Safety
of electric batteries
in electric / hybrid vehicles
in the vehicle industry
Foreword

The interest in electric and hybrid vehicles has increased considerably in recent years and that trend will undoubtedly continue in the coming years. The Agoria member companies from the automotive industry are coordinating their activities more and more on the ‘green’ mobility of tomorrow or are preparing themselves for it. However, that is going to require a lot of organizational changes.

In particular, the safety aspects that have to be taken into account in the production of electric and hybrid vehicles are fundamentally different from those of conventional vehicles. This applies not only to factors that have an impact on the development of new vehicles but also for the storage of High Voltage Batteries (HV-batteries) for electric and hybrid vehicles, along with the assembly and the handling and storage of finished vehicles.

This instruction manual brings you the necessary basic knowledge about working safely with/on HV batteries for electric and hybrid vehicles and related components. These are the topics that are covered:

• General guidelines, as well as risk analyses for the various production steps in the assembly of electrical and hybrid vehicles.
• Specific safety requirements (risk analyses) with the delivery and storage of HV-batteries, the processing thereof in production, any repair activities (including a flowchart of the ‘ideal’ operating procedure), the internal transport of the final assembly to the collection point for shipment…
• The training requirements for the employees involved.

This manual and the accompanying risk analyses are intended for anyone working on the development or production of electric or hybrid vehicles: members of engineering departments, production managers, training managers...

The text should be supplemented here and there by the automobile manufacturers themselves because some features as well as safety and training aspects may differ depending on the type of vehicle and HV battery.

The manual and risk analyses were prepared by an Agoria working group of experts and prevention advisors, including from some major automotive manufacturers. The conclusions of this working group together with these documents are made available by Agoria to all its members of the vehicle industry.

You may obviously adapt the interpretation thereof to the specific situation in your company. Moreover, it is clear that if you are considering the introduction of HV batteries - a technology that is only at the beginning of a long evolution - the input of the battery producer is an essential supplementation.

Agoria will constantly keep the manual up-to-date and also regularly add other experiences from the sector.

Geert De Prez
November 2012
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2. INTRODUCTION

2.1. General

The short, but brutal Arab-Israeli war of October 1973 led to the first energy crisis in Europe. The car-free Sundays made our reliance on petroleum very tangible. From 1946 to 2011, the price of crude oil (in US dollars) increased by 370.78% (adjusted for inflation). In 2012, petroleum, gas and coal provide more than 80% of the entire world's energy needs. However, the reserves of fossil fuels are not inexhaustible. The IEA (International Energy Agency) estimates that in 2010, the non-OPEC oil producing countries had already reached their peak with regard to petroleum production.

A growing environmental awareness also came about, especially with the sharp increases in oil prices since 2007. Thus, for example, in Belgium under the Kyoto Protocol, greenhouse gas emissions in Belgium in the period 2008-2012 had to be 7.5% lower than in 1990.

The concern for rising oil prices and the growing environmental awareness have increased the interest of manufacturers and consumers in hybrid and electric vehicles. Fuel consumption of a hybrid vehicle is substantially lower than that of a conventional vehicle and as a consequence the emissions are also lower.

2.2. Electrically driven vehicles and hybrid vehicles

2.2.1. Definitions

Some common definitions:

UNECE (United Nations Economic and Social Council) gives the following definition:

Hybrid electric vehicles (HEV):

"Hybrid electric vehicle (HEV)" means a vehicle that, for the purpose of mechanical propulsion, draws energy from both of the following on-vehicle sources of stored energy/power:

a) A consumable fuel;
b) An electrical energy/power storage device (e.g.: battery, capacitor, flywheel/generator etc.)

Comment: A hybrid vehicle is not a purely electric vehicle. In a hybrid vehicle there are at least two different systems for energy conversion and two different energy storage systems. A hybrid electric vehicle is in fact driven by two sources of energy: fuel and stored electrical energy.

2.2.2. Advantages

According to the VITO (Flemish Institute for Technological Research) there are a number of reasons why hybrid vehicles are more economical - especially in urban traffic.

- The hybrid system offers the possibility of regenerating braking energy whereby energy can be more efficiently used.
- The combustion engine can be dimensioned for average load, not peak load.
- A hybrid vehicle may be equipped with a relatively small engine which is optimally adjusted to a defined number of revolutions per minute and that runs at nearly full power. For example, a yield of 35 to 40% can be achieved while a conventional car engine achieves no more than 18% in urban traffic.
- Exceptional drive line due to rapid deployment of the available power.
Electric and hybrid vehicles also have advantages in terms of emissions:

- Because the energy consumption of a hybrid is lower than that of a conventional vehicle, the emissions are correspondingly lower. The environmental benefits of a hybrid car are certainly smaller than for a fully electric car.
- The emission characteristic of a hybrid car is most favourable when the engine is not directly used for the drive, but as a generator to recharge the battery. With this system, it so happens that the motor can run at optimum speed with which the efficiency is maximal and the emission level is minimal. With a hybrid system, account should be taken of additional losses associated with the conversion of mechanical energy to electrical and vice versa, of electrical energy into mechanical.
- No emission when the electric motor only is used. In an urban area one can drive fully electrically.
- When stopping and starting, one can drive fully electrically with a hybrid vehicle.
- With a hybrid vehicle one can reduce emissions when starting from cold. With petrol driven vehicles, these cold start emissions are a big problem. During the first few minutes of a journey the car emits relatively the most. The cold start emissions are to a large extent caused by the mixture enrichment and the fact that the catalyst is not up to temperature. Hybrid vehicles can drive the first part of the journey electrically, while the catalyst can be electrically heated, prior to the internal combustion engine being started.
- Electric and hybrid vehicles make less noise than conventional vehicles.

In principle, the maintenance costs are lower with hybrid/electric vehicles.

### 2.2.3. Disadvantages of electric vehicles

- Electric: when they only make use of the electric drive system, electric vehicles have a limited range. A HV battery has a limited life, and there is still no standard battery which fits in all vehicles.
- Electric: charging takes longer than diesel or petrol fuelling
- Electric: the maximum speed is often limited
- Electric: the range is limited
- Electric: the efficiency of the HV battery decreases at cold temperatures
- Electric: charging points are not yet available everywhere
- Hybrid: complex operation of the vehicle.
3. COMPONENTS SPECIFIC TO HYBRID AND ELECTRIC VEHICLES

Each vehicle manufacturer has its own design. The components that always reappear are the electric motor (which also acts as a generator), the transformer (DC to AC and vice versa), the HV battery, the control units and one or more junction boxes.

3.1. General schematic

The description of these components varies depending on the battery producer and the vehicle manufacturer.

3.2. High Voltage (HV) connectors and (High Voltage (HV) cables

3.2.1. HV connector

3.2.1.1. Technical description

- Traction connectors are constructed to be finger proof so that touching is without danger because they are designed with an HVIL system (Hazardous Voltage Interlock Loop).
  The HVIL (Hazardous voltage Interlock Loop) is a safety loop (closed circuit with a very small current) that switches off the hazardous voltage beforehand by disconnecting the HV battery from the traction system if, for example, a hazardous traction connector becomes disconnected or a cover is opened, behind which lies hazardous voltage.
- Measures in order to make swapping of poles (+) and (-) impossible (error proofing or poka-yoke design). This is done through mechanically coding the connectors.

3.2.1.2. Types

Dependent on the vehicle manufacturer.
The vehicle manufacturer may add specific information here.

3.2.1.3. Drawing

Dependent on the vehicle manufacturer.
The vehicle manufacturer may add specific information here.

3.2.2. HV cable

3.2.2.1. Technical description

- The outermost insulation sheath is orange coloured for clear recognition;
- Number of conductors:
- The protective metal sheath of the cable is connected to the metal connector. This is important for the insulation resistance measurements;
- Equipped with HVIL.

3.2.2.2. Types

Dependent on the vehicle manufacturer.
The vehicle manufacturer may add specific information here.

3.2.2.3. Drawing

Dependent on the vehicle manufacturer.
The vehicle manufacturer may add specific information here.
3.3. **General safety regulations**

- Since cables and connectors are electrified with hazardous voltage they should be treated with caution.
- A HV connector should never be disconnected while the vehicle is 'running'. Safety systems can, as we know, fail. Hence it is necessary to always use a procedure to put the vehicle out of operation. The connectors may be disconnected only after completing this procedure. (see 7.7.4 and 7.7.5).
- Damaged cables HV and HV connectors may not be repaired but must always be replaced immediately.
- The protective sheath of the cable is connected to the metal connector! This sheath must not be damaged.
- Undesirable contact with pins of the traction connector! Insulation- and HVIL-problem! must be free of dirt and mechanical damage.

These regulations are dependent on the vehicle manufacturer. The vehicle manufacturer may add specific information here.

3.4. **Electrical architecture of the HV system with associated control modules**

Schematic overview to be added by the vehicle manufacturer.

3.5. **HV battery**

3.5.1. **What does an HV battery do?**

The HV battery (also called Energy Storage System (ESS)) ensures the storage of electrical energy and provides all electrical components with power such as the transformers and electric motor that drives the vehicle. The HV battery is an energy package and the primarily energy source. The voltage is dependent on the charge status and amounts to approximately 600 VDC (this is dependent on the vehicle manufacturer). The State of Charge (SOC) is the charge status of the HV battery. Minimum and maximum are dependent on the vehicle manufacturer.

3.5.2. **Possible components**

The vehicle manufacturer may add specific information here.

3.5.3. **Battery Management Unit/System (BMU/BMS)**

This system ensures the monitoring of the operation of the battery, possible short circuits (only checks the safety, not the functionality of the HV battery).

3.5.3.1. **Battery/Service Disconnect Unit (BDU/SDU)**

- Switching the HV voltage on and off is done with contactors (= relay).
- Comprises pre-charge circuits in order for the closing of the contacts to run smoothly.
- Measure the current and the voltage the traction system.
3.5.3.2. **HV main fuse**

BDU and main fuse operate together. With small currents the BDU interrupts the traction system first, but with large currents main fuse breaks first.

3.5.3.3. **Signal connector (24/12 VDC)**

3.5.3.4. **HV connectors and HV cables**

3.5.3.5. **Cooling system (dependent on the vehicle manufacturer)**

- The cooling system serves to allow the HV battery to operate in ideal conditions.
- The ideal temperature in the HV battery is between 25 and 30°C (battery dependent). At a lower temperature there is a loss of power/energy and a higher temperature will result in a rapid aging of the battery cells and likewise, in a loss of power/energy.

The different electrical and hybrid components need cooling. The cooling may be done with different cooling systems and cooling circuits.

