Mersen in Brief
A France-headquartered traded company with global positions

Sales
€950M

Staff
7,000

Geographies
- 33% North America
- 34% Europe
- 33% Asia and Rest

Advanced Materials

Anticorrosion Equipment
World’s no. 1-2 in graphite equipment

Graphite Specialties
World’s no. 1-2 in high-temperature applications

Power Transfer Technologies
World’s no. 1-2 in brushes for industrial motors

Electrical Power

Electrical Protection & Control
World’s no. 2 in industrial fuses

Solutions for Power Management
World’s no. 2 in passive components for power electronics

* As of December 31, 2019
OVER 130 YEARS OF EXPERIENCE

1885 - Shawmut Fuse Wire Company formed in Boston, Massachusetts

1889 - Boston Fire Underwriters require fuses (later known as NFPA)

1928 - Ferraz Fuse found by Lucien Ferraz in France

1946 - M Schneider founded

1952 - Eldre Founded
1953 - Laminated Bus Bar Introduced by Eldre

1958 - Chase Shawmut acquired by I-T-E Imperial

1981 - R-Theta founded

1982 - Ferraz acquired by Telemecanique

1985 - Carbone Lorraine acquires Ferraz

1988 - First heat-sinks by R-Theta

1999 - Carbone Lorraine acquires Gould-Shawmut and forms Ferraz Shawmut

Ferraz-Shawmut acquisitions:
2007 - Power fuse
2008 - Mingrong
2008 - R-Theta
2010 - M. Schneider

2010 - Carbone Lorraine becomes

Mersen acquisitions:
2012 - Eldre
2014 - Cirprotec
2015 - ASP
2016 - Idealec
2018 - FTCap
SPM PRODUCT PORTFOLIO

**High-speed Fuse and Hybrid Pyro-fuse**
- UL Round and Square Body
- British Standard AC Protection
- IEC Cylindrical and Square Body (French / DIN)
- AC Low and Medium Voltage
- DC Rated For Traction
- DC protection for EV and EES

**Cooling Solutions**
- Air and Liquid Cooled Heatsinks
- Embedded Heat-Pipe Heatsinks
- Heat-pipe Assemblies

**Bus Bar**
- Laminated / Multi-layer
- Flexible / High T° / Low L
- Battery cell connection
- Powder Coated

**Capacitors**
- Customized capacitors:
  - Film
  - Electrolytic
  - Sub-assembly

**SiC Semiconductors**
- Protection devices
- Custom designs
Mersen Solutions for EV/HEV

One of 16 Trophée Andros 2021, 100% electric race car, equipped with Mersen Busbar and Fuses
EV/HEV MARKET SEGMENT PERFORMANCE ADDED-VALUES

Electric Power

<table>
<thead>
<tr>
<th>Duty-cycle severity</th>
<th>Non-premium car BEV</th>
<th>Premium luxury car</th>
<th>e-truck</th>
<th>Sport car</th>
<th>e-bus</th>
</tr>
</thead>
<tbody>
<tr>
<td>500V</td>
<td>BEV</td>
<td>BEV</td>
<td>BEV</td>
<td>BEV</td>
<td>BEV</td>
</tr>
<tr>
<td>800V</td>
<td>HEV</td>
<td>BEV</td>
<td>HEV</td>
<td>HEV</td>
<td>HEV</td>
</tr>
<tr>
<td>&gt; 250kW</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
</tbody>
</table>

Bubble diameter: relative market size by 2020
Mersen Solutions in EV/HEV Applications

- PDU: Power Distribution Unit
- BDU: Battery Disconnect Unit
- SPD: Surge Protection Device

