ESO safety training for work on vehicles with high-voltage systems

Society of Automotive Engineers of Japan, Inc.

Introduction

- As part of the safety training for the EV class of the Formula SAE Japan Competition organized by the Society of Automotive Engineers of Japan, ESO training will be provided. **ESOs of EV Class participating teams must review the training materials provided by the organizer, pass the web-based test with the required score.**
  The purpose of this examination is to enhance safety knowledge and does not certify qualification by the Society.

- This slide provides important knowledge and procedures for working safely.
  It is recommended that not only ESOs (Electrical System Officers), ESAs (Electric System Advisors) and FAs (Faculty Advisors), but also **all team members involved in the design and work, understand how to work safely from this document**.

- Work on vehicles containing storage low voltage batteries with ground voltages exceeding 50 volts is designated as "dangerous or hazardous work", and operators are required to provide the specified special training when workers are engaged in dangerous or hazardous work (Industrial Safety and Health Act under the Japanese Law).
  This document is an excerpt of the above special training and in addition applies it to the unique structure of vehicles used in the Formula SAE Japan Competition organized by the Society of Automotive Engineers of Japan, Inc.

Explanation of terminology

- Voltage of 750 V DC or lower is classified as "low voltage" under Japanese Law.
  However, note that the term "High Voltage" is used in accordance with the terminology used in the latest Formula SAE® Rules to clarify the difference from low-voltage circuits that are driven by 12V/24V.

ESO's role in safe operations?

The ESO is the person **responsible for the safety management of with directly directing the high-voltage work**

SAE Rule EV.11.1.1

- Is the only person on the team that may declare the vehicle electrically safe to allow work on any system
- Must accompany the vehicle when operated or moved at the competition site

The ESO’s need to know the role and responsibilities from this document.

Teams need to be able to electrical work safely.
All team members should aim to work safely.

What about members taking risks?

- No or little supervision
- No safe procedures
- Neglect, poor risk awareness
- Human error, misjudging

One person's risky behavior puts everyone at risk

Team's responsibilities "Create a culture of working safely"

- Ensure that mistakes do not lead to accidents
- Share knowledge of possible risks among team members and work without fear

Members have to aspire to safety to carry out your responsibilities.

ESOs direct your members based on knowledge and information.

Team's responsibility
"Organizing safe work under HV risks"

HV: high-voltage

Responsibilities of ESO

- Direct the work directly
- Prevent deviations from predetermined safe procedures
- Gather information and make improvements to prevent accidents

This text provides

Knowledge required for safe work
- Components, vehicle systems
- High-voltage risks
- Rules, protective equipment

ESO will be given・・・

Progressive information from work
- Worker's personality & health
- Conversation between members
- Status of tasks

ESO need to understand what is going on

Responsibilities of all members

- Follow the rules to prevent accidents
- Work together to prevent disasters
  - Report accidents, near misses, and hazards promptly
  - Learn what they need to know about the work

Always follow the rules set by the team for the safety of all members

Structure of this text

The text addresses the following chapters on the three required topics on HV work

- Competence of members
  competence: Ability to work
  - Hazards of working with high voltage (chapter 1)
  - Knowledge of EV systems and components (chapter 2)
  - Knowledge of protective equipment (chapter 3)
  - Rules for working with high voltage (chapter 4)
  - Examples of past troubles (Chapter 5)
  - First aid in case of incident (Chapter 6)
- Procedure of the work
  - Knowledge of systems and electrical wiring specific to the team's vehicle
  - Actual procedures to avoid possible risks
  - Safety for EV Work (Chapter7)
- Personal protective equipment and other equipment to be used (chapter-3)

Contents

Chapter 1

Low Voltage Electricity Hazard

(Low-voltage in Japanese Law is “≤750V DC, ≤600V AC”)

Classification of electricity

Electricity is classified into "low voltage“, “high voltage" and "special high voltage" according to DC/AC and voltage magnitude.
(Industrial Safety and Health Regulations Article 36, Japanese Law)

In Formula SAE EVs, the battery voltage is DC 60V~600V, so it is classified as "low voltage".

In chapter 2 following chapters, circuits below 750Vdc are defined as “high-voltage” circuit to distinguish them from “low-voltage” circuit (12V/24Vdc).
(”The latest Formula SAE® Rules” terminology compliant)

	DC	AC
Low Voltage	750V or less	600V or less
High Voltage	over750V～7,000V or less	over600V～7,000V or less
Extra High Voltage	Over 7,000V	

Industrial Safety and Health Regulations Article 36

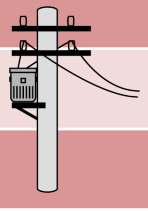
Electric Shock

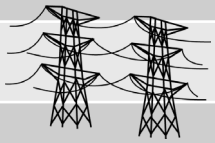
More than 10 deaths due to electric shock occur every year.
The highest number of accidents occurs at low voltage range such as 100 V and 200 V.
You must work very carefully in Formula SAE EV.

Number of deaths and ratio from electric shock per voltage range (2006~2010)

(Unit : person)

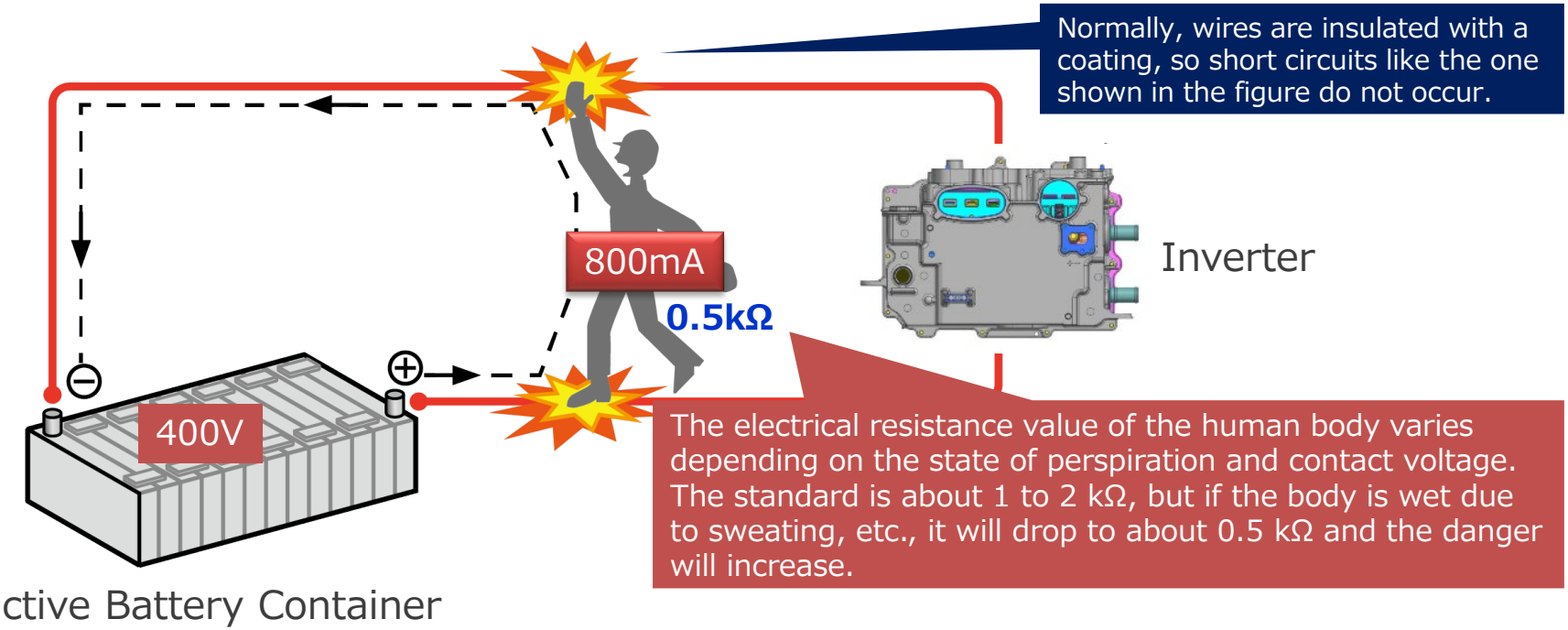
Year	Voltage range		Lightning Strike	Total
	Low Voltage ≤750Vdc, ≤600Vac	High Voltage & Extra High Voltage		
2006	15	3	1	19
2007	9	5		14
2008	10	10	1	21
2009	11	3		14
2010	11	2		13
Total	56	23	2	81
Ratio	69%	28%	3%	100%





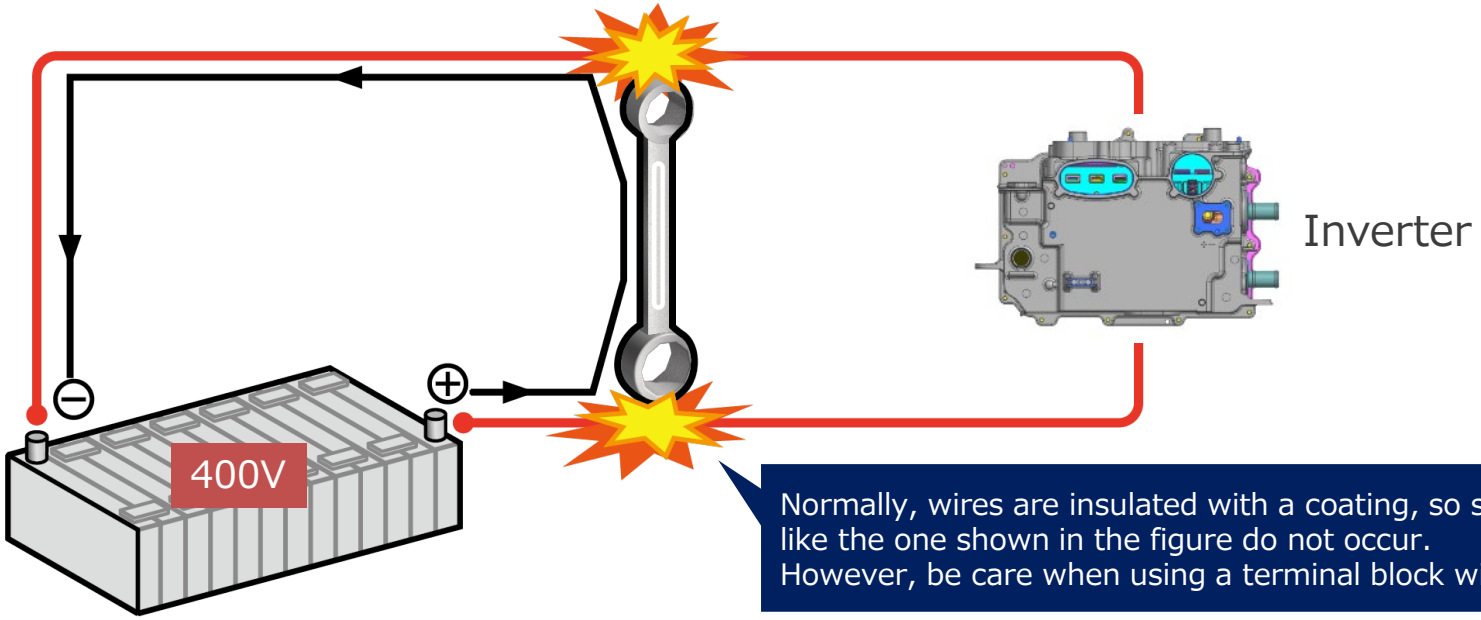
(Data from Ministry of Health, Labour and Welfare)

Electric shock and effects on the human body



Electric current in human body (mA) (DC、1 second continuous)	Effects on the human body
0.5 ~ 1mA	電流を感知する程度（ピリッ）
5mA	人体に悪影響を及ぼさない最大許容電流値
10 ~ 20mA	筋肉痙攣（握った電線を離すことができなくなる）
50mA	心臓の律動異常の発生、呼吸器系等への影響
100mA以上	**心室細動の発生、心肺停止、極めて危険な状態に**

Short-circuit



Tractive Battery Container

$$I\ (\text{Current}) = \frac{E\ (\text{Voltage})}{R\ (\text{Resistance})} = \frac{400\text{V}}{\text{nearly } 0\,\Omega} = \infty\ (\text{Large current})$$

Since a short circuit causes a large current to flow, the wire harness is burned, resulting in burns or fire.

Short circuits are often caused by operating errors such as dropping non-insulated tools on non-insulated high-voltage terminals.

Therefore, it is important to cover high-voltage terminals and to insulate metal tools.

Short-circuit

A battery pack or inverter capacitors
short circuit current is several 1,000 A

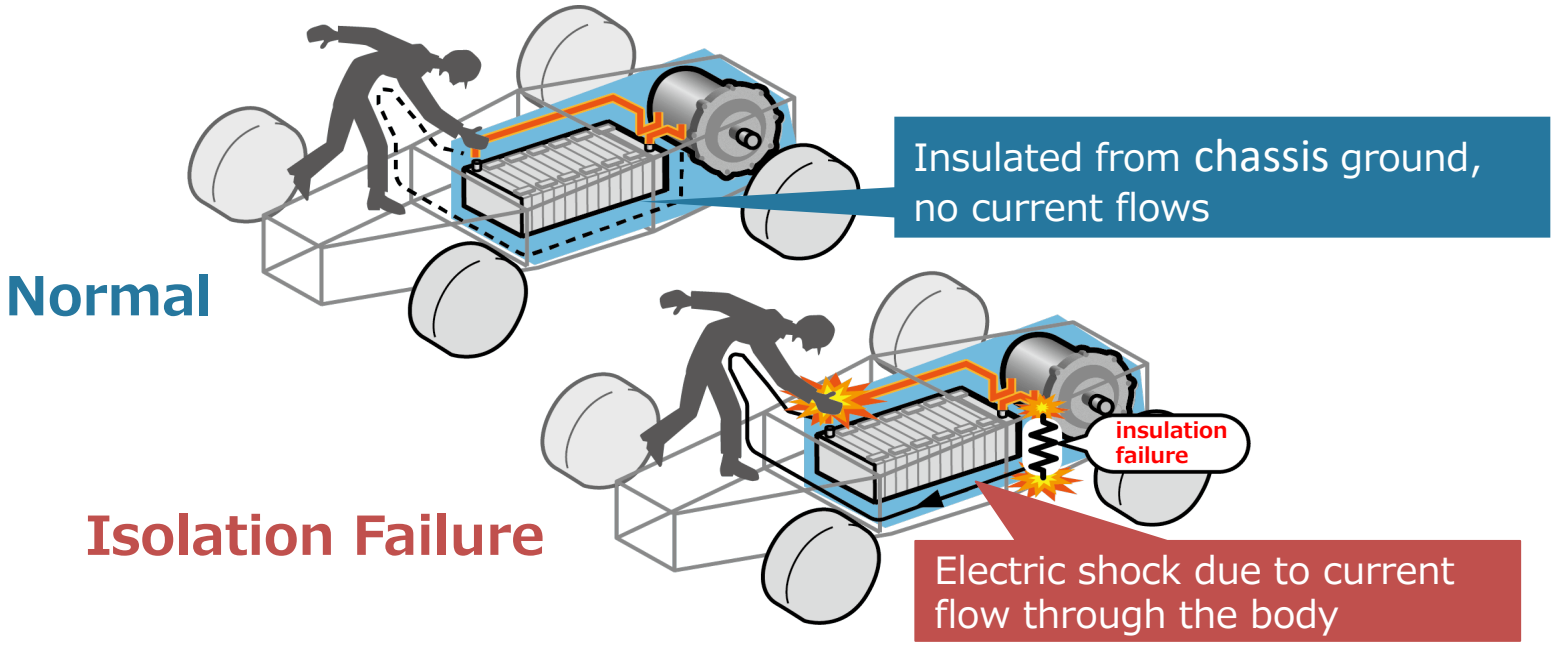
Superheating of plug/connector/wire (excessive current)

Cord reel

Applied excessive force may
result in ignition or short circuit

写真引用元：独立行政法人 製品評価技術機構, https://www.nite.go.jp/jiko/chuikanki/poster/kaden/01200301.html

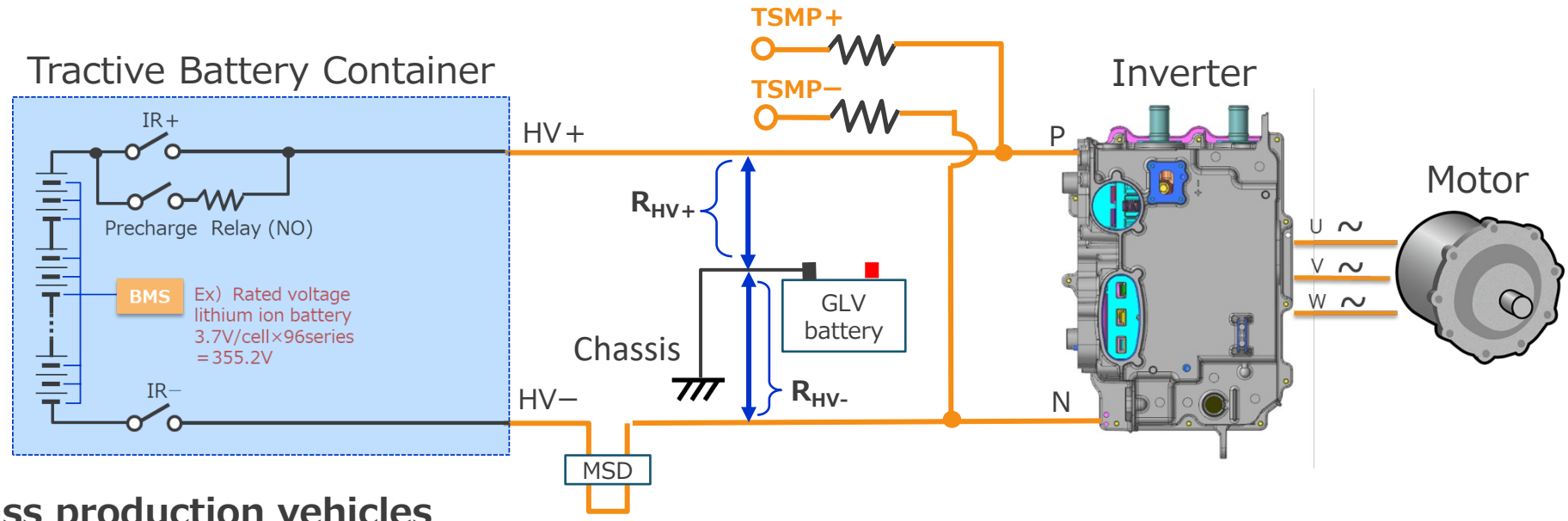
Electrical insulation failure



When normal , the electrical circuit of the tractive system (=TS) is isolated from the vehicle chassis (chassis ground).
Even if a person touches both the HV live-part and the body ground, there is no current flows.

If HV isolation failure occurs, current flows and it can cause an electric shock.
Causes of insulation failure include damage or aging of the wire insulation coating, etc.
The wires must be secured to the chassis to protect them from damage.

Insulation Resistance



Mass production vehicles

If the insulation resistance between the HV and the low-voltage (LV) ground is ≤ 100 Ω/V （R_{HV+} R_{HV-} in figure above） , the vehicle must alert the driver.
(The Ministry of Land, Infrastructure, Transport and Tourism in Japanese Law)

Formula SAE EVs

In the latest Formula SAE® Rules ~~2025~~ (IN.4.5.3), **insulation resistance must be ≥500Ω/V**.
If the **“Insulation Monitoring Device (IMD)" detects insulation failure (<500Ω/V),**
the HV should be disconnected (AIRs should be switched off by a shutdown circuit).

Note for vehicle maintenance

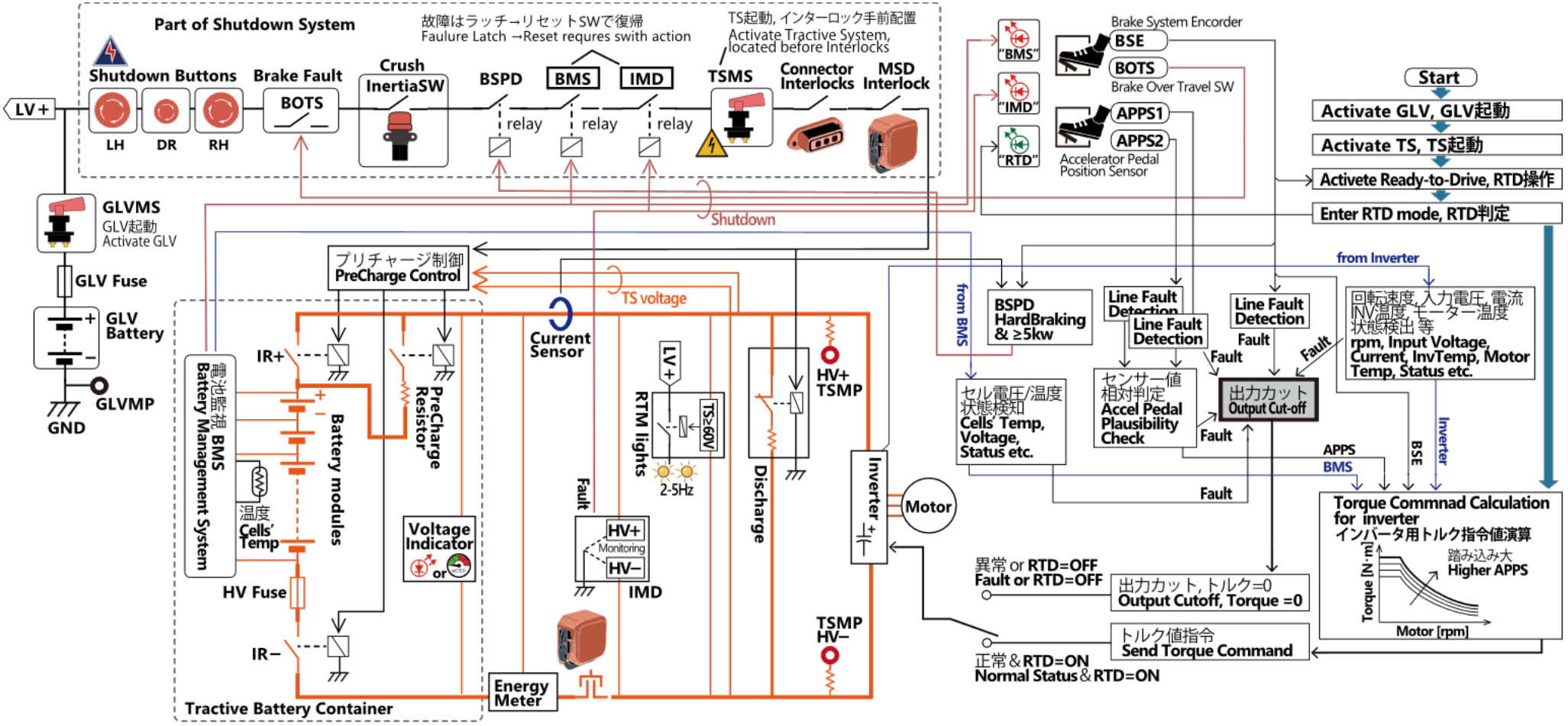
Before and after HV maintenance of the vehicle, insulation resistance must be measured with an "**isolation resistance tester**“ instead of a general multimeter. (see chapter.3)
Wear HV insulating gloves when using the isolation resistance tester as high voltage is applied.