Given that the availability of hybrid components differs greatly - according to temperature - 1 or more cooling circuits are provided.

The cooling water in the HSS battery circuit must be able to be both heated up and cooled down.

The cooling circuit is specific for the HV battery. The specifications may be furnished by the battery producer.

3.5.3.5.1. Cooling circuits

The vehicle manufacturer may add specific information here.

Schematic

3.5.3.5.2. Heating circuit

The vehicle manufacturer may add specific information here.

Schematic

Attention to the safety aspects

3.5.3.6. **Lifting points**

These lifting points serve for the lifting of the HV battery and hence for the purpose of working safely.

3.5.3.7. **Indications, safety signage**

Instructions, symbols, warnings, safety instructions, etc. are installed by the vehicle manufacturer based on the risks that may occur with storage, during the assembly process, during repair, with emergency interventions and for the traceability.
3.6. **Vehicle Junction Box - (high/low voltage)**

There are several junction boxes present in the vehicle, including the HV battery.
The vehicle manufacturer may add specific information here.

3.6.1. Technical description

3.6.2. Examples

3.6.3. Drawing, schematic

3.7. **DC-DC transformer**

The vehicle manufacturer may add specific information here.

3.7.1. Technical description

3.7.2. Examples

3.7.3. Drawing, schematic

3.8. **DC-DC transformer**

The vehicle manufacturer may add specific information here.

3.8.1. Technical description

3.8.2. Examples

3.8.3. Drawing, schematic

3.9. **AC-DC transformer**

The vehicle manufacturer may add specific information here.

3.9.1. Technical description

3.9.2. Examples

3.9.3. Drawing, schematic
3.10. **Electric motor**

We refer to an electric motor because as well as a motor this also serves as generator for charging the HV battery.

The vehicle manufacturer may add specific information here.

3.10.1. **Technical description**

The stator windings in the electric motor produce a voltage in accordance with the rotational speed of the rotor shaft. The electric machine drives the wheels (electric motor mode) but is also able to charge the HV battery (generator operation), during braking or when driving downhill.

3.10.2. **Examples**

3.10.3. **Drawing, schematic**

3.11. **Transmission unit**

The vehicle manufacturer may add specific information here.

3.11.1. **Technical description**

3.11.2. **Examples**

3.11.3. **Drawing, schematic**

3.12. **On board Charger**

The vehicle manufacturer may add specific information here.

3.12.1. **Technical description**

The charger is intended to charge the battery directly and also the 12V battery, indirectly by means of mains current (230V/400V).

3.12.2. **Examples**

3.12.3. **Drawing, schematic**

3.13. **Combustion engine**

The vehicle manufacturer may add specific information here.

3.13.1. **Technical description**

3.13.2. **Examples**

3.13.3. **Drawing, schematic**
3.14. HV generator
The vehicle manufacturer may add specific information here.


3.14.2. Examples

3.14.3. Drawing, schematic

3.15. Steering and control units
The vehicle manufacturer may add specific information here.

3.15.1. Technical description

3.15.2. Examples

3.15.3. Drawing, schematic

3.16. Other electrical/hybrid components
The vehicle manufacturer may add specific information here.

3.16.1. Technical description

3.16.2. Examples

3.16.3. Drawing, schematic
4. SAFETY SYSTEMS IN HYBRID AND ELECTRIC VEHICLES

During the development of these vehicles, built-in safety systems were thought of in order to eliminate the risk of serious personal injury through contact with live components.

There are two important criteria in the field of electrical safety.

4.1. Guarding against contact

People must be prevented from coming into contact with hazardous live components. A monitoring system was built in for the purpose of turning off the hazardous voltage before a person can come into contact with hazardous live parts provided a strict procedure is followed.

The vehicle manufacturer may add specific information here.

4.1.1. Technical description

4.1.2. Examples

4.1.3. Drawing, schematic

4.2. Failure of components

One should prevent metal parts ( housings, connectors, etc.) from becoming live with dangerous voltage due to an insulation fault.

It is possible that components which are not normally live, may become so with hazardous voltage as a result of wear and tear. The insulation resistance of the electrical system must always be treated with care. An insulation monitoring system in the HV battery detects insulation faults. Each vehicle manufacturer determines what the minimum insulation value may be in order that the HV voltage is interrupted (e.g. 300kOhm).

The vehicle manufacturer may add specific information here.

4.2.1. Technical description

4.2.2. Examples

4.2.3. Drawing, schematic
5. ELECTRICAL QUANTITIES

5.1. Electrical voltage

Electrical voltage means the electrical thrust that puts the electrons into motion and that makes the current flow. The greater the difference in charge between the two source terminals, the greater the electrical voltage at the terminals and also the danger of electrocution.

The value of the voltage determines the current that flows through the body and therefore the danger that arises for humans.

We call the voltage at the terminals of a source “terminal voltage”.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>U</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit</td>
<td>1 Volt (1 V)</td>
</tr>
<tr>
<td></td>
<td>1 millivolt = 1 mV = 0.001 V</td>
</tr>
<tr>
<td></td>
<td>1 kilovolt = 1 kV = 1000 V</td>
</tr>
</tbody>
</table>

5.1.1. Areas of voltage

See article of the AREI (Belgian General Regulation on Electrical Installations, (equivalent to BS 7671 “Requirements for electrical installations”).

The configuration of electrical installations in areas of voltage is done based on the nominal voltage $U$ between the active conductors.

A voltage smaller than 25VAC is considered as a very low safety voltage (VLSV).

AREI considers three voltage areas:
- very low voltage (VLV);
- low voltage (LV)
- high voltage (HV).

<table>
<thead>
<tr>
<th>Alternating current</th>
<th>Direct current</th>
</tr>
</thead>
<tbody>
<tr>
<td>With ripple</td>
<td>Without ripple</td>
</tr>
<tr>
<td>very low voltage (VLV)</td>
<td>U ≤ 50</td>
</tr>
<tr>
<td>Low voltage (LV) 1st cat.</td>
<td>50 &lt; U ≤ 500</td>
</tr>
<tr>
<td>Low voltage (LV) 2nd cat.</td>
<td>500 &lt; U ≤ 1 000</td>
</tr>
<tr>
<td>High Voltage (HV) 1st cat.</td>
<td>1 000 &lt; U ≤ 50 000</td>
</tr>
<tr>
<td>High Voltage (HS) 2nd cat.</td>
<td>U &gt; 50 000</td>
</tr>
</tbody>
</table>

The maximum permissible voltage with VLV is 50 V with AC voltage and 120 V with DC voltage.

5.1.2. Alternating current (AC)

An alternating current is a current that is constantly changing in size and flow direction.

The number of times per second that voltage / current changes, is called the frequency, represented by “$f$” and expressed in "Hertz (Hz)".
A source, in which the polarities always change, is called an alternating current source. A generator that provides alternating current is called an “alternator”.

The mains frequency in Europe is: 50 Hz

Examples:
- Mains voltage in household installations in Belgium = 220 V AC
- Voltage in a hybrid vehicle: 600 V DC en 400 V AC

5.1.3. Direct current (DC)

A source in which the polarities (+ en -) of the voltage always remain the same, is called a direct current source. Because the polarities remain fixed, the current supplied by a direct current source always flows in the same direction (conventionally: outside of the source from plus to min.).

DC sources without moving parts are called static DC sources

Examples:
- Car battery 12 V DC
- AA battery 1.5 V DC
- Lorry battery 24V DC (2 x 12V DC)
- Voltage in a hybrid vehicle: 600 V DC and 400 V AC
Attention:

The voltage of hybrid vehicles can amount to 600VDC/AC and 400 VAC!

Voltages of hybrid vehicles can run up to 600VDC/AC and 400 VAC

Pay attention to the following warning sign!
Do not consider low voltage as a low voltage!
A low voltage of 400 or 600 V is a high voltage and hence dangerous!
5.2. **Electric current**

The displacement of electrons in a closed loop is called electric current. The electron flow is the number of electric charges that flow in a circuit at a given point during a certain period of time.

It is a flow rate of electric charges. In order to convert the electrical energy of the source into another energy form (e.g. mechanical energy with an electric motor) an electric current is necessary.

The electrical direct current flows out of the source from the positive to the negative terminal. In a diagram, the flow direction is indicated by an arrow along the connector wires.

In general we assume that a current greater than 30 mA presents a serious danger to humans! Consider the differential switch in a household installation that protects humans from this current.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unit</strong></td>
<td></td>
</tr>
<tr>
<td>1 Ampère (1 A)</td>
<td></td>
</tr>
<tr>
<td>1 milli-Ampère = 1 mA = 0.001 A</td>
<td></td>
</tr>
<tr>
<td>100 milli-Ampère = 100 mA = 0.1 A</td>
<td></td>
</tr>
<tr>
<td>1000 mA = 1 A</td>
<td></td>
</tr>
</tbody>
</table>

### 5.2.1. Alternating current

See also 5.1.1

Example:

A current consumption of a 60 W consumer at 220 V = 0.27 A

### 5.2.2. Direct current

See also in 5.1.2

A current consumption of a 60 W consumer at 12 V = 5 A

(Formula: $P=U \times I$)

- 60 W and 12 V (I = 5 A)
- 60 W and 220 V (I = 0.27 A)
5.3. **Electric resistance**

The resistance is an obstacle that the current encounters, in any component of an electrical circuit. Each conductor, each consumer, each voltage source forms a resistance for the electric current.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.3.1.1.1.1. 1 Ohm (1 Ω)</td>
</tr>
<tr>
<td></td>
<td>5.3.1.1.1.2. 1 milli-Ohm = 1 mΩ = 0.001 Ω</td>
</tr>
<tr>
<td></td>
<td>5.3.1.1.1.3. 1 kilo-Ohm = 1 kΩ = 1000 Ω</td>
</tr>
<tr>
<td></td>
<td>1 Mega-Ohm = 1 MΩ = 1 000 000 Ω</td>
</tr>
</tbody>
</table>

Examples:
- Input resistance of a digital multimeter = 10MΩ
- Specific resistance of copper = 0.0175 Ω.mm²/m
- Insulation resistance:
  General rule = 1000 x system voltage
  (e.g. insulation resistance of 230V → 1000 x 230 = 230 kΩ)

**Body resistance**

We generally assume that the body resistance of the human fluctuates around 3 kΩ, greatly depending on certain circumstances and from person to person: humidity, sweat, stress, location of contact points...