Illustration courtesy of Renault™
DC BATTERY
OVER CURRENT PROTECTION

MAIN AND AUXILIARY FUSE AND PYRO-FUSE
# DC PROTECTION FOR EV BATTERY

## 2 TECHNOLOGY PATHS

<table>
<thead>
<tr>
<th>Product range</th>
<th>Monolithic technology</th>
<th>Hybrid pyrofuse technology</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>EVpack-fuse</strong></td>
<td><strong>χ_p series</strong></td>
</tr>
<tr>
<td>Core technology</td>
<td><strong>DC-Fuse</strong></td>
<td><strong>Pyro actuator + Fuse</strong></td>
</tr>
</tbody>
</table>

### Value-proposition

<table>
<thead>
<tr>
<th>Monolithic technology</th>
<th>Hybrid pyrofuse technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultra fast-acting fuses (for large fault currents)</td>
<td>Fast-acting protection &lt; 1ms</td>
</tr>
<tr>
<td>Cost-effective &amp; proven technology</td>
<td>Low-cost technology</td>
</tr>
<tr>
<td>DC specific design</td>
<td>Close-to-zero conduction loss</td>
</tr>
<tr>
<td></td>
<td>Operates for small or large fault current</td>
</tr>
<tr>
<td></td>
<td>Fully configurable</td>
</tr>
<tr>
<td></td>
<td>Very compact size</td>
</tr>
<tr>
<td></td>
<td>High cycling performances</td>
</tr>
<tr>
<td></td>
<td>High inrush current capabilities</td>
</tr>
</tbody>
</table>

### Visuals

- [Image of EV fuse]
- [Image of Pyro fuse]
EV TYPICAL PROTECTION SCHEME

Main battery pack
1 to 16 battery modules assembled in series/parallel

Main protection
(main fuse + DC contactor)
500 to 1,000 Vdc
Up to 600 A

Aux. protection
4x to 8x
(500V or 1000Vdc)

Inverter
+ Motor

1x (or 2x)

500 → 1,000 V

Up to 600 A

Pre-charge
Air Conditioning
Heater/PTC
DC/DC
Charger

Up to 150A for charger

10 → 50 A for aux.
2 FAMILIES OF PROTECTION AND OPERATION DEVICES FOR DC APPLICATIONS

- EV Battery Pack fuse Protection
  - MSD / BDU / Junction Box
- Hybrid DC protection
- EVpack-fuse
- Battery Module Protection
- m-fuse

Graph showing the range of voltages (V) on the y-axis and currents (Amp) on the x-axis.
8 DC FUSE SERIES FOR BATTERY PROTECTION

- **MEV70 series**: $700 \text{V}_{\text{DC}}$ – 35 to 600 Amp
- **MEV80 series**: $800 \text{V}_{\text{DC}}$ – 100 to 350 Amp
- **MEV100 series**: 1,000 $\text{V}_{\text{DC}}$ - 8 to 350 Amp
- **MEV100V series**: Designed for large inrush current
- **MEV50A**: 500 $\text{V}_{\text{DC}}$ – up to 800 Amp
- **MF series**: 100 $\text{V}_{\text{DC}}$ – 50 to 200A
- **Battery Module Fuse**
- **BDU / Aux. Fuse**
- **MSD / main Fuse**

Voltage (Volt)

In (Amp)
FEATURES & BENEFITS

- Voltage: 500VDC - L/R ≤2.5ms
- Ratings from 60 to 800A
- 5 compact sizes
- Long life cycle
- Visual identification code & serial number for traceability
- Customizable design
- Tested and validated with market leading contactors (Panasonic, Hongfa, TE, etc.)

PERFORMANCE

- Low Minimum Breaking Capacity (4xIn or 2kA) to secure contactor protection
- High interrupting rating of 30kA to address all types of battery
- Highly energy efficiency with low power losses
- Excellent cycling capability
- Compliant with ISO 8820 and international electrical standards

PRODUCT HIGHLIGHT: MEV50A SERIES – 500Vdc EV FUSE
**Mersen EVpack-fuse** have been designed to match DC contactor operation.

