy paper is to investigate if and how take advantage of the automotive passenger cars and vans (Light Duty Vehicles - LDVs) e-powertrain components in LEV applications (e-components shareability).

At the beginning, in order to identify the possible opportunities and synergies, it is presented an overall picture of the hybridised LDVs based on the typologies, the voltage classes, the grid connection (where present) and the e-powertrain components size
The e-components shareability investigation is performed in two different scenarios:

- as new components (fitting the electromechanical and electronics components)
- as second life of automotive components (fitting as first the electrochemical components)
- The opportunities are presented splitting the e-powertrain components in four groups:
- e-motors/inverters
- DC/DC converters
- on-board chargers
- batteries

At the end, the conclusions with some recommendations are presented. In particular:

- for e-motors/inverters and DC/DC converters groups, in the case of urban LEVs (mechanical power not higher than 15 kW), there is a really promising opportunity to use components and architectures designed for LDV mild hybrids whose power levels match the LEV needs and whose voltage (class A with max DC voltage not higher than 60 V) makes possible to manage the e-safety in a simple, cheap and effective way
- for on-board chargers, the synergies today can be identified using LDV BEV and P-HEV chargers only for voltage B class (with DC voltage higher than 60 V and lower than 1500 V) extended range LEVs (mechanical power higher than 15 kW). Differently, for voltage A class LEVs this opportunity will be possible only if, in future, LDV P-HEV at 48 V are put in production
- for batteries, there is a potential opportunity to use on LEVs (as second life) cells and modules coming from LDV BEVs and P-HEVs (Plug-in HEVs)

1 BACKGROUND

1.1 E-MOBILITY IN THE DIFFERENT GEOGRAPHICAL AREAS

Battery Electric Vehicles (BEVs) are today available on the market in lots of geographical areas (in particular, in European, North American and Far East countries) with a large offer of solutions. At the same time, their high-volume introduction in these markets and their wider availabilities in other geographical areas (as for instance in Africa, South America and many Asian countries) is still to come and their diffusion is not fast as expected/announced.

In the first group of geographical areas, there are is multiple policy supports in place for e-mobility, with increasing specific standards and regulatory frameworks (at national and in Europe at least also at continent level). In the standards area, often they are the basis for the global standardization activities (for instance at ISO [(International Standardization Organization]) and IEC [(International Electrotechnical Commission) level).

1.2 BARRIERS AND OPPORTUNITIES

With specific reference to the urban and suburban mobility, LEVs (Light Electric Vehicles) are a key element for the realization of a balanced and effective e-mobility model.
A large LEVs diffusion largely depends on their price and reliability. The usage of e-powertrain components developed as first for hybridized LDVs (Light Duty Vehicles) can be an important opportunity to reach this goal being already designed for high volumes and severe reliability/safety targets.

2 APPROACH

The aAim of this technical policy paper is to investigate the opportunities coming by using automotive e-powertrain components in L Category EVs (LEVs - Light Electric Vehicles) and in particular in the bigger sizes part of them, being the L Category family organized as follow (with power limitations where to be considered as shown)[1]:

- vehicles with 2 wheels:
    - light two-wheel powered vehicles (L1e) with maximum continuous rated or net power ≤ 4 kW
    - motorcycles (L3e):
    - for the Low-performance motorcycle (L3e-A1) with maximum continuous rated or net power ≤ 11 kW and with power/weight ratio ≤ 0,1 kW/kg
    - for the Medium-performance motorcycle (L3e-A2) with maximum continuous rated or net power ≤ 35 kW and with power/weight ratio ≤ 0,2 kW/kg

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[1] European Regulation ECE R168 Annex I

- vehicles with 3 wheels:
  - moped (L2e) with maximum continuous rated or net power ≤ 4 kW
  - two-wheel motorcycle with side-car (L4e) with maximum continuous rated or net power ≤ 4 kW
  - three-wheelers (L5e)

- vehicles with 4 wheels:
  - light quadricycles (L6e):
  - for the Light on-road quad (L6e-A) with maximum continuous rated or net power ≤ 4 kW
  - for the Light quadri-mobile (L6-B) with maximum continuous rated or net power ≤ 6 kW
  - heavy quadricycles (L7e): for the Heavy on-road quad (L7e-A) and the Heavy quadri-mobile (L7-C) with maximum continuous rated or net power ≤ 15 kW

The investigation is performed starting from a high-level picture of the hybridized LDVs to identify the-powertrain components of potential interest for/applicability to LEVs.
The e-powertrain components level sharing opportunities are referred to new and in some cases second life components and is looking at: e-motors/inverters, DC/DC converters, batteries and On-Board Chargers (OBC).

3 MAIN CONTENT

Starting from the analysis of the Voice of the Customer (VoC) investigations, the EVs purchasing price combined with the extra-costs payback time is one of the first reasons for the customers not to move from standard ICE- based Vehicles (ICEVs) to BEVs. The pay-back time is in general considered too long, and also difficult to be correctly predicted due to the large impact on the Total Costs of Ownership (TCO), and, in particular on the operational costs part, of the charging costs (directly related to the electricity prices and their fluctuation).