5.4. **Electrical power**

The power of a consumer determines how much electrical energy the consumer will convert into light, heat or mechanical energy if it is connected to a voltage. Each electrical consumer is designed to operate at a certain voltage. At this voltage the consumer will take a particular current from the network. The power developed (P) is the product of voltage (U) and current (I) or $P = U \times I$.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 Watt (1 W)</td>
</tr>
<tr>
<td></td>
<td>1 milli-Watt = 1 mW = 0.001 W</td>
</tr>
<tr>
<td></td>
<td>1 kilo-Watt = 1 kW = 1000 W</td>
</tr>
<tr>
<td></td>
<td><strong>Power expressed in hp:</strong></td>
</tr>
<tr>
<td></td>
<td>1 hp = 736 W</td>
</tr>
<tr>
<td></td>
<td>1 W ≈ 0.00136hp</td>
</tr>
</tbody>
</table>

Power expressed in hp (old unit for power); use of this is statutorily no longer permissible.

1 hp = 736 W
1 W = 0.00136hp
6. HAZARDS OF ELECTRICITY

6.1. Influence of electric current on the human body

Sensitivity to electrical current flow

Article 3 of the AREI defines very low safety voltage (VLSV) as a voltage the value of which remains limited:

- in normal operating conditions; and
- under faulty conditions, including earth faults in other current paths, up to that of the conventional absolute voltage limit (U<sub>L</sub>) defined in Article 31.02.

<table>
<thead>
<tr>
<th>Current (mA)</th>
<th>Influence on the human body</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 1</td>
<td>No noticeable influence (= no risk).</td>
</tr>
<tr>
<td>1 – 15</td>
<td>Cramping of muscles (arms and fingers), self-discharge is more difficult...</td>
</tr>
<tr>
<td>15 - 30</td>
<td>Hardly bearable pains, arm muscle contractions, difficulty breathing and blood pressure rise...</td>
</tr>
<tr>
<td>30 - 50</td>
<td>Increase in blood pressure, strong muscle contraction, cardiac fibrillation with longer exposure, unconsciousness,</td>
</tr>
<tr>
<td>50 - 500</td>
<td>Cardiac fibrillation, unconsciousness, quick death possible...</td>
</tr>
<tr>
<td>&gt;500</td>
<td>Cardiac arrest with possibility of resuscitation, immediate death possible...</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Code</th>
<th>Condition of the human body</th>
<th>Absolute conventional voltage limit U&lt;sub&gt;L&lt;/sub&gt; in volts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Alternating current</td>
</tr>
<tr>
<td>BB1</td>
<td>Completely dry skin or moist due to perspiration</td>
<td>50 V</td>
</tr>
<tr>
<td>BB2</td>
<td>Wet skin</td>
<td>25 V</td>
</tr>
<tr>
<td>BB3</td>
<td>In skin submerged in water</td>
<td>12 V</td>
</tr>
</tbody>
</table>
6.1.1. **Primary and secondary injuries**

The presence of electrical voltage cannot be detected by the human senses. The risks cannot be estimated visually! A voltage in a socket outlet cannot be seen, heard or felt (without making contact).

*Note!* A burning lamp is visible, but is the result of the current which flows through it.

Electrical accidents are divided into two types:

6.1.1.1. **Primary injuries**

These are attributable to an electric current through the body (= electrocution).

The following risks may occur:
- Cardiac contraction (cardiac fibrillation)
- Poisoning (boiling of the blood with which toxins are released from internal bleeding)
- Burns
R = Body resistance $= 3 \, \text{k}\Omega = 3000 \, \Omega$

Note! The resistance depends from person to person, moisture (sweat), contact point...

How big is the current when making contact with 24 V?

\[
\text{Current (A)} = \frac{\text{Voltage (V)}}{\text{Resistance (}\Omega\text{)}} = \frac{24 \, \text{V}}{3000 \, \Omega} = 0.008 \, \text{A} = 8 \, \text{mA}
\]

An electric current of 8mA through the body is not life threatening!
Some will flinch because their muscles cramp, others hardly feel anything...

6.1.1.2. Secondary injuries

Suppose that a person touches the poles of a 12 V-battery by accident. The current running through their body ($= \text{mA}$) will not have serious consequences because the muscles do not contract dangerously. Use Ohm’s law for this wherein $R = \text{body resistance approx. 3 k}\Omega$.

**No primary injuries!**

**HOWEVER:**

The same person makes an accidental short circuit between the poles of a 12 V-battery with a spanner (conductive), with which an extremely large short-circuit current flows. Due to the heat released and any sparks, it is likely that they will suffer serious injuries such as burns or eye injuries!

These are secondary injuries.

**Hence:**

With dangerous electrical installations, we must always take safety precautions in order to minimize possible risks of injury such as:

- Burns and/or eye damage from sparks, short circuit, electric arcs
- Fractures and/or other injuries through falling
6.2. Ohm’s law and the human body

Ohm’s law

The Ohm’s law is the **constitution of electricity and electronics**!
The law explains the relationship between voltage, current and resistance in a simple way.

\[ U = I \times R \]

**Important!**
The larger the voltage and/or smaller the body resistance, the larger and more dangerous the electric current through our body will be!

The use of personal protective equipment such as rubber electro gloves and helmet with face guard is necessary with hazardous voltages!

A current greater than 30 mA (0.03 A) is highly dangerous!

We generally assume that the body resistance of the human fluctuates around 3 kΩ, but it is greatly dependent both on certain circumstances and from person to person (condition of the human body: dry or damp skin), sweat, stress, location of contact points...

**Important!**
The higher the voltage and/or smaller the body resistance, the greater and more dangerous the electric current through our body will be!
The use of personal protective equipment such as rubber electro gloves and helmet with face guard is necessary with hazardous voltages!

A current greater than 30 mA (0.03 A) at 220V is extremely dangerous!
6.3. Current flow through the body

6.3.1. Direct contact

With a direct contact, one comes into contact with an uninsulated “active” component that, under normal circumstances, without a fault occurring, is live.

How do you protect against direct contact?
- Work with very low safety voltage (VLSV).
- Use of devices with dual insulation (Class II).
- Equipped with obstacles, enclosing installation(s) and components.
- Insulation
- Insulation monitoring (insulation resistance monitor):

Example:
In the case of a household installation this is e.g. a phase in an outlet socket.

6.3.2. Indirect contact

With an indirect contact one comes in contact with “accidentally” live masses (e.g. metal housings, metal cable sheathing, metal connectors).
This involves masses that are not live under normal circumstances, without the occurrence of an insulation fault.

Example:
In a household installation this might be the metal housing of a washing machine.
How do you protect against indirect contact?

\[
\text{Current (A)} = \frac{\text{Voltage (V)}}{\text{Resistance (Ω)}} = \frac{600 \text{ V}}{3000 \text{ Ω}} = 0.2 \text{ A} = 200 \text{ mA}
\]
Examples of contact points:

This applies for an earthed installation!
6.3.3. What do you do in the event of electrocution?

**FIRST AID IN THE EVENT OF ELECTROCUTION**

**REMOVE THE VICTIM AWAY FROM THE SOURCE OF ELECTRICAL CURRENT IN A SAFE MANNER**

**ENSURE THAT THE AXIS OF THE SPINAL COLUMN IS PRESERVED WHEN MOVING THE VICTIM**

**CONSCIOUS?**

1. **NO, unconscious**
   - Make the airways free
   - Make the neck/throat free
   - Tip the head backwards
   - Tilt the chin upwards
   - Call 112 or 100
   - Reassure the victim
   - Check the victim regularly
   - Wait for help

1. **INDEED, conscious**
   - Make the airways free
   - Make the neck/throat free
   - Tip the head backwards
   - Tilt the chin upwards
   - Call 112 or 100
   - Reassure the victim
   - Check the victim regularly
   - Wait for help

**BREATHING?**

2. **NO, is not breathing**
   - Look
   - Feel
   - Listen
   - 10 seconds
   - Slowly breath air into them twice
   - Safety position
   - Reassure the victim
   - Check the victim regularly
   - Wait for help

2. **YES, is indeed breathing**
   - Safety position
   - Reassure the victim
   - Check the victim regularly
   - Wait for help

**HEARTBEAT?**

3. **NO, no heartbeat**
   - Feel the carotid artery for the heartbeat (10 seconds max.)
   - Commence reanimation (CPR)
   - 15x heart massage
   - 2x breathing
   - 4 series per minute
   - Call 112 or 100
   - Reassure the victim
   - Check the victim regularly
   - Wait for help

3. **YES, heartbeat Indeed**
   - Breath into the victim
   - 1x breath per 5 seconds

**CHECK THE BREATHING (LOOK, FEEL, LISTEN) AND THE HEARTBEAT (CAROTID ARTERY) EVERY MINUTE**

**IN THE EVENT OF SERIOUS ACCIDENT WITH VICTIM => Call 112 or 100**
7. SAFETY PRECAUTIONS WHEN WORKING ON ELECTRIC/HYBRID VEHICLES

7.1. Risk analysis

The Royal Decree of 27 March 1998 concerning welfare policy stipulates that the employer draws up a risk analysis taking into account the activities of the company.

More specifically, article 8 of this RD stipulates the following:

The risk analysis is done at the level of the organization as a whole, at the level of each group of workstations or functions and at the level of the individual.

It consists consecutively of:
1° identifying threats to the wellbeing of the employees in the performance of their work;
2° establishing and further determining risks to the wellbeing of the employees in the performance of their work;
3°evaluating risks to the wellbeing of the employees in the performance of their work.

Appended to this document is a risk analysis for the 4 essential process steps (group of workstations) at the vehicle manufacturer, namely the inbound (appendix 1), the assembly (appendix 2), the repair (appendix 3) and the outbound (appendix 4). It concerns a generic analysis wherein the specific elements of each vehicle manufacturer should be supplemented or added.

This risk analysis addresses various risks that may be associated with the different process steps. They are certainly not just about the electrical risks.

7.2. Personnel training

7.2.1. Statutory framework

Initially we think of the obligations arising from the AREI. Article 47 stipulates the competence of employees to work on electrical systems. Because the energy supply and distribution within a vehicle are not subject to the AREI, the BA1 to BA5 do not apply. Nevertheless, the principles of article 47 are included here so that in this context we speak of different levels (and not of BA).

Level 0:
Basic information at the factory gate of the company for own uninvolved employees, visitors and third parties.

Level 1:
For employees who possibly have access to the vehicle but where the components are not live

Level 2:
For employees who can disconnect and de-activate the battery and who can carry out specific tasks (see risk assessment) on the vehicle

Level 3:
For employees who may carry out work on electrical components of the vehicle with activated battery.
It is important to underline that the employer should lay down the professional competence of the different levels. The procedures for this (e.g. establishing the competence in a document) can be derived from those set forth in article 47 of the AREI (see also “Working on and in the vicinity of electrical installations” - Code of good practice).