Contents

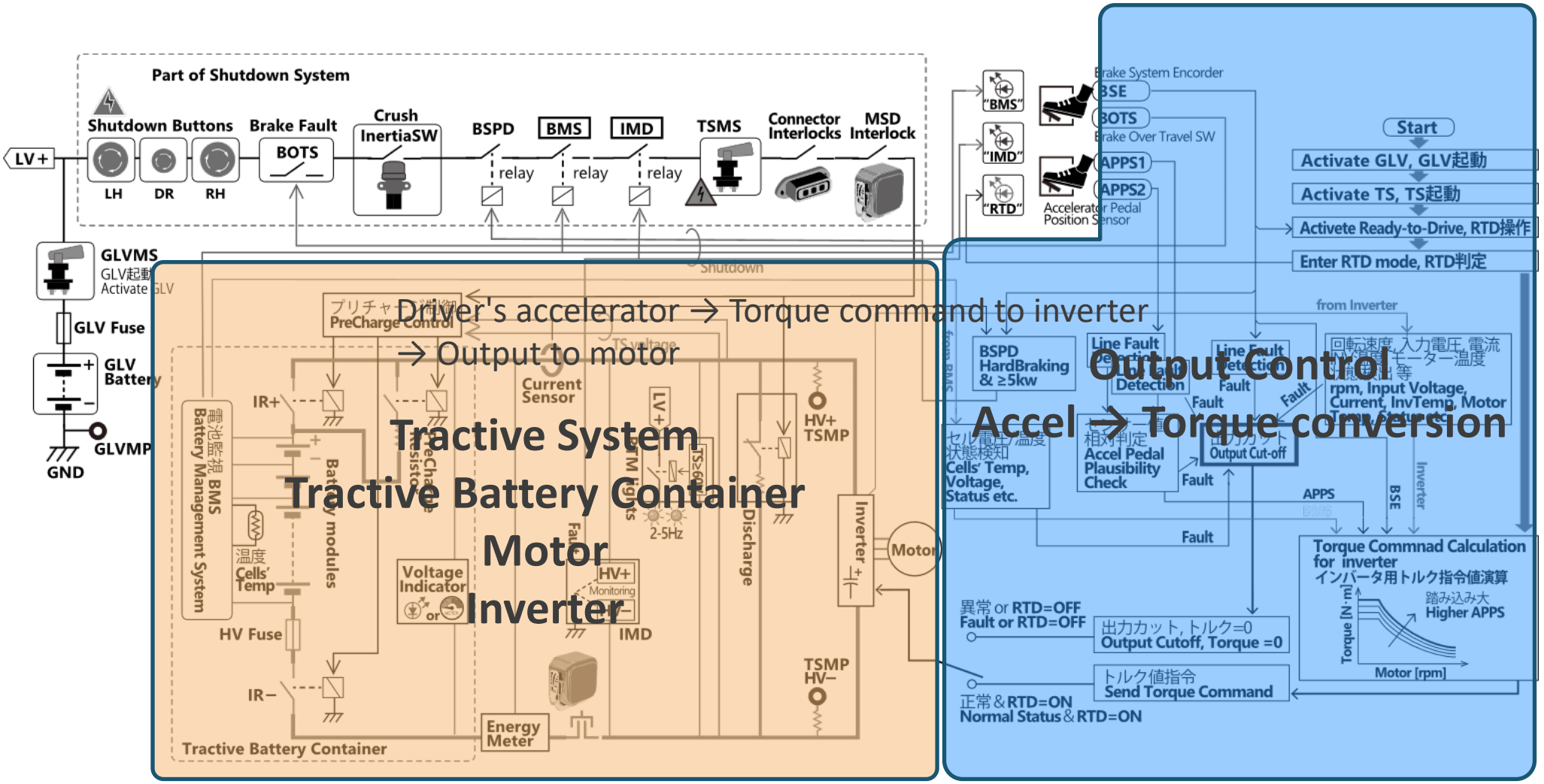
Chapter 2

Basic knowledge of high-voltage components in Formula SAE EVs

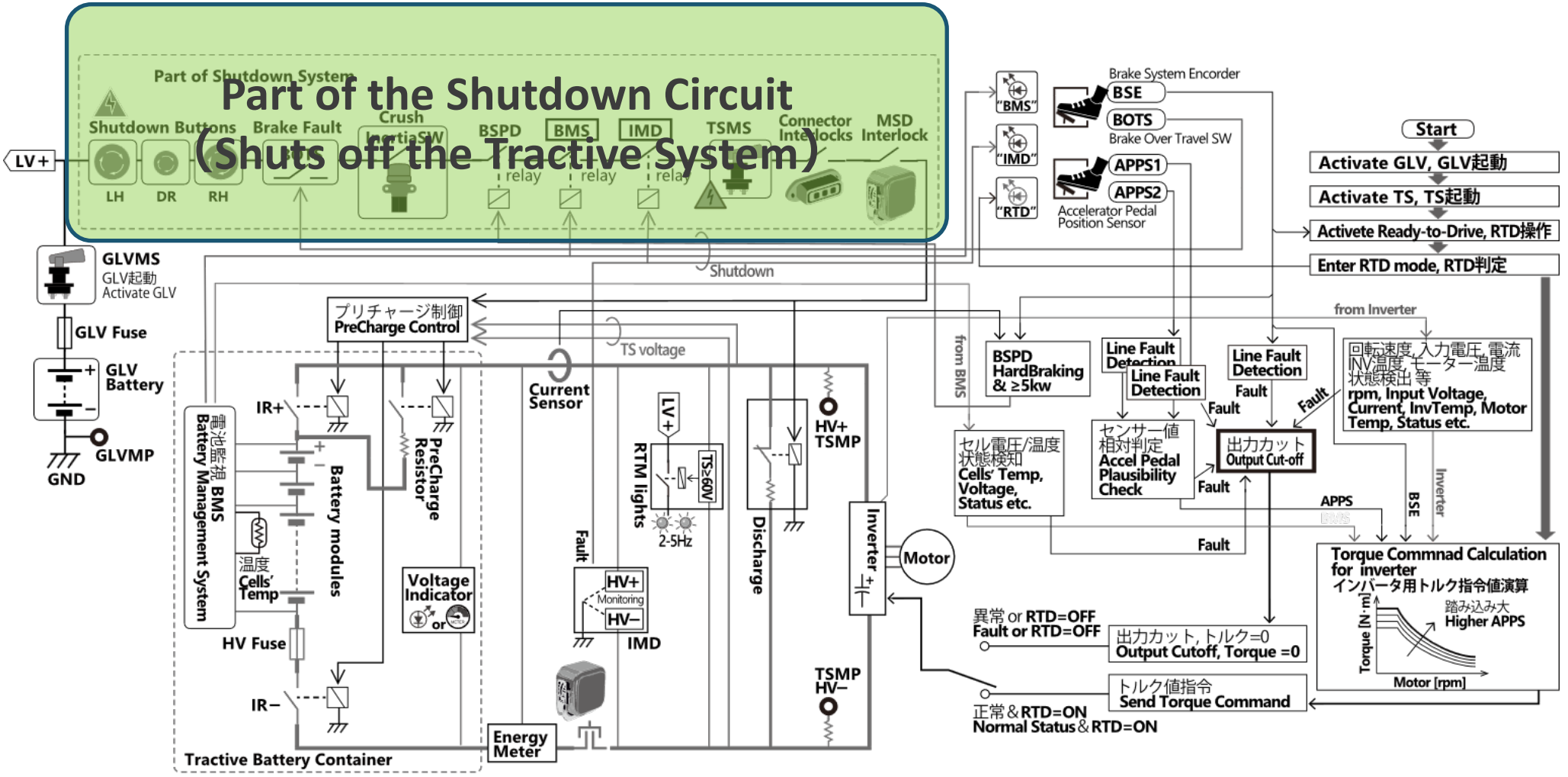
Example configuration of the vehicle system (Vehicle System: components + control)



Driver's accel → Torque command to inverter → Output to motor



Shutdown circuit cuts off Tractive System

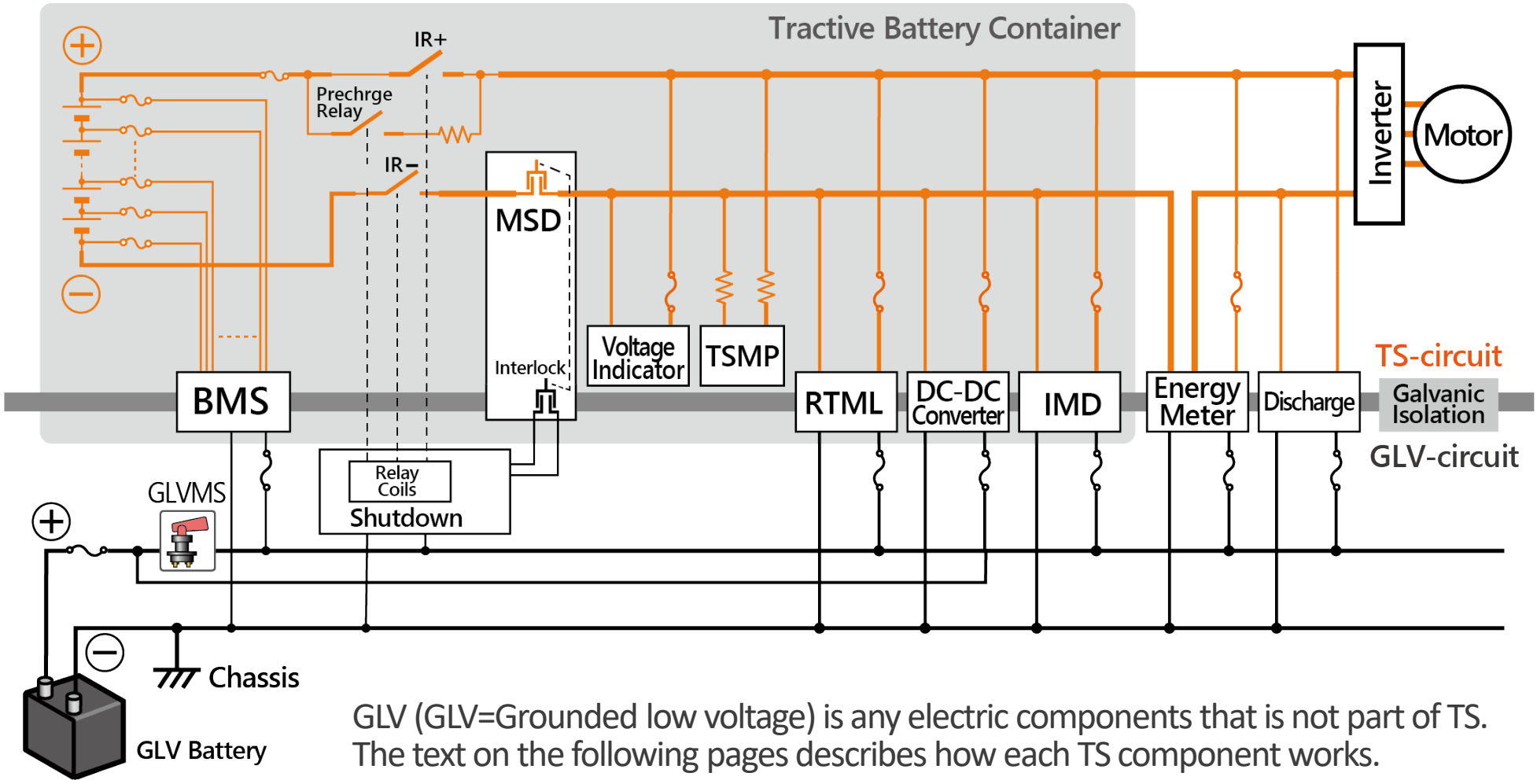


Isolation between TS-circuits and GLV-circuits

Components on the gray-line and above gray-line are TS components.

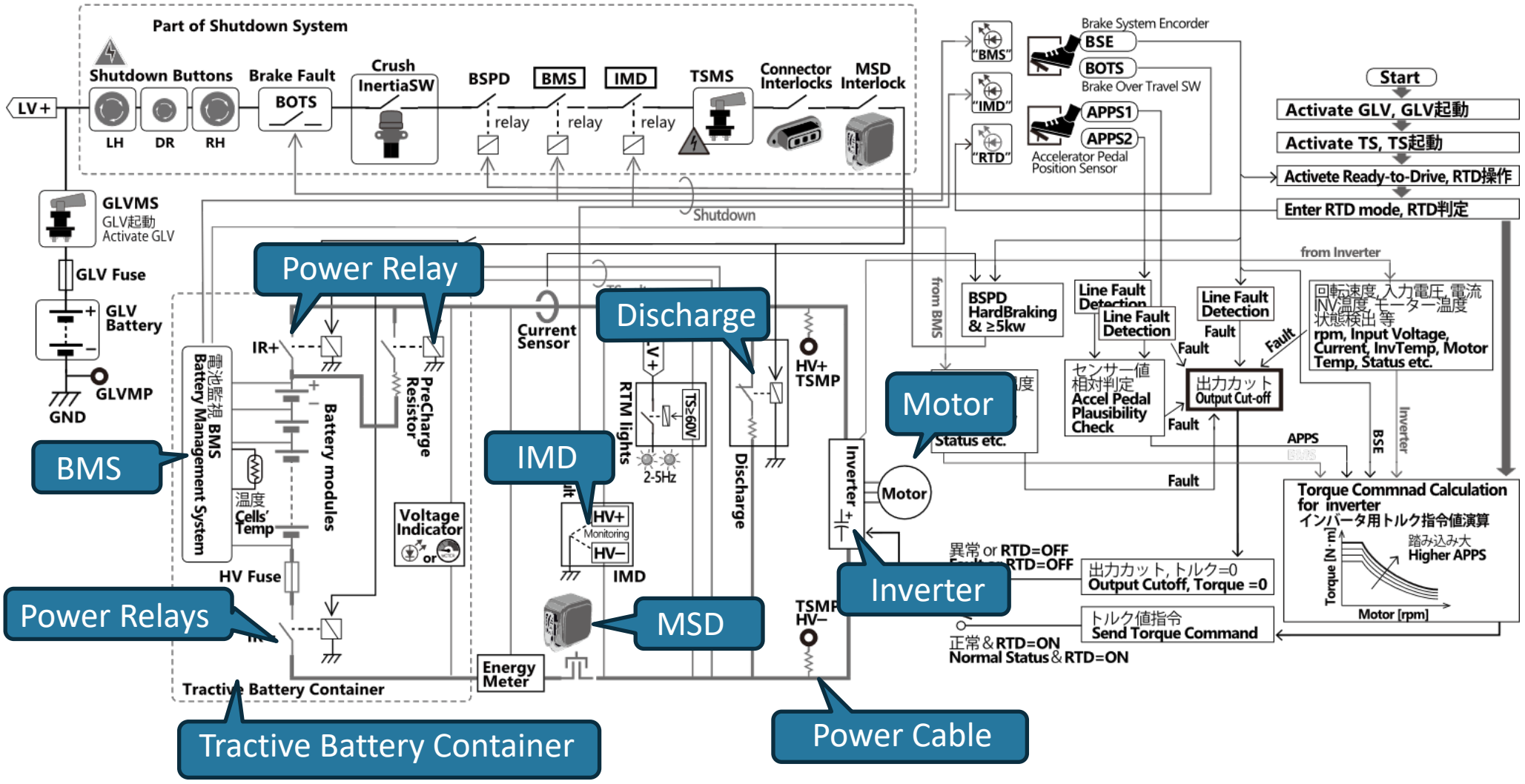
Galvanic isolations are needed on the gray-line boundary in the below schematic, if TS is >60V.
If TS is not isolated, there is risk of electrical shock.

Galvanic isolations : Energy or information can be exchanged without current flow, e.g., inductive, optical, etc.



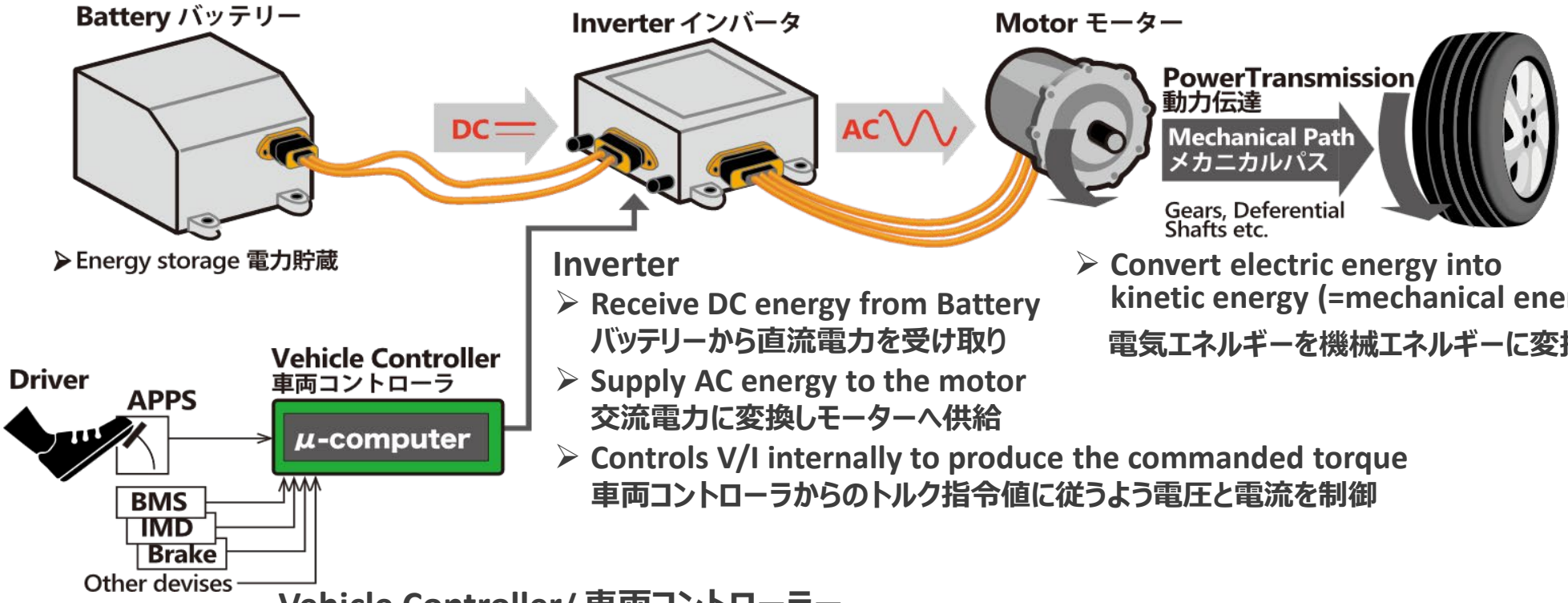
GLV (GLV=Grounded low voltage) is any electric components that is not part of TS.
The text on the following pages describes how each TS component works.

下図の主要なコンポーネンツについて次ページから説明する
Main components are explained starting on the next page



Energy Conversion from Battery to Wheels

The inverter converts DC into AC for the motor
The stored electrical energy is converted into kinetic (mechanical) energy for driving



➢ Energy storage 電力貯蔵

Inverter

- ➢ Receive DC energy from Battery
  バッテリーから直流電力を受け取り
- ➢ Supply AC energy to the motor
  交流電力に変換しモーターへ供給
- ➢ Controls V/I internally to produce the commanded torque
  車両コントローラからのトルク指令値に従うよう電圧と電流を制御

➢ Convert electric energy into kinetic energy (=mechanical energy)
電気エネルギーを機械エネルギーに変換

Vehicle Controller/ 車両コントローラー

➢ Calculate motor torque from APPS and Fault conditions
APPS や Fault異常 などの情報からモータートルクを演算する

Motor

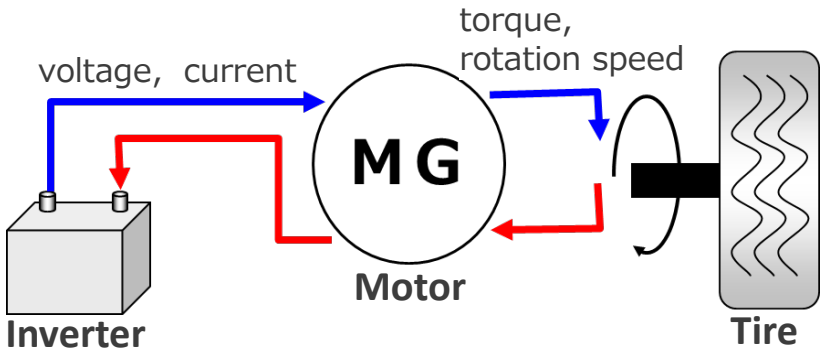
Motor has both motor and generator functions.

The motor receives electrical energy and converts into kinetic energy (**Motor function**),
, and receive kinetic energy and converts into electrical energy (**Generator function**).
These two functions are controlled by the invertor.

Motor	Electrical energy	→	kinetic energy = Acceleration
Generator	Electrical energy	←	kinetic energy = Deceleration (Regeneration)

Role of inverter for motor

The inverter controls the voltage and current supplied to the motor.



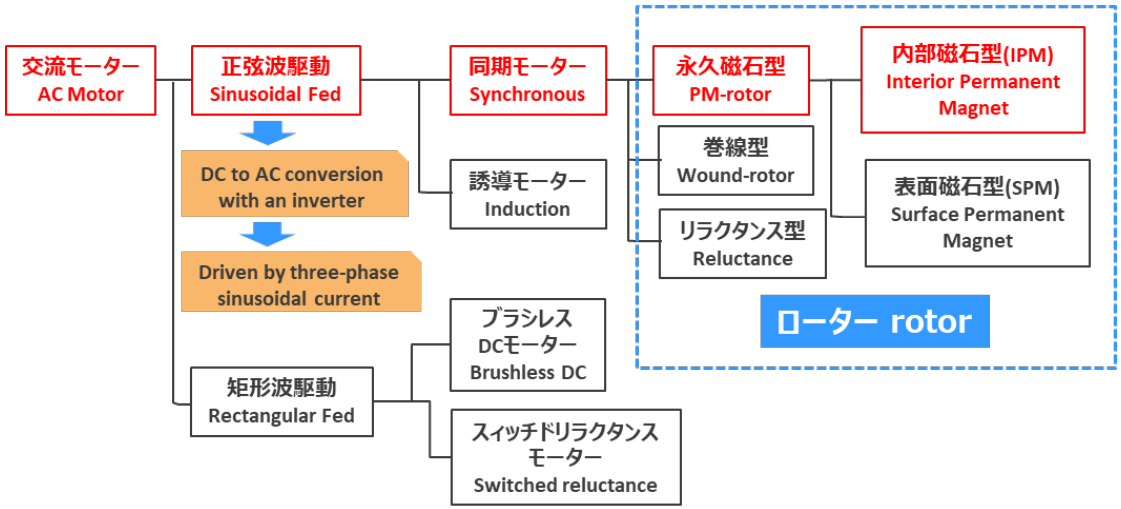
voltage ∝ rotation speed
current ∝ torque

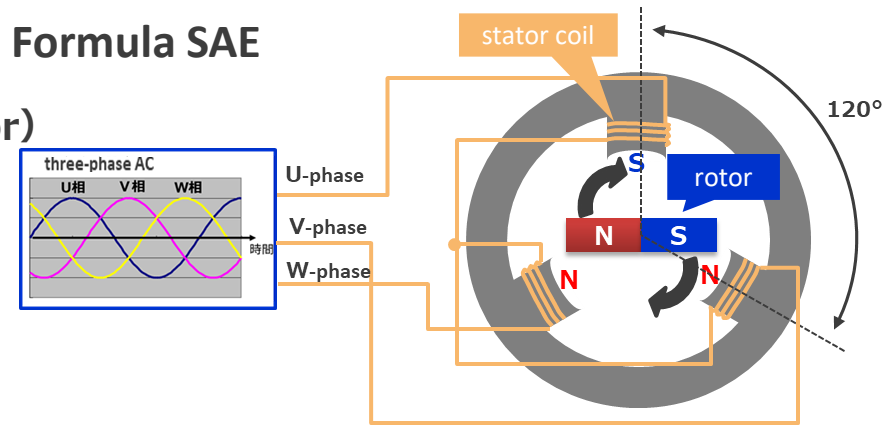
The voltage received by the motor is proportional to the rotation speed.
(When the voltage becomes higher, the rotation speed become higher.)

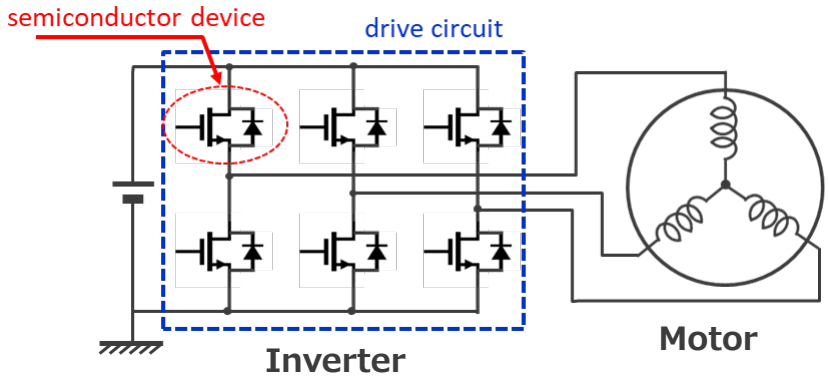
The current received by the motor is proportional to the torque.
(When the current flow become larger, the torque become larger.)

Motor :AC synchronous motor is very popular in Formula SAE

AC synchronous motor（permanent magnet rotor）







How an AC Motor works

- A rotating magnetic field is generated by applying a three-phase sinusoidal current to the stator coil.
- A motor is rotated by the repulsion/attraction between the magnets in rotor and the magnetic field generated by the current flowing through the coil.

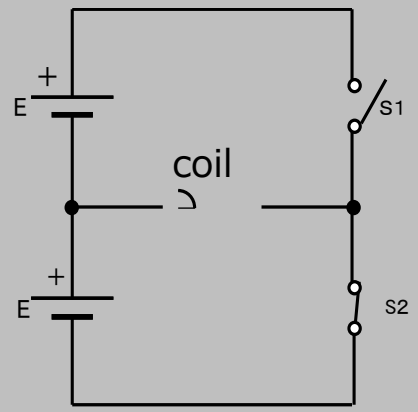
Characteristics

・Maintenance-free ・No sparking noise ・Easy rotation speed control
・Heat release easily from the surface that is vicinity of hot coils
・A drive circuit in the inverter using a semiconductor device is required.

Inverter The inverter converts DC to AC for the motor.