**MBC value matters…**

- **Matching DC contactor with DC fuse is not trivial. Contactors offer a limited max. breaking capacity value beyond which the fuse must clear the circuit in the eventuality of a default. Typical matching scheme looks like:**

- **Evpack-fuse line-up has been designed to protect DC contactors, offering MBC values <3kA over the full range.**
HYBRID PYRO-FUSE (XP-SERIES) FUNDAMENTALS

HOW PYROFUSE ALLOWS BETTER COORDINATION WITH CONTACTOR WHATEVER THE VOLTAGE & CURRENT

- **Within EV battery protection scheme,** fuse and contactor should coordinate together whatever current and voltage conditions.

- **In reality it’s not!** A “grey zone” remains where none of them can safely operate.

- **Pyrofuse allows extending the “fusing” operation towards smaller current and enables full coordination.**

- **Pyrofuse is now also requested to operate even if no current (0-amp).**
Laminated & Monitoring Busbar
ENGINEERING AND MANUFACTURING EXPERTISE

- Leveraging over 65 years of experience in designing, manufacturing and testing bus bar solutions
- Global Engineering & R&D teams
- Extensive in house manufacturing capabilities and vendor network
- Wide array of bus bar types and Value Add Assemblies
- Serving customers with high complexity business

Laminated  Powder Coated  Busbar-Cap sub-assembly
Mersen Supplies 3 Different Types of Busbar in the EV Industry

**Battery busbar**
To connect cylindrical, pouch or prismatic cells

**Inverter busbar**
To connect power electronics components

1. Battery cell connection busbar with monitoring
2. Battery interconnection busbar
3. Inverter busbar
SMART MONITORING BUSBAR TO HANDLE BOTH HIGH POWER AND SMALL SIGNAL IN A SINGLE CONNECTION SOLUTION

- **ALL-IN-ONE CONNECTION SOLUTION:**
  - Connect Li-ion or supercap cells together
  - Monitor small signals such as
    - Individual cell voltage
    - Local temperature

- **CUSTOMER’S BENEFITS:**
  - Ease assembly process
  - No wiring errors
  - Reduced voltage drop
  - Increase current carrying capability
  - High resistance to shocks and vibrations
INFINI∞CELL: LOW-COST AUTOMATED LAMINATION PROCESS FOR MODULAR BATTERY CELL CONNECTION

INFINI∞CELL
Always moving ahead.
**INFINI∞CELL: A NEW CONCEPT FOR BATTERY CELL CONNECTION**

In the frame of a collaboration with laser-welding equipment manufacturer F&K Delvotec (GE) we have developed a prototype of battery pack, connecting cells (21700 type), with a single-layer interleaved busbar, and using an automated high-speed lamination process:

**Termination conductors**

**Laminated busbar** (Nickel-plated copper 200/300µm)

**Monitoring**

**Junction bar**

A demonstrator is now available for showcasing, including:
- A laminated busbar (with monitoring)
- Cooling plate
- Mersen fuse

A video of the process assembly is available here: [YouTube](https://www.youtube.com/watch?v=example_video_id)
INFINI∞CELL CONCEPT: A FULLY FLEXIBLE PROCESS

A single-layer interleaved busbar, allowing + and – welded on the same side:

Raw material: A duplication of the same pattern, forming a foil of, virtually, infinite length:

Full customization and adaptation by adjusting the foil in width and/or in length:

On request, foil can be split in 2 or more parts to reduce the final length. In this case, junction bar is used to connect foils together:
INFINI∞CELL: FOCUS ON LASER WELDING PROCESS

- **Laser welding process has been developed in partnership with F&K Delvotec, a German expert in laser welding equipment and process.**

- **Laser welding is >4x faster than wire bonding.**
  - 2 in 1 TAB welding (+ and – poles are soldered in one pass) is inherently >4x faster than conventional wire/ribbon insertion & cutting.

