



Safety, Tools & Hazard Management

Diagnostics of EVs & HEVs · Topic 2 — working safely on high-voltage vehicles

BSc Sustainable Transportation · Year 4, Semester 7 · 6 ECTS

Sustainable Transportation within the Framework of Green Deal - SPHERE

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WHY THIS MATTERS

Safety first — the voltages can kill

The blunt truth

The AC or DC voltages used on electric vehicles can kill, have killed, and will kill again. EV traction batteries and motors carry high electrical and magnetic potential that can severely injure or kill if mishandled.

Two rules that keep you safe

- 1 Use common sense — don't fool about.
- 2 If in doubt, stop and seek help.

Traction voltages have only climbed

144 V

Honda Insight

201.6 V

Toyota Prius (2004)

400 V

Typical EV today

up to 700 V+

High-performance

AGENDA

What we will cover today

1

The hazard landscape

General vehicle risks and what makes EVs uniquely dangerous

2

Electricity & the body

Voltage classes, AC vs DC, electric shock, arc flash

3

Personal protection

PPE, insulating gloves, identifying high-voltage parts

4

Isolate & prove dead

The non-live state and the structured safe-work process

5

Hazard management

Work categories, first response, EV fire & thermal runaway

6

Tools & competence

Insulated tools, CAT-rated meters, regulations & qualification



One principle above all

Never work on a live high-voltage system. Isolate it, secure it against reconnection, and prove it dead — every time.

THE HAZARD LANDSCAPE

General risks on any vehicle

Before the EV-specific hazards, remember the risks present on every vehicle — and how to reduce them:



Electric shock

Insulated tools; only work on HV systems if trained



Battery acid

Corrosive; use overalls, gloves, goggles, apron



Raising vehicles

Chock wheels, use axle stands, lift on strong points



Running engines

No loose clothing; keep the key on you



Exhaust gases

Extract fumes indoors — CO and carcinogens



Short circuits

Disconnect battery; very high current burns



Fire

No smoking; mind the heat–fuel–oxygen triangle



Manual handling

Lift only what is comfortable; use aids

THE HAZARD LANDSCAPE

What makes EVs different

Electrification adds hazards that a conventional vehicle simply does not have:

**Lethal high voltage**

HV components and orange cabling can deliver a fatal shock

**Stored energy**

Capacitors and the pack retain dangerous voltage even when 'off'

**Silent movement**

Electric drive is silent — the vehicle can move unheard

**Magnetic fields**

Motor magnets can disturb pacemakers and medical devices

**Battery chemistry**

Damaged cells can release gases, heat or catch fire

**Unexpected motion**

Magnetic forces or drive wheels can move the car

ELECTRICITY & THE BODY

Low voltage vs high voltage

'High voltage' is a defined term. The IEC classifies supply-system voltages as:

IEC class	AC	DC	Defining risk
High voltage	> 1000 Vrms	> 1500 V	Electrical arcing
Low voltage	50–1000 Vrms	120–1500 V	Electric shock
Extra-low voltage	< 50 Vrms	< 120 V	Low risk



For electric vehicles specifically (UN Reg. 100):

'High voltage' = a working voltage > 60 V and ≤ 1500 V DC, or > 30 V and ≤ 1000 V AC (rms). Treat anything above the familiar 12 V / 24 V as dangerous.

ELECTRICITY & THE BODY

AC vs DC — how each affects you

Alternating current (AC)

- ▶ Causes repeated muscle contractions — can freeze the hand to the source, prolonging exposure
- ▶ Strong tendency to throw the heart into fibrillation
- ▶ Mains-frequency AC (50/60 Hz) is ~3–5× more dangerous than DC of the same voltage
- ▶ Fibrillation typically from ~30 mA (rms); let-go current ≈ 22 mA

Direct current (DC)

- ▶ Causes a single strong contraction — often throws the victim clear of the source
- ▶ Tends to stop the heart rather than fibrillate it
- ▶ Needs more milliamps than AC to be fatal at the same voltage
- ▶ Fibrillation typically from ~300–500 mA; let-go current ≈ 88 mA

Both kill. EV traction systems are DC at the battery, switched to AC for the motor — you face both.