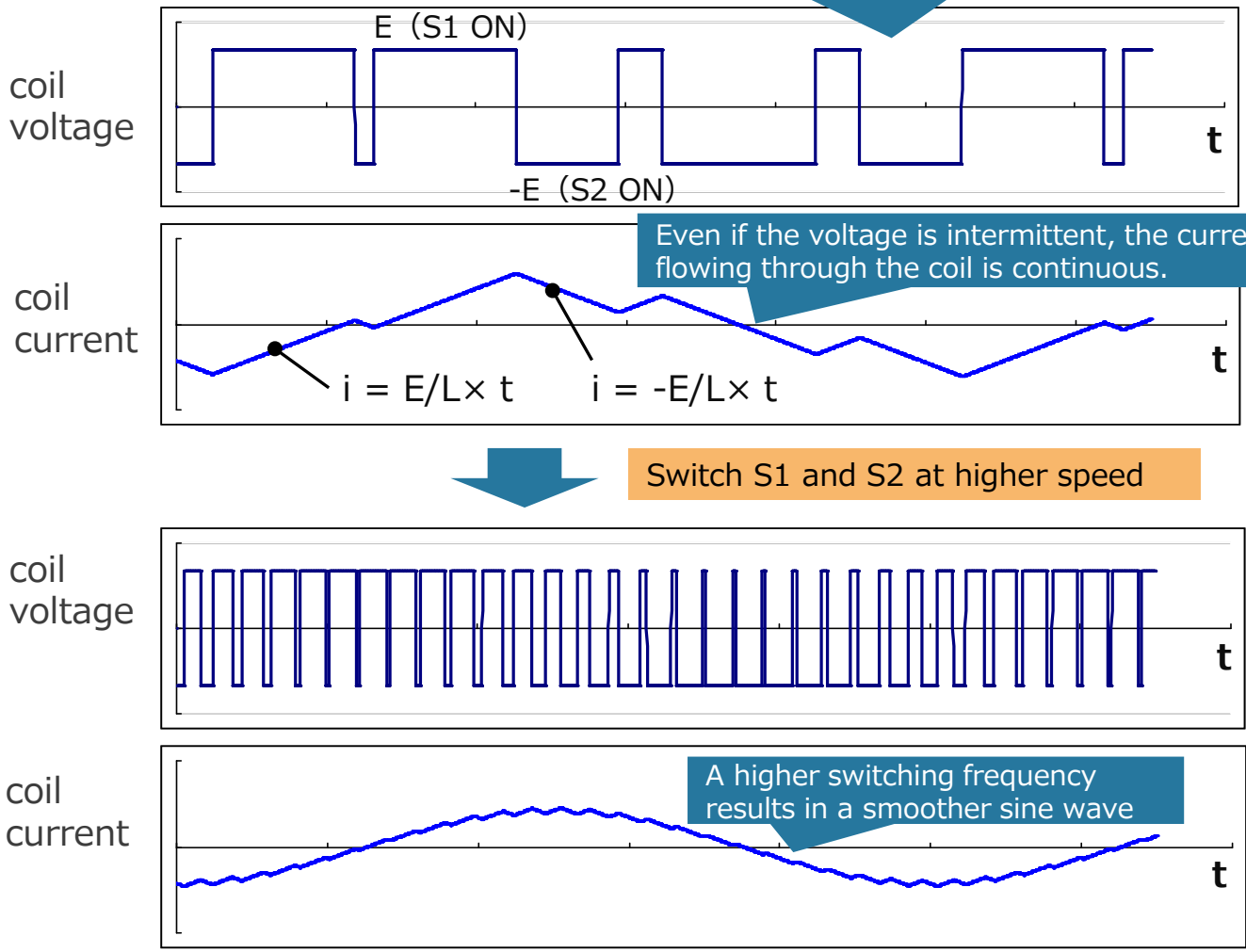
Basic operation ①

Half bridge circuit
When the two switches S1 and S2 are alternately turned ON/OFF at specified intervals,
Both voltage and current are applied to the coil alternatively.



The coil in above fig. represents the motor.
S1 and S2 are inside the inverter.

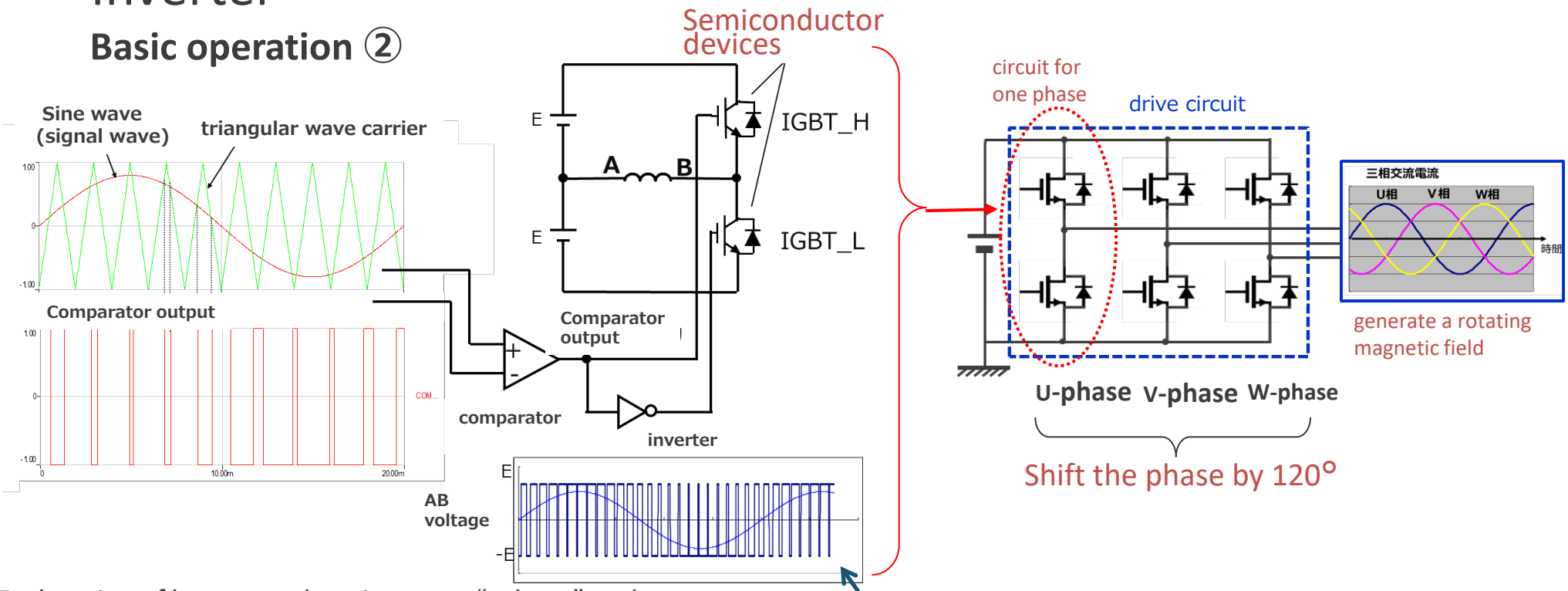
Control the amount of current with the width of ON and OFF (PWM control)



- The current flow is controlled by the ON/OFF width of switches S1 and S2. (PWM control：Pulse Width Modulation）.
- If the load is an inductance such as a coil, the current will flow continuously even if the switches are off.
- If the switch is turned on and off at a higher frequency, the current flow will be a smooth sine wave.
  Higher frequency is given by IGBTs （IGBT：Insulated Gate Bipolar Transistor）

Inverter

Basic operation ②



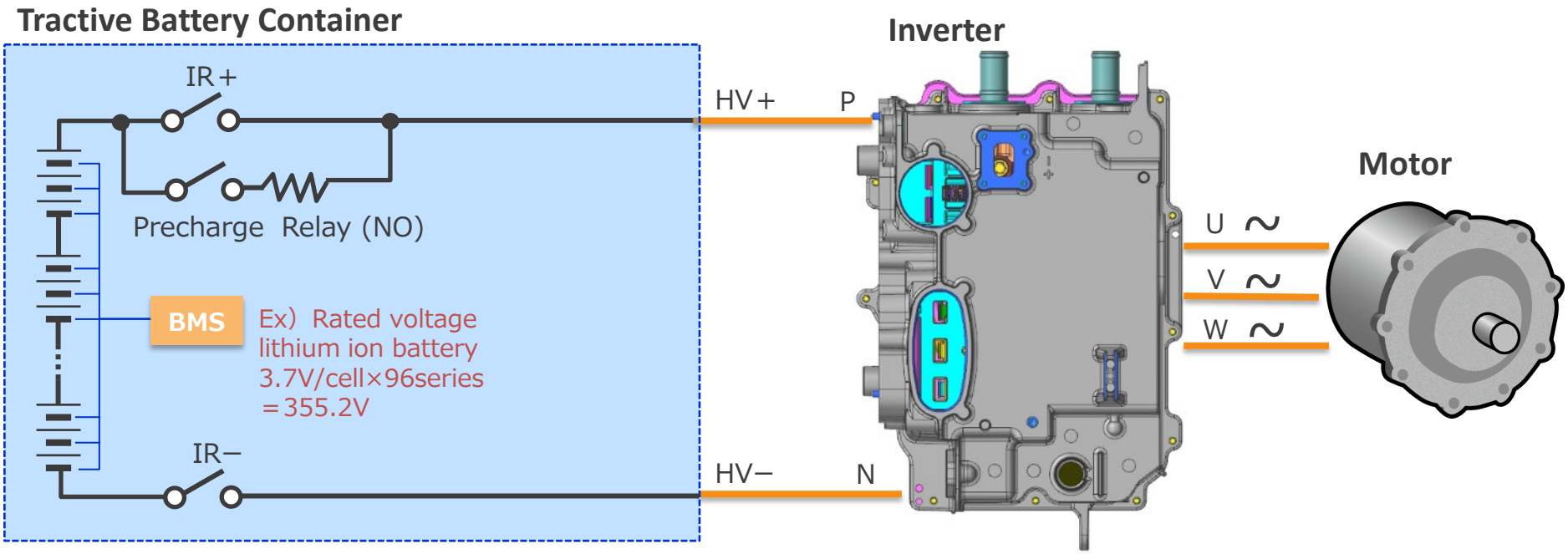
Explanation of how to apply a sine-wave “voltage” to the motor

- The Inverter converts DC voltage from Tractive Battery container into AC voltage with high-speed switching of semi-conductors (IGBTs).
- This specific switching control is known as PWM, which is calculated by comparing sine signal and triangle wave.
  This “sine signal” is calculated inside the inverter.
  This triangle wave is based on switching frequency.
- After PWM switching, the voltage output become sine-wave.
  The current sine waveform is given from same PWM method.

- A 3-phase (U, V, W) sin-wave current with a phase difference of 120° is passed through each stator coil .
- The motor rotation speed is controlled by the frequency of the sine signal.
- The motor torque is controlled by the amplitude of the sine signal.

■ The information on this page is only for your reference. (this is not main topic of high-voltage work).

Tractive Battery Container （=Battery pack for Formula SAE EVs）



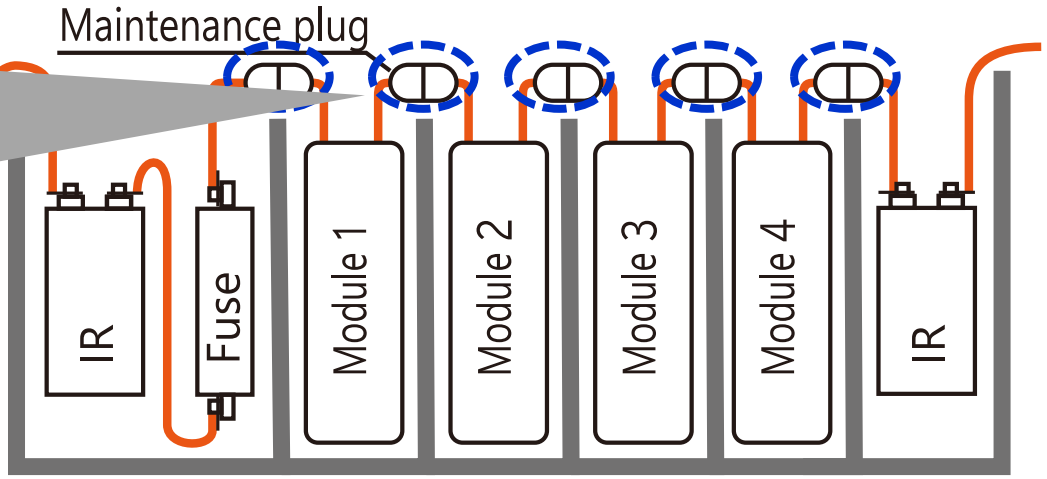
- The Tractive Battery Container (TBC) is a high-voltage power storage and supplies energy to the motor.
- The energy was stored multiple battery cells that are connected in series to generate high voltage.
  The cells are mainly lithium-ion batteries.
  The Tractive Battery's voltage rating (=rated cell voltage x number of cells) is typically from 100V to 400V.
  The maximum TS voltage should be calculated from (maximum cell voltage x number of cells).
- Power relays inside the TBC connect or disconnect electrical path to the inverter.
  Power relays is called IRs (IR = Isolation Relay).

Tractive Battery Container

Information required by ”Latest Formula SAE® Rules”

- The structure, strength and fastening method are subject to approval during SES review.
- The TBC must be removable without disassembling, and must be charge separated from the vehicle.

Example of maintenance plug

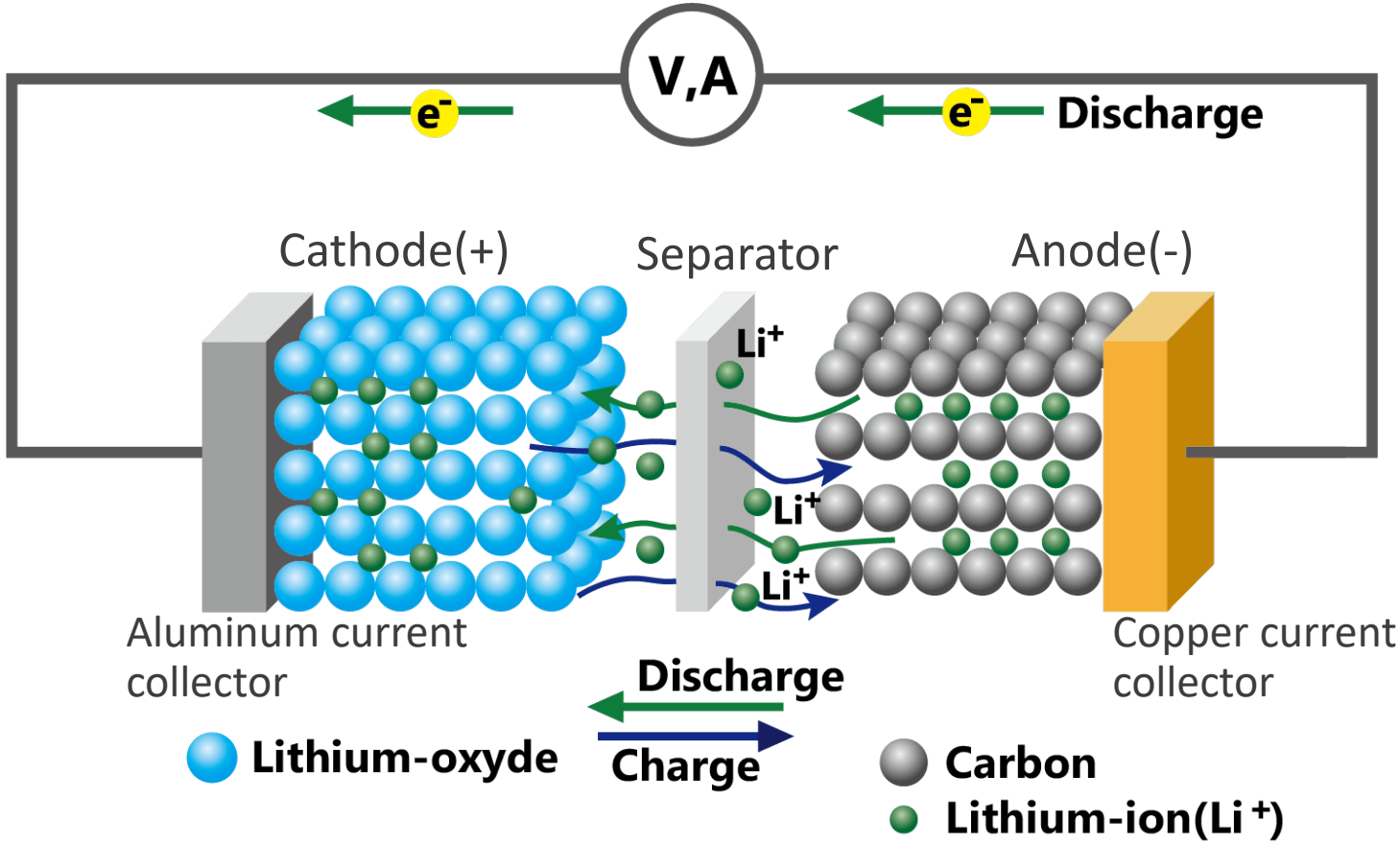


- Maintenance plugs must have positive locking mechanism, must be removable without tools.
- Voltage Indicator must be installed.

Lithium-ion battery cells

- Li-ion (Li+) move between positive and negative electrode through organic electrolyte.

- Organic electrolyte has higher resistance than water-based electrolyte
  The electrodes are separated by a very thin separator



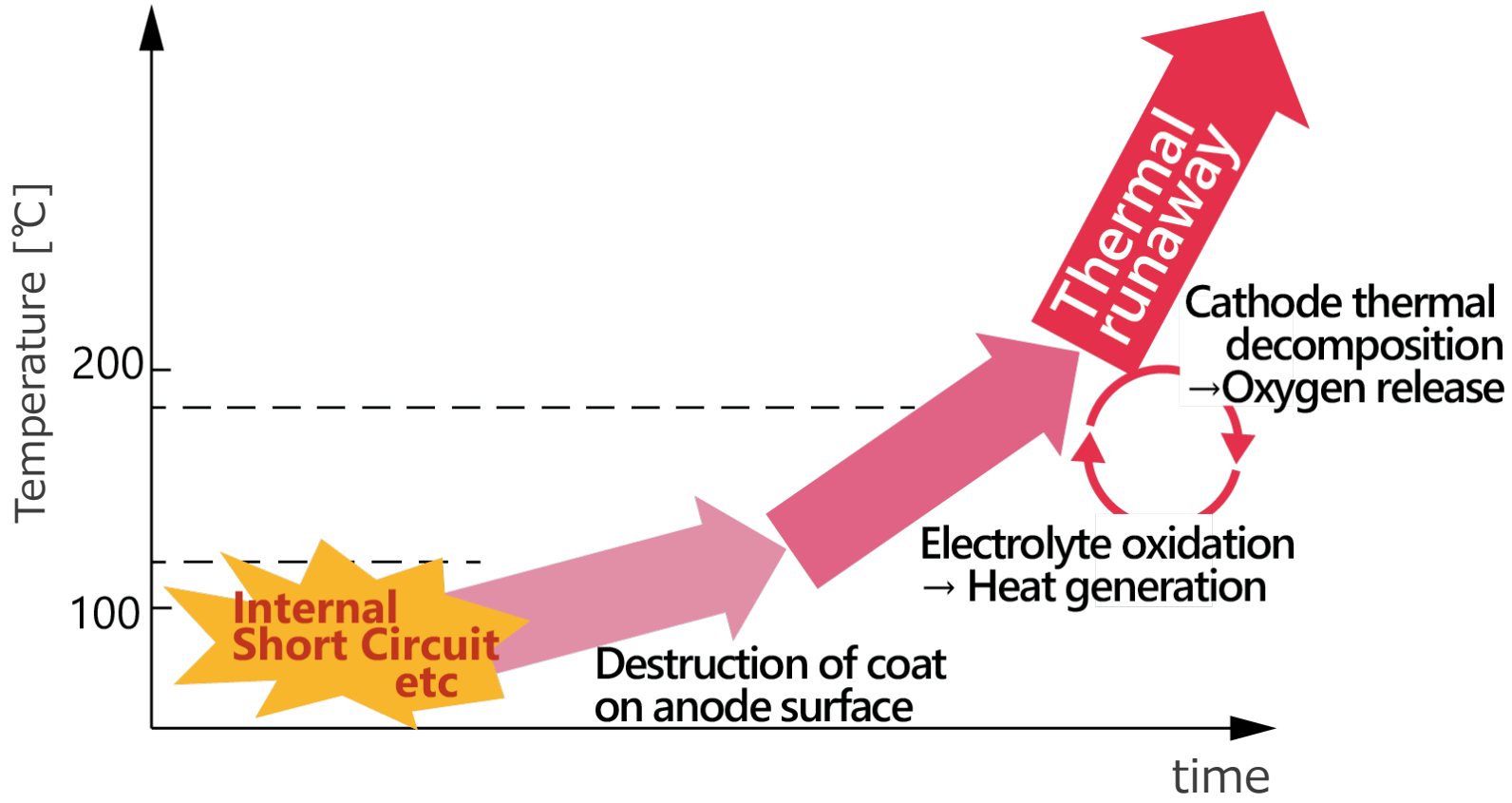
Organic electrolyte is flammable

	Solvent	Flash Point ℃	Ignition Point ℃
Components of electrolyte	Propylene carbonate　P C	1 3 5	4 3 5
	Ethylene carbonate　E C	1 5 3	4 6 5
	Diethyl carbonate　D E C	2 5	4 4 5
	Ethyl methyl carbonate　E M C	1 5 3	4 6 5
	Dimethyl carbonate　D M C	1 8	4 5 8
	Gasoline	－4 0	3 0 0
	Kerosene	4 0～7 5	2 4 0

出所：引火点，発火点は三菱化成、キシダ化学，ENEOSのSDSによる

Ignition mechanism of lithium-ion batteries

High temperatures lead to oxidation of the electrolyte and generation of heat.
Overheating leads to **thermal runaway** and ignition.



出所：江田信夫, データに学ぶLiイオン電池の充放電技術 CQ出版社, （2020）をもとに作成

The case of a pouch cell is very thin, so a short circuit will quickly catch fire.

The Internal resistant of cells is very low (≤ 1m Ohm).
If you short circuit the cells, the current flow is extremely high. It can cause firing.

（The photo above shows an example of an “overcharged” cell swelling and then bursting）

写真引用元： GWL, “Dangerous vs. Safe batteries, Explosion and fire test!”, https://www.youtube.com/watch?v=Qzt9RZ0FQyM

How to deal with damaged batteries

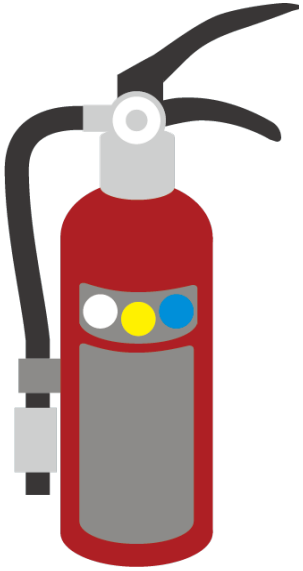
Prepare fire extinguishers and personal protective equipment.

Lithium-ion's electrolyte is flammable.

Electrolyte has a risk of "chemical burns" and poisoning.

Flammable

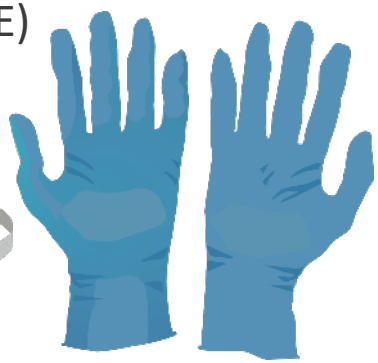
Toxic



personal protective equipment (PPE)

Goggles
for eye protection

Gas mask
for organic gases

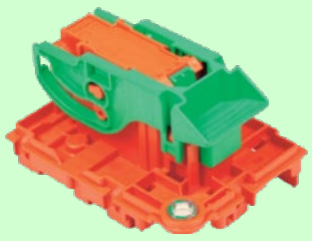


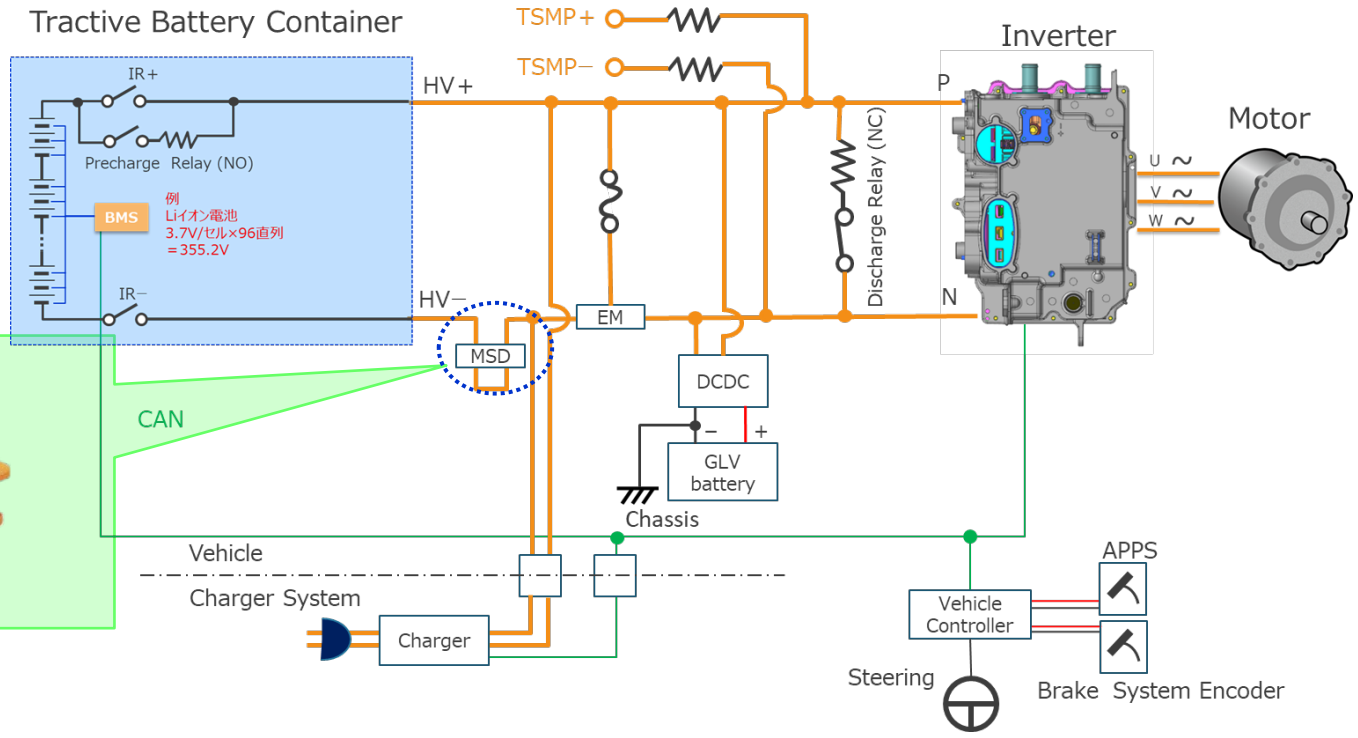
Non-permeable
gloves

MSD（Manual Service Disconnect）

MSD is a device for disconnecting one or both poles of the Tractive Battery container.