- **It uses a powerful 1kW CW 1070nm laser in addition to a bond force up to 60N applied at the same time by the tool.**

- **Zero gap certain**
  - The tool touches every weld in +/-1µm.
INFINI∞CELL: VALUE PROPOSITION

- **High modularity to fit any battery module size and type**

- **Ultra thin single-layer busbar**
  (total thickness down to 1mm)

- **No significant overheating**
  (Thermoelectric simulations)

- **Lower cost**

- **Designed for high volumes**

- **Compatible with automated high-speed lamination process**

- **Both + and – contacts are soldered on the top. Battery bottom is free to be used for thermal management**
COOLING SOLUTIONS
THREE COOLING TECHNOLOGIES
TO MEET CUSTOMER’S NEED AT THE CLOSEST

Air heat-sink  Phase Change  Liquid cold plate

Aluminum  Copper  Embedded heat-pipe MeHP  Heat-pipe assembly  Tubed cold plate  Aluminum cold plate  Copper cold plate  IsoMAXX

Thermal Performance
Higher
Lower
Battery usage segmentation

Cooling type depends on C-rate value

- **Air-cooling**
  - Natural convection, forced air, or cabinet air conditioning

- **Liquid-cooling**

- **Marine**

- **EV**
  - Sport car
  - Passenger e-Bus / e-Truck

- **Grid**
  - (Freq Regul.)
  - (peak shaving, load leveling)

- **HEV**
- **pHEV**
- **UPS in Data Center**

Battery capacity

0.1C  1C  2C  3C  4C  5C  6C  10C
EXAMPLE OF 7MM-THICK AL VACUUM-BRAZED LIQUID COLD-PLATE FOR BATTERY COOLING (HERE WITH OPTIONAL DIELECTRIC LAYER)
SPECIALTY CAPACITORS
ALUMINUM ELECTROLYTIC CAPACITORS

- Screw Terminals
- Snap-In
- Solder Lug
- Motor Start
- Special Type
- Axial
- Cuboid Axial
- Cuboid Radial
- Discharge Capacitors
Metalized Film Capacitors

Coax Cap

Energy Cap

High Voltage

Power Box

Special Types

Joule Cap

Castor Cap

Power Link
SPECIAL FOCUS ON SiC ELECTRONICS IN THE EV INDUSTRY
INTRODUCTION: Mersen is active all over the SiC value-chain
CRYSTAL GROWTH, EPITAXY AND POWER CONVERSION

Crystal Growth
Sublimation PVT reactors
SiC ingot “boule”

Wafering Polishing

Epitaxy
SiC Wafer

Wafer carriers
SiC epi-wafer

Crystal Growth
Graphite insulation & components

Crystal Growth
Graphite insulation & components

Wafering Polishing

Epitaxy

Front-End
Bare-die “chip”
Diode, MOSFET, J-FET

Lithography, deposition, etching, implantation, metallization...

Applications
Power Converter
Busbar, Cooling, Capacitors, Fuses....

Packaging
Binning, pick-and-place Packaging, Housing

Discrete

Power module

Packaging

Binning, pick-and-place Packaging, Housing

Discrete

Power module
Mersen has a comprehensive range of graphite and insulation solutions for SiC production

**Graphite crucible**
- contributes to the chemical composition of the single crystal
- controlled CTE, controlled reactivity with the gases, controlled thermal conductivity
- extreme purity (7N) of the graphite

**CALCARB® insulation**
- spatial consistency,
- low thermal conductivity at 2,400 °C
- ability to be precision machined
- high purity

<table>
<thead>
<tr>
<th>Running temperature</th>
<th>Cycle duration</th>
<th>Ingot weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,400° C</td>
<td>3-5 days</td>
<td>5-10 kg</td>
</tr>
</tbody>
</table>
INFLUENCE OF SILICON CARBIDE ON SELECTED POWER COMPONENT SPECIFICATIONS

- **Full SiC @ 100kHz**
  - High power density specific cooling
  - Ultra-low induct. Busbar
  - Ultra-low induct. Fuses
  - High T° busbar & film caps

- **Full SiC @ 48kHz**
  - Advanced small dimension cooling
  - Low induct. Busbar
  - Low induct. Fuses
  - Film caps

- **Full SiC @ 24kHz**
  - Advanced small dimension cooling
  - Low induct. Busbar
  - Low induct. Fuses
  - Film caps

- **Full SiC @ 16kHz**
  - Advanced small dimension cooling
  - Laminated busbars
  - Advanced fuses
  - Advanced caps (film or elect.)