In respect of the purchasing price:

- also the request of a larger range (one of the other barriers to a wide and quick EVs market introduction) is addressed through bigger size batteries and/or higher technology/class of the battery cells, as a consequence, negatively impacting on the vehicle price
- for passenger cars and vans (Light Duty Vehicles - LDVs), the vehicle purchasing price element is increasingly relevant moving from the bigger to the smaller segments and coherently become also more important moving from M and N to L category EVs (LEVs (Light Electric Vehicles)

In this view, the e-powertrain components play a key role being a relevant part of the EV costs. Moreover, their behavior largely impacts on the vehicle reliability and the makers/users/operators safety.

For all these reasons, the opportunity to share the e-powertrain components designed, developed and manufactured for hybridized LDVs also in LEVs would be really interesting being them already produced in high volumes (helping their cost reduction) and with high quality standards/effective applicability also in severe environmental conditions.

The investigation will be done with a particular attention to the usability on the L-category vehicles designed for urban and suburban operation (key element of the future e-mobility model) and considering particularly the ones with voltages in Class A (maximum DC voltage not higher than 60 Vdc) solving in this way the electric shock risk at the root.

3.1 CONCEPTS CATEGORIZATION

As first step of this investigation, the M/N category hybridized vehicles are grouped on the basis of:

- their hybridisation typology
- the voltage classes
- the grid connection (where present)
- the e-powertrain components power size

LDVs hybridized solutions can be classified on the basis of the e-powertrain architecture:

- Simple hybrids (made of two elementary taction systems. One ICE based and one e-motor based):
  - › Parallel Hybrids (the two elementary traction systems are mechanically connected)
  - › Series Hybrids (the two elementary traction systems are electrically connected)

- Complex hybrids (made of three elementary taction systems. One ICE based and two e-motor based):
  - › Compound Hybrids (the series and parallel modes can used one a time)
  - › Split Hybrids (the series and parallel modes can used also in combined way)