Examples of MSD





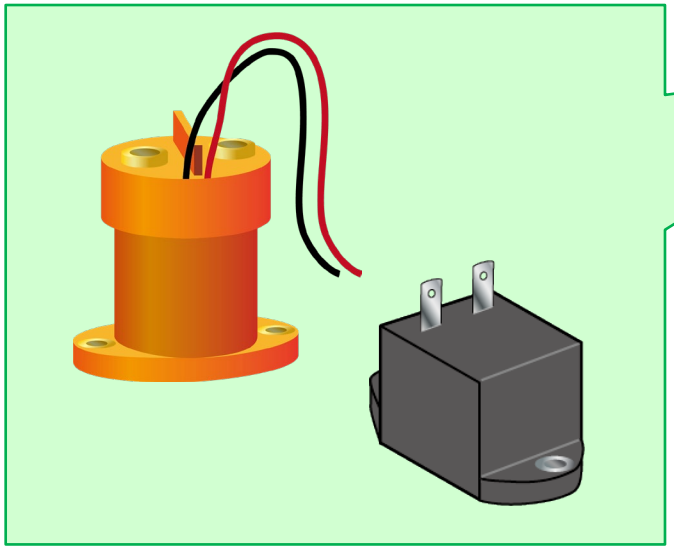
Information required by ”Latest Formula SAE® Rules”

- Must be easily visible when standing behind the vehicle.
- Must be directly accessible by hand and operable in 10 seconds or less by an untrained person without removing any bodywork or obstruction or using tools
- Must be directly operated (remote control mechanism is not permitted)

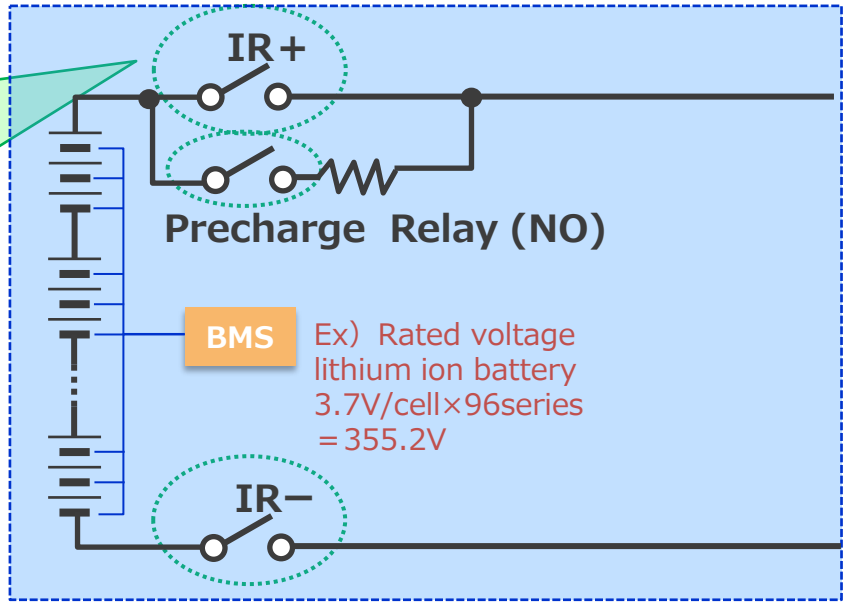
Power Relay

Power relays are used to connect or disconnect the positive and negative battery poles.
Connect or disconnect signals are come from host controller or shutdown circuit.

Power Relay example



Tractive Battery Container

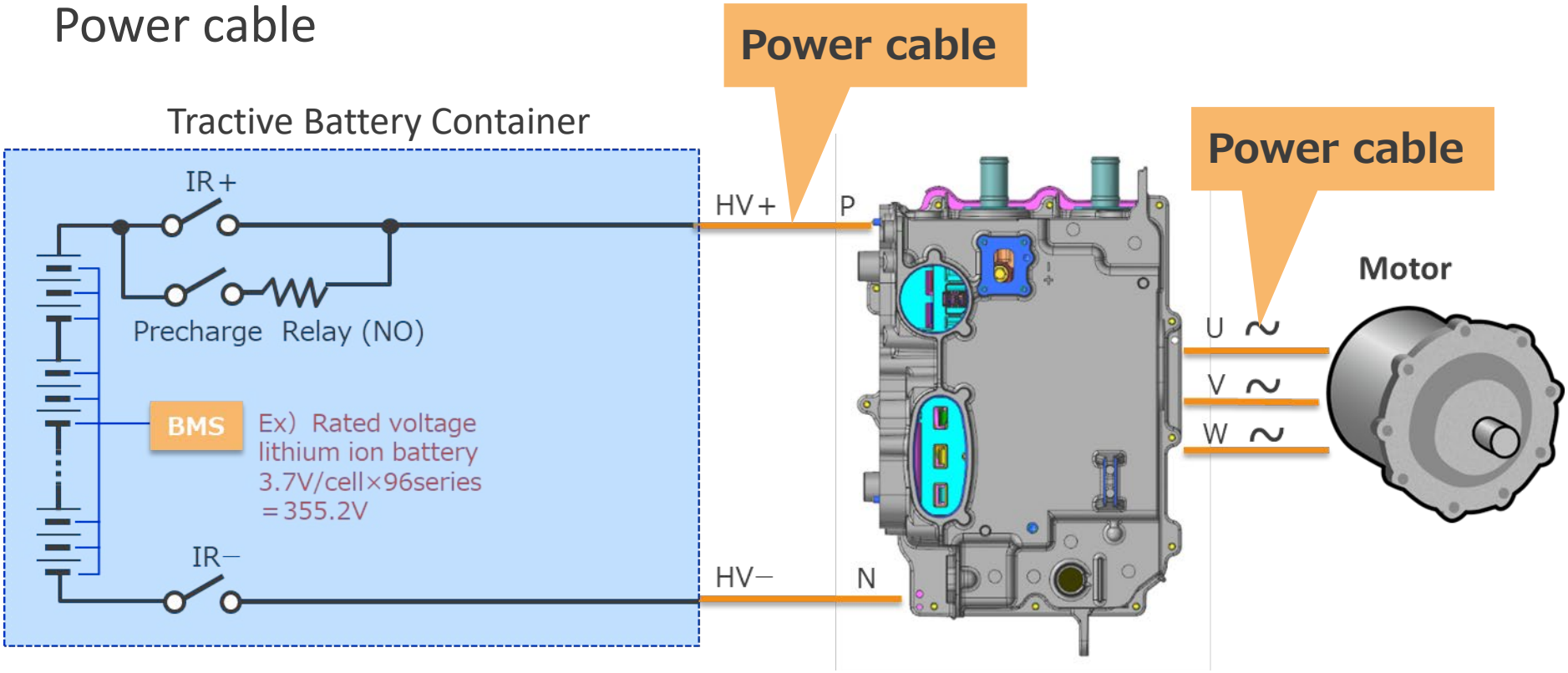


Information required by ”Latest Formula SAE® Rules”

- Power relays are both IRs and pre-charge relay.
  Those must be mechanical relays and normally open type.

- The IRs must open both the positive and negative poles of the Tractive Battery Container.

Power cable



- TS wiring (Power Cable) connecting high voltage components (TBC, Inverter, Motor, etc.) must use orange shielded cable or conduit.
- Orange cables must not be used in the wiring harnesses of 12V and 24V power systems.
- Unless local rules apply, bolted connections in the high-current TS path must include a positive locking mechanism to prevent unintentional loosening.

IMD（Insulation Monitoring Device）

An insulation monitoring device is required for EVs.

The IMD must monitor the Tractive System for an **isolation failure** and a **failure of the IMD function**.

BENDER
The Power in Electrical Safety®

ISOMETER® IR155-3203/IR155-3204

Function

The ISOMETER® iso-F1 IR155-3203/-3204 generates a pulsed measuring voltage, which is superimposed on the IT system via terminals L+/L- and E/KE. The latest measured insulation condition is available as a pulse-width-modulated (PWM) signal at terminals M_{HS} (for IRI55-3204) or M_{LS} (for IR155-3203). The connection between the terminals E/KE and the chassis ground (▸ Kl.31) is continuously monitored. Therefore it is necessary to install two separated conductors from the terminals E or KE to chassis ground.

Once power is switched on, the device performs an initialisation and starts the system state (SST) measurement. The ISOMETER® provides the first estimated insulation resistance during a maximum time of 2 seconds. The DCP measurement (▸ continuous measurement method) starts subsequently. Faults in the connecting wires or functional faults will be automatically recognised and signalled.

During operation, a self test is carried out automatically every five minutes. The interfaces will not be influenced by these self tests.

Information required by ”Latest Formula SAE® Rules”

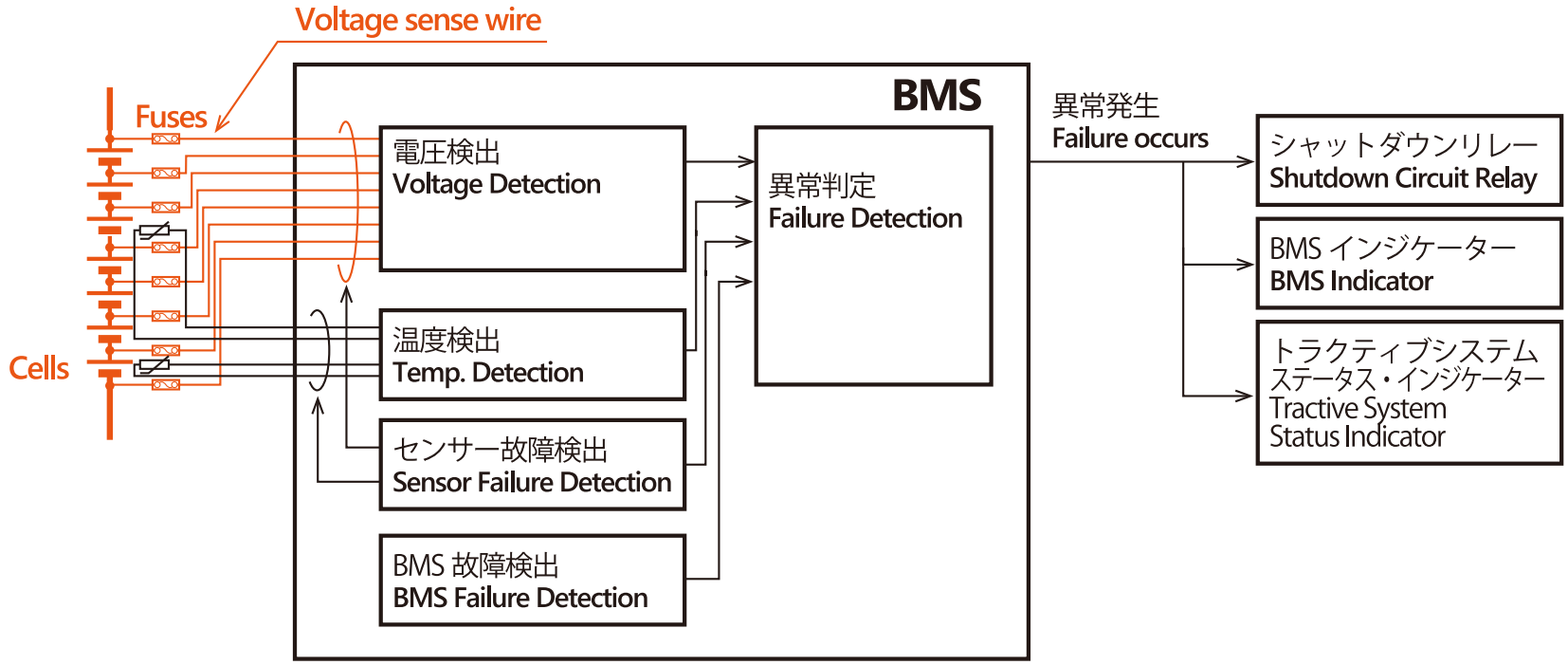
- The IMD must be a Bender ISOMETER® IR155-3203 or IR155-3204 or equivalent IMD.
- The response value of the IMD must be set to 500 Ohm / Volt or higher, related to the maximum Tractive System operation voltage.
- If the IMD detects isolation failure or a failure in the IMD itself,
  it must open the shutdown circuit and turn on the IMD indicator to the driver.

BMS（Battery Management System）

- バッテリーセルの状態を監視し 異常時にはシャットダウン回路を開く指令を出す。
  BMS monitors the Battery Cells Status and opens the shutdown circuit on fault.

- BMSは全セル電圧と、代表点のセル温度が通常動作範囲であることを監視する。
  BMS monitors all cell voltages and key temperature points to ensure they stay in the normal operating range.

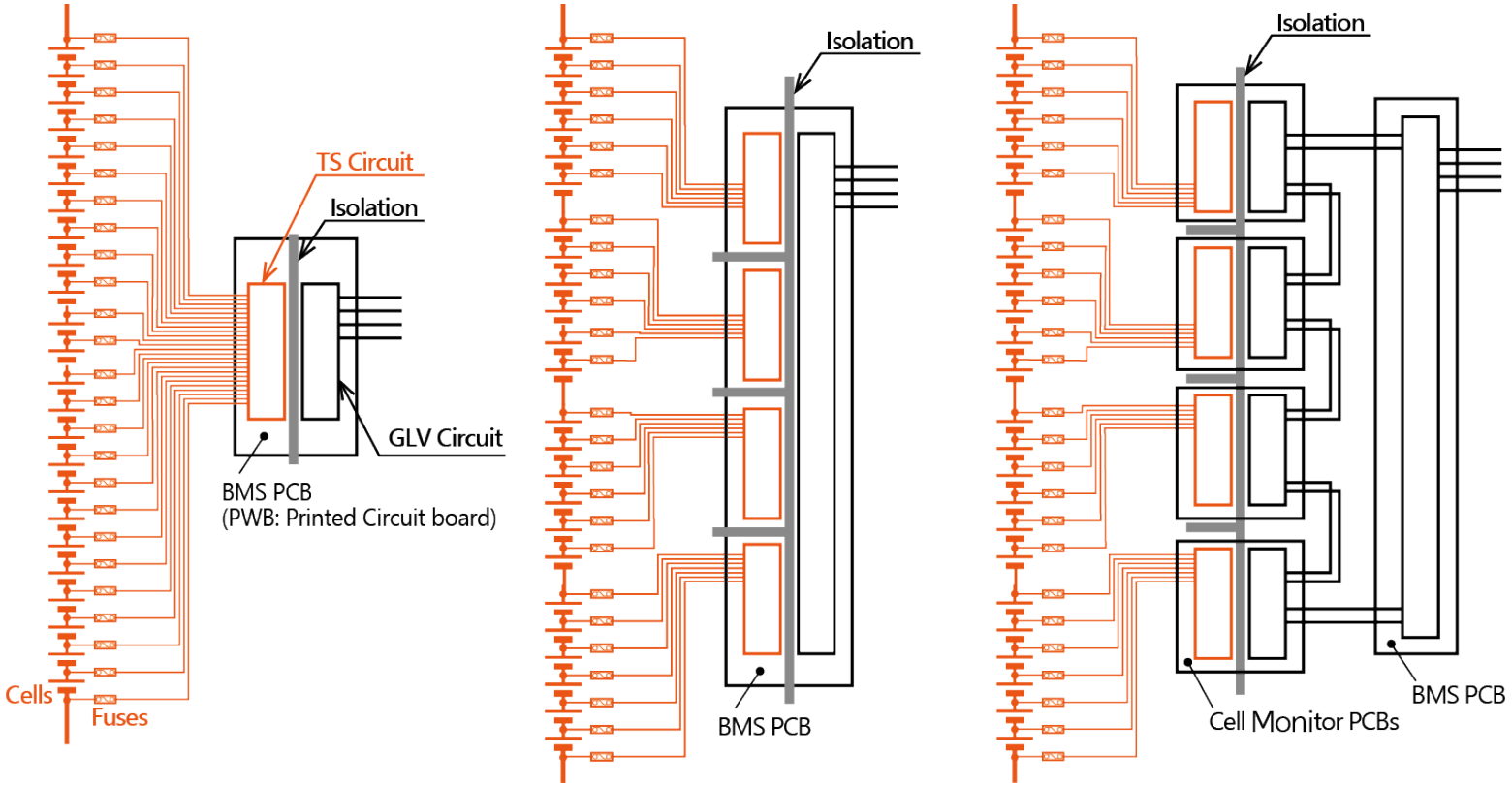
- セル電圧やバッテリー温度が取得できないトラブルの際にもシャットダウン回路を開くことが求められる。
  BMS must open the shutdown circuit, if voltage or temperature cannot be monitored.



BMS ブロック図, Block Diagram

BMS（Battery Management System）

- BMSでは、TS回路はGLV回路から絶縁されている。どのように絶縁されているかは機種や設計により異なる。
  In BMS, the TS circuit is galvanically isolated from the GLV circuit.
  Isolation structure is depended on the model and its circuit method as below.

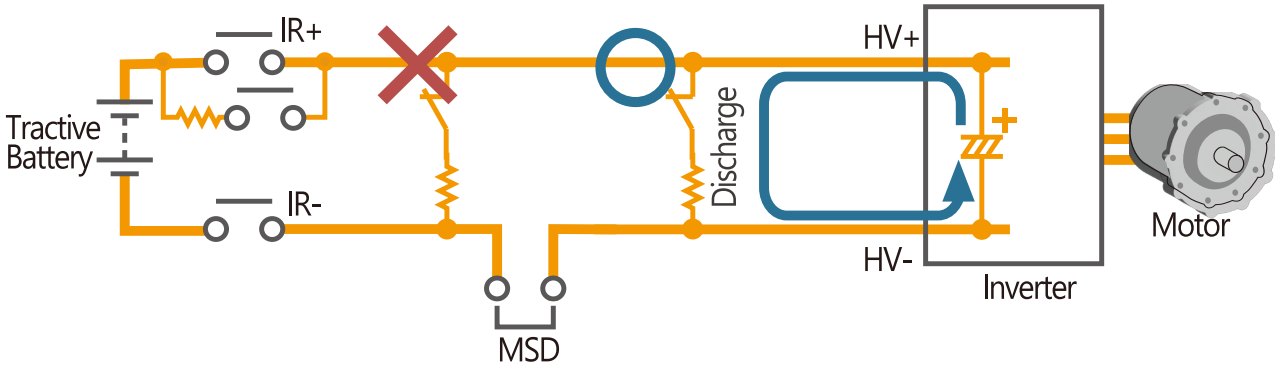


ディスチャージ回路 Discharge Circuit

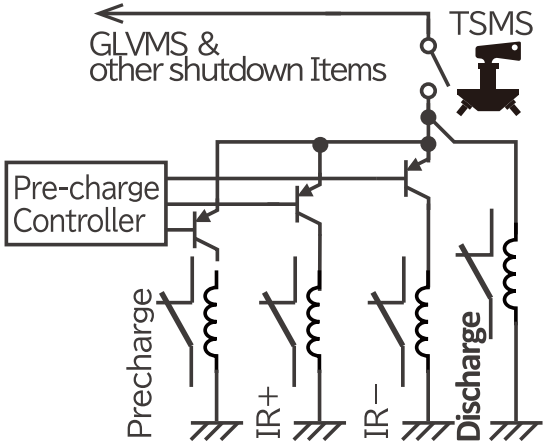
- インバータ内には大容量のコンデンサが電荷を蓄えている。
  ディスチャージ回路はシャットダウン回路が開いたときに、残留電荷を自動的に放電するものである
  The inverter contains large capacitors that store energy.
  The discharge circuit automatically releases the stored charge when the shutdown circuit opens.

- MSDが抜かれても電荷が放電できること
  The inverter can discharge even when the MSD is removed.

- ディスチャージが繰り返されると、Discharge用の抵抗やプリチャージ抵抗が発熱するので注意を要する
  Ensure the discharge/precharge resistors can handle heat from repeated discharges.



MSDが抜かれても電荷が放電できること
The inverter can discharge even when the MSD is removed



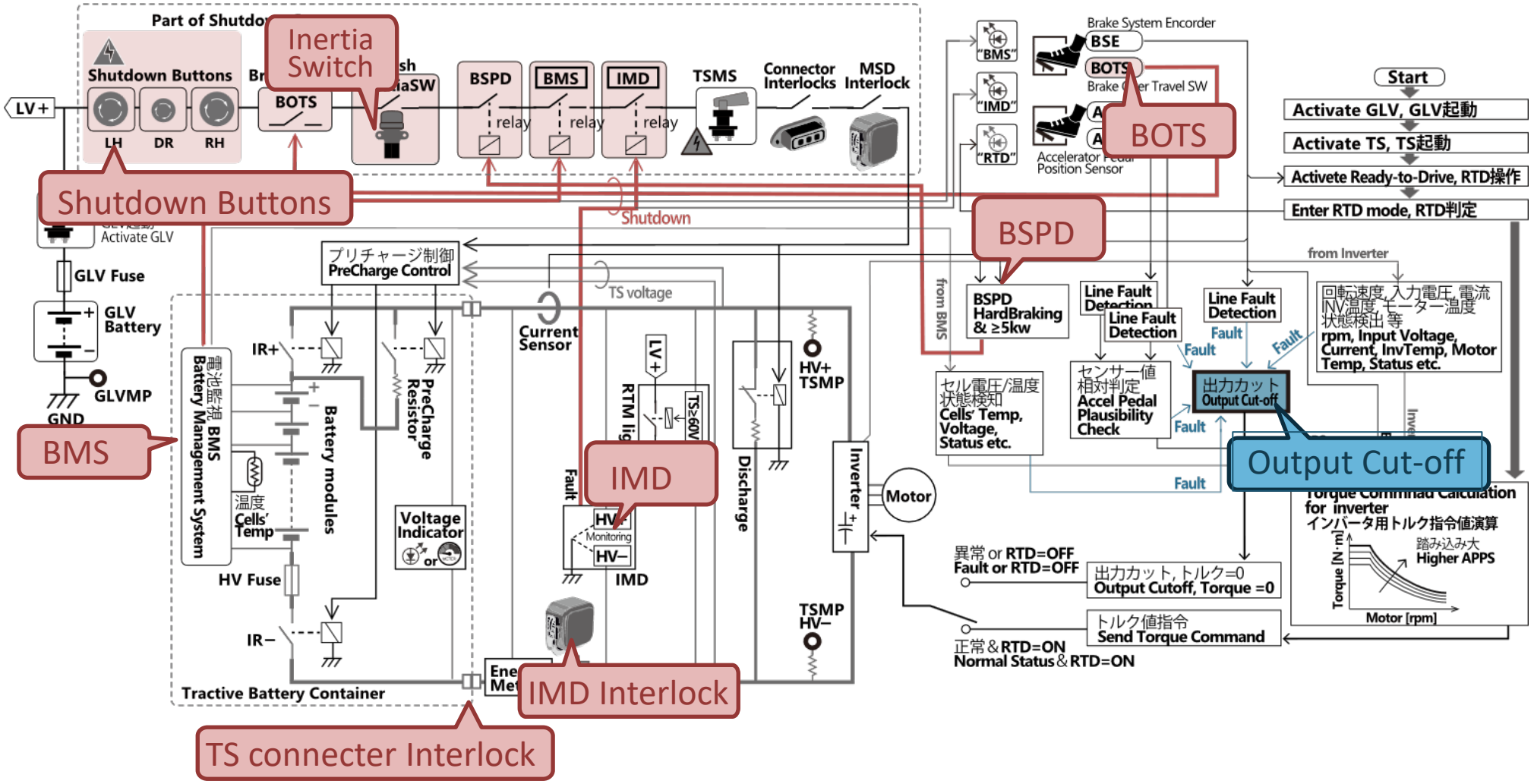
回路例
Example of discharge circuit

Brief summary of major components

Name	Function
Motor	Converts inverter power into rotating torque
Invertor	Outputs current to the motor that corresponds to the torque determined by the VCU
Tractive Battery Container	Battery Pack
MSD	Manually disconnects pole(s) of the Tractive Battery to cut off power to the TS bus
Power Relays	Connects and disconnects both poles of the Tractive Battery.
Power Cable	Orange high-voltage power cables that connect the Tractive Battery container, inverter, and motor.
IMD	Shuts down the system when leakage current or an IMD fault is detected.
BMS	Monitors cell voltages and temperatures. Shutdown the system when abnormal voltage, temperature, or other faults are detected.
Discharge Circuit	Discharges inverter charge
VCU	Calculates inverter torque
Ready to Move Light	Flashes amber if TS bus voltage exceeds 60Vdc
Tractive System Status Indicator	Normally lights green, but flashes red to indicate an abnormality in the BMS or IMD

What is TS Shutdown

- When the system is shut down, power to the outside of the TBC is cut off, and the discharge circuit releases the electric charge accumulated in the inverter's capacitors. As a result, the TS voltage drops to zero, and the vehicle becomes unable to move.
- In the event of a rule-defined failure, the system must shut down.
- A rule-defined failure must also reduce motor output to 0 kW.