ELECTRICITY & THE BODY

Electric shock — what determines the danger

An electric shock affects the muscular, circulatory and respiratory systems and can cause severe burns. Severity depends on:



Current magnitude

It is the current — not the voltage — that injures



Duration

A small current for a long time can still be fatal



Path through body

Hand-to-hand or hand-to-foot across the heart is worst



Body resistance

Sweaty or wet skin lowers resistance → higher current



Contact area & pressure

Larger, firmer contact lets more current flow



Frequency

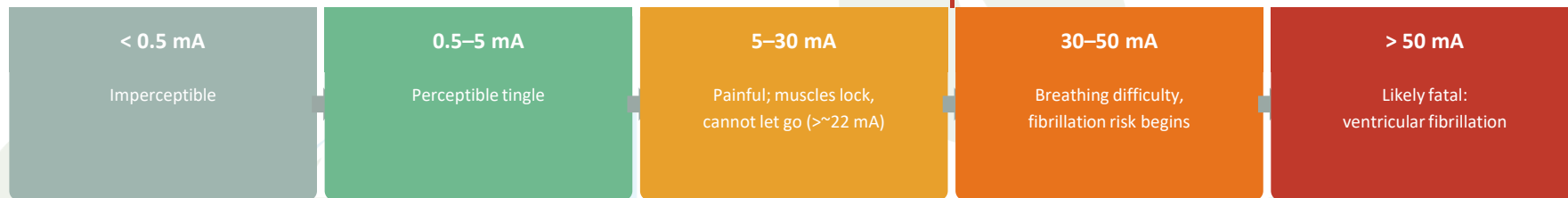
Low-frequency mains AC is especially hazardous

Because $\text{current} = \text{voltage} \div \text{resistance}$, voltage matters only insofar as it drives current. Survival limits: $\sim 0.2 \text{ s}$ at 500 mA , $\sim 2 \text{ s}$ at 50 mA .

ELECTRICITY & THE BODY

Current severity — the 30 mA threshold

Effect of AC current passing through the body (hand to feet), after IEC 60479-1:



← 30 mA: RCD trip point →

Why this number matters

- ▶ Above ~30 mA AC through the body, death is likely unless the current is interrupted quickly
- ▶ This is exactly why residual current devices (RCDs) trip at ~30 mA — fast enough to prevent death
- ▶ Duration counts: shorter exposure shifts the boundary; an RCD removes the current in milliseconds

ELECTRICITY & THE BODY

Beyond shock — arc flash, burns & fire

Careless work on electrical systems at any voltage can cause far more than a shock:



Arc flash

Light and heat from an electric arc — temperatures hotter than the Sun's surface, intense radiation and vaporised metal. Even a welding arc liquefies steel at ~24 V DC.



Arc blast

The pressure wave from a high-voltage arc: deafening noise, a concussive shock front and super-heated shrapnel.



Resistive burns

Current heating tissue causes deep burns; damaging temperatures are reached in seconds.



Fire, explosion & gases

Shorts and damaged cells can ignite; batteries can release explosive gases, fumes and chemicals.

PERSONAL PROTECTION

PPE for high-voltage work

Beyond normal workshop PPE, HV work requires:

- ▶ **Electrical safety gloves** rated insulating gloves — NOT ordinary work gloves
- ▶ **Eye protection** goggles when required
- ▶ **Protective footwear** rubberised soles, non-metallic toe caps
- ▶ **Overalls** with non-conductive fasteners

Insulating glove classes (EV-relevant)

- ▶ **Class 00** max 500 V AC / 750 V DC — adequate
- ▶ **Class 0** max 1000 V AC / 1500 V DC — recommended (voltages keep rising)
- ▶ **Class 1** max 7500 V AC / 11,250 V DC — heavy HV