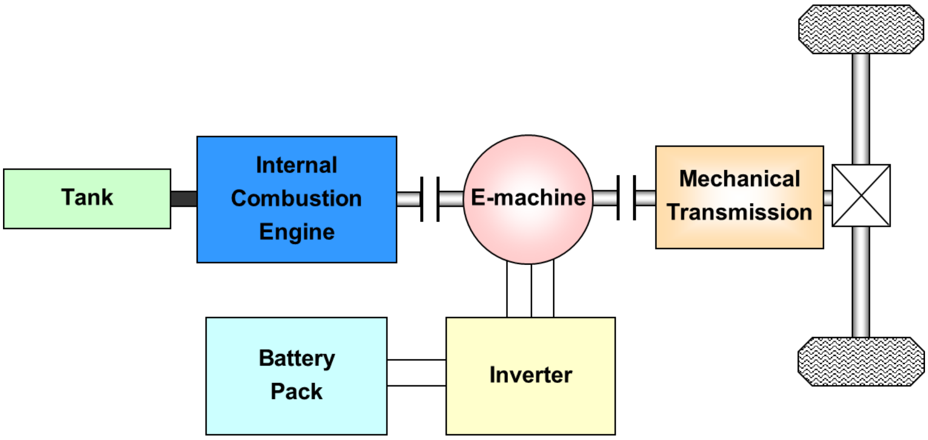


Figure 1 – Example of Simple Parallel Hybrid

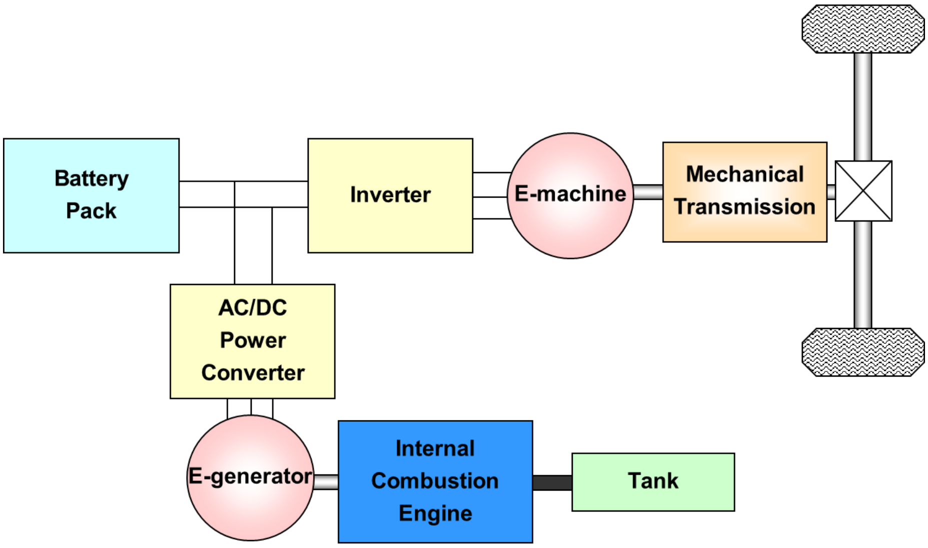


Figure 2 - Example of Simple Series Hybrid

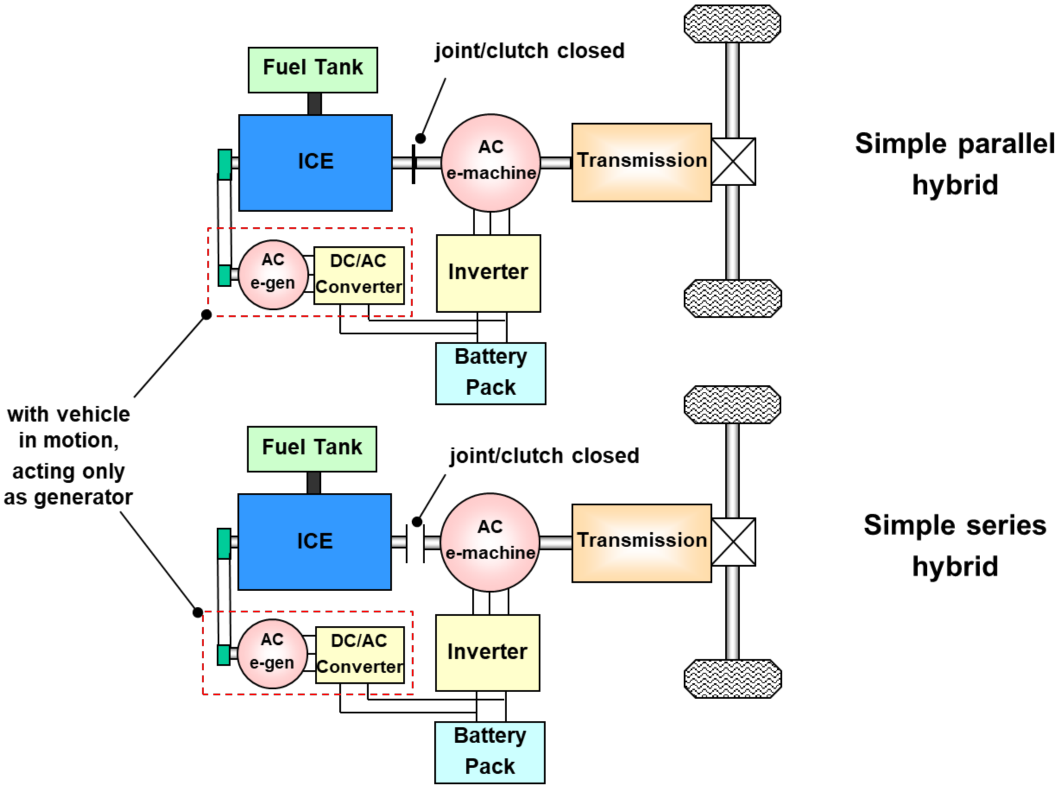


Figure 3 - Example of Complex Series-Parallel Compound Hybrid

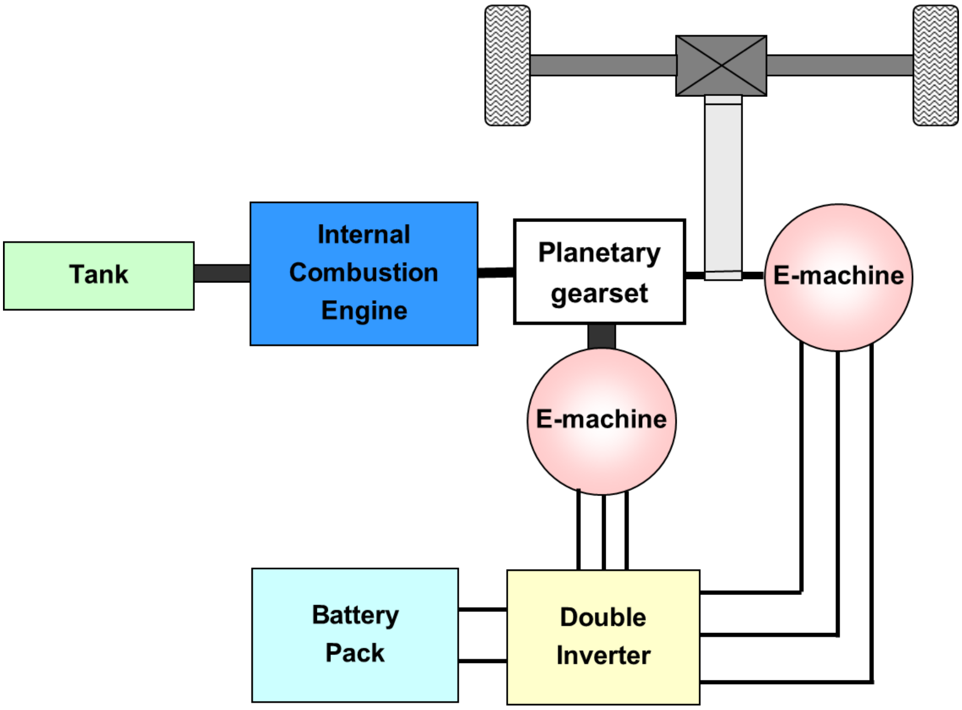


Figure 4 - Example of Complex Series-Parallel Split Hybrid

All the previously listed architectures can be used both in HEVs and P-HEVs.
HEVs have no OBC (On-Board Charger), while in general all the P-HEVs have a single only or a single + 3 phase OBC whose power is usually between 3 kW and 11 kW (single phase) and up to 22 kW (3 phase).

Another way to classify the hybrids relies on the position of the e-machine in respect of the ICE and goes under the name of P-method:

- **P1**: e-machine always turning with the ICE. E-machine positioned:
  - in place of the alternator: **P1f** (f = front side of the engine if in longitudinal layout) with a reduction-multiplying ratio (pulleys and belt coupling)
  - in place of the flywheel (that becomes the e-machine rotor): **P1r** (r = rear side of the engine if in longitudinal layout) in general with a direct 1:1 speed ratio