Summary of Shutdown Causing Events

- The events that cause shutdown are shown in the table below.
- Some events must be designed to latch the state so that the system does not automatically return to normal even after the fault is fixed. In this case, the TSSI must flash red.

Name	Events that cause a shutdown	Latch
GLVMS, TSMS	Manually operated by team members	
Shutdown button	Manually operated by team members	
BOTS	Full depression of the brake pedal is detected by a non-resettable switch	
Inertia Switch	Impact at the moment of a collision	
BSPD	An abnormal condition is detected when motor output (≥5 kW) and brake operation occur simultaneously.	
BMS	・Cell voltage or cell temperature outside the operating range ・Disconnection of the cell voltage sensing line ・Failure of the BMS itself, including the voltage detection system or the temperature measurement system	○
IMD	Detection of leakage current, or loss of the leakage detection function	○
Connector Interlocks	Disconnect the HV connector.	
MSD Interlocks	Disconnect the MSD.	
Outboard Motor Interlocks	Detachment of the motor from the vehicle body	

Contents

Personal protective equipment(PPE)

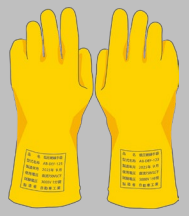
The role of PPE is to shield the source of the hazard by attaching it to the body.
Use protective equipment appropriate to the source of the hazard.
Insulating protective equipment and insulating tools are also used for high voltage work.

PPE

Protective cap

Safety glasses

HV insulating gloves



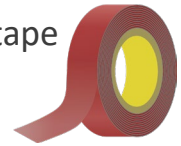
Protective shoes

Gas mask

Non-permeable gloves

In general, PPE does not include appropriate clothing.

Insulation tape



Insulated tools

Insulation sheet

Shield against hazard

Example of Hazard on HV work

High-voltage

Spark

Lithium-ion cells

Toxic

Flammable

PPE: Personal protective equipment

The PPEs are to shield the human body and the high-voltage components

Safety glasses

Eye protection from sparks, substance

HV insulating gloves

Voltage specs are determined.
The specified voltage range needs to exceed the maximum voltage of TS.
As stated in Formula SAE® Rules, HV insulating gloves within 12 months of the test date are required.

Protective shoes with insulation

Protective shoes are mandatory for the competition, and insulating shoes are recommended.
In general, voltage is not standardized by law

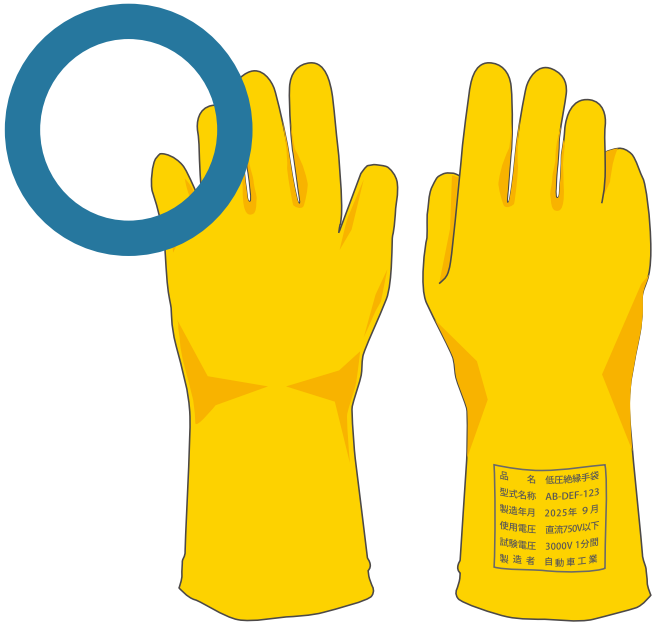
Clothing

Long sleeves and long pants are mandatory for the competition.

絶縁手袋の材質 Material of HV insulating gloves

保護すべき部分（指～手の甲～手首）は 連続した絶縁体層 で覆われていること
Both sides of the hand, from the fingers to the wrist, must be covered by a continuous layer of insulating material.

IEC60903参照， See IEC 60903:2014 for more information.

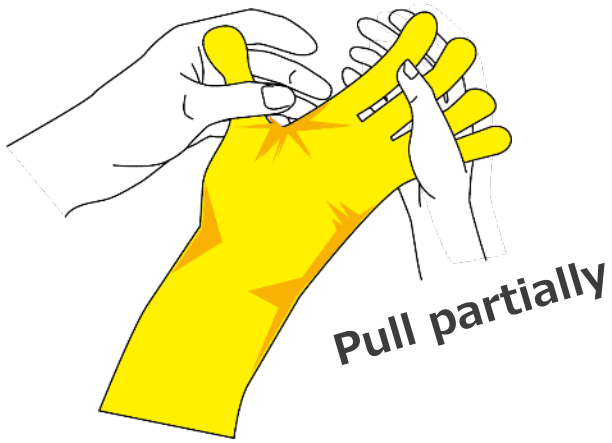


材質はゴムなどのエラストーマーであること
Material must be rubber or other suitable elastomer.

Pre-use inspection of HV insulating gloves

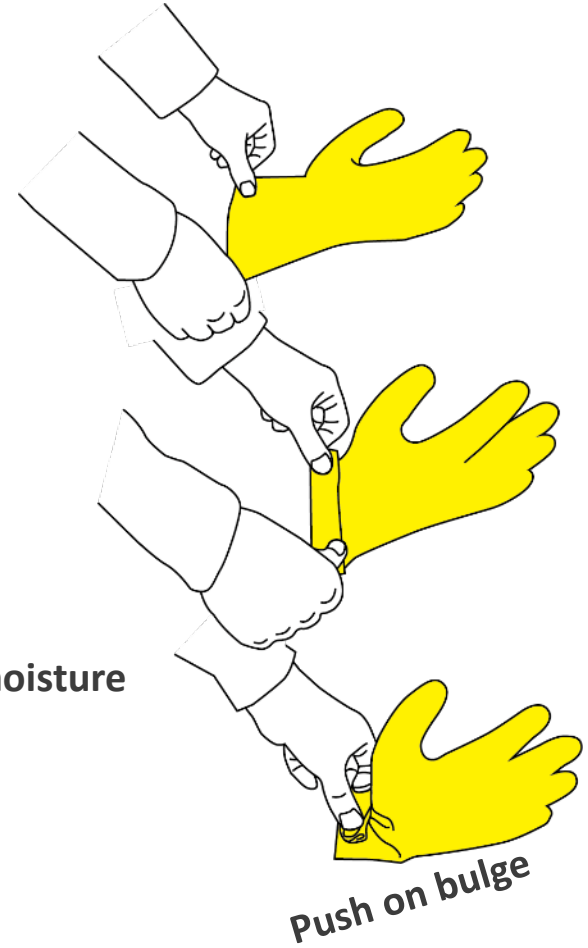
Check! before every operation to ensure the safety

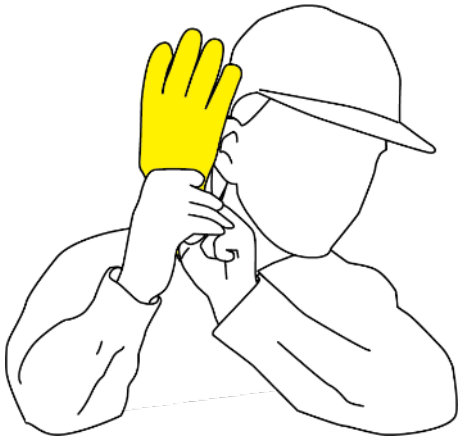
① Visible Check



Surface :
Cracks, Breaks
Adhesions of foreign substances, moisture

② Pinhole Inspection





Check the sound of leaking air

Insulation sheet

Made of rubber or resin (PVC, PU etc.)
Before disassembling Tractive Battery container, work space should be covered by insulation sheet
Insulation specs according to DIN EN61112 (VDE 0682-511),

Transparent

➢ **Cover adjacent live components**

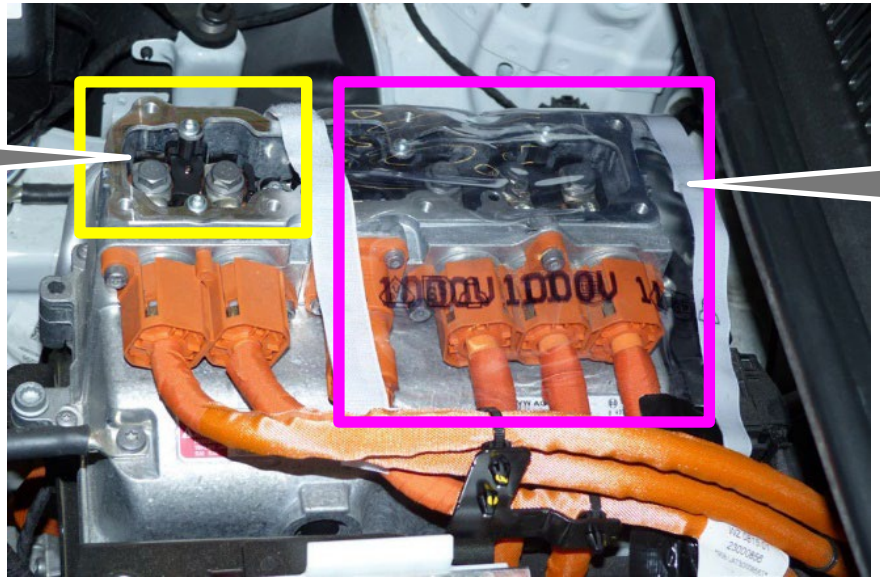


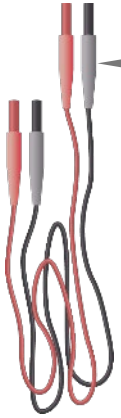
Photo: DGUV Information 209-093, Qualifizierung für Arbeiten an Fahrzeugen mit Hochvoltsystemen, August 2021

Electrical test equipment

Equipment is used to check whether components or wiring are live or not.

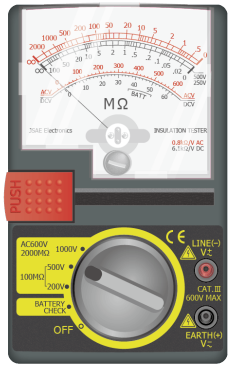
Multimeter

Check “0V” before work



Protected by sleeve from HV touch
CATⅢ, 600V

Insulation resistance tester
(Megger)



Measure resistance at high voltages to verify insulation.

- Measurement-voltage is Range is ≥ 500V
  Excessive voltage will destroy components,
  too low voltage will not be detected failure or weakness
- Wrong measurement point will damage the vehicle
  ex. Apply 500V to LV components directly

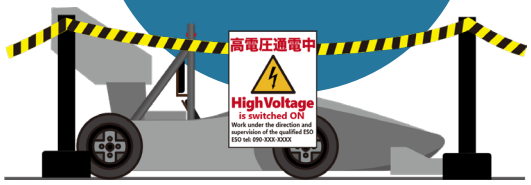
Be careful of electric shock due to the high voltage generated when measuring insulation resistance.

Usage of insulation resistance tester

Insulation check before and after work

Before work

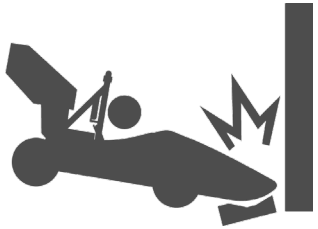
Repair and/or maintenance



After work

Vehicle runs

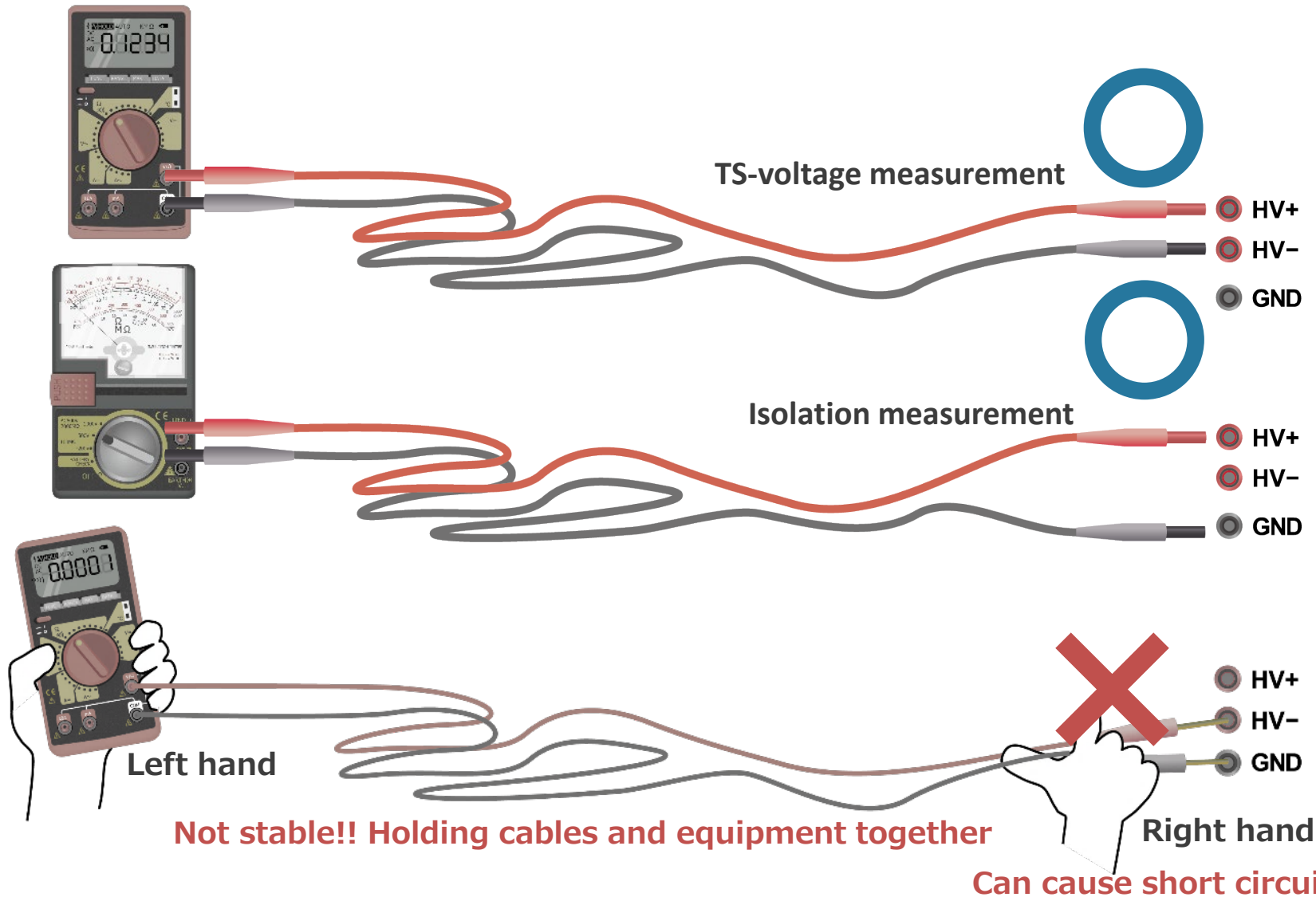
In the event of crush



Check before touch to the vehicle

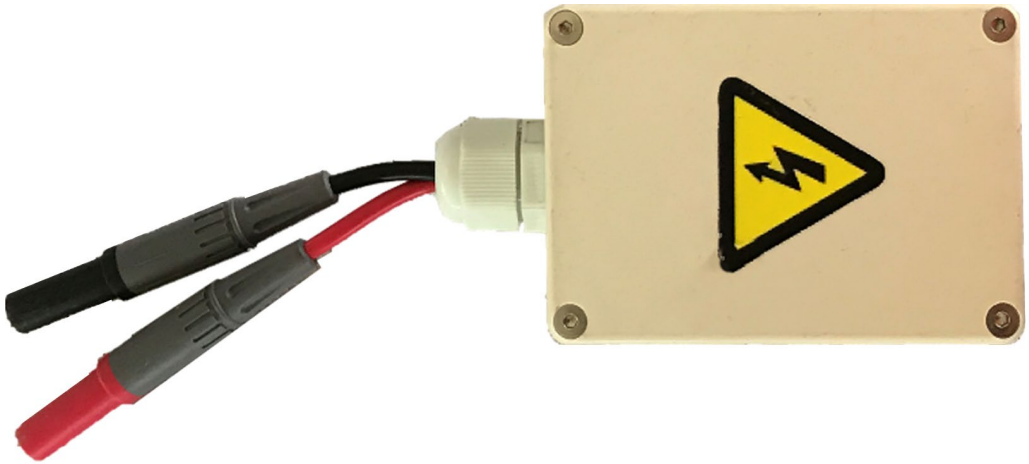
Disconnect TSMS,MSD

Use probe with protected probe tips to measure TSMPs



Insulation monitoring device inspection

The figure below is example of a test resistor for connect between TSMP and GLVMP.



Other safety equipment

Insulated tools

Mistakes can be made in the work
Prevent short circuits due to falling or accidental contact of tools

Use HV insulating gloves when using insulated tools
Before using insulated tools, make sure that the insulation coating is not damaged.

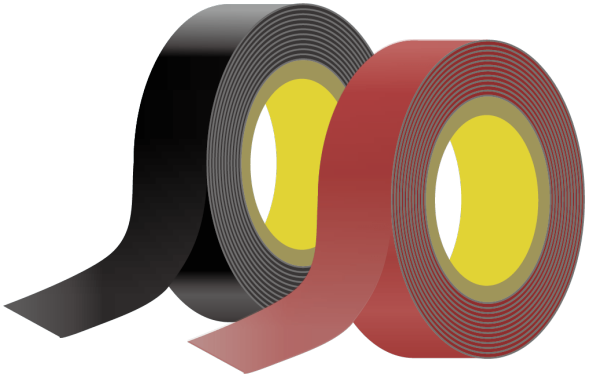
There is no Japanese standard for insulated tools, which conform to international standards.
Insulators are made of polyvinyl chloride or fluorine resin.

Add insulation tape onto normal tool

If insulated tools cannot be prepared unfortunately, cover the metal parts with insulation tape.

Other safety equipment

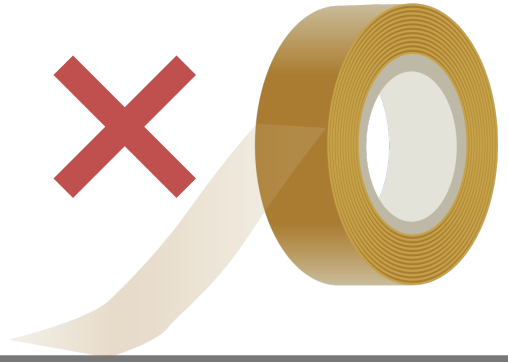
Insulation tape



High insulation performance
Used to bunding cables and cover the end of terminal

Not used alone mechanical strength are required

Mostly made of polyvinyl chloride
Rubber-rubber, acetate-based (cloth tape), and others are also available.
Specialty materials are heat-resistant glass fiber and moisture-resistant, high-strength butyl rubber, which is resistant to moisture and high strength



※ Do not confuse insulation tape with normal cellophane tape.
Do not use cellophane tape, masking tape, or packing tape for insulation

Summary Basic knowledge of personal protective equipment and tools

- **Wear protective equipment when working with high-voltage**

- **HV insulating gloves should be checked for scratches, foreign objects, and pinholes on the surface before use.**

- **Check “0V” and "insulation resistance" using a multimeter and an insulation resistance tester before work.**

Contents

High-voltage work different degree of skills

ESOs should determine the work level of their members.
Work by unskilled members is dangerous.
High-voltage work without power disconnection requires skills comparable to ESO's.

High-voltage Work in the Live State

Example:
Troubleshooting
Development and validation of TS circuits

High-voltage Work in Non-live State

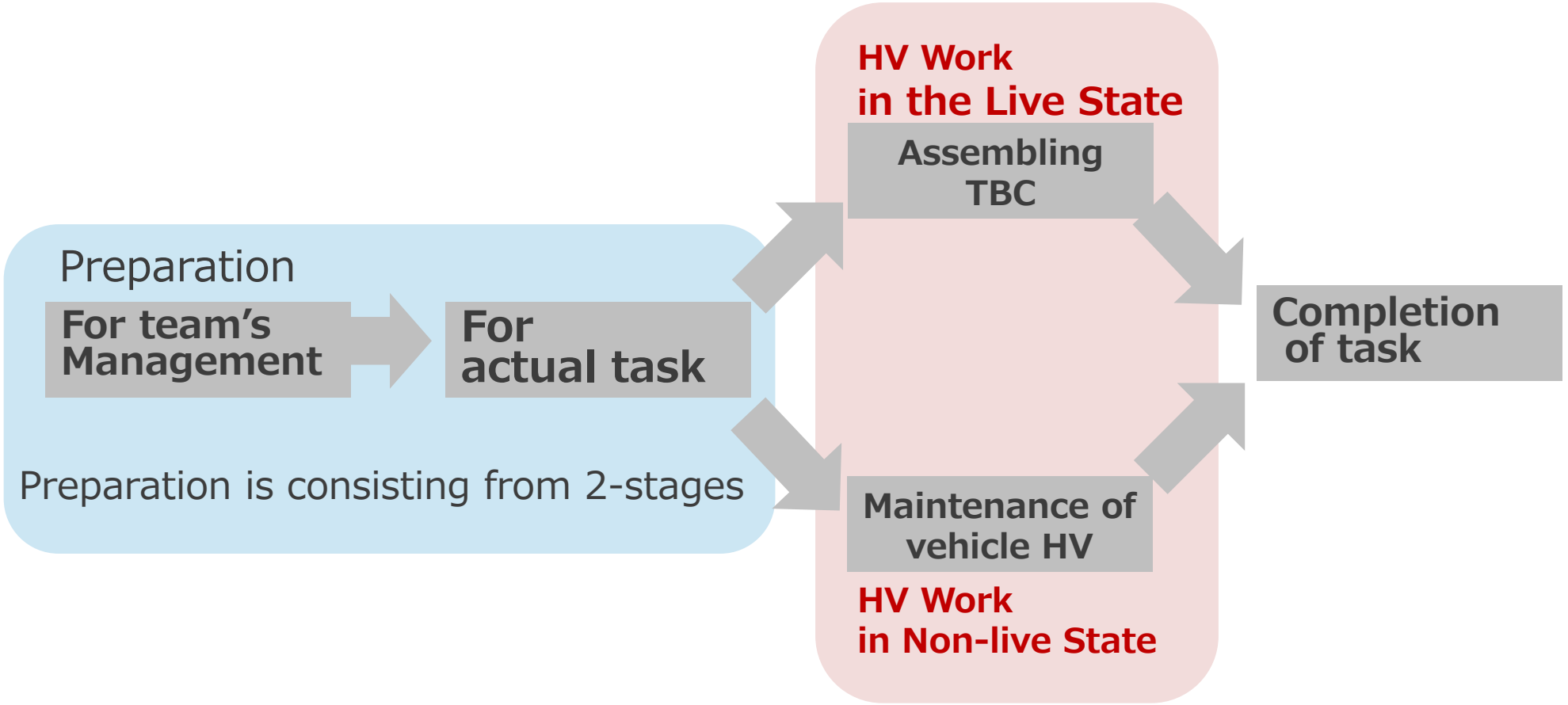
Example:
Maintenance of TS wiring after removing TSMS/GLVMS keys

Work on low-voltage electrical circuits (12V systems)

Example:
Maintenance of GLV wiring

Safe Work flow

Good preparation is essential for safe work.
Work on vehicles and Tractive Battery containers are shown as examples below