We also refer to the RD policy of 27 March 1998 in which the obligation is included to take into account the following elements when assessing the ability of the employee:

- The knowledge of the employee(s) with respect to the risks of the installation (see RD policy March 27, 1998: risk analysis), gained through training or experience within or outside the establishment of the employer;
- The nature and diversity of the installation (type of electric network system, low voltage, high voltage, type of equipment, ...);
- The diversity of activities on or in close proximity to an electrical installation (insulated working [working with live voltage], earthed working [working without voltage] ...).

The competency assessment, including a description of the installation (s) and the activities for which the assessment applies, is traceable.
7.2.2. Training programme

TRAINING/PROVISION OF INFORMATION
for electric and hybrid vehicles

Employees who are, in one way or another, exposed to the risks of the HV battery, should receive appropriate training. In the table below a first attempt is made linking the different levels of training to the various risks (levels 0 -> 3).

<table>
<thead>
<tr>
<th>AREI codification</th>
<th>Target groups</th>
<th>Approach</th>
<th>who</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level 0</strong>&lt;br&gt;No direct access/contact to High Voltage vehicles and High Voltage parts</td>
<td>Basic info at the factory gate for all visitors and employees and third parties</td>
<td>- Brief explanation of electrical vehicles, hazards and preventive measures as part of the site general safety instructions.</td>
<td>Security service personnel from external companies</td>
</tr>
<tr>
<td><strong>Level 1</strong>&lt;br&gt;Can have access to vehicles and parts when either parts and/or vehicles are not put under High Voltage.</td>
<td>- Information via team leader (meetings, leaflets,…)&lt;br&gt;- Providing information about: dangers of electrocution, fire, explosion, recognizing safety labels / clothing, use of PPE / tooling, which services to notify in case of accident (emergency number).&lt;br&gt;- Presentation/information by involved HV engineer(s).&lt;br&gt;- Presentation via TQM sessions by team or work leader(s).&lt;br&gt;- Site general safety instructions&lt;br&gt;- Contact person: nominate contact person&lt;br&gt;- Foresee refreshment training</td>
<td>Evaluate operators, hierarchical level, logistics / material handling, maintenance and other relevant persons (first aid …) personnel from external companies.</td>
<td></td>
</tr>
<tr>
<td>Finished vehicles</td>
<td>- Information via team leader (meetings, leaflets ….)&lt;br&gt;- Providing information about: dangers of electrocution, fire, explosion, recognizing safety labels / clothing, use of PPE / tooling, which services to notify in case of accident (emergency number).&lt;br&gt;- Presentation/information by involved HV engineer(s).&lt;br&gt;- Presentation via TQM sessions by team or work leader(s).&lt;br&gt;- Site general safety instructions&lt;br&gt;- Contact person: nominate contact person&lt;br&gt;- Foresee refreshment training</td>
<td>(drivers and truck loaders) from external companies.</td>
<td></td>
</tr>
</tbody>
</table>

**Level 1**: INFORMATIVE for people who go into production hall

**CONTENTS**

Information boards (with meaning) where hybrid components are to be found
### Level 2 (Competent)

- Persons that (disconnect and (de-)activate the battery and perform specific electrical repairs (via risk analysis) on the car with deactivated battery.

- Contact person for technical assistance:
  - nominate contact person
  - foresee refreshment training

- Electrical repair or other authorised persons
  - Suggestion: Person is visually recognizable

**Level 2**: training provides practical test

### Level 3 (Qualified/Specialist)

- Persons that perform electrical repairs (via risk analysis) on the car with activated battery.

- Operator performs risk assessment of all repairs on High Voltage components of vehicles (decides which education level is needed to do the repair).

- Contact person for technical assistance:
  - nominate contact person
  - foresee refreshment training

- Authorised person
  - Suggestion: Person is visually recognizable
  - Suggestion: Rules for separately employed worker applicable?

**Level 3**: training provides theoretical and practical test

Comment: Defining an extra (sub) level is always possible.

### 7.3. Safety procedure ‘Working on electrical components of electric and hybrid vehicles’

The employer should lay down the professional competence of the different levels. The procedures for this (e.g. establishing the competence in a document) can be derived from those set forth in article 47 of the AREI.

We also refer to the RD policy of 27 March 1998 with the obligation to take into account a number of elements when assessing the ability of the employee (see 7.2.1.)

### 7.3.1. Assigning a codification level 2-3 or own codification system

The employer will take into account the following elements for the purpose of declaring a worker authorized to work on certain electrical components of an electric/hybrid vehicle:

- only he assigns the authority to an employee;
- description of content of course material;
- description of training programme;
- evaluation at the end of the training (documented);
- certificate with a description of the permitted activities, with any special limitations, type of vehicle which may be worked on, type of electrical installations;
- Conditions for retention of certificate;
- validity of the certificate;
- lists of employees with their codification, expiry date of certificate;
- identification of employees with a particular level so that they are recognizable on the work floor;
- description of further training;

7.3.2. Committee for Prevention and Protection at Work

The Committee for Prevention and Protection at Work (CPPW) must be informed about the following:

- Applied safety procedure for ‘Working on electrical components of electric and hybrid vehicles’
- Assignment and establishment of the levels (levels 1 -> 3)
- The recognisability of the level 3 employees (possibly also level 2)
  Example: The work trousers can be equipped with one or more hazard labels. Other systems are always possible (e.g. via badge).

7.4. Safety signs and safety labelling

The location(s) in the company where the electrical components are stored, installed, repaired and possibly if the vehicle is stocked, may be provided with the necessary sign boards. Unauthorized persons can thus be excluded from a particular zone.

There are danger signs, warning signs, prohibition signs, warning signs, command signs (including personal protective equipment), signs for fire fighting.

Important note: extra attention to the information for non-native speaking employees or third parties (e.g. suppliers).

Low voltage is not the same as low voltage without danger. A low voltage of 400 or 600 V is indeed a 'high' voltage and therefore dangerous.
# Meaning of the signs used

## Warning signs

<table>
<thead>
<tr>
<th>Sign</th>
<th>Description</th>
</tr>
</thead>
</table>
| ![Triangle with lightning bolt](image) | **Dangerous electrical voltage!**  
Access for authorised personnel only. |

<table>
<thead>
<tr>
<th>Sign</th>
<th>Description</th>
</tr>
</thead>
</table>
| ![Triangle with exclamation mark](image) | **Danger!** Read instructions:  
Access for authorised personnel only. |

## Prohibition signs

<table>
<thead>
<tr>
<th>Sign</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="No entry symbol" /></td>
<td><strong>Unauthorised access forbidden!</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sign</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="No fire symbol" /></td>
<td><strong>Fire and flames prohibited!</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sign</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="No water symbol" /></td>
<td><strong>Extinguishing with water or foam prohibited!</strong></td>
</tr>
</tbody>
</table>

## Command signs

<table>
<thead>
<tr>
<th>Sign</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Gloves" /></td>
<td><strong>Electro gloves obligatory when disconnecting traction connectors after the hybrid system has been live!</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sign</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Face shield" /></td>
<td><strong>Face guards obligatory when disconnecting traction connectors after the hybrid system has been live!</strong></td>
</tr>
</tbody>
</table>

## Fire fighting

<table>
<thead>
<tr>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fire fighting:</strong> powder extinguisher (Class ABC) in the immediate environment of the HV Battery.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fire fighting of a mechanically damaged HV battery:</strong> powder extinguisher (Class D = metal fires).</td>
</tr>
</tbody>
</table>
7.5. Fire

As HV batteries contain chemical substances, extra attention should be paid to the risks of fire. It is therefore useful to contact the local fire service to make the necessary arrangements.

Attention should also be paid to a potential modification of the internal emergency plan.

Shown below are some areas that deserve attention.

7.5.1. Fire prevention

General:
- Avoid exposure to extreme heat or fire.
- Prohibit welding activities being carried out in the vicinity of the HV battery
- Use thermal protection during painting activities, when the vehicle needs to be painted
- Keep to the guidelines drawn up by the vehicle manufacturer (manufacturer specific)

7.5.2. Fire fighting

Some points of attention for fire fighting are shown below.

General: when using extinguishing agents, the battery producer’s instructions must be followed.
- With extinguishing operations on closed HV batteries, use a class ABC powder extinguisher (follow battery producer’s recommendations)
- By extinguishing/cooling the fire with water, toxic hydrogen fluoride may be released. The necessary protective equipment should be complied with for protection;
- Fire fighting with closed HV battery in the car: powder extinguisher (class ABC) and LOTS of water (verify with battery producer);
- Fire fighting with open HV battery: powder extinguisher (Class D = metal fires), and dry sand. (Verify with battery producer)

Specific training is required for these types of fire fighting.

7.6. Handling and Transport of the HV battery

For the following processes it should be checked as to which necessary safety measures are to be taken and which procedures to be drawn up (is an adaptation of the ISO system (or other) necessary?)

The vehicle manufacturer may add specific information here.

7.6.1. Reception and unloading of lorry

7.6.2. Internal transport to warehouse

7.6.3. Storage in warehouse

7.6.4. Internal transport to assembly line

Always keep the HV battery in the specified mounting position (discuss this with the HV battery producer). If tilting during production process is required, this should be discussed in advance with the HV battery producer.
7.6.5. General safety measures:

- Avoid storage of the HV battery in the proximity of metal components or other heavy objects that could fall on the battery and cause short circuiting, leakage, overheating, smoke emission, bursting, etc...
- Provide a procedure for rejected batteries (NOK parts);
- Storage, transport and labelling of rejected HV batteries should be separated from good HV batteries
- Measures should be provided for collection of leakages when storing a damaged HV battery.
- Use the lifting points provided on the HV battery during installation.
- Handle a used and/or damaged HV battery alone with the necessary personal protection equipment (gloves, face guard, ...);
- Protect an ‘open’ HV battery or unprotected cells (e.g. after a fall) from water or water solutions.
- Do not stack unpacked HV-packages on top of one another.
- Always store the HV battery using closed service hatches;
- The electrical connectors must always be provided with protective caps to exclude short circuits and electrical hazards but also to protect against dust and dirt;
- Provide a well-ventilated dry area for the storage of the HV battery/batteries.

7.7. Assembling and repairing hybrid and electric vehicles

Listed below are a number of points that are important during the various process steps. The instructions of the battery producer are obviously very important and may be specific to the type of HV battery.

A procedure for repairing and electric/hybrid vehicle is included in appendix 5.