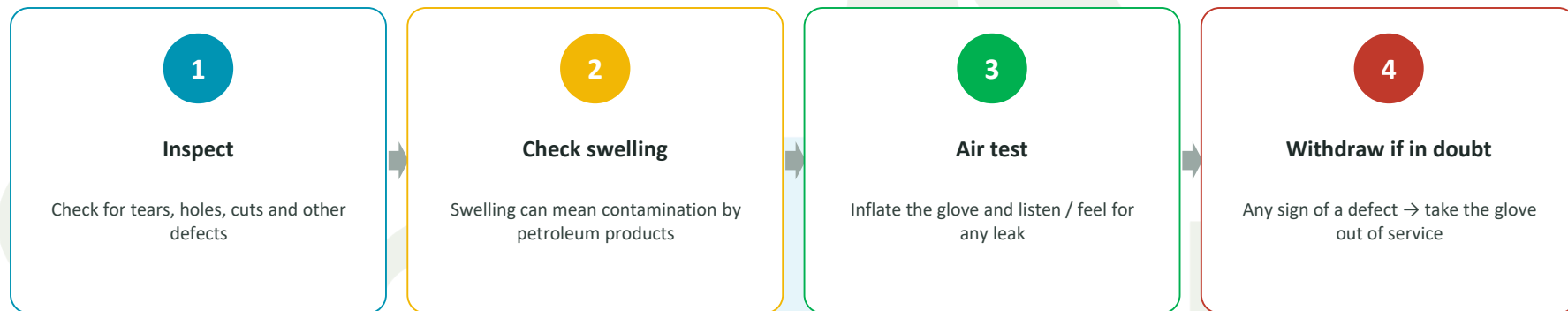
Gloves are your last line of defence

They protect you while you isolate and verify — they are not a licence to work live. Class 0 is the practical choice for modern EV voltages.

PERSONAL PROTECTION

Inspect your gloves — every time

Insulating gloves only protect you if they are intact. Before every use:



Store insulating gloves correctly and re-test them periodically. A glove that has been compromised by oil, a nick, or UV ageing can fail silently — and you will not get a warning. The air (inflation) test is quick: trap air in the glove and check that it holds.

PERSONAL PROTECTION

Identifying high-voltage parts

You cannot avoid what you cannot identify. High-energy parts are flagged three ways:

**Colour**

High-voltage cables are always ORANGE

**Warning symbols**

Hazard triangles and the HV lightning symbol

**Warning signs & labels**

Danger stickers on covers and components

Orange = high voltage. Never disturb it without isolating first.



Most HV components are combined in a sealed metal power unit — often behind the rear seats or under the floor (the entire floor in some vehicles).



If you see orange, assume it is live until you have proven otherwise.

ISOLATE & PROVE DEAD

The non-live state — three steps

Never work on live HV parts. A safe, non-live state is achieved by three steps — in order:

1 · Isolate

Switch off ignition; remove the service plug / maintenance connector or main battery switch; remove LV fuses/battery where appropriate.

2 · Safeguard

Remove and secure the key; lock away the service plug; prevent any unauthorised reconnection (lockout).

3 · Verify dead

Using a manufacturer-approved tester, prove the system is dead. Until verified, assume it is LIVE.



Lock-off and prove dead. Even an isolated battery is still live internally, and components can retain dangerous voltage. Verification — not assumption — is what makes the system safe to touch.

SAFE WORK PROCESS

Stage 1 — before work starts

Denton frames the safe-work process in four stages. Stage one prepares the safe state:

- ▶ Take protective measures against shock, short-circuit and arc before any work begins
- ▶ Turn OFF the ignition and remove the key
- ▶ Switch off the battery module switch or de-energise the system
- ▶ Wait at least 5 minutes so storage capacitors can discharge
- ▶ Confirm the junction-board / bus voltage has fallen to near 0 V
- ▶ Apply the three-step rule: Isolate → Safeguard → Verify dead

The 5-minute rule

After isolating, the wait lets capacitors bleed down. Don't skip it — a charged capacitor can deliver a shock long after the battery is disconnected. Only when the bus reads ~0 V and you have proven dead is it safe to proceed.

SAFE WORK PROCESS

Stage 2 — during work

- ▶ Remember: a disconnected battery is still live — treat it with full respect
- ▶ Prevent shorts to earth and between components, even disconnected ones
- ▶ Shroud or cover adjacent live parts before working nearby
- ▶ Always wear suitable PPE (insulating gloves) for the system voltage
- ▶ Use insulated tools for all service procedures on the HV system — this prevents accidental short-circuits
- ▶ Keep untrained people away from the work area

Key fact: a battery that has been disconnected still holds its full voltage internally. 'Disconnected' is not 'safe'. Insulated tools and gloves are what stand between you and a short across hundreds of volts.