Preparations

For team's Management → **For actual task**

More intended to management

Members must be provided with appropriate information in advance

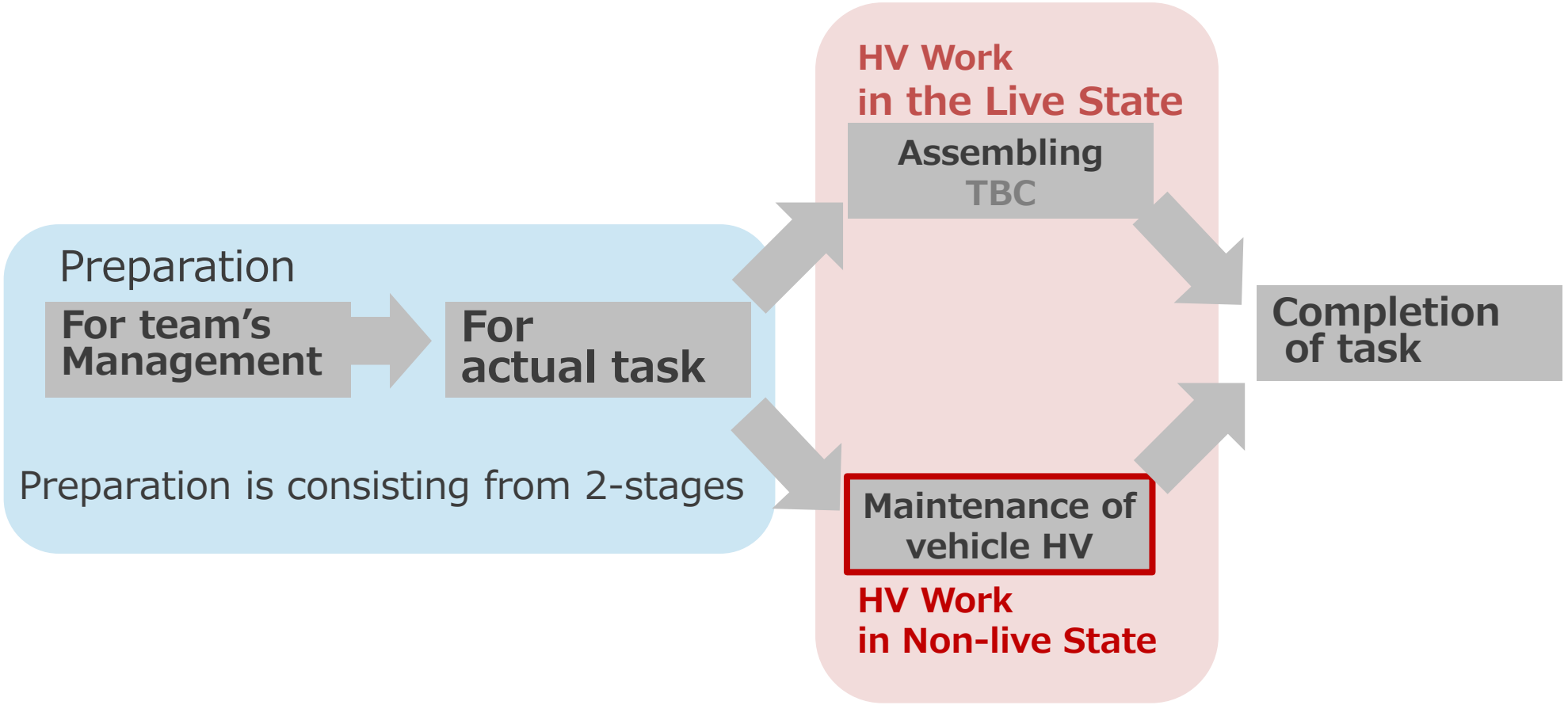
- Provide high-voltage safety training & accident cases
- Create work rules
  - Wearing protective equipment
  - Protective covers to live parts
  - "Do not work alone."
- Foster skillful ESOs and members for high-voltage work

Share procedure and information Distributable tasks between members

- Create written procedure
- Members need to understand entire system
  - Drawings：Wire-harness, Diagram
  - Actual products and components
- Share **possible info of risks** with members

Safe Work flow

Good preparation is essential for safe work.
Work on vehicles and Tractive Battery containers are shown as examples below



Preparations

For actual task

- Checking and wearing PPE

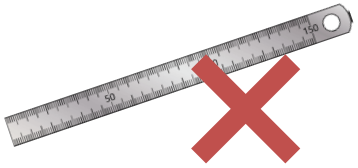
Safety glasses

HV insulating gloves

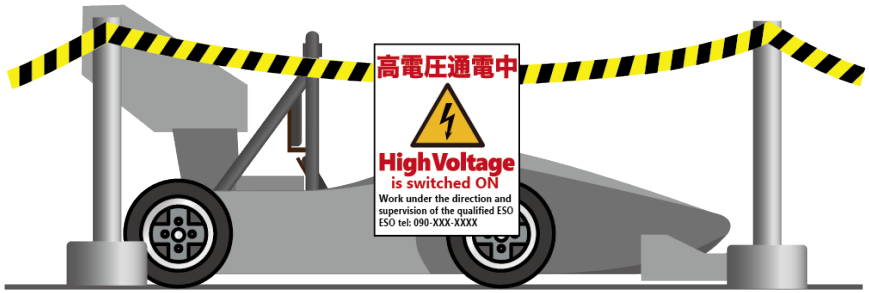
Protective shoes with insulation

- Metal items should be removed from the body and clothing, to avoid short circuit of HV

Pencils, necklaces
Scales



- Safeguarding work area



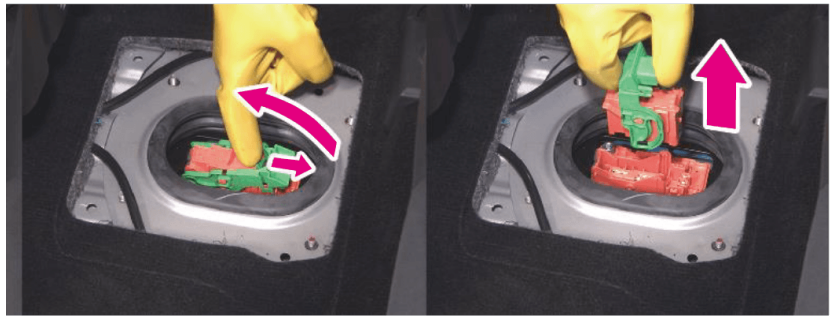
During tasks maintenance of vehicle HV

Unlock power

- Pull out TSMS & GLVMS (Lockout)
- Secure against being switched on again (Tagout)

Photo shows lockable MS

- Remove MSD with HV insulating gloves ※1 写真

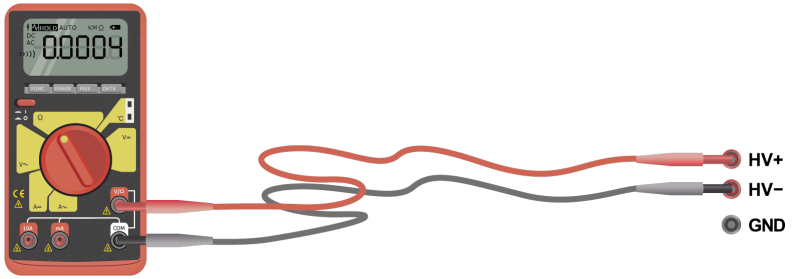


- Dummy MSD is useful prevent dust/water and re-switching on
- Disconnect 12V on-board battery (=GLV battery)

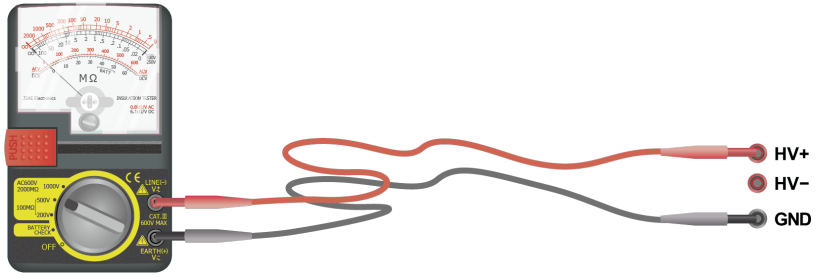
Determine absence of voltage in the multiple ways

- Voltage indicator on TBC =OFF and/or (RTML=OFF and TSSI=OFF) (1st check)

- **Check with a multimeter that TSMP voltage is 0V (2nd check)**



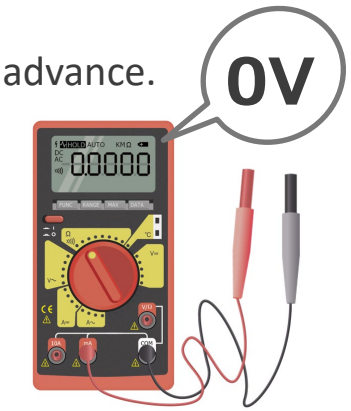
- Check with an **insulation resistance tester** that the value is greater than or equal to predetermined value.



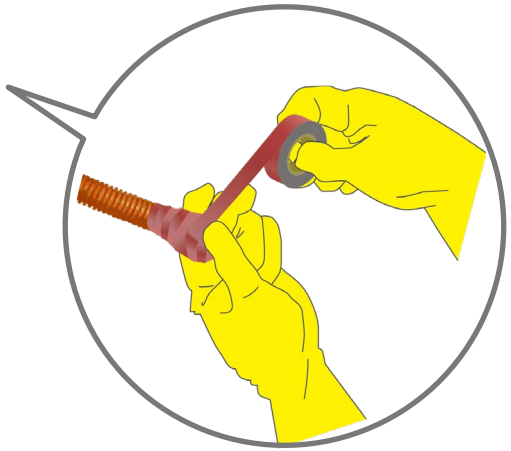
※1 写真引用元：OUTLANDER PHEV Model year: 2016 – 2020
https://www.mitsubishi-motors.com/en/RS/oceania/OUTLANDER_PHEV/pdf/GGW-ANRS-EN02.pdf

Notice on work

- **Check “0V” with a multimeter as necessary**
  Ex: When removing the input terminals of an inverter, measure the voltage in advance.
  ・Purpose of “0V” check
  a) Verify that the stored energy is zero and that there is no risk of electric.
  b) To confirm that the system is as you thought it would be.
  *Even after checking “0V”, HV insulating gloves should be worn at work.



- **Insulate removed connectors and terminals.**
  Insulate them so that they cannot be easily removed.

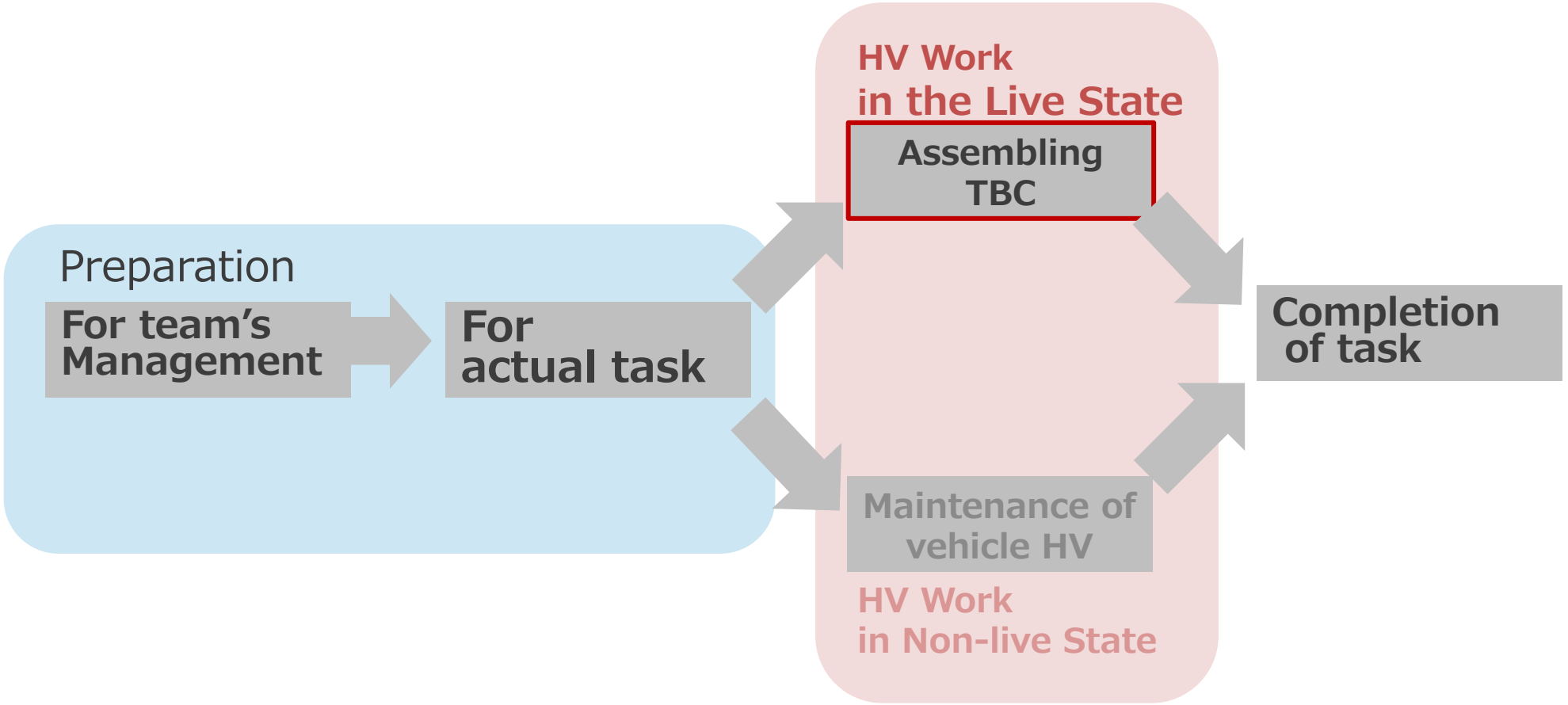


- **Use a torque wrench to install the terminals of the high-current path**

- At the end of the work on the vehicle,
  check the TSMP for 0 V and measure the insulation resistance
  to make sure it is safe to work on the vehicle.

Work in a Tractive Battery container

HV work should be done after de-emerging HV components
However, if it is necessary to work on live HV components, **cover the live parts**
This section shows work in a Tractive Battery container that HV voltage cannot be switched off.



HV Work in Live State

- Wear suitable PPE (same as Non-live state)

- **Reduce the voltage level to be worked**
  e.g., Removing maintenance-plugging to split between segments

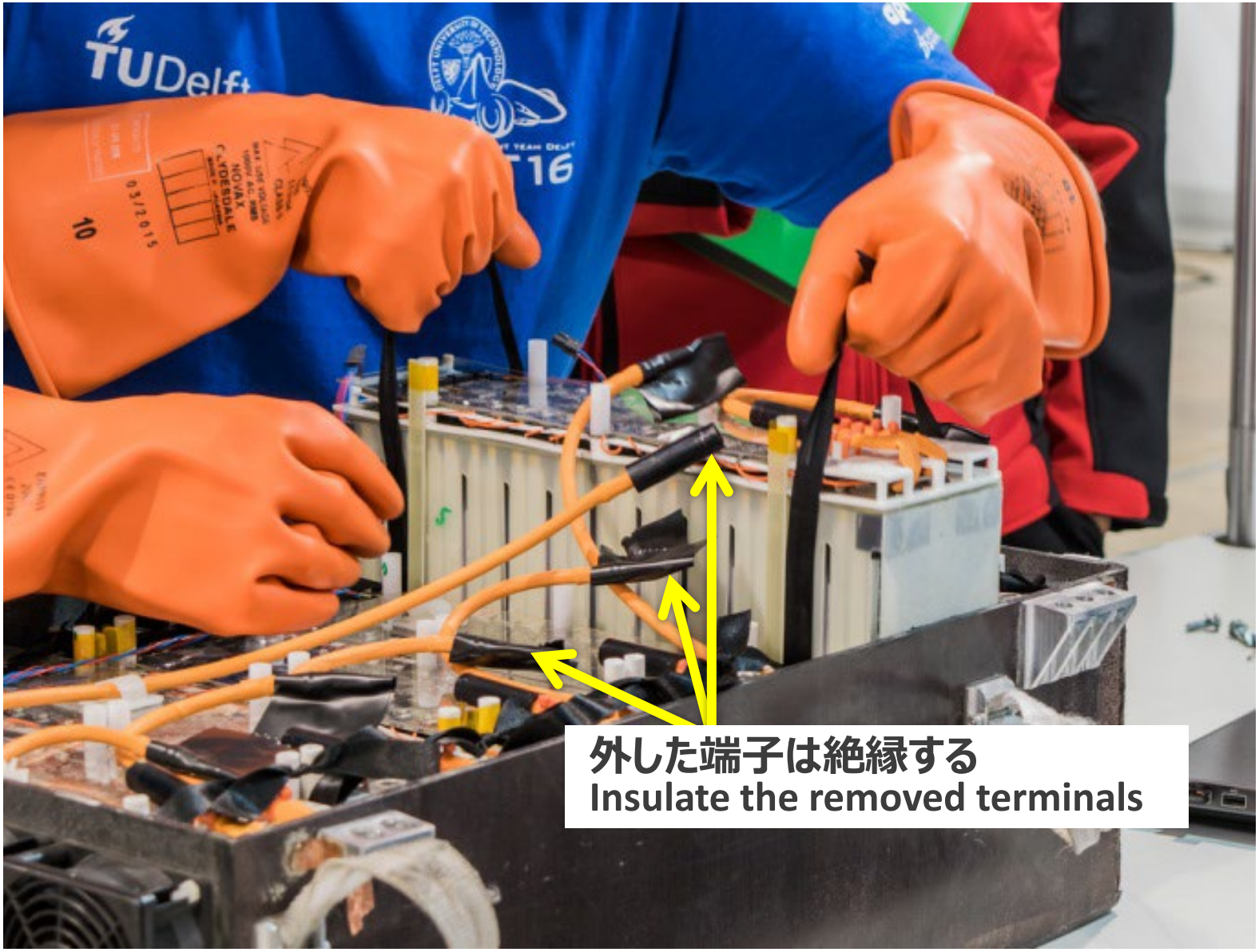
- **Cover adjacent live components**

Insulator means transparent resin plates, cover cloths according to DIN EN 61112 etc.

Pre-cautions during installation of insulators
• Insulators must be installed starting from the front of the operator and removed from the far side
• **Action must be one by one** When installing insulators with multiple workers, ➢ one worker must do the work at a time, ➢ other workers who must not work at the same time must stand by and monitor the workers installing the insulators to ensure that they are not in danger of receiving an electric shock.
• Secure the insulator so that it will not come off.

Example of High-voltage Work in the Live State

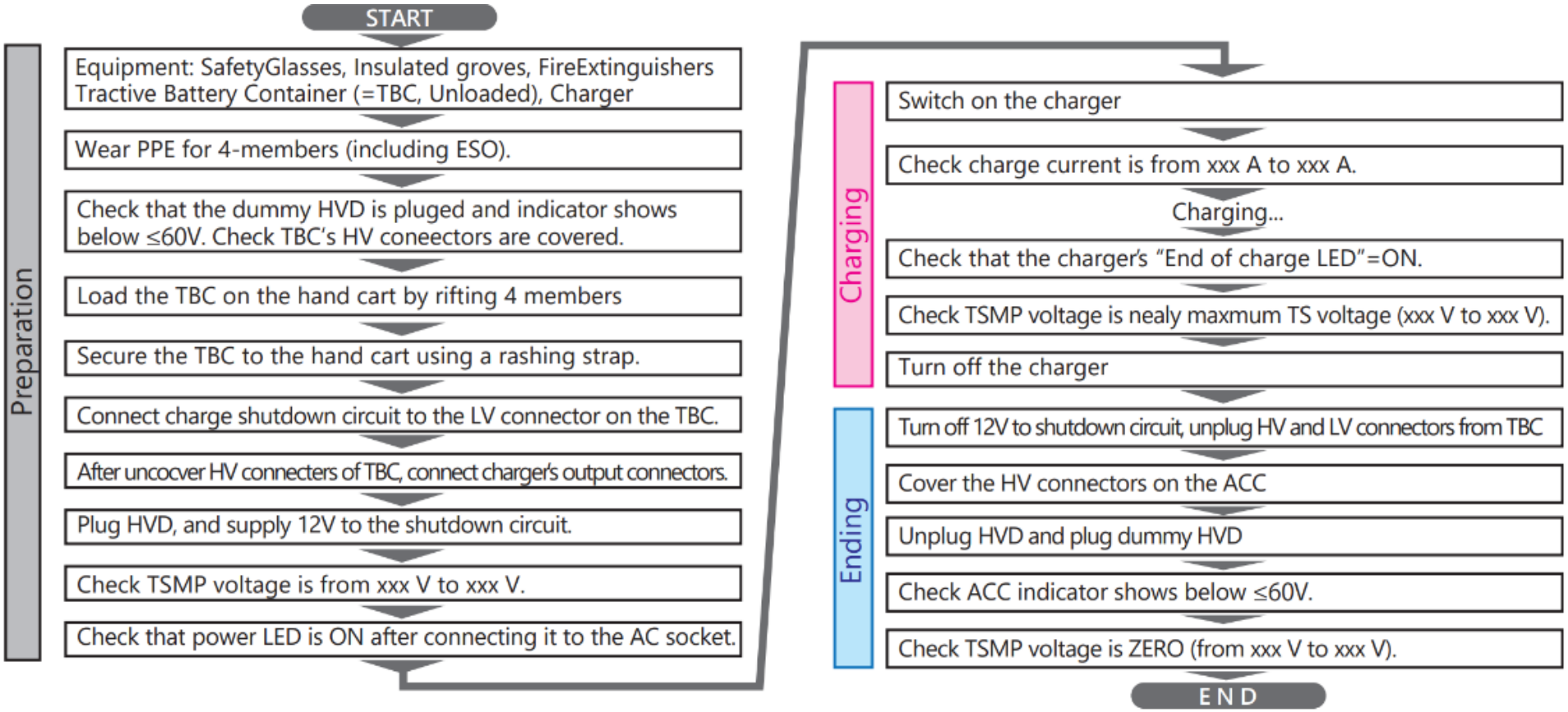
Example of High-voltage Work in the Live State



Charging Tractive Battery container

Charging lithium-ion batteries requires special management due to risks about fire and other hazard.
At the competition, charging of the Tractive Battery container is a high-voltage task and must be supervised by the ESO.

- Prepare a written charging procedure in advance
- Procedures should include stopping charge on the way, and smoke/fire ignition



Example of normal charging procedure

Examples of team's rules

Members has different of skills normally
Simple rules could be understood clearly and improve the entire level of teams.
Items below shows example of know-how about HV work **Start with what you can do !**

DO'S

- Do plan and discuss procedure and risks
- Do isolate the circuit and electrical equipment that will be worked on
- Do tagout/lockout Master Switches
- Wear appropriate PPE after test equipment
- Cover MSD hole with dummy-plug after removing MSD
- Always check "0V" before HV work
- Always cover arms, legs and body with clothes
- Always maintain exit paths clear

DON'TS

- DON'T try to save time by eliminating procedure
- DON'T HV work only you
- DON'T trust safe after only checking indicator
- DON'T work not isolating HV
- Fail to insulate cover for short periods of time
- DON'T work in a small space without cleaning up
- DON'T HV work with rings, watches, and bracelets

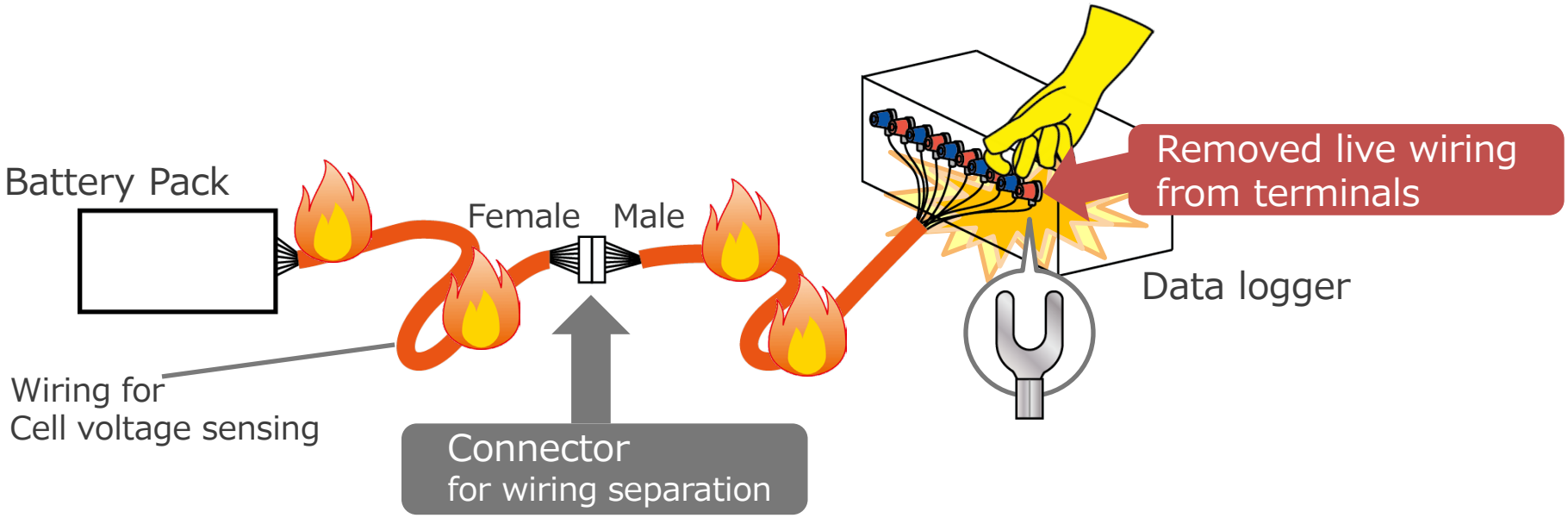
Contents

Case 1

Cells voltage wiring were short-circuited and the entire wire caught fire.