7.7.1. Lay-out of assembly line and zone for repairs

Some attention points:
- Indication of electrically harmless operations
- Indication of electrically hazardous operations
- Indication of locations for repair activities to electrical components

7.7.2. (Sub)assembly of HV components

Some attention points:
- Identification of the components with indication of the electrical voltage;
- Drawing up of work instructions;
- Drafting of safety measures (people, material, machine, environment, organization);
- Always keep the HV battery in the mounting position. If tilting during production process is required, this should be discussed in advance with the battery producer (under no circumstances should the HV battery be tilted);
- Use the lifting points provided during assembly.
- Equipped with safety signs and safety labelling for:
  o Zone
  o Components
7.7.3. **Assembly of HV components in the vehicle**

The following are some attention points:
- Identification of the components with indication of the electrical voltage;
- Drawing up of work instructions;
- Drafting of safety measures (people, material, machine, environment, organization);
- Always use the lifting points provided on the HV battery during assembly.
- Equipped with safety signs and safety labelling for:
  - Zone
  - Components

7.7.4. **Putting electric hybrid installation into operation**

The following measures can be recommended:
- Identification of the components with indication of the electrical voltage;
- Drawing up of work instructions;
- Drafting of safety measures (people, material, machine, environment, organization);
- Control of the insulation resistance:

In the vehicle, it is extremely important that the HV voltage, under no circumstances, comes into contact with metal housings, connectors, etc. It is precisely those components which an employee may come into contact with. It is therefore necessary that insulation resistances are measured prior to the HV voltage (normal voltage of the battery) being switched on. The vehicle manufacturer determines the values of the insulation resistance.

Use of an insulation resistance meter:

When using an insulation resistance meter, an ‘adjustable’ voltage up to 1000 VDC may be used for a reliable insulation resistance measurement. Generally, we know that the current is in relation to the voltage present, but in the case of the insulation resistance meter, the test current for example, is limited to 1 mA for safety reasons. This can be compared with the electric (pulsating) shock you experience when grasping an electric fence wire around a meadow: high voltage, but low ‘safe’ currents.

To check if the insulation resistance is in order, carry out some measurements with a suitable insulation resistance meter with an adapted measuring range. The prescribed personal protective equipment must be worn (electro gloves and face protection).

- Insulation measurements should only be performed on circuits made currentless; One should never measure the signal connectors (12/24 V). It is likely that sensitive components such as control units will be irreparably damaged;
- At the start of the measurement, the fuse of the insulation resistance meter should be checked. (Note: provide a procedure if the fuse is faulty)

What is needed to set up the insulation resistance meter?
- Description
- Calibration
- Drawing

- Check whether error codes (DTCs: Diagnostic Trouble Codes) appear. The error codes themselves are specific for the HV battery producer.
- Check various points prior to making hybrid installation live (via check list). All steps that have to be taken must be safeguarded and documented.
7.7.5. **Procedure for taking vehicle out of operation**

The following measures can be recommended:

- Also see information from HV battery producer;
- Drafting work instructions;
- Drafting of safety measures (people, material, machine, environment, organization);

*Example:*

- Remove ignition key from ignition (note: provide procedure for vehicles with “keyless” starting; Switching off the voltage using the main circuit breaker with the aid of the remote control. The ignition key (also see “keyless”) should not be in the ignition lock in order to make breaking possible;
- Disconnect the signal connector (12/24 V) of the HV battery;
- Disconnect the 12 V-accumulator by means of:
  - disconnecting the cables from the batteries
  - cutting through the power or ground cable.
- Disconnecting the ground cable;

The hybrid system is designed so that it is turned off when the 24 V/12V - power supply is disconnected. Or in other words, the HV battery will quickly be switched off by disconnecting the 24V/12 V-power supply.

The ‘hazardous’ traction voltage may be eliminated in various ways, dependent on the reason/situation for switching off, but ... keep in mind that it takes at least 5 seconds (HV battery producer dependent), after switching off, before the HV battery voltage drops to a safe level (60 Volts).

Which procedure should be followed? When disconnecting the ground cable on 12/24 -accumulators, a procedure must be followed (via check list?). The HV battery producer will have to be consulted on this.

There are no residual voltages present in the hybrid/electric vehicle. They are component dependent):

1. A residual voltage remains present because of built-in capacities (capacitors) in various hybrid/electric components (such as in the electrical transformers). This residual voltage is ‘automatically’ lead away, after the HV battery power supply is disconnected via the discharge system that consists of resistors built into the hybrid components. This discharge process of the residual voltage may take several seconds to complete (HV battery producer dependent).

2. Each length of cable represents a capacitive link in relation to the chassis. In addition, capacitive couplings are installed between the plus (+) pole and the chassis and between the min. (-) pole and the chassis in order to comply with EMC requirements. The capacities thus resulting may charge to a ‘dangerous’ voltage.

   **Attention:** This voltage is not automatically discharged by switching off the hybrid/electric vehicle installation, hence also not when taking the power supply of the HV battery out of operation.

**Use of a voltage tester:**

In order to control whether residual voltage is still present, voltage measurements should be carried out using a suitable voltage tester (e.g. DUSPOL device). The prescribed personal protective equipment must be worn (face guard, electro gloves).
The voltage is measured:
- between the positive and negative conductors of the traction system;
- between the positive conductor of the traction system and the chassis;
- between the negative conductor of the traction system and the chassis;

If a residual voltage smaller than 25 V (see 5.1.1: areas of voltage) is measured, the condition is safe.

Settings of the voltage tester:
- Description
- Drawing

General:
- With taking it out of operation, the HV battery producer stipulates via instructions how much time is needed before the residual voltages are sufficiently low. Always use the lifting points provided on the HV battery with disassembly.
- Safety signs and safety labelling
  - Zone
  - Components, vehicle

7.7.6. Starting and driving a hybrid/electric vehicle

The following measures can be recommended:
- Identifying the vehicle;
- Drawing up work and driving instructions;
- Drafting safety measures (people, material, machine, environment, organization);
- Safety signs and safety labelling of the:
  - Zone
  - Components
8. DRIVING AN ELECTRIC OR HYBRID VEHICLE

Below is an example describing a number of issues when driving an electric or hybrid vehicle.

The vehicle manufacturer may add specific information here.

8.1. General

Driving an electric or hybrid vehicle is different from driving a conventional vehicle. It is important to become acquainted with the functions of the new controls on the instrument panel before one goes on the road with an electric or hybrid vehicle.

Instructions may be given with a synoptic board or with a computer simulation program.

8.2. Differences in relation to a classical combustion engine

- The combustion engine may suddenly fall silent because one may drive electrically, and vice versa.
- The starting gear may be higher, gear changes are less frequent and the vehicle can move silently. Attention for the environment since ‘silent’ vehicles still rarely occur on our roads;
- In electric mode, the start torque considerably higher: watch out for collisions;
- Anticipatory braking (no hard braking) ensures that the HV battery is properly charged.

The synoptic board below (for example) is a simulation of a hybrid vehicle and consists of two components:

1) Control panel
   - This will allow the instructor to simulate different modes taking into account important conditions / parameters.
   - The students can follow all the operations on the synoptic board.

2) Synoptic board/panel
   - The synoptic board consists of an illustration of the driver's compartment (see example on page 41) and top view of an electric/hybrid vehicle (orange is typical for electric/hybrid components).

   Using LEDs students can follow what actions the instructor (driver) carries out and what happens to the various components in the electric/hybrid vehicle.
8.3. **Normal modes (see vehicle manual)**

A number of specific properties for electric/hybrid vehicles are elucidated below. They are vehicle manufacturer dependent and may therefore be adapted/supplemented depending on the situation.

8.3.1. **Starting the vehicle**

8.3.2. **Driving an electric/hybrid vehicle.**

New to an electric/hybrid vehicle is the higher starting gear!
Given the high torque at low rpm, the starting gear in the hybrid or full electric mode can be much higher than with a conventional vehicle...

8.3.3. **Parking the vehicle**

Specific for vehicle manufacturer with explanation of the key points of interest when parking the vehicle.

8.3.4. **‘ELECTRIC/HYBRID’ Mode**

8.3.5. **Full Electric Mode (driver)**

- No emission - exhaust.
- Seeing as the combustion engine is not running, the vehicle drives extremely quietly!

Points of attention

- The range for electric driving depends on the charging status of the HV battery
- The way in which the driver of the vehicle drives, is extremely important for increasing the action radius. Example: Slowing down by releasing the accelerator whereby the electric motor is used as a brake and also produces electricity for the HV battery.

8.3.6. **‘Safe For Later’ Mode or Full Electric Anticipation (driver)**

The driver has the option to select the mode for a future important autonomy in the ‘Full Electric’ mode or when using electric power consumers.
The mode should bring the charge status of the HV battery to a good level while driving (not when idling) prior to driving the vehicle fully electrically.
While driving, use of the electric motor will be avoided, giving priority to charging the HV battery, i.e. allowing the electric motor to work as an alternator.

8.3.7. **Sport driving Mode in the ‘sport’ mode**

The combustion engine provides the drive of the vehicle with a greater torque, if necessary assisted by the electric motor.

8.4. **Special modes**

These are vehicle manufacturer specific.
The vehicle manufacturer may add specific information here.

8.5. **Braking strategy**

Braking energy can be recovered whereby the HV battery can be charged. The electric motor may be seen as an ‘auxiliary brake’ Any other ‘auxiliary brakes’ may be provided by the vehicle manufacturer.
9. TRACING FAULTS

In order to trace faults, the employee must have prior knowledge of the electrical system of the electric or hybrid vehicle.

In order to trace faults, information and instructions are required from the vehicle manufacturer.

The vehicle manufacturer may add specific information here.

9.1. Control units on an electric/hybrid vehicle.

These are vehicle manufacturer specific.

9.2. Summary of fault codes

See DTCs (Diagnostic Trouble Codes of the HV battery producer).

These are vehicle manufacturer specific.

9.3. Equipment

9.3.1. General

It is essential that an employee has the right tools available in order to carry out work on an electric or hybrid vehicle. The tools are prescribed by the vehicle manufacturer.

9.3.2. Tools

Check which specific tools are needed to work on electric/hybrid vehicles.

9.3.3. Measuring instruments

Since hazardous electric voltage is being worked with, the employees must use reliable measuring devices that have been checked beforehand for correct functioning. A multi-meter is not recommended because a correct measurement range is not always selected.

The measuring instruments must comply with all safety norms and must always be set to the correct measurement range. The user instructions provided by the producer must be followed.