  Someone refers to P1f as P0 and to P1r as P1 only
- **P2**: functional extension of P1r thanks to an added second clutch on the e-motor ICE-side (in this case the engine needs anyway a passive flywheel even if smaller than the one of an ICEV application)
- **P3**: e-machine connected to the shaft that in the ICE longitudinal layout is linking the mechanical transmission with the rear differential unit (where in some Commercial Vehicle is positioned the retarder unit).
  Solution not applied in layouts with transversal engine being in this case the transmission and the differential usually realized in one single unit
- **P4**: e-machine on the ”other axle” (other in respect of the one propelled by the ICE). Its integration in the vehicle is really challenging in the ICE longitudinal layout being the “other” axle the front one and having the engine positioned under the hood

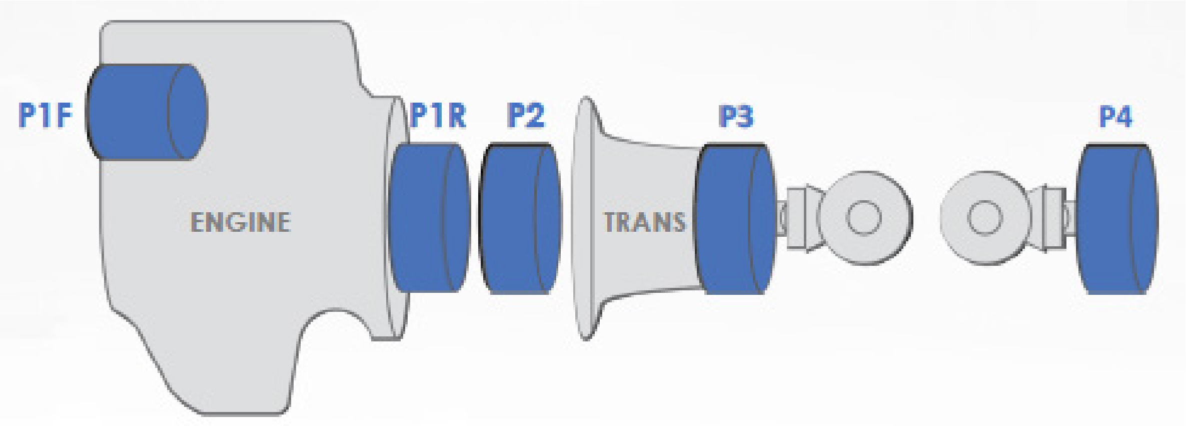


Figure 5 – P-Method

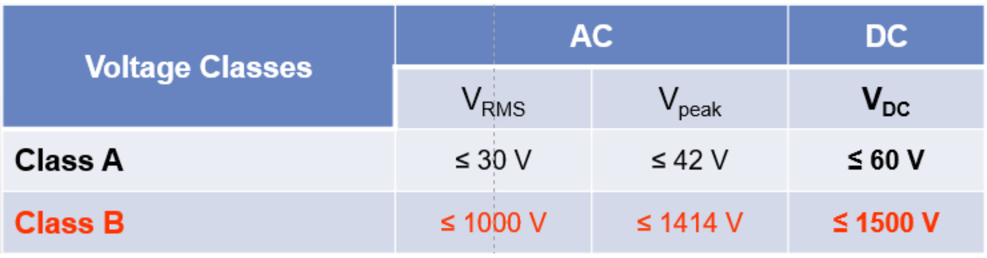
Finally, considering the user perspective, hybrids can be classified on the basis of their power/voltages as follow:

- **Mini HEVs (mini hybrids):**
  12V solution in general with one BSG (Belt driven Starter Generator) and two 12V batteries (one lead and one lithium) directly or indirectly connected.
  Max e-Power levels: few kW
- **Mild HEVs (mild hybrids):**
  48V solution in general with one e-machine (in P1f, P1r or P2 position) with one 48V lithium-based battery and one 48-12V DC/DC converter.
  Max e-Power levels: some kW up to around 15 kW
- **Full HEVs (full hybrids):**
  HV solution (in general hundreds of volts) with one (or two) e-machines (with different possible positions) with one HV power sized battery and one galvanically insulated HV-12V DC/DC converter.
  Max e-Power levels: from lot of tens up to some hundreds of kW
- **P-HEVs (plug-in hybrids):**
  at least nowadays it is a HV full HEV with a HV battery with an available energy enabling a pure EV range of at least some tens of km (with an increasing trend) and an on-board battery charger

3.2 E-COMPONENTS SHAREABILITY LEVEL

In terms of voltage classes, in the automotive field, there are two voltage classes:

- Class A: for DC maximum voltages up to 60 V (in AC: 30 Vrms / 42 Vpeak)
- Class B: for DC maximum voltages higher than 60 V and not higher than 1500 V (in AC: 1000 Vrms / 1414 Vpeak)



Voltage Classes	AC		DC
	V_{RMS}	V_{peak}	V_{DC}
Class A	≤ 30 V	≤ 42 V	**≤ 60 V**
Class B	≤ 1000 V	≤ 1414 V	**≤ 1500 V**

Table 1: Voltage Classes A and B and related AC and DC limit values

Voltage Class A is also called “Low Voltage” (LV) and Voltage Class B “High Voltage” (HV). As anticipated in the previous paragraph, for vehicles with “Voltage Class A only” electric circuits, there is no risk of electric shock (in case of contact with the two voltage potentials, the current flowing in the body is not dangerous for the human being).

Differently for vehicles with also “Voltage Class B” circuits (in automotive hundreds of volts), to protect against the electric shock, the HV circuit has to be insulated (both poles) in respect of the vehicle chassis with shielding/mechanical barriers and multiple protection and monitor strategies and systems have to be implemented.

Considering the user perspective hybrid classification presented in the previous paragraph, here below the voltage classes scenario:

- **Mini hybrids:** Voltage Class A only (12+12V) both for the power net and the signal one
- **Mild hybrids:** Voltage Class A only (48+12V) with 48V for the power net and 12V for the signal one
- **Full hybrids:** Voltage Class B (hundreds of volts) and Voltage Class A (12V) with hundreds of volts for the power net and 12V for the signal one
- **Plug-in hybrids:** Voltage Class B (hundreds of volts) and Voltage Class A (12V) with hundreds of volts for the power net and 12V for the signal one

In the following table, the power net part of the previously descripted picture is summarized in a graphical form:

	LV (CLASS A)		HV (CLASS B)
	12V	48V	hundreds of V
Mini hybrids	X		
Mild hybrids		X	
Full hybrids			X
Plug-in hybrids			X