SAFE WORK PROCESS

Stage 3 — interruption of work

If you must stop part-way through — with HV components uncovered or disassembled — leave the vehicle in a guaranteed-safe state:



Keep it de-energised

The vehicle stays isolated and de-energised throughout the interruption



Ignition off, key removed

No way to re-energise the system while you are away



Battery switch / plug stays off

Service connector or battery module switch remains disconnected



No unsupervised access

Keep untrained people out to prevent any unintended contact

SAFE WORK PROCESS

Stage 4 — completion & re-energising

Before re-energising after repairs are complete, confirm every point below:

- ▶ All tools, materials and equipment removed from the work and hazard area
- ▶ Guards refitted and warning signs removed
- ▶ All terminals tightened to the specified torque
- ▶ No HV wires or terminals damaged or shorted to the body
- ▶ Insulation resistance checked between each HV terminal you disturbed and the vehicle body

Only then **lift the lock-off and re-energise**. Working on EVs is not dangerous IF these guidelines and the manufacturer's procedures are followed — but always check the latest data and never take chances.

ISOLATE & PROVE DEAD

Stored energy — the hidden hazard



'Off' does not mean 'safe'

Some electronic components store dangerous amounts of energy even when the vehicle is off and the battery isolated. Capacitors can hold a lethal charge; the pack retains its full voltage internally. Always wait, verify, and follow manufacturer data on discharging stored energy.

Practical consequences

- ▶ Wait the specified time (≈ 5 min) for capacitors to bleed down
- ▶ Confirm the bus voltage has fallen to ~ 0 V
- ▶ After a collision, full isolation may be impossible — follow maker's instructions
- ▶ Only suitable insulated tools and approved testers go near the system
- ▶ Never assume — verify dead before contact

ISOLATE & PROVE DEAD

Circuit protection devices

Indirect protection against excess current and shock uses four devices:

Fuse

A deliberate weak link — a metal element that melts and breaks the circuit when current is too high.

MCB

Miniature circuit breaker — does a fuse's job but trips faster and resets by a switch; thermal or magnetic.

RCD

Residual current device — detects current leaking to an unintended path (e.g. through a person) and cuts power fast.

RCBO

RCD + overload protection in one — protects life against leakage AND protects the circuit against overload.

First-line (direct) protection still comes first: enclosure (keep things covered), insulation (orange), and location to prevent accidental contact.

HAZARD MANAGEMENT

Four categories of work

Risk and required competence rise with the category of work (after HSE guidance):



1 · Valeting & sales

Lower-risk activities. Keep remote keys away so the vehicle can't power up or move; mind silent movement; avoid pressure-washing HV parts.



2 · Incident response

Emergency services & recovery. Visually check for damage; isolate the HV system if safe; remove the key; avoid towing unless proven safe.



3 · Maintenance (non-HV)

Repairs not on HV systems. Keys locked away; visually check orange cabling; isolate the HV battery unless the task needs it energised.



4 · Working on HV systems

The highest tier. Isolate, secure, and prove dead before any work; trained & competent personnel only.

HAZARD MANAGEMENT

Initial assessment & first response

First responders carry out a visual risk assessment, wearing personal protection, before acting.

People who may be at risk

- ▶ Vehicle occupants
- ▶ On-lookers and bystanders
- ▶ Recovery personnel
- ▶ Emergency-service personnel

May require evacuation and site protection.

A fire- or impact-damaged EV can present:

- ▶ Electric shock
- ▶ Burns
- ▶ Arc flash and arc blast
- ▶ Fire
- ▶ Explosion
- ▶ Chemicals
- ▶ Gases and fumes

HAZARD MANAGEMENT

EV fire & thermal runaway

Battery fires behave differently from fuel fires and demand specific tactics.

Thermal runaway

A rising cell temperature changes conditions so as to drive a further temperature rise — uncontrolled positive feedback that can become destructive. A pack fault can self-propagate into a fire.

Fighting a battery fire

- ▶ Needs a large, sustained volume of water
- ▶ Water/standard agents pose no electrical hazard to firefighters
- ▶ Li-ion packs can re-ignite after extinguishing — monitor with thermal imaging
- ▶ Leave a battery fire to the Fire Brigade

Also remember: a fire can defeat the vehicle's built-in anti-electrocution measures — normally-open HV relays can fail closed if heat-damaged. If there is no threat to life or property, a battery fire is often best allowed to burn out under monitoring.

TOOLS & COMPETENCE

Insulated tools & HV test equipment

Only suitable, rated tools and test equipment go near a high-voltage system.