9.3.4. Personal protection equipment

- Electro gloves class 0 (suitable to 1000 V)
- Tester for electro gloves (with instructions for use)
10. APPENDICES

- Model of risk analysis for inbound (appendix 1), assembly (appendix 2), repair (appendix 3) and outbound (appendix 4)
- Model of repair procedure (appendix 5)
- Summary of skills for the purpose of being able to work on electric/hybrid vehicles (training plan)
## Appendix 1 – (Inbound (internal handling of supplier -> assembly line))

<table>
<thead>
<tr>
<th>Effect or severity</th>
<th>Exposure frequency E</th>
<th>Probability P</th>
</tr>
</thead>
<tbody>
<tr>
<td>injury</td>
<td>damage [€]</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>minor injury with no lost time</td>
<td>&lt; 250</td>
</tr>
<tr>
<td>3</td>
<td>major injuries with lost time</td>
<td>250 – 2500</td>
</tr>
<tr>
<td>7</td>
<td>seriously, disability, irreversible injury</td>
<td>2500 – 125000</td>
</tr>
<tr>
<td>15</td>
<td>very serious, I dead</td>
<td>125000 – 250000</td>
</tr>
<tr>
<td>40</td>
<td>disaster, some dead</td>
<td>&gt; 2500000</td>
</tr>
<tr>
<td>100</td>
<td>catastrophe, many dead</td>
<td>&gt; 25000000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Date</th>
<th>Issue</th>
<th>Team leader</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Activity or handling

<table>
<thead>
<tr>
<th>Activity or handling</th>
<th>Risks associated with the activity or action</th>
<th>Potential risks resulting from the hazard</th>
<th>Risk-evaluation</th>
<th>Measures to be taken (non-exhaustive list)</th>
<th>Risk-evaluation</th>
<th>Responsible</th>
<th>Date at OK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Handling of traction battery from trailer &amp; internal transport</td>
<td>Damaged component: dropped, impact</td>
<td>Toxic Fumes</td>
<td>3</td>
<td>6</td>
<td>0.5</td>
<td>9</td>
<td>Part handling review (guidelines); Packaging, Training internal transport</td>
</tr>
<tr>
<td>Handling of traction battery from trailer &amp; internal transport</td>
<td>Damaged component: puncture</td>
<td>Fire</td>
<td>40</td>
<td>6</td>
<td>1</td>
<td>240</td>
<td>Investigation of handling equipment, fire protection equipment, Information and training.</td>
</tr>
</tbody>
</table>
| Handling of HV electrical components | residual current on high/traction voltage components | Severe injuries - electrocution through contact with live components | 15 | 6 | 0.5 | 45 | - Equip components with self-discharging device  
- Charge indication on components  
- Short circuit power terminals  
- Training/Instructions |
| Handling of battery storage and line feeding | live battery - unsafe handling process leading to electrical risks | Severe injuries | 15 | 6 | 0.1 | 9 | - Check safety condition of battery  
- Develop measurement process/tool  
- Training |
| Employment of untrained staff | damaging of battery and components Electrocution/legislation/ too late staffing | Accidents-electrocution and fire | 40 | 2 | 1 | 80 | - Identification of trained staff  
- Awareness toward leadership |
| Line feeding of traction battery | Stress due to late delivery to assembly line, damage of component & building/conflict with pedestrians | Incidents/Accidents due to chemical/electrical hazard (weight not included) | 7 | 6 | 0.5 | 21 | - To be studied together with Logistics Engineering  
- Battery fed on conveyor or suitable transportation equipment  
- Training of staff involved  
- Robust packaging |
| No FIFO on bulk material with exceeded storage time | empty batteries to line | Rework (disassembly) will create additional risks: injuries, electrical risk | 7 | 2 | 3 | 42 | - Appropriate logistic process and storage (internal/external)  
- Order traction battery by sequence (JIT) |
| handling (transport, storage, line feeding) | no suitable packing | damaged battery : electrical and mechanical risk; injury | 15 | 2 | 1 | 30 | investigate packaging and handling process (Pieter gives info) |
| handling (transport, storage, line feeding) | insufficient documentation, e.g. labelling, battery storage requirements, fire prevention | incorrect handling (risk of injuries and accidents) | 40 | 6 | 0.5 | 120 | level of general and safety documentation expected. Info to be provided by supplier of batteries |
| handling (transport, storage, line feeding) | lack of resources (poor method work, late or incomplete design input, insufficient staff (and consequently miss start)) | injuries, accidents, rework | 7 | 6 | 1 | 42 | project management and awareness |
### Handling (transport, storage, line feeding)

<table>
<thead>
<tr>
<th>Risk Score</th>
<th>Risk Score</th>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 20</td>
<td>No measures required</td>
<td>Stop work immediately and implement interim measures. Determine the long-term measures.</td>
</tr>
<tr>
<td>20 &lt; R &lt; 70</td>
<td>Attention required</td>
<td>Identify and implement temporary measures immediately. Determine the long-term measures.</td>
</tr>
<tr>
<td>70 &lt; R &lt; 200</td>
<td>Reduce risk</td>
<td>Disable risks or change the system of risk management to achieve an agreement with normal standards of good management</td>
</tr>
<tr>
<td>200 &lt; R &lt; 400</td>
<td>Immediately reduce</td>
<td>Existing measures compared with a conventional management (location in prevention hierarchy). Determine new measures (improving protection and limiting the increased risks).</td>
</tr>
<tr>
<td>R &gt; 400</td>
<td>Stop work</td>
<td>No immediate measures are required</td>
</tr>
</tbody>
</table>

#### Risk Conclusions

<table>
<thead>
<tr>
<th>Risk Score</th>
<th>Conclusions</th>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 20</td>
<td>The risk is insignificant. It is not expected to increase rapidly.</td>
<td>No immediate measures are required</td>
</tr>
<tr>
<td>20 &lt; R &lt; 70</td>
<td>Risk is controlled to an acceptable level, but may increase in the future.</td>
<td>Existing measures compared with a conventional management (location in prevention hierarchy). Determine new measures (improving protection and limiting the increased risks).</td>
</tr>
<tr>
<td>70 &lt; R &lt; 200</td>
<td>Risk that is insufficiently controlled.</td>
<td>Disable risks or change the system of risk management to achieve an agreement with normal standards of good management</td>
</tr>
<tr>
<td>200 &lt; R &lt; 400</td>
<td>Serious risk that is not sufficiently controlled.</td>
<td>Identify and implement temporary measures immediately. Determine the long-term measures.</td>
</tr>
<tr>
<td>R &gt; 400</td>
<td>Very serious risk</td>
<td>Stop work immediately and implement interim measures. Determine the long-term measures.</td>
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</table>
### Appendix 2 - Assembly

<table>
<thead>
<tr>
<th>Effect or severity</th>
<th>Exposure frequency E</th>
<th>Probability P</th>
</tr>
</thead>
<tbody>
<tr>
<td>injury</td>
<td>damage [€]</td>
<td></td>
</tr>
<tr>
<td>1 minor injury with no lost time</td>
<td>&lt; 250</td>
<td>0.5</td>
</tr>
<tr>
<td>3 major injuries with lost time</td>
<td>250 – 2500</td>
<td>1</td>
</tr>
<tr>
<td>7 seriously, disability, irreversible injury</td>
<td>2500 – 125000</td>
<td>2</td>
</tr>
<tr>
<td>15 very serious, 1 dead</td>
<td>125000 – 250000</td>
<td>3</td>
</tr>
<tr>
<td>40 disaster, some dead</td>
<td>&gt; 250000</td>
<td>6</td>
</tr>
<tr>
<td>100 catastrophe, many dead</td>
<td>&gt; 2500000</td>
<td>10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Date</th>
<th>Issue</th>
<th>Team leader</th>
</tr>
</thead>
<tbody>
<tr>
<td>Team members</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Activity or handling</th>
<th>Risks associated with the activity or action</th>
<th>Potential risks resulting from the hazard</th>
<th>Risk-evaluation</th>
<th>Measures to be taken (non-exhaustive list)</th>
<th>Risk-evaluation</th>
<th>Responsible</th>
<th>Date at OK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Junction box connections</td>
<td>Electric hazard &gt; 60 V DC or &gt;25 V AC</td>
<td>Electrocuton, fire, human electrocution</td>
<td>15</td>
<td>10</td>
<td>1</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>Assembly high/low voltage components</td>
<td>Residual current on High/low voltage components</td>
<td>Electrocuton through contact with live components</td>
<td>15</td>
<td>10</td>
<td>1</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>Installation of components during assembly process</td>
<td>Damage to high voltage components in vehicle</td>
<td>Electrocuton, fire, short circuit, injuries</td>
<td>15</td>
<td>10</td>
<td>3</td>
<td>450</td>
<td></td>
</tr>
<tr>
<td>Activity</td>
<td>Description</td>
<td>Risk Factors</td>
<td>Score</td>
<td>Priority</td>
<td>Risk</td>
<td>Likelihood</td>
<td>Significance</td>
</tr>
<tr>
<td>-------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------</td>
<td>-------</td>
<td>----------</td>
<td>------</td>
<td>------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Routing cables</td>
<td>Chafing of high voltage/traction cables against other components</td>
<td>Short circuit/leakage currents, Electrocuton, fire, short circuit,</td>
<td>15</td>
<td>2</td>
<td>3</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>Connection of battery cooling system</td>
<td>Cross connection traction battery water pipes</td>
<td>No cooling, temp rises, battery durability risk, field problems</td>
<td>3</td>
<td>0.5</td>
<td>0.5</td>
<td>0.75</td>
<td></td>
</tr>
<tr>
<td>Connection of cooling circuits</td>
<td>Water leakages, liquid on floor, residual fluid in box</td>
<td>Slipping, sliding</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>Dragging/towing vehicle in case vehicle doesn't start</td>
<td>Vehicle weight/speed</td>
<td>Crushing, hitting operator</td>
<td>7</td>
<td>6</td>
<td>1</td>
<td>42</td>
<td></td>
</tr>
<tr>
<td>Dragging/towing vehicle in case vehicle doesn't start</td>
<td>Regeneration of high/traction voltage</td>
<td>Electrical shocks when repairing</td>
<td>15</td>
<td>6</td>
<td>0.5</td>
<td>45</td>
<td>To be evaluated based/depending on concept</td>
</tr>
<tr>
<td>Mounting electrical components</td>
<td>Accessibility, handling, weight, stiffness</td>
<td>Ergonomic impact,</td>
<td>7</td>
<td>6</td>
<td>6</td>
<td>252</td>
<td>Avoid blind connections, risk of loss of components</td>
</tr>
<tr>
<td>Assembly operations of HV/traction components</td>
<td>Employment of staff with incomplete knowledge/untrained staff/insufficient number of staff</td>
<td>Accidents/injuries</td>
<td>15</td>
<td>10</td>
<td>6</td>
<td>900</td>
<td></td>
</tr>
<tr>
<td>Insufficient labelling of connectors &amp; cables (pole coding)</td>
<td>Cross-connection (e.g. HV battery)</td>
<td>Fire, burns, short circuits, malfunctioning of vehicle</td>
<td>7</td>
<td>6</td>
<td>6</td>
<td>252</td>
<td></td>
</tr>
<tr>
<td>Competence management in assembly process</td>
<td>Added complexity on an already high diversity variant mix</td>
<td>Faults on vehicle, bad quality and injuries</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>No scores. To be evaluated based/depending on concept</td>
</tr>
<tr>
<td>Assembly activity</td>
<td>cables not visually damaged upon electrical activation</td>
<td>sparks, short cut, damaged components, bad quality</td>
<td>1</td>
<td>2</td>
<td>0.5</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Assembly of HV/traction voltage battery</td>
<td>defective battery not possible to verify</td>
<td>Injuries due to extra handling during repair</td>
<td>7</td>
<td>1</td>
<td>3</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>Paint repair finished vehicle</td>
<td>Impact paint repair in oven (high voltage and electrical components)</td>
<td>degradation of components (such as BMS: battery management system)</td>
<td>0</td>
<td>To be evaluated based/depending on concept</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roller bench testing, loading of vehicles</td>
<td>Insufficient ground clearance. Crushing of operator</td>
<td>Injuries,</td>
<td>7</td>
<td>1</td>
<td>3</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>Roller bench testing, loading of vehicles</td>
<td>Insufficient ground clearance. Damage to HV/traction voltage battery</td>
<td>damage to HV/traction voltage battery</td>
<td>7</td>
<td>1</td>
<td>3</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>Test procedure (attention during pilot phase)</td>
<td>Defective components in surrounding area of operator</td>
<td>Injuries caused by damaged components and during rework</td>
<td>0</td>
<td>To be evaluated based/depending on concept</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Handling of battery in assembly and sub-assembly area's</td>
<td>Weight &amp; size</td>
<td>Ergonomics, injuries, damage, crushed limbs</td>
<td>7</td>
<td>10</td>
<td>6</td>
<td>420</td>
<td></td>
</tr>
<tr>
<td>Assembly and sub-assembly operations on HV components, also when building first (pilot) vehicles</td>
<td>Lack of procedures towards operator safety, fault handling.</td>
<td>accidents, errors</td>
<td>15</td>
<td>10</td>
<td>6</td>
<td>900</td>
<td>make HV visual</td>
</tr>
<tr>
<td>Commissioning of vehicle (making test-ready on the line) area insufficiently secured (earth connections assembly chain, equipotentials), distance to other objects &amp; persons</td>
<td>No test procedure available</td>
<td>Electrocution</td>
<td>15</td>
<td>10</td>
<td>0.5</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>Power-up HV/traction voltage system</td>
<td>Damage to Electronic Control Units, burned cables etc. from short circuit to chassis.</td>
<td>Risks of later short circuits or electrocution if damages are not detected (2 insulation faults in series)</td>
<td>15</td>
<td>10</td>
<td>0.5</td>
<td>BMS system. Insulation measurements</td>
<td>75</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>-----------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>-----------------------------------</td>
<td>---</td>
</tr>
<tr>
<td>Automatic charging of HV battery by thermal engine.</td>
<td>Unexpected engine start up (start/stop)</td>
<td>Contact with moving parts (injuries)</td>
<td>7</td>
<td>10</td>
<td>3</td>
<td>210</td>
<td></td>
</tr>
<tr>
<td>Insufficient access restriction in the area’s where activities on high voltage take place (in batch of mixed up?): attention for external personnel such as contractors, external fire service</td>
<td>untrained persons (internal, external)</td>
<td>Unauthorised, untrained persons approach or touch high voltage connections, electrocution</td>
<td>15</td>
<td>2</td>
<td>0.5</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Assembly/connection of wiring to the battery</td>
<td>Safe state of traction battery uncertain/battery date expired</td>
<td>Unsafe process leading to electrical risks/risks during disassembly (repair)</td>
<td>15</td>
<td>6</td>
<td>0.2</td>
<td>18</td>
<td></td>
</tr>
</tbody>
</table>