Table 2: Hybrids and their Voltage Classes

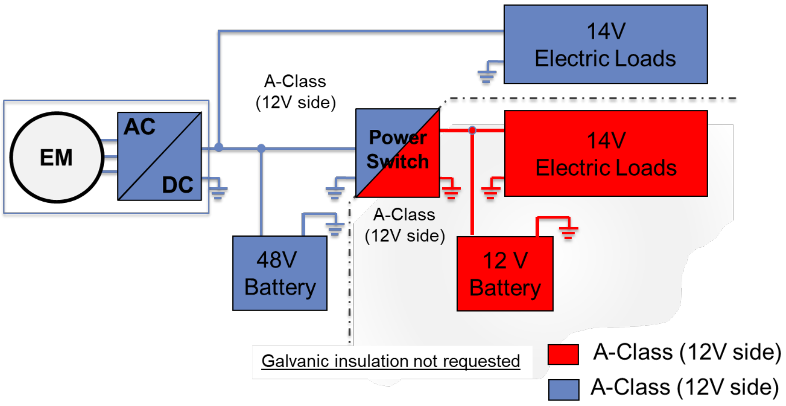


Figure 6 – Mini HEVs electrical architecture

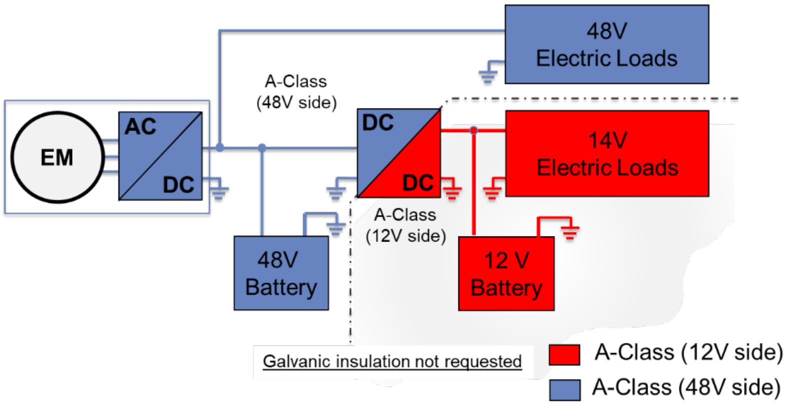


Figure 7 – Mild HEVs electrical architecture

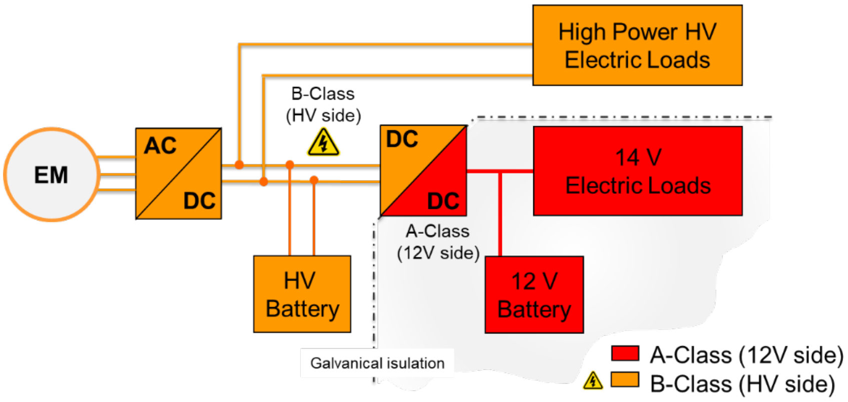


Figure 8 – Full HEVs electrical architecture

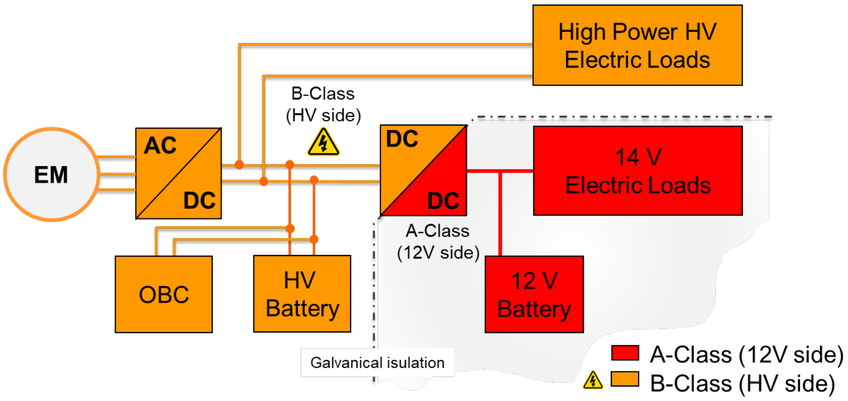


Figure 9 – Eexample of P-HEVs electrical architecture based on a simple HEV typology

The e-components shareability and usage in L-category vehicles can be investigated in terms of voltage class of the components as follow:

- **LV 48Vdc** (Low Voltage Class B) for traction solutions with mechanical power also at low SoC (State of Charge) today: up to around 15 kW (and in the future, according to the expected evolution trends from up to 20 kW (in the coming years) up to around 30 kW (in the long term)
- **HV typically 400 or 800Vdc** (High Voltage Class B) for traction solutions with mechanical power also at low SoC (State of Charge) from some tens to different hundreds of kW

Looking at the LEVs for urban use (in case with also some suburban applicability), the 48V e-powertrain components (the ones typically developed and used in mild hybrid LDVs) seem the most promising, being their maximum power levels in line with these LEVs needs (see paragraph 2) and their cost lower in respect of the HV e-powertrain components (also in terms of electric vehicle architecture). In particular:

- **2W vehicles:**
    - L1e (light two-wheel powered vehicles): power ≤ 4 kW
    - L3e-A1 (low-performance two wheel motorcycles): power ≤ 11 kW
    - L3e-A2 (medium-performance two wheel motorcycles): power >11 kW (only if ≤ 15 kW)
- **3W vehicles:**
    - L2e (moped): power ≤ 4 kW
    - L4e-A1 (low-performance two wheel motorcycles + sidecar): power ≤ 4 kW
    - L4e-A2 (medium-performance two wheel motorcycles + sidecar): power >11 kW (only if ≤ 15 kW)
    - L5e (powered tricycle): power > 4kW (only the ones with power ≤ 15 kW)
- **4W vehicles:**
    - L6e (light):
    - L6e-A (on-road quad): power ≤ 4 kW
    - L6e-B (quadri-mobile): power ≤ 6 kW
    - L7e (heavy):
    - L7e-A (on-road quad): power ≤ 15 kW
    - L7e-C (quadri-mobile): power ≤ 15 kW