- **Hybrid Si IGBT + SiC diode @ 16kHz**
  - Standard cooling
  - Cables or busbars
  - Standard caps
  - Standard fuses

- **Reference: Full Silicon: Si IGBT + Si diode @ 16kHz**

Credit: ABB
Low inductance [cap-bus bar] connection: Fischerlink™

Cooling solutions for SiC applications

High temperature Capacitors

High temperature bus bar, 130°C and 180°C, Low Partial discharge, creepage and clearance up to 10kV. Mhi-Txx™ series
It is now certain that TJ most-likely won’t increase as initially forecasted, exceeding 200°C for both Silicon and SiC over the next decade, for various reasons:

- Most of the power module packaging materials (Gel filling, housing polymer…) cannot handle such T° values
- Gate oxide layer in SiC MOSFET rapidly degrades beyond 200°C
- Chip-to-substrate soldering compounds are very unstable above 200°C
- Overall conversion efficiency decreases as T° increases
- We estimate Tj max will reach ~165°C for Silicon and < 200°C for SiC
Embedded heat-pipe: Pushing the limits of air cooled heat-sink

~30% reduction in $T^\circ$ rise compared to standard Al heat-sink

A heater block, simulating a power module, has been placed at the same location on 3 different heat sinks (Al + MeHP, Al and Cu) with same geometry. $T^\circ$ rise is measured at the heater location as a function of air velocity.

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**Comparison Table**

<table>
<thead>
<tr>
<th></th>
<th>Al blank</th>
<th>Cu blank</th>
<th>Al + MeHP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average $T^\circ$ rise</td>
<td>Ref = 1</td>
<td>-23%</td>
<td>-30%</td>
</tr>
<tr>
<td>Cost comparison</td>
<td>Ref = 1</td>
<td>x 4</td>
<td>x 1.25</td>
</tr>
<tr>
<td>Weight</td>
<td>Ref = 1</td>
<td>x 3.5</td>
<td>1</td>
</tr>
</tbody>
</table>
IMPACT OF eHP ON SiC MODULE THERMAL SPREADING

NO HOT-SPOT ANYMORE!

BLANK HEATSINK

EMBEDDED HEAT PIPE MeHP

(INSERTED INSIDE THE BASEPLATE)
**IsoMAXX™: The Ultimate Liquid Cooling Solution for Modules**

**No ΔT module-to-module, no ΔT chip-to-chip**

- **AN INNOVATING COUNTER-FLOW “WAVY SPIRAL” DESIGN, HAS BEEN DEVELOPED FOR IMPROVING THERMAL MANAGEMENT OF LATEST GENERATION OF Si & SiC POWER MODULES. IT OFFERS:**
  - Better thermal performances: $R_{th} \sim 6 \, ^\circ C/kW$
    (EG 50%, 250 mm modules, 3kW power losses and 5 liter/min per component.)
  - Lower pressure drop than all existing designs (~600mbar)
  - Thermal homogeneity chip-to-chip (all chips at the same $T^\circ$) and module-to-module on a multi-module cooling plate
  - Compact design: distance between modules can be optimized → Inverter size reduction
  - Modular solution: covers all PrimePACK™ types, whatever the number of modules on the plate
  - Cost competitive compared to others efficient designs

---

**Homogeneity: no ΔT module-to-module**

**Homogeneity: < 2° C ΔT chip-to-chip**

Pressure drop: 565 mbar
**Recent trends in WBG power conversion**

*How to reduce stray inductance while increasing overall power density and junction $T^\circ$?*

**Reduce stray inductance together with higher $T_j$**

- **New module design**
  Power module makers are working on new designs for their power modules in order to stay competitive against press-packs for high-voltage devices. The most popular solution is reducing the distance between internal connections.