**Risk score and actions**

<table>
<thead>
<tr>
<th>Risk</th>
<th>Conclusions</th>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>R &lt; 20</td>
<td>The risk is insignificant. It is not expected to increase rapidly.</td>
<td>No immediate measures are required</td>
</tr>
<tr>
<td>20 &lt; R &lt; 70</td>
<td>Risk is controlled to an acceptable level, but may increase in the future. It may be a risk, but there is no evidence that it can lead to illness or injury.</td>
<td>Existing measures compared with a conventional management (location in prevention hierarchy). Determine new measures (improving protection and limiting the increased risks).</td>
</tr>
<tr>
<td>70 &lt; R &lt; 200</td>
<td>Risk that is insufficiently controlled.</td>
<td>Disable risks or change the system of risk management to achieve an agreement with normal standards of good management</td>
</tr>
<tr>
<td>200 &lt; R &lt; 400</td>
<td>Serious risk that is not sufficiently controlled.</td>
<td>Identify and implement temporary measures immediately. Determine the long-term measures.</td>
</tr>
<tr>
<td>R &gt; 400</td>
<td>Very serious risk</td>
<td>Stop work immediately and implement interim measures. Determine the long-term measures.</td>
</tr>
<tr>
<td>Risk Level</td>
<td>Action</td>
<td></td>
</tr>
<tr>
<td>------------</td>
<td>-------------------------</td>
<td></td>
</tr>
<tr>
<td>≤ 20</td>
<td>No measures required</td>
<td></td>
</tr>
<tr>
<td>20 &lt; R ≤ 70</td>
<td>Attention required</td>
<td></td>
</tr>
<tr>
<td>70 &lt; R ≤ 200</td>
<td>Reduce risk</td>
<td></td>
</tr>
<tr>
<td>200 &lt; R ≤ 400</td>
<td>Immediately reduce</td>
<td></td>
</tr>
<tr>
<td>R &gt; 400</td>
<td>Stop work</td>
<td></td>
</tr>
</tbody>
</table>
### Appendix 3 - Repair

<table>
<thead>
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<th>Effect or severity</th>
<th>Exposure frequency E</th>
<th>Probability P</th>
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<tr>
<td>injury</td>
<td>damage [€]</td>
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<td>1 minor injury with no lost time</td>
<td>&lt; 250</td>
<td>very rarely (&lt; once per year)</td>
</tr>
<tr>
<td>3 major injuries with lost time</td>
<td>250 – 2500</td>
<td>rarely (yearly)</td>
</tr>
<tr>
<td>7 seriously, disability, irreversible injury</td>
<td>2500 – 125000</td>
<td>sometimes (monthly)</td>
</tr>
<tr>
<td>15 very serious, I dead</td>
<td>125000 – 250000</td>
<td>occasionally (weekly)</td>
</tr>
<tr>
<td>40 disaster, some dead</td>
<td>&gt; 250000</td>
<td>regularly (daily)</td>
</tr>
<tr>
<td>100 catastrophe, many dead</td>
<td>&gt; 2500000</td>
<td>continuously</td>
</tr>
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<tr>
<th>Date</th>
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<th>Team leader</th>
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<tr>
<td>Activity</td>
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<table>
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<tr>
<th>Activity or handling</th>
<th>Risks associated with the activity or action</th>
<th>Potential risks resulting from the hazard</th>
<th>Risk-evaluation</th>
<th>Measures to be taken (non-exhaustive list)</th>
<th>Risk-evaluation</th>
<th>Responsible</th>
<th>Date at OK</th>
</tr>
</thead>
<tbody>
<tr>
<td>repair activity</td>
<td>Electric hazard &gt; 75 V DC/120V (with/without ripple) DC junction box during fault tracing</td>
<td>Electrocution</td>
<td>15</td>
<td>6</td>
<td>1</td>
<td>90</td>
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</tr>
<tr>
<td>repair activity</td>
<td>Residual current on convertor</td>
<td>Electrocution</td>
<td>15</td>
<td>6</td>
<td>1</td>
<td>90</td>
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<tr>
<td>Repair Activity</td>
<td>Risk Factor</td>
<td>Injuries During Test (Repair and Road Test)</td>
<td>Risk Value</td>
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<td>-----------------</td>
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</tr>
<tr>
<td>Repair of battery cooling system</td>
<td>Cross connection (No cooling, temp rises, battery durability risk)</td>
<td>Injuries during test (repair and road test)</td>
<td>15 1 0.5 7.5</td>
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<tr>
<td>Repair of battery cooling system</td>
<td>Disconnection (No cooling, temp rises, battery durability risk)</td>
<td>Burn injuries</td>
<td>7 1 1 7</td>
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<tr>
<td>Dragging/towing vehicle in case vehicle doesn’t start</td>
<td>Vehicle weight/speed</td>
<td>Crushing, hitting operator</td>
<td>7 6 1 42</td>
<td></td>
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<tr>
<td>Dragging/towing vehicle in case vehicle doesn’t start</td>
<td>Regeneration of high/traction voltage</td>
<td>Electrical shocks when repairing</td>
<td>15 6 0.5 45</td>
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<tr>
<td>Repair activity</td>
<td>Accessibility, handling, weight, stiffness</td>
<td>Ergonomic impact</td>
<td>3 3 3 27</td>
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<tr>
<td>Repair activity</td>
<td>Incomplete knowledge/documentation of how &amp; what is needed to secure training &amp; replacement routines (staffing too late). Procedure lacking</td>
<td>Injuries/electrocution</td>
<td>15 1 1 15</td>
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<td>Dismount high voltage components</td>
<td>Residual current on components Damage of other components due to difficult accessibility</td>
<td>Injuries/electrocution (risk upon arcing?)</td>
<td>15 6 1 90</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>De-energized vehicle</td>
<td>De-energizing process not ok or not performed in correct way</td>
<td>Injuries/electrocution (risk upon arcing?)</td>
<td>15 6 1 90</td>
<td></td>
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</tr>
<tr>
<td>Issue</td>
<td>Description</td>
<td>Weight</td>
<td>Size</td>
<td>Stiffness</td>
<td>Additional Details</td>
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<tr>
<td>Difficult routing &amp; clipping of cables (non high voltage) weight,</td>
<td>Loose cables, chafing, ergonomics</td>
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<td>2</td>
<td>0.5</td>
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<td></td>
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<tr>
<td>size, stiffness</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Repairability and impact of certain repairs unclear</td>
<td>different competence levels based on repair activity)</td>
<td>15</td>
<td>6</td>
<td>1</td>
<td>injuries/electrocution (risk upon arcing?)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insufficient labelling of connectors &amp; cables (coding)</td>
<td>cross connection (e.g. HV battery)</td>
<td>7</td>
<td>0.5</td>
<td>6</td>
<td>fire, burns, short circuits, malfunctioning of vehicle</td>
<td></td>
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<tr>
<td>Competence management in repair process</td>
<td>added complexity on an already high diversity variant mix</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>no scores. To be evaluated based/depends on concept</td>
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<tr>
<td>State of charge; what to do for vehicles standing in yard for long</td>
<td>Non starting vehicle</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>time</td>
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<td></td>
<td>no scores. To be evaluated based/depends on concept</td>
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<td>paint repair finished vehicle</td>
<td>impact paint repair in oven (high voltage and electrical components)</td>
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<td></td>
<td></td>
<td>degradation of components (such as BMS: battery management system)</td>
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<tr>
<td>Dragging/towing vehicle in case vehicle doesn't start</td>
<td>Vehicle weight/speed</td>
<td>7</td>
<td>6</td>
<td>1</td>
<td>Crushing, hitting operator</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dragging/towing vehicle in case vehicle doesn't start</td>
<td>Regeneration of high/traction voltage</td>
<td>15</td>
<td>6</td>
<td>0.5</td>
<td>Electrical shocks when repairing</td>
<td></td>
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</tr>
<tr>
<td>Activity Description</td>
<td>Risk Description</td>
<td>Score</td>
<td>Rating</td>
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<td>------------------------------------------------------------------------------------</td>
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<td>-------</td>
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<tr>
<td>Automatic charging of HV battery by thermal engine.</td>
<td>Unexpected engine start up (start/stop)</td>
<td>7</td>
<td>10</td>
<td>3</td>
<td>210</td>
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<tr>
<td>Repair activity on/around high voltage cooling ventilator</td>
<td>Automatic start-up of cooling system</td>
<td>7</td>
<td>6</td>
<td>1</td>
<td>42</td>
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<tr>
<td>Repair activities by unauthorised personnel/visitors</td>
<td>Insufficient access; restriction in the area where activities on high voltage take place; attention for external people such as contractors, external fire service</td>
<td>15</td>
<td>3</td>
<td>3</td>
<td>155</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Missing parts related to high voltage components on vehicles</td>
<td>Incorrect protective measures when putting truck into yard.</td>
<td>15</td>
<td>1</td>
<td>1</td>
<td>15</td>
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<tr>
<td>Repair/replacement power cables</td>
<td>Power cables damaged during repair process</td>
<td>7</td>
<td>1</td>
<td>1</td>
<td>7</td>
<td></td>
<td></td>
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<tr>
<td>Driving vehicle</td>
<td>Missing vehicle noise</td>
<td>7</td>
<td>10</td>
<td>1</td>
<td>70</td>
<td></td>
<td></td>
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<tr>
<td>Repair activities in isolated condition by 1 operator</td>
<td>No scores. To be evaluated based/depends on each activity mentioned above</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Repair activity on air-conditioning system (flammable gasses)</td>
<td>Flammable gasses</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Exposure</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>electric/hybrid vehicles in &quot;EX&quot; area's</td>
<td>flammable gasses</td>
<td>exposure</td>
<td>actions</td>
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<td></td>
<td></td>
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<tr>
<td>----------------------------------------</td>
<td>------------------</td>
<td>----------</td>
<td>---------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>welding activities on finished vehicles</td>
<td>heating HV battery, damage of HV components, cables</td>
<td>insulation failures, field claims</td>
<td>no scores. To be evaluated based/depends on each activity mentioned above</td>
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**Risk**