For all the other L-category vehicles with higher mechanical power:

- 2W vehicles:
    - L3e-A2 (medium-performance two wheel motorcycles): when power >15 kW and ≤ 35 kW
    - L3e-A3 (high-performance two wheel motorcycles): power > 35 kW
- 3W vehicles:
    - L4e-A2 (medium-performance two wheel motorcycles + sidecar): when power >11 kW and ≤ 35 kW
    - L4e-A3 (high-performance two wheel motorcycles + sidecar): power > 35 kW
    - L5e (powered tricycle): the ones with power > 15 kW
- 4W vehicles:
    - L7e-B (heavy all terrain quad): power > 15 kW

the Class B e-powertrain components are needed. The synergies can be found with the LDV full HEV and P-HEV e-powertrain components.

In both cases (Voltage Class A and B e-powertrain components), the sharing can be considered in two different scenarios:

- as new components
- as second life of components with a first life on passenger cars or vans

The first case can be applied to all the different e-powertrain components, while the second one has a particular reason to be considered for the batteries (being the LDV batteries potentially replaced when still with a relevant available energy (SoH around 70% and in some cases also more)).

Moreover, being the battery packs made of many battery cells series (and sometimes) also parallel connected, the synergies can be evaluated both considering the first life battery pack as it is, as a modified version (for instance with a different, usually simplified thermal management) or also at cell level only (disassembling the cells from the first life LDV application and recombining them for the L-category vehicles). In this last case, also battery used during their first life in LDV BEVs can be considered.

3.3 OPPORTUNITIES FOR E-POWERTRAIN COMPONENTS

For the synergy's investigation purpose, the e-powertrain components can be split in four categories:

- e-Motors and Inverters (traction electric drives)
- DC/DC Converters
- On-board Battery Chargers (OBC)
- Batteries

As already explained in the previous subparagraphs, for the L-category electric vehicles to be used in urban environment (included some extra-urban missions), being a mechanical power up to around 15 kW fitting the needs, the LDVs @48V (mild hybrids) are the most convenient and promising area to be considered. For all the other ones for extended usage (mechanical power also largely higher than 15 kW), at least today the LDVs @hundreds of volts (full hybrids and plug-in hybrids) are the only possible area to be considered.

Here below the overall picture:

L-CATEGORY E-VEHICLES FOR:	**URBAN USAGE**	**EXTENDED USAGE**	
LDVs hybridisation typology:	Mild HEVs (48V)	Full Hybrids (hundreds of V)	P-HEVs (hundreds of V)
e-Motors and Inverters	X	X	X
DC/DC converters	X	X	wX
On- Board Chargers			X
Batteries	(X)	(X)	X

Table 3: E-PWT components vs. hybrid typologies

For the e-motor and Inverters, the ones of the LDV P1f and P4 hybrids are the first to be considered being "add-on native" (lower/no integration with the Internal Combustion Engine). Therefore, they are simpler to be used in the L-category electric vehicles.

The integrated e-motor/inverter solutions are lighter and with minor EMC/EMI problems in respect of the ones with standalone inverter but can create higher installation geometrical constraints.

The LDV e-motor/inverter are in general liquid cooled. In their usage in L-category electric vehicles to be verified if it is needed too or not (depending as first on the needed peak transient/continuous power and the selected e-motor & inverter size).

For the **DC/DC converters**, the different possible options have to be taken into account:

- the 48V-12V Mild HEV ones are in general standalone or in few cases integrated in the battery housing
- the HV-12V Full HEV ones are in general standalone or in few cases integrated in the inverter housing
- the HV-12V P-HEV ones can be case by case or standalone or integrated with the OBC

For the usage in the L-category e-vehicles, the LDV standalone solutions are in general more flexible.

All the HV solutions have inside a transformer to realize the HV-12V galvanic insulation. The LDV DC/DC converters are in general liquid cooled. In their usage in L-category electric vehicles to be verified if it is needed too or not (depending on the max power to be transferred and the selected DC/DC converter size).

For the **On-Board Chargers** (OBCs), the synergies can come only from the LDV P-HEVs. Having them e-powertrain components in Voltage Class B (in general 400-800 V), today no synergy can be realized for 48V applications (LEVs for urban usage).

In the Voltage Class B LDV solutions, the OBCs can be case by case or standalone or integrated with the HV-12V DC/DC converter.

All the LDV OBCs have inside a transformer to realize the insulation with the grid during charging.

The OBCs are in general liquid cooled. In their usage in L-category electric vehicles to be verified if it is needed too or not (depending on the requested charging power and the selected LDV OBC size).