- **Use of external laminated busbar with low inductance connection**
  Outside the module, using laminated busbar offers strong reduction of parasitic inductance.

- **Use of internal laminated busbar**
  Along with the emergence of SiC, the switching frequency reaches several ten’s of kHz. Internal laminated busbar can offer a real added-value to decrease the inductance while connecting the chips together.

*Credit: CREE*
A PERFECT MATCHING [INSULATION – RESIN/GLUE]

- In order to perfectly match customer's specifications, Mersen aims at selecting the right material (Insulation and Resin / Glue) with the highest Temperature, Voltage and Mechanical resistance, keeping insulation as thin as possible (to meet low inductance value requirements)

EXAMPLES OF MATERIAL SELECTION AND RELATED THICKNESS RANGE AS A FUNCTION OF MAX. OPERATING T°:

<table>
<thead>
<tr>
<th>T°</th>
<th>Material Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>230°C</td>
<td>PI (Kapton Thick. 25 to 125 µm)</td>
</tr>
<tr>
<td>230°C</td>
<td>Polyaramid (Nomex Thick. 50 to 250 µm)</td>
</tr>
<tr>
<td>120°C</td>
<td>PAEK (Aptiv), PPS (Fortron), PTFE (Teflon)</td>
</tr>
<tr>
<td>120°C</td>
<td>Polyester (Mylar Thick 38 to 330 µm)</td>
</tr>
<tr>
<td>65°C</td>
<td>PC (Lexan), PVDF (Kynar), PA6 (Nylon)</td>
</tr>
<tr>
<td>65°C</td>
<td>PMMA, PP, PE</td>
</tr>
</tbody>
</table>

Insulation dielectric layer

Resin / Glue

BMI

Silicone

PBI

Epoxy Thick. 12 to 20 µm

Polyurethane

Acrylic thick. 38 µm

Now up to 180°C
**Inductance Fundamentals in Power Converter Design**

*High inductance creates voltage overshoot and surge at commutation*

---

**ON**
- Short-circuit
- \( V_{ce} = 0 \) V
- \( I_{ce} \neq 0 \) A

**OFF**
- Open circuit
- \( V_{ce} \neq 0 \) V
- \( I_{ce} = 0 \) A

**CCL: Commutation current loop**

**Surge voltage**

\[ V_{surge} = L_s \frac{di}{dt} \]

\( L_s \) = inductance of CCL

---

**DC-link capacitor**
LOW-INDUCTANCE [BUS BAR-CAP] CONNECTION FOR SiC DC-LINK

FischerLink™

- **Shorter connection of the cap winding to the busbar by direct connection of the winding tabs to the busbar by laser welding**
- Up to +20% capacitance in a given volume (e.g. from 400µF to 480µF @ 1100 Vdc | 4-cap assembly)
- Extremely low inductance <9nH
- Capacitors and busbars packaged together as sub-assembly and single part #
- Pre-assembled and 100% tested before delivery → ready for final assembly
INTERNAL LAMINATED BUSBAR FOR WBG POWER MODULES
SOLUTIONS TO HANDLE 180° TJ @ 100 KHz FSW... AND BEYOND!

**THE AIM:**
- Get very low internal inductance by
  - laminated/symmetrical bus bar structure
  - Maximizing metallic conductor overlap
- 50% reduction in switching loss for higher switching frequency (> 20KHz)
- Safe turn-off possible at large current without snubber capacitor

**THE ACHIEVEMENT**
- Our bus bars can now handle up to 200°C Tj with inductance as low as 35nH and a lifetime operation of 25 years