<table>
<thead>
<tr>
<th>Risk</th>
<th>Conclusions</th>
<th>Actions</th>
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<tbody>
<tr>
<td>$R &lt; 20$</td>
<td>The risk is insignificant. It is not expected to increase rapidly.</td>
<td>No immediate measures are required</td>
</tr>
<tr>
<td>$20 &lt; R &lt; 70$</td>
<td>Risk is controlled to an acceptable level, but may increase in the future. It may be a risk, but there is no proof that it may lead to illness or injury.</td>
<td>Existing measures compared with a conventional management (location in prevention hierarchy). Determine new measures (improving protection and limiting the increased risks).</td>
</tr>
<tr>
<td>$70 &lt; R &lt; 200$</td>
<td>Risk that is insufficiently controlled.</td>
<td>Disable risks or change the system of risk management to achieve an agreement with normal standards of good management</td>
</tr>
<tr>
<td>$200 &lt; R &lt; 400$</td>
<td>Serious risk that is not sufficiently controlled.</td>
<td>Identify and implement temporary measures immediately. Determine the long-term measures.</td>
</tr>
<tr>
<td>$R &gt; 400$</td>
<td>Very serious risk</td>
<td>Stop work immediately and implement interim measures. Determine the long-term measures.</td>
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</table>

**Risk score and actions**

<table>
<thead>
<tr>
<th>Risk score and actions</th>
<th>Actions</th>
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<tr>
<td>No measures required</td>
<td>$R &lt; 20$</td>
</tr>
<tr>
<td>Attention required</td>
<td>$20 &lt; R &lt; 70$</td>
</tr>
<tr>
<td>Reduce risk</td>
<td>$70 &lt; R &lt; 200$</td>
</tr>
<tr>
<td>Immediately reduce</td>
<td>$200 &lt; R &lt; 400$</td>
</tr>
<tr>
<td>Stop work</td>
<td>$R &gt; 400$</td>
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## Appendix 4 – Outbound -> assembly line -> parking factory ready to transport to client

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<tr>
<th>Effect or severity</th>
<th>Exposure frequency E</th>
<th>Probability P</th>
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<tr>
<td>injury</td>
<td>damage [€]</td>
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<tr>
<td>1</td>
<td>&lt; 250</td>
<td>0.5</td>
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<tr>
<td>3</td>
<td>250 – 2500</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>2500 – 125000</td>
<td>2</td>
</tr>
<tr>
<td>15</td>
<td>125000 – 250000</td>
<td>3</td>
</tr>
<tr>
<td>40</td>
<td>&gt; 250000</td>
<td>6</td>
</tr>
<tr>
<td>100</td>
<td>&gt; 2500000</td>
<td>10</td>
</tr>
<tr>
<td>minor injury with no lost time</td>
<td>very rarely (&lt; once per year)</td>
<td>hard to imagine</td>
</tr>
<tr>
<td>major injuries with lost time</td>
<td>rarely (yearly)</td>
<td>practically impossible</td>
</tr>
<tr>
<td>seriously, disability, irreversible injury</td>
<td>sometimes (monthly)</td>
<td>unlikely but possible in borderline cases</td>
</tr>
<tr>
<td>very serious, l dead</td>
<td>occasionally (weekly)</td>
<td>unusual</td>
</tr>
<tr>
<td>disaster, some dead</td>
<td>regularly (daily)</td>
<td>quite possible 1 to 2 times</td>
</tr>
<tr>
<td>catastrophe, many dead</td>
<td>continuously</td>
<td>expected at each exposure</td>
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<table>
<thead>
<tr>
<th>Date</th>
<th>Issue</th>
<th>Team leader</th>
</tr>
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<th>Team members</th>
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<table>
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<tr>
<th>Activity</th>
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<tr>
<th>Activity or handling</th>
<th>Risks associated with the activity or action</th>
<th>Potential risks resulting from the hazard</th>
<th>Risk-evaluation</th>
<th>Measures to be taken (non-exhaustive list)</th>
<th>Risk-evaluation</th>
<th>Responsible</th>
<th>Date at OK</th>
</tr>
</thead>
<tbody>
<tr>
<td>transfer of ok vehicles from assembly area to ok vehicle yard (ready for shipment)</td>
<td>collision, non-starting vehicle</td>
<td>injuries,</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>load vehicle on to trailer/train/boat</td>
<td>vehicle stuck/immobilized on loading platform</td>
<td>damaged components/ injuries</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>outbound handling (i.e. load vehicle on to trailer, park for long period)</td>
<td>Incomplete knowledge of how &amp; what is needed to secure training &amp; replacement routines</td>
<td>to be evaluated depending on design</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>driving vehicle</td>
<td>missing of vehicle noise</td>
<td>collision with pedestrians</td>
<td>7</td>
<td>10</td>
<td>1</td>
<td>70</td>
<td>use hazard lights</td>
</tr>
<tr>
<td>employment of untrained staff</td>
<td>collision</td>
<td>accidents</td>
<td>7</td>
<td>2</td>
<td>6</td>
<td>84</td>
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<table>
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<tr>
<td>R &lt; 20</td>
<td>The risk is insignificant. It is not expected to increase rapidly.</td>
<td>No immediate measures are required</td>
</tr>
<tr>
<td>20 &lt; R &lt; 70</td>
<td>Risk is controlled to an acceptable level, but may increase in the future. It may be a risk, but there is no evidence that it can lead to illness or injury.</td>
<td>Existing measures compared with a conventional management (location in prevention hierarchy). Determine new measures (improving protection and limiting the increased risks).</td>
</tr>
<tr>
<td>70 &lt; R &lt; 200</td>
<td>Risk that is insufficiently controlled.</td>
<td>Disable risks or change the system of risk management to achieve an agreement with normal standards of good management</td>
</tr>
<tr>
<td>200 &lt; R &lt; 400</td>
<td>Serious risk that is not sufficiently controlled.</td>
<td>Identify and implement temporary measures immediately. Determine the long-term measures.</td>
</tr>
<tr>
<td>R &gt; 400</td>
<td>Very serious risk</td>
<td>Stop work immediately and implement interim measures. Determine the long-term measures.</td>
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**Risk score and actions**
<table>
<thead>
<tr>
<th></th>
<th>No measures required</th>
<th>Attention required</th>
<th>Reduce risk</th>
<th>Immediately reduce</th>
<th>Stop work</th>
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<td>70 &lt; R &lt; 200</td>
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<tr>
<td>R &gt; 400</td>
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</tbody>
</table>
Appendix 5 – High Voltage Vehicles Workflow

Injuries, accidents, rework electric/hybrid HV

Risk Analysis
Repair completed?

N

Execute Risk Analysis
Level 3

Define qualification level by level 3

Info risks & preventive actions level 3 -> level 1 & 2

Implement safety precautions

Yes

Start the commissioning

repair by level 1, 2 or 3

commissioning by level 3

release vehicle

No

rework by level 1 and 2 optional level 3
LITERATURE REFERENCES


2 Inflationdata.com (http://inflationdata.com) Historical Crude Oil Prices (Table), Updated January 19, 2012.