For the **Batteries**, to use the LDV solutions as they are, the synergies with the L-category electric vehicles must be investigated at battery pack level. Considering the really poor installed energy of the mild HEVs (hundreds of Wh) and the Full HEVs (one-two kWh), the only ones of real applicability are those using the LDV PHEV battery packs (at least 10 kWh and more) that are fitting the extended usage higher power L-category electric vehicles being these battery packs in Voltage Class B.

On the contrary, moving to the cells level, it is possible to envisage important opportunities both for the use of new cells developed for LDVs (with in general high quality and costs that can take advantage of large production volumes) and for the use of second life cells coming from the first life in LDV P-HEVs and also BEVs. This second option asks for specific skills in the correct and safe disassembly of the donor battery pack and the repurposing of its the modules/individual cells without damaging them.

4 POLICY RECOMMENDATIONS

The aim of this policy section is to provide strategic recommendations to facilitate the adoption and integration of automotive e-powertrain components in LEVs. These recommendations are designed to address the technical, economic, and regulatory challenges identified, and to promote a more efficient, cost-effective, and reliable deployment of L category EVs.

For financial and investment policies, targeted subsidies and financial incentives specifically for manufacturers who integrate automotive e-powertrain components into LEVs could be explored. Funds to support the initial higher costs associated with integrating advanced components could be allocated by the government. This can be achieved through tax breaks, grants, or rebates. Ensuring these incentives are accessible and well-publicized will help overcome barriers related to the high upfront costs. Local production of LEVs using automotive e-powertrain components could be further explored through investment in local manufacturing facilities and supply chains where feasible.

When it comes to research and development (R&D), grants could be granted to academic and research institutions and smaller private enterprises focusing on the adaptation and integration of automotive e-powertrain components for use in various L category LEVs, focusing on cost reduction and reliability improvements. In such cases, clear criteria for grant eligibility and ensuring that funds are directed towards projects that demonstrate potential for scalability and impact should be established. Moreover, collaboration among academic and research institutions, automotive industry leaders and smaller LEV manufacturers should be encouraged to share knowledge and resources.

Policies promoting the use of second-life e-powertrain components from LDVs in LEVs, ensuring these components meet reliability and safety standards, could be investigated and developed. To address the possible gap in implementation, certification programs to verify the quality and safety of second-life components could be created.

Local standards with international regulations (e.g., ISO, IEC) for e-powertrain components used in LEVs should continue to be aligned to ensure compatibility and interoperability. Standardization efforts should involve stakeholders from government, industry, research institutions, and consumer groups to create comprehensive and practical standards.

By implementing these policy recommendations, governments can effectively support the integration of automotive e-powertrain components into LEVs. This will drive down costs, improve reliability, and accelerate the transition towards sustainable urban and suburban mobility solutions. Tailoring these policies to local contexts will ensure their feasibility and maximize their impact.

5 CONCLUSION

- For the L category electric vehicles with mechanical power up to around 15 kW, the choice of a battery voltage in Voltage Class A (not more than 60 Vdc), makes the systems intrinsically “electric shock risk free” and simpler/cheaper
- For the L category electric vehicles with mechanical power higher than 15 kW, the battery voltage has to be, at least today, in Voltage Class B (more than 60 Vdc)
- The usage of LDVs (Light Duty Vehicles) e-powertrain components in LEVs of L-category can be evaluated accordingly
- For e-motors/ inverters and DC/DC converters:
  - › from 48V Mild HEV for L category electric vehicles with mechanical power up to around 15 kW
  - › from HV Full HEVs and P-HEVs for L-category electric vehicles with mechanical power higher than 15 kW
- For on-board chargers, the synergies today can be identified using LDV P-HEV (and BEV) chargers that are realized in Voltage Class B fitting only L-category electric vehicles with mechanical power higher than 15 kW.
- For the L-category electric vehicles with mechanical power not higher than 15 kW, the synergy will be possible only if in future LDV P-HEV at 48 V are put in production
- For batteries, there is a potential opportunity to use P-HEVs battery packs that are realized in Voltage Class B fitting L-category electric vehicles with mechanical power higher than 15 kW.

  Moving at cells/modules level, there are opportunities for all the L-category electric vehicles considering both new and second life cells/modules respectively developed for and used in LDV P-HEVs (and also BEVs)

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- Part 2: Vehicle operational safety
- Part 3: Electrical safety (ref. IEC)
- Part 3 Amendment 1: Withstand voltage test for electric power sources
- Part 4: Post crash electrical safety

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- Part 1: On-board rechargeable energy storage system (RESS)
- Part 2: Vehicle operational safety
- Part 3: Electrical safety

ISO 18243: Electrically propelled mopeds and motorcycles - Test specifications and safety requirements for lithium-ion battery systems
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- **ECE R100**: Uniform provisions concerning the approval of vehicles with regard to specific requirements for the electric power train
- **ECE R136**: Uniform provisions concerning the approval of vehicles of category L with regard to specific requirements for the electric power train

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