- During charge, a data logger was recorded cells voltage from the inputs on the back. After charge, data logger should be divided using **a connector on the wiring**

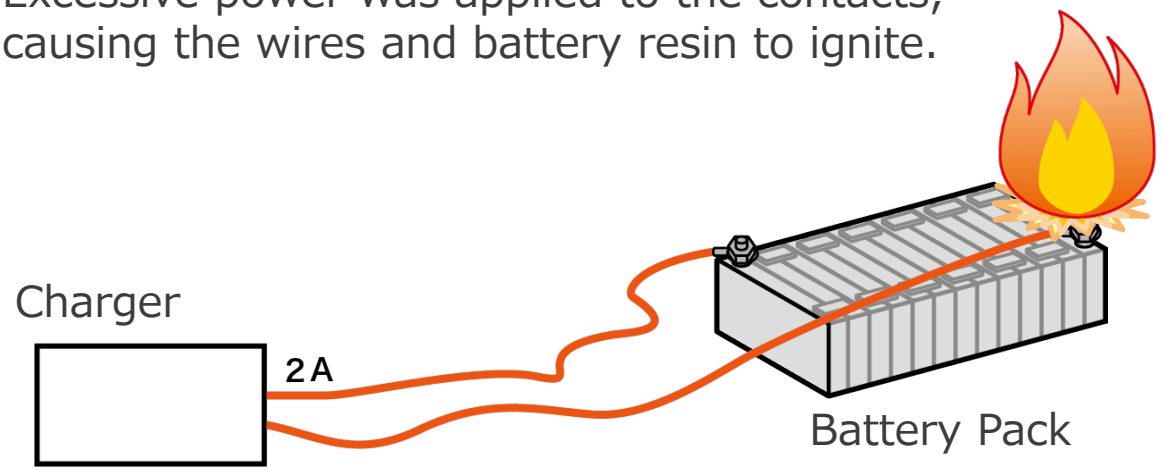
- The member who didn't know the connector on wiring, removed Y-terminals from the data logger's input.
- The Wiring shorted the battery pack through the terminals .



Case 2

The member hand-tightened the nut on the HV terminal.
During charging, the battery caught fire.

- Setting 2sq wiring for DC2A charging.
- The member hand-tightened the wiring to the terminals, and start charging.
  After the member leave there, the battery caught fire.
- Insufficient torque resulted in an increase in the resistance of the terminal's contacts.
  Excessive power was applied to the contacts,
  causing the wires and battery resin to ignite.

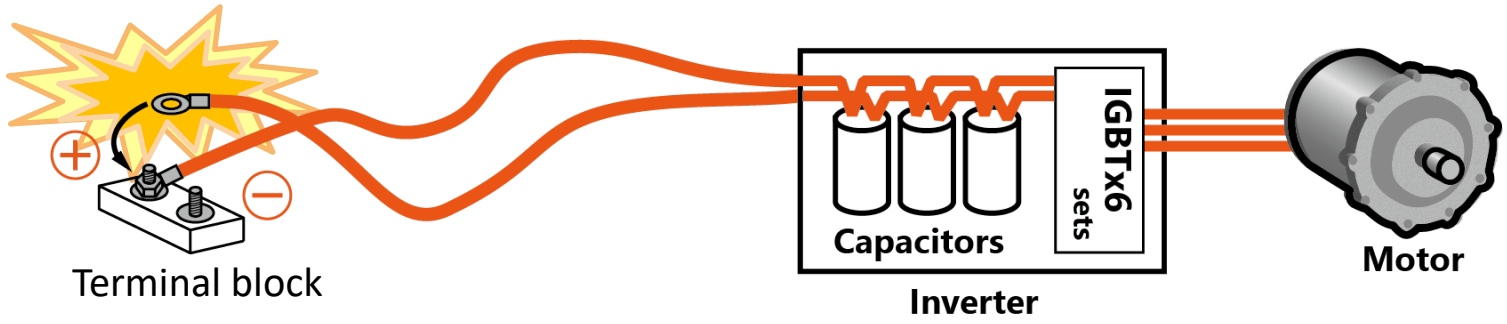


Similar Ex.
Energy Meter, melted wiring

Case 3

Disconnect the battery from the inverter.
The next day, the inverter wiring was short-circuited during re-assembly.

- The members could not foresee the danger of remaining electricity on the capacitors.
- He did not check voltage with a multimeter before operation.
- He did not apply insulation protection to the free terminals.

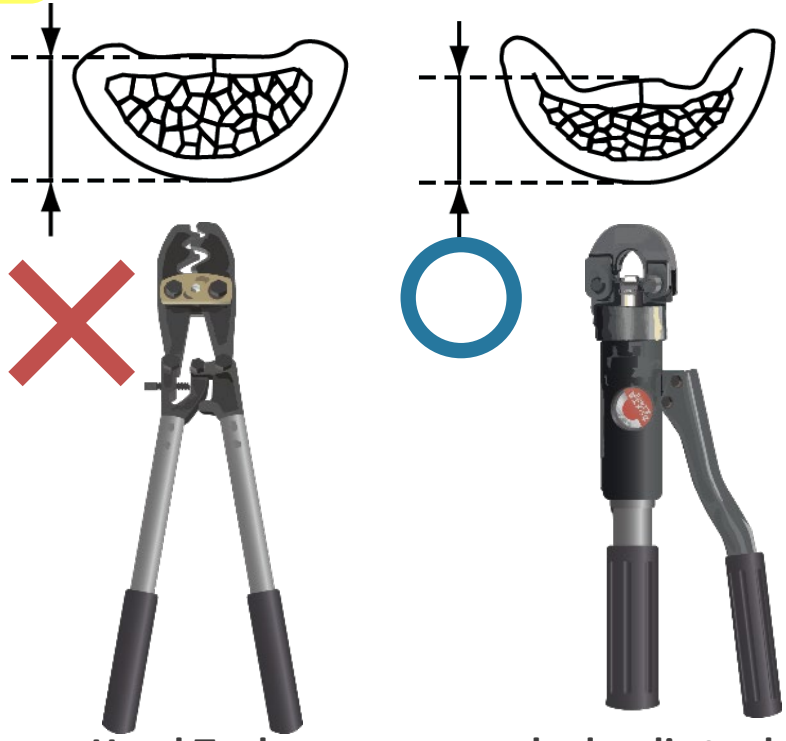


The short circuit made a boom and the member could not hear anything for some tome.
The part of bolt on the terminal block was gone out.

Case 4

The hand-crimping resistance increased after repeated assembly and disassembly

- Insufficient hand tool crimping
- Lack of knowledge of correct crimping criteria



Hand Tool
with bad skill

hydraulic tool

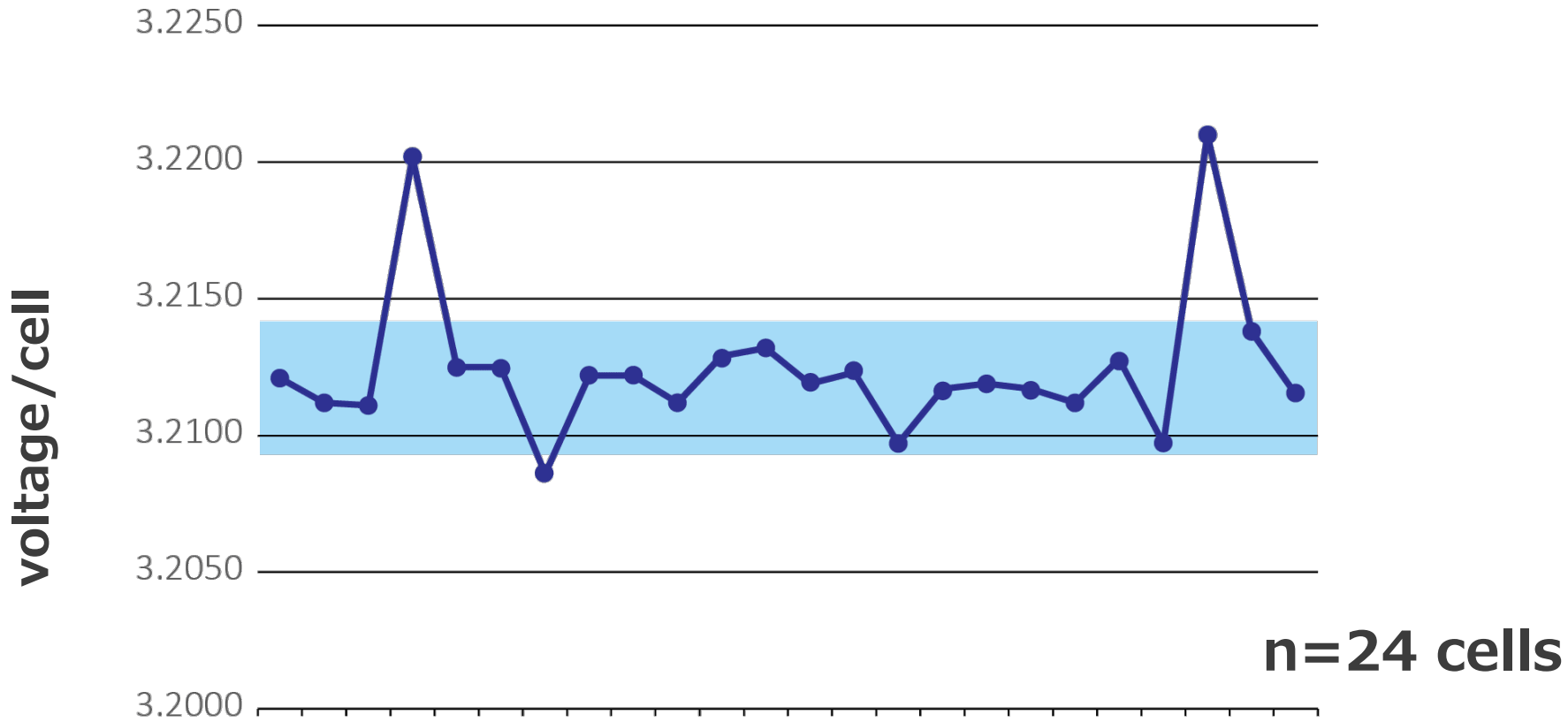
Case 5

Injured by sparks when connecting the modules in parallel during TBC assembly.

- Before connecting the modules, there are a voltage difference.
- A current flow between modules caused a big spark.

Actual cell voltages (via Aliexpress)

The chart shows actual voltage differences just after the delivery.
Need adjusting cell voltage before assembly.



Normally difference of mass production cells voltages are ≤10mV
Large voltage differences are considered as differences in the history of each cell.

Case 6

When connecting the wiring inside the TBC and his arm touched the metal case of the TBC, he had an electric shock.

- The invisible wiring/terminal contacted to the metal case.
- He has his arms up because of the hot summer.
- Isolation between high voltage circuit and ground had not been verified prior to operation.

Case 7

Tractive Battery container caught fire while charging without BMS control.

- The battery ECU (BMS) was determined to be faulty because it frequently shut down even after charging.

- The TBC was charged by DC power supply without a shutdown circuit
  After that, a fire broke out with a boom.

- After the fire broke out, the fire extinguishers could not extinguish it.
  A large quantity of water was spilled from a fire hose.

Case 8

The battery cell ruptured during charge after a member went out.

- The member was charging a cell with recording temperatures and voltages to adjust cell voltage.
- Then he went out to buy an evening meal. it means neglect of monitoring
- When he came back, he found white smoke inside the room.
  He opened the windows to ventilate the air.

Case 9

When charging the auxiliary battery, the cell swelled and the battery case cracked.

The charger
with cell monitoring

The auxiliary battery was charged to a unique charger on the desk.

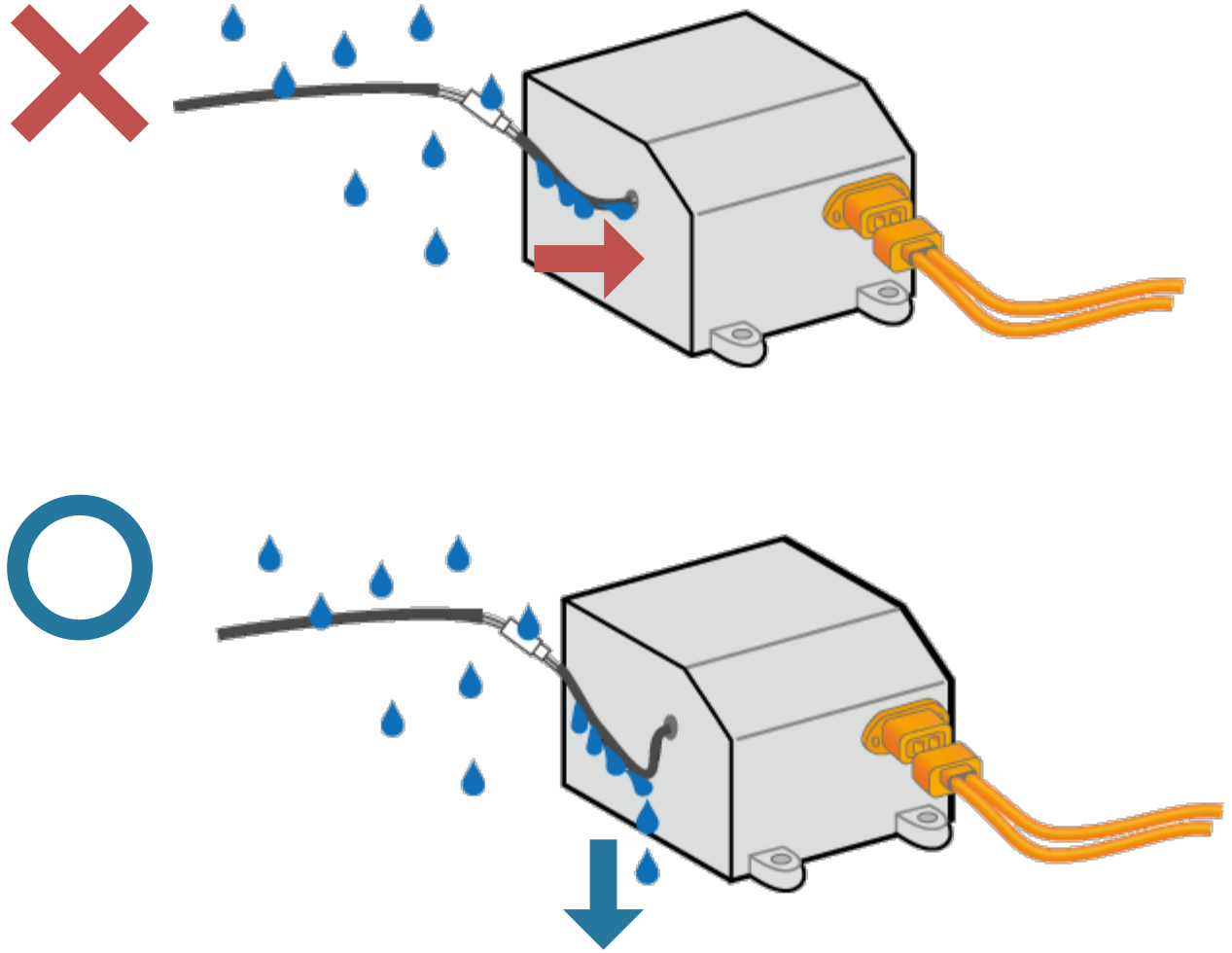
After a while, the auxiliary battery case was cracked and the cells were leaking a little electrolyte.

Finally Auxiliary battery was filled with sand and sealed in a metal container

Case 10

The wiring has allowed water to enter the Tractive Battery container

and there is an electrical leak. This case shows insufficient preparation for the rain test.



Trouble in the past

1. Cells voltage wiring were short-circuited and the entire wire caught fire.
2. Wiring with hand-tightened HV nut caught fire during charging.
3. The inverter made a large short current 1-day after using it.
4. The crimping resistance increased after repeated assembly and disassembly.
5. Short circuit causes sparking when battery cells are connected in parallel.
6. Electrical shock occurred when a worker touched to the metal of the Tractive Battery container during assembly.
7. During Charging No.1: Tractive Battery container caught fire during charging without BMS.
8. During charging No. 2: Battery ruptured during cell charging.
9. During charging No. 3: Cells swelled and the case cracked when charging the auxiliary battery.
10. The wiring has allowed water to enter the Tractive Battery container.

Contents

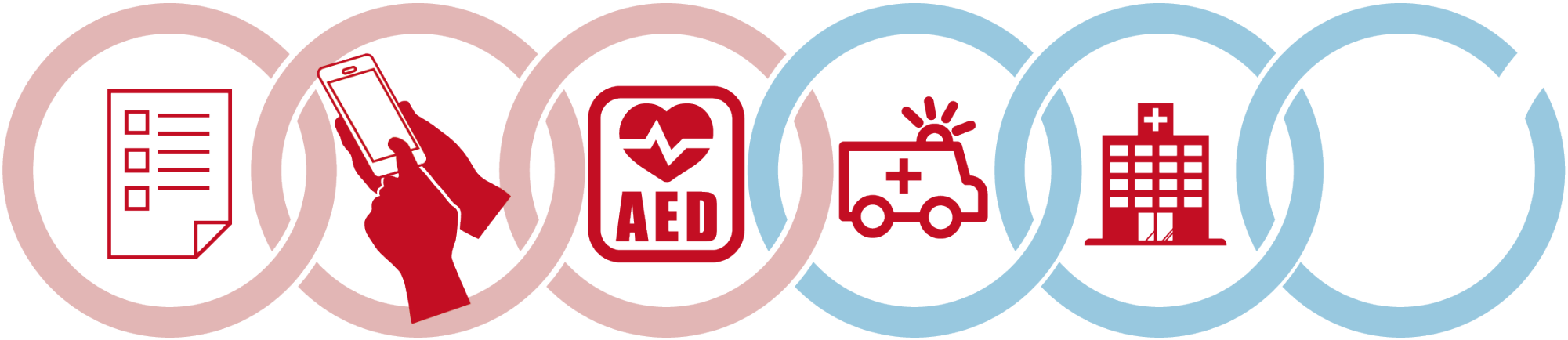
First aid

- Medical, organizational and caring measures on sick or injured persons with **simple means** including the emergency call.
- Seamless help from the scene of the incident to the hospital can only be ensured by **organizational measures**.
- In the event of an emergency, those present are required to **take action to save lives without harming themselves**

Member's role in seamless support from the field to the hospital

In the event of an emergency, members should take the necessary steps until handover to medical personnel within its own education and training

Team members | **Medical professionals**



Preparing in advance for emergencies, Member education

Emergency call

Organized first aid

Process should be simple！

Prepare emergency instruction

- **Emergency situations require quick and precise action.**
- **The following minimum preparations should also be educated to members so that they can take action.**

Type	Procedure
In the event of an emergency	(1) Notification via the university's emergency contact network (2) Call 119 (3) Provide first aid (4) Guide emergency vehicles to
First Aid	• Ventricular fibrillation → AED/cardiac massage, follow #119 instructions • Burn →Cool with water • Bleeding →Compression to stop bleeding • Accidental ingestion →Identify what was swallowed using empty bottles, etc. • Heat stroke →Cool the body in the shade, use vaporization heat, drink water • Adhesion →Rinse with water for at least 15 minutes
Fire Extinguishing	(1) Call 911 (2) Rescue of human life (3) Extinguish with a fire extinguisher Run away if the height of the fire exceeds the height of a person.

- **Make sure fire extinguishers, hydrants, and AEDs are located.**

Prior education for team members

- **All team members are aware of the minimum measures to be taken in case of an emergency**
  Online textbooks are available from the Tokyo Fire Department and other sources.
  - 一般市民向け 応急手当WEB講習 オンラインテキスト, 消防庁
  - 普通救命講習 (短縮救命講習用) オンラインテキスト, 東京消防庁
  - Hands-Only CPR, American heart association

- **It is desirable to receive instruction from experts at public institutions**
  Municipal fire departments offer various training courses

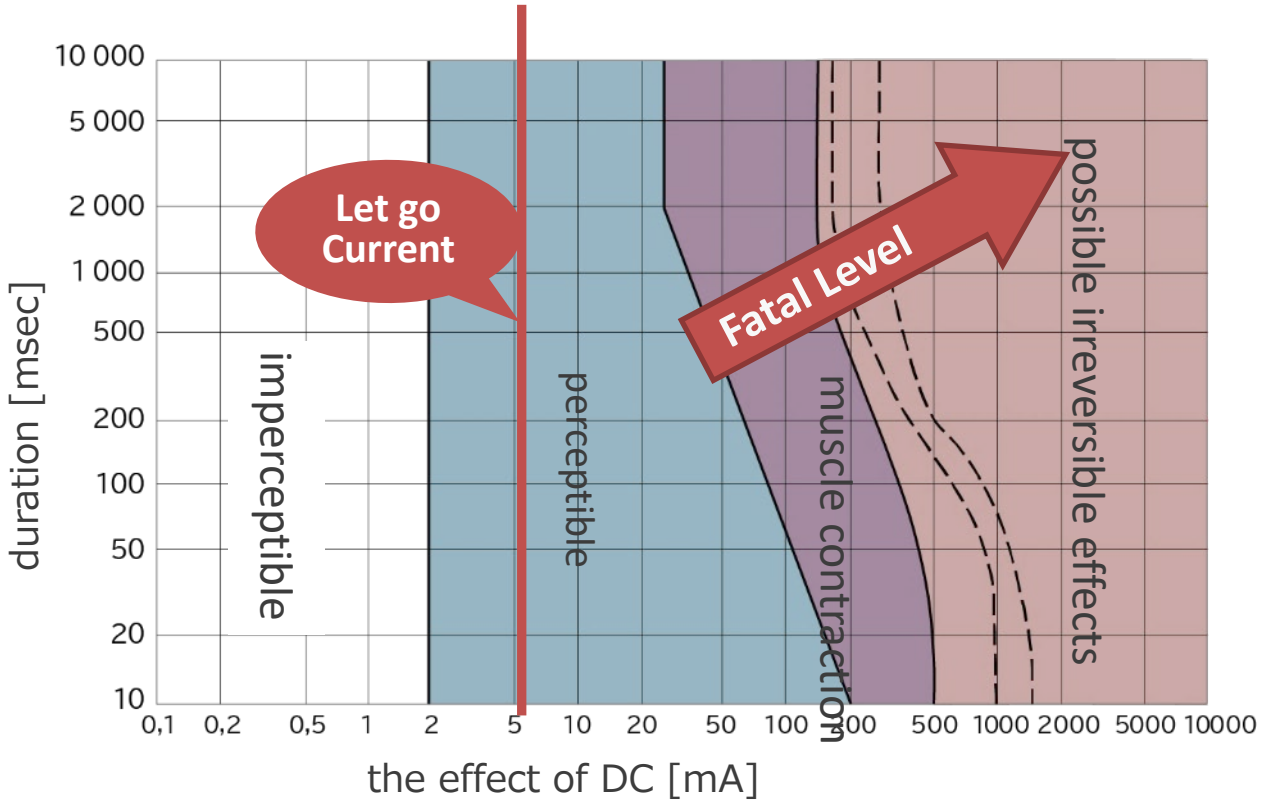
The chart below from Tokyo Metropolitan Fire web page https://www.tfd.metro.tokyo.lg.jp/lfe/kyuu-adv/life01-1.htm

応急手当コース					
講習種別	講習時間	講習内容	認定証等の交付	有効期限	お問合せ先
応急救護講習	希望する時間	けがの手当てなどを学ぶコース	交付はありません。	―	都内各消防署
救命入門コース	４５分	小学校高学年の方、普通救命講習の受講希望はあるが講習時間が取れない方、これから普通救命講習を受講される方等を対象とした、胸骨圧迫やＡＥＤを中心に学ぶコース	救命入門コース（４５分）受講証	―	
	９０分		救命入門コース（９０分）受講証	―	
普通救命講習	３時間	心肺蘇生やＡＥＤ、異物除去、止血法などを学ぶコース ※小児や乳児に対する心肺蘇生を中心とした内容をご希望する場合は都内各消防署にご相談ください。	救命技能認定証	3年間	都内各消防署 又は 公益財団法人東京防災救急協会
普通救命（自動体外式除細動器業務従事者）講習	４時間	普通救命講習の内容に、ＡＥＤの知識確認と実技の評価が加わったコース	救命技能認定証（自動体外式除細動器業務従事者）		
普通救命再講習	２時間２０分	前回の普通救命講習受講日から３年以内に再度受講するためのコース。（知識の確認と実技の評価を実施します。）			
上級救命講習	８時間	普通救命（自動体外式除細動器業務従事者）講習の内容に加えて、小児・乳児の心肺蘇生、傷病者管理、外傷の応急手当、搬送法など学ぶコース	上級救命技能認定証		・「団体」は都内各消防署 ・「個人」は公益財団法人東京防災救急協会
上級救命再講習	３時間	前回の上級救命講習受講日から３年以内に再度受講する方のためのコース（知識の確認と実技の評価を実施します。）			

Electrocution may result in cardiac arrest

Men and women cannot move, if the current exceeds 9 mA and 6 mA respectively

High current can cause ventricular fibrillation (cardiac arrest, heart lost normal beating)