Insulated hand tools

Electrically insulated tools compliant with GS38 — prevent accidental shorts across the bus



Voltage tester / DMM

To prove the system dead; must be category-rated for the voltage (see next slide)



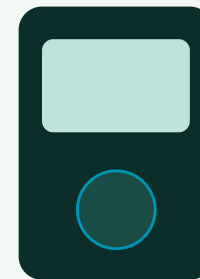
Insulation tester (Megger)

Applies a high test voltage to stress insulation and reveal faults an ohmmeter would miss



Inductive amp clamp

Measures current without breaking the circuit — safer on HV cables, less accurate at low values



Use the right instrument

An insulation tester's high test voltage will not kill you — it cannot sustain current — but it still hurts. Handle it with care.

TOOLS & COMPETENCE

Meter CAT ratings — choose correctly

A meter's CAT rating is its safe 'voltage-withstand' category, including transient surges. For EV HV work, use CAT III or CAT IV meters AND leads.

Category	Where it applies
CAT I	Protected electronics; signal level
CAT II	Single-phase receptacle-connected loads
CAT III	Distribution / fixed installation — and EV HV systems
CAT IV	Origin of supply; highest transient energy

Rule of thumb

Pick a meter rated to the highest category it could possibly meet — err on the side of safety. A higher category withstands bigger transient surges, which matters more than the headline voltage number.

Within a category, a higher working voltage also means a higher transient rating — but never compare across categories on voltage alone; source impedance differs.

TOOLS & COMPETENCE

Proving dead — measurement good practice

- ▶ Always test and prove a HV cable or component is dead before working on it
- ▶ **Voltage** connect the meter in parallel; most EV measurements are DC
- ▶ **Resistance** isolate the circuit first, or you will damage the meter
- ▶ **Current** break the circuit in series, or use an inductive clamp (safer on HV)
- ▶ Use a meter with high input impedance ($\geq 10\text{ M}\Omega$) to avoid loading or damaging circuits

Beware the 'ghost' voltage

A high-impedance voltmeter can show a phantom reading from capacitive coupling when the leads are open — and it also reads 0 V before connection. So how do you trust a 0 V reading?

Shake the leads: a ghost voltage fluctuates, a real voltage does not. Better still, prove the tester on a known live source first, then on your circuit, then live again.

TOOLS & COMPETENCE

Regulation, competence & qualification



Trained personnel only

Only work on HV EV/HEV systems if you are trained and competent in them. Knowledge or supervision is a legal requirement.



Electricity at Work 1989

UK regulations require competence to prevent danger when working on electrical systems (Reg. 3, 16, 29).



IMI TechSafe™

Professional registration scheme ensuring technicians are qualified and keep competence current through annual CPD.



COSHH

Control of Substances Hazardous to Health — governs handling of hazardous battery chemicals and leakage.

WRAP-UP

Key takeaways

- 1 EV voltages can kill — treat anything above 12/24 V as dangerous; high voltage starts at 60 V DC / 30 V AC.
- 2 It is current and duration that injure; ~30 mA AC is the danger threshold and the reason RCDs trip there.
- 3 Identify high voltage by orange cabling, symbols and labels — and assume it is live until proven dead.
- 4 Never work live: Isolate → Safeguard against reconnection → Verify dead. Mind stored energy in capacitors.
- 5 Follow the four-stage process — before, during, interruption, after — and use insulated, CAT III/IV tools.
- 6 Only trained, competent people work on HV systems; manage hazards including thermal-runaway fire.

SOURCES

References & further reading

Primary reference for this topic

T. Denton

Electric and Hybrid Vehicles, 2nd ed., Taylor & Francis, 2020 — Chapter 2: Safe working, tools and hazard management.

Supporting references & standards

- ▶ I. Husain — Electric and Hybrid Vehicles: Design Fundamentals, 3rd ed., CRC Press, 2021
- ▶ A. Khajepour, S. Fallah, A. Goodarzi — Electric and Hybrid Vehicles: Technologies, Modeling and Control, Wiley, 2014
- ▶ IEC 60479-1 — Effects of current on human beings and livestock; IEC 61010 — safety of measuring equipment
- ▶ UN Regulation No. 100 — electric powertrain safety; UK Electricity at Work Regulations 1989; HSE & IMI TechSafe guidance

Illustrations in this deck are original recreations of concepts described in the references, not reproductions of published figures.

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Thank you for your attention!

A large, faded version of the SPHER2 logo, serving as a background for the slide. It includes the word "SPHER2" in a light blue/grey font, with a green leaf icon above the "H" and a blue lightning bolt icon above the "E".