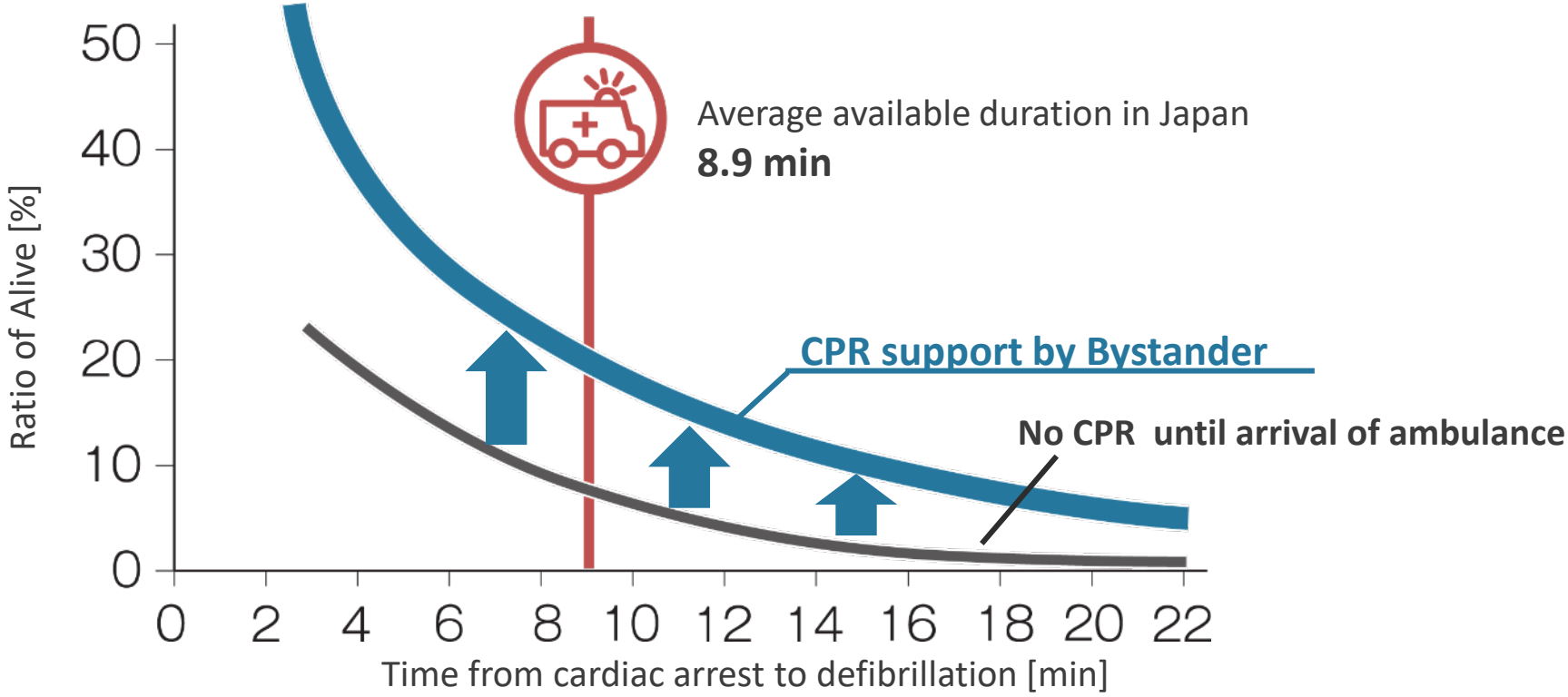
出所：IEC 60479-1:2018, Effects of current on human beings and livestock - Part 1: General aspects

Ventricular fibrillation： Resuscitation related to Chest Compression and AED

- **C**ardio**p**ulmonary **r**esuscitation (**CPR**) can be performed by anyone
  Perform CPR, If a person collapses in front of you and his/her heart or breathing has stopped

- **Heart massage (human chest compressions) for cardiopulmonary resuscitation**

- **Apply AED for restoring normal heart function (defibrillation)**



グラフ出所　：Effect of bystander cardiopulmonary resuscitation in out-of-hospital cardiac arrest patients in Sweden. Resuscitation 2000: vol47-1, Pages 59-70
到着時間出所：総務省消防庁, 令和3年版 救急所の現状 救急編（p.3）

Procedures in case of cardiac arrest

With every minute, the chance of survival of affected persons with ventricular fibrillation decreases by 10-12 %**.†1
The following steps should be taken promptly

Call #119 **Emergency number**

Chest compressions

Transport oxygen to the tissues

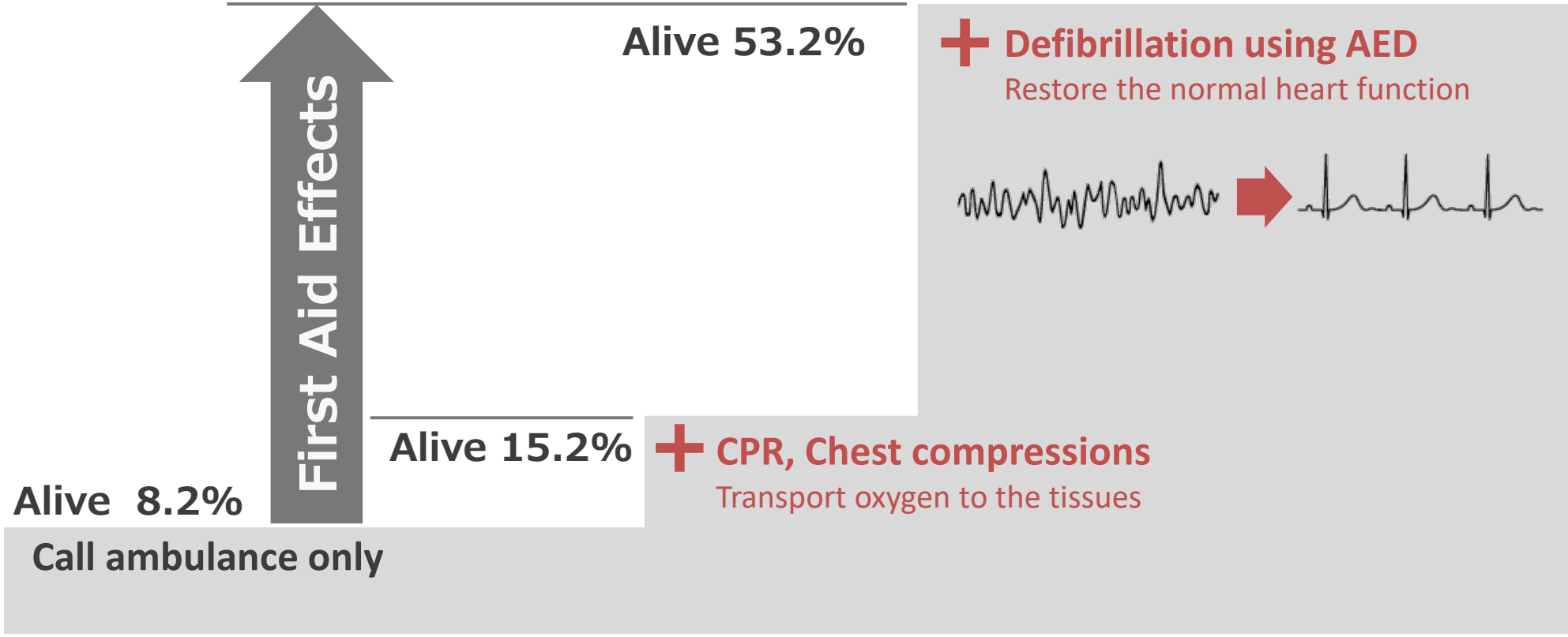
AED automated external defibrillator

Restore normal heart function

†1 出所　　：Part 4: The Automated External Defibrillator: Key Link in the Chain of Survival. Resuscitation 46 (2000) 73±91
イラスト引用元：日本救急医療財団, 救急蘇生法の指針 改訂6版 市民用, (2020)

First aid increases the survival rate

Chest compressions (cardiac massage) and AED play different roles
AED improves survival rate dramatically, but only about 2% of all patients are saved
Preparing to use an AED is most important thing



Survival rate of the general public witnessing a cardiac arrest

出所　：総務省 プレスリリース,「『令和3年版 救急・救助の現況』の公表」, 2021年12月24日

When you see a person on the ground, call emergency #119 immediately

If the person does not respond to your voice, call emergency before attempting CPR

Observe response

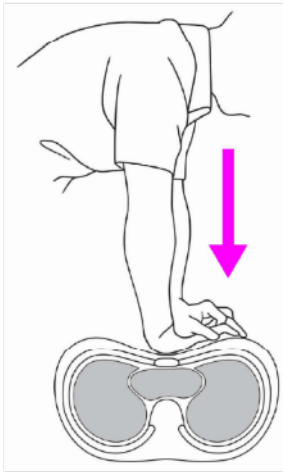
Call for help

Call emergency

引用元：日本救急医療財団, 救急蘇生法の指針 改訂6版 市民用, (2020)

Start CPR, Chest compressions, before arriving AED

Base of palm



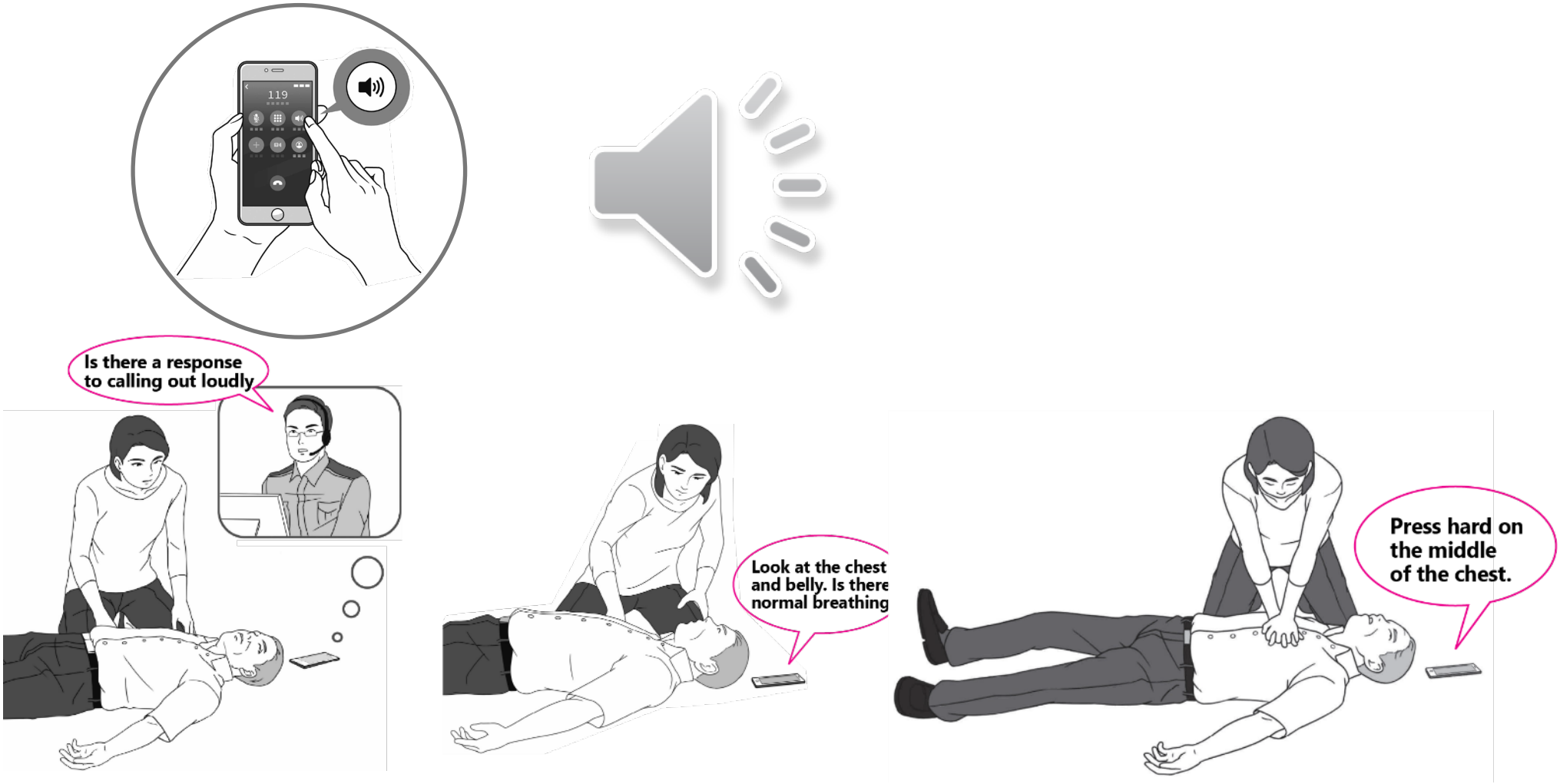
Stretch out your elbow

Push 100-120 times per minute

The procedure is given by voice from emergency contact

引用元：日本救急医療財団, 救急蘇生法の指針 改訂6版 市民用, (2020)

The procedure is given by voice from emergency contact



引用元：日本救急医療財団, 救急蘇生法の指針 改訂6版 市民用, (2020)

The AED will give you voice instructions on how to proceed

Even if you are not sure whether the patient is responsive or breathing,
act as if the patient is in cardiac arrest

Apply electrode pads to the chest

Follow the AED's voice message

Do NOT touch the body
when instructed to administer electroshock

引用元：日本救急医療財団, 救急蘇生法の指針 改訂6版 市民用, (2020)

Summary: First aid in the case of incident

- **Prepare contact information and procedures in advance**
  to respond quickly in case of an emergency.

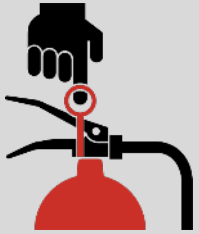
- **Provide at least minimum training to members for organized activities**

- **Call emergency #119, if you find a person lying on the ground**
  If cardiac arrest is suspected,
  - Start CPR immediately to transport oxygen to the tissues
  - Prepare AED to help the person recover the normal heart beating

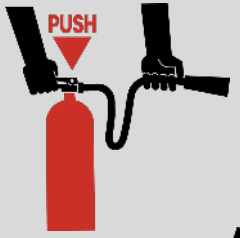
How to Use Powder fire extinguisher

Warn of fire at first !
Escape immediately, when fire exceeds the height of man

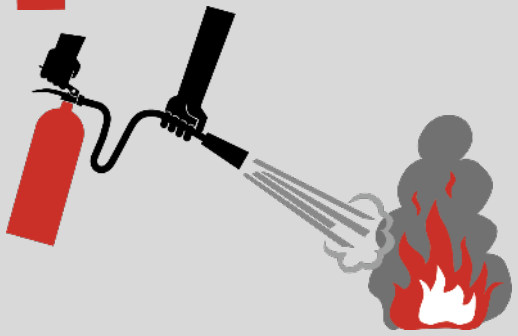
3 to 5 meters from the fire
Pull out the safety pin



Aim the hose nozzle
at the fire



Squeeze the lever tightly
Aim at the bottom of the flame.

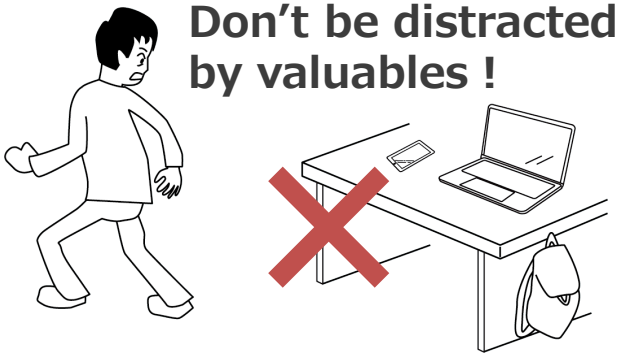


3kg Powder
10~15 seconds

In the building, escape before smoke coming

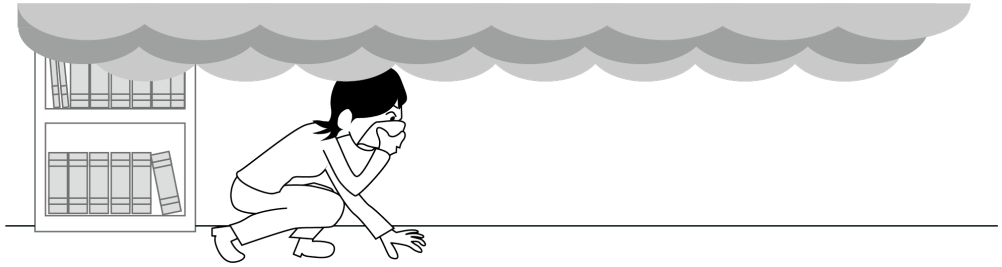
Warning call for specific action
Emergency call

Start evacuating as soon as possible!



Don't be distracted by valuables !

Your life > Your phone

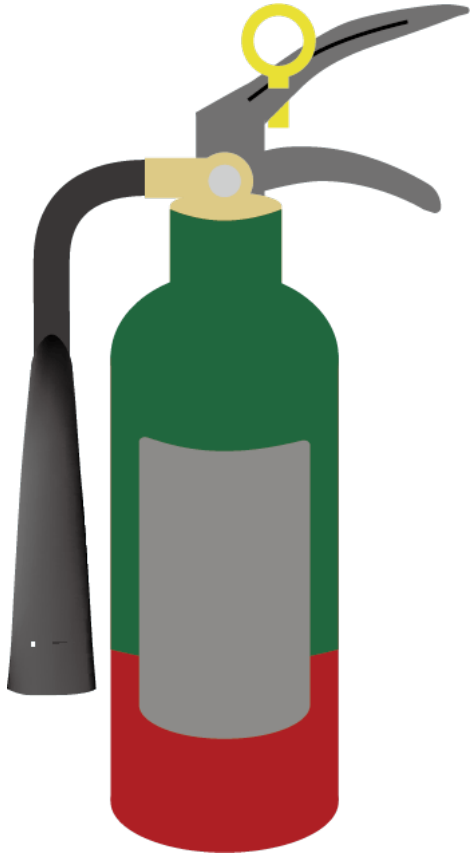


Duckwalk under the smoke

In a building CO2 fire extinguishers are not safe

- **CO2 concentrations used to extinguish fires(≥35%) cause immediate loss of consciousness**

10%	Loss of consciousness in a few minutes
3-6%	headache, dizziness, nausea in a few minutes



*The Aichi Sky Expo Hall, site for the 2024 Formula SAE Japan event, is equipped with a ventilation system, allowing the use of CO2 fire extinguishers.

Expert knowledge of lithium-ion batteries or battery fires

Lithium-ion batteries can overheat, thermal runaway and ignite for a number of reasons.
In most cases, cells are closely installed in the Tractive Battery container. If one cell ignites, the fire spreads to neighboring cells and may not be extinguished with a few fire extinguishers.

Indoor fires present a significant risk of carbon monoxide poisoning.
Avoid gas poisoning, save your own life, and wait for skilled firefighters arriving.

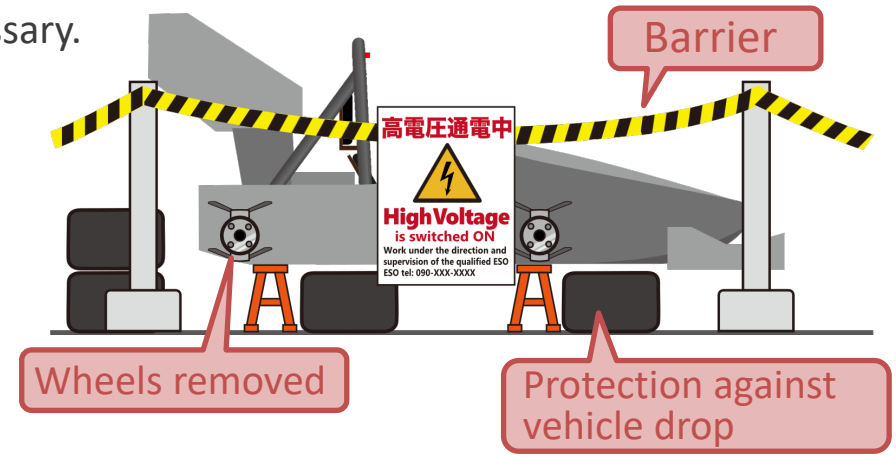
Lithium-ion batteries should be stored without risk of falling down or dropping.
Cells and the Tractive Battery containers should be stored away from cardboard and other flammable materials. (to preventing the spread of fire)

Contents

Regular operation on competition site

< HV Work in the Live State (work involving to vehicle parts other than TS) >

- The work area must be protected with barriers to prevent unauthorized access.
- Check RTML is off and TSSI is off
- Check the voltage between HV+ and HV- is less than 60V
- When not working with the TS on, it is strongly recommended to remove the MSD and insert the dummy plug.
- ESO must control the disconnected MSD
- Disconnect the positive terminal of the GLV Battery when necessary.



＜ HV Work in the Non-Live State＞

- The work area must be protected with barriers to prevent unauthorized access.
- Mark the work area with a high voltage warning sign
- The ESO must supervise all work on the TS.
- Work to be done with TS turned OFF
  - TSMS must be turned off and the ESO must control the disconnected TSMS key
  - Confirm that TS voltage is 0V　(Confirm that there is no remaining voltage in the inverter input capacitors.)
- Work to be done with TS turned ON (active state) (failure analysis, adjustment, etc.)
  - Use insulated tools
  - Wear safety glasses and HV insulating gloves
  - Always jack up the driven wheels (It is recommended to remove the tire)

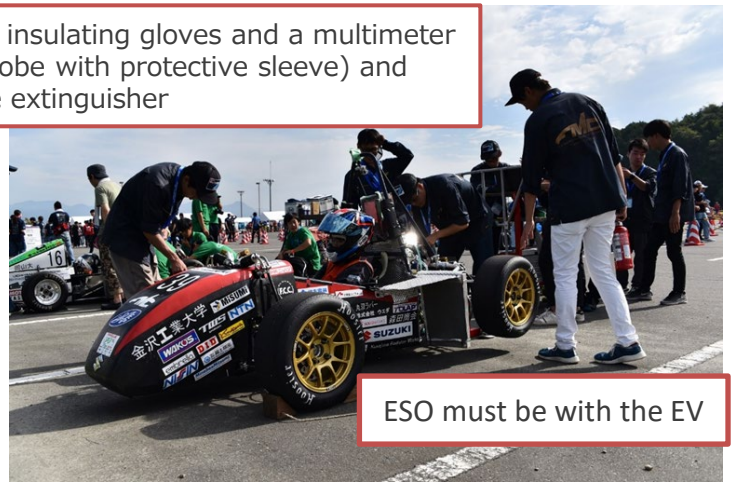
＜ Works related to Tractive Battery＞

WARNING: No TBC-opening or module/cell work in the pit area. Use the Repair Workshop.

Basics at the Competition Site

<Preparation before dynamic event>

- **ESO must be with the EV**
- HV insulating gloves and a multimeter(probe with protective sleeve) and fire extinguisher must be accompany the EV

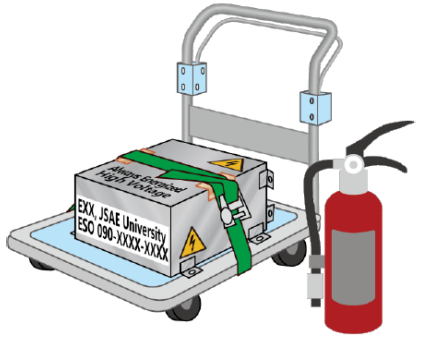


< Pushing the vehicle on site>

- **ESO must be with the EV**
- TSMS is disconnected and the ESO must control the TSMS key
- Insert a dummy MSD after disconnect the MSD
- The ESO must control the disconnected MSD (except when the officials move the EV in the dynamic event)
- HV insulating gloves and a multimeter(probe with protective sleeve) and fire extinguisher must be accompany the EV

Charge at the competition site

- The Tractive Battery Container must be charged at a designated area
- **ESO must be with the Tractive Battery Container**
- During transport and charging, the Tractive Battery Container removed from the vehicle must be secured to the hand cart
- Fire extinguisher(s) must accompany the Tractive Battery Container
- If one cell ignites, the fire spreads to neighboring cells and may not be extinguished with a few fire extinguishers.
  Save your own life, and wait for skilled firefighters arriving.
- The following signs will be posted in the charging area.



火災に関する注意 充電エリア

火災が発生時には落ち着いて行動し オフィシャルに通知してください。
すぐに行動する必要がある場合には、下記の情報に基づき、最も安全な行動を取ってください。

アキュムレーターコンテナ(ACC)の 異臭 / 異音 / 発火に気づいたら

- すみやかに充電器の電源を切ってください
- 大声でオフィシャルを呼んでください

充電に際しては

- ACCはハンドカートに固定すること
- 充電 及び 異常時の手順書の双方を準備すること
- 充電手順の知識を持つメンバーが少なくとも1人は残ること

FIRE SAFETY NOTICE CHARGING AREA

IN THE EVENT OF FIRE, STAY CALM. NOTIFY THE OFFICIALS. IF YOU MUST TAKE IMMEDIATE ACTION, USE YOUR JUDGEMENT AS TO THE SAFEST COURSE OF ACTION, GUIDED BY THE FOLLOWING INFORMATION:

If the Odor/Noise/Fire is from the Accumlator Container(ACC)

- TURN OFF the charger immediately
- CALL Officials LOUDRY

At the charging

- The ACC(s) must be securely attached to the hand cart
- Keep charging & abnormality charing procedures at hand
- At least one team member who has knowledge of the charging procedures must stay

Safety guidelines for EV operations

・The table below summarizes the work safety requirement for each situation (including switches conditions, ESO supervision, signage, and other factors).
・In all situations, the preparation of a fire extinguisher is mandatory.

Classification	Status	GLVMS	TSMS	MSD	ESO supervision	Work area barriers	high voltage warning sign	Cautions
Movement within the competition venue	TS OFF	OFF	OFF	Removal	Must	Not required	Not required	MSD inserts a dummy plug
Non-energized work	TS OFF	ON/OFF	OFF	Insertion	Optional	Required	Not required	Disconnect the battery positive terminal when GLVMS is not switched ON
	Charging TBC unit alone	—	—	—	Must	Required	Required	Follow the procedure manual thoroughly to avoid omissions
HV Work in the Live State ESO supervision required	TS ON	ON	ON	Insertion	Must	Required	Required	Always jack up the driven wheels, assuming the tires may rotate （Removing the tires is recommended）
	Work with exposed live parts	Case-dependent	Case-dependent	Case-dependent	Must	Required	Required	PPWear PPE、Use insulated tools
	Work within TBC	—	—	—	Must	Required	Required	PPE is not required until the cover is removed

End of Slides