



M1 VCU Application in Electric Vehicles User Guide



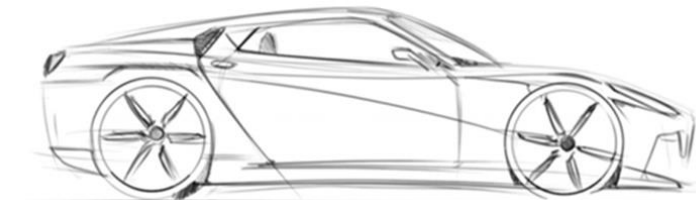
► INTRODUCTION

MoTeC contributes to intelligent electric race cars and transportation solutions with expertise built on 30 years' experience in developing automotive electronics and control systems for motorsport and commercial applications.

MoTeC has a wide range of products that can be used in EV system design. In particular, the M1 Series Control Units prove to be highly suitable as Vehicle Control Units (VCU) in an electric vehicle application. In combination with MoTeC's advanced programming and calibration tools these Control Units facilitate the design and development phases and speed up the testing and validation process of any EV application project.

► THE EV DRIVELINE

In this document the term 'EV driveline' refers to the power transmission system from the battery pack to the wheels, including all sub-systems that are required for driving the vehicle.



EV Driveline Sub-systems Overview

The EV driveline typically includes the following sub-systems and components:

- Vehicle Control Unit (VCU)
- Energy Storage System (ESS)
- Battery Management System (BMS)
- High Voltage Power Distribution Unit (HV-PDU)
- Liquid cooling system for the HV sub-systems and components
- Electric drivetrain
- Motor Controllers (MC)
- DC/DC converter

In addition, EV applications include sub-systems and components like those used in traditional Internal Combustion Engine (ICE) applications, such as low voltage power distribution modules, dash/displays and logging devices.

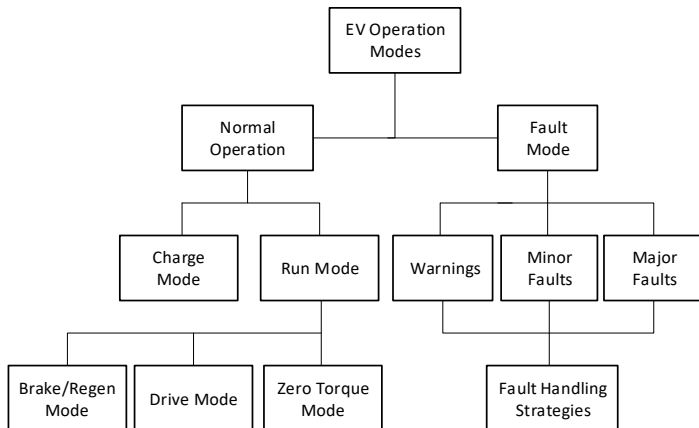
The type and configuration of the sub-systems are dependent on the EV application, Energy Storage System (ESS) and drivetrain configuration. They can be either dedicated units or integrated in another EV driveline component.

Vehicle Control Unit (VCU)

This central or master supervisory controller acts as the vehicle's 'brain'. It controls and monitors the EV driveline including all HV sub-systems. In an optimised EV design solution, the Vehicle Control Unit is responsible for all functions associated with:

- **System Functional Control:** This includes the control of each individual local controller and the management of the functional relationships and interactions between these local controllers.
- **Operation Modes Control:** The Vehicle Operation Mode Control is the supervisory layer above the System Functional Control. The VCU is responsible for determining the correct mode of operation of the EV according to the driver demands, EV driveline status and diagnostics reporting.

Although EV operation modes are highly dependent on the specific system design and type of application, the generic model as shown, covers most situations.



Generic EV Operation Modes Model

- Diagnostics and Fault Handling Strategies:** These strategies are the most critical functions of the VCU. The automotive industry considers voltages above 60 V as high voltage applications requiring specific regulations for system electrical design and monitoring. As such, most EV systems are high voltage and need to adhere to these regulations.

Energy Storage System (ESS)

The ESS stores the electric energy to power and run the vehicle. It is typically made up of multiple li-ion cells packaged into modules. The modules are assembled into one or more battery power packs, depending on the vehicle requirements. Li-ion cells need protection against overcharging, excessive discharge, and high and low operating temperatures.

Battery Management System (BMS)

The BMS is responsible for the safe operation of the battery. It reads and monitors the individual cell voltages, their temperatures and the battery pack current to calculate battery parameters such as State of Charge (SoC), State of Health (SoH), and maximum and minimum cell voltages and temperatures. The BMS sends this information to the VCU to process and to act on according to the existing control strategies.

The BMS topology can be a single unit for the complete pack which monitors the cells, calculates the parameters and implements the control strategies as directed by the VCU.

The system can also consist of multiple slave monitoring units that only read cell voltages and temperatures and send this information to a master BMS unit via CAN. In this topology the master BMS carries out the calculations for the battery pack and implements the control strategies as directed by the VCU.

HV Power Distribution Unit (HV-PDU)

The HV-PDU includes the HV contactors and all the required protection and safety measurements such as HV line voltage, current, temperature and isolation measurement. In most OEM passenger EVs, this unit is embedded in the battery pack, while in heavy-duty EVs and custom or retrofit EV solutions, there is an independent HV-PDU.

In both cases, a controller is needed for the activation of the HV connection/disconnection, the required diagnostics and safety related functionalities. The HV-PDU can be controlled by either the BMS or the VCU.

The HV-PDU is also responsible for connecting the battery charger (whether onboard or external) to the battery.

Cooling System for HV Components

HV sub-systems such as electric motors, MC and DC/DC converter require liquid cooling to optimise their performance.

Electric Drivetrain

The electric drivetrain is defined as the propulsion system which includes the electric motor, reduction gearboxes and differentials, and the physical connections to the drive wheels. There are many different drivetrain configurations possible in EV applications.

Motor Controllers (MC)

The MC controls the drivetrain electric motors in response to the requested torque/speed commands from the driver via VCU. Most EV MCs include control algorithms for various electric motor types such as IPM (Interior Permanent Magnet), SPM (Surface Permanent Magnet) and ACIM (AC Induction Motor). In some cases,

the algorithms can be partly parameterised by the customer. By requirement, the MC includes hardware protections. In addition, it includes software safety features to ensure potential electric faults are avoided.

DC/DC Converter

The DC/DC converter charges the low voltage (12 or 24 V) battery system from the HV battery pack. It is typically controlled by the VCU via CAN.

► MoTeC EV PRODUCTS

MoTeC products and software tools provide a modular, dynamic platform to develop control solutions for EV and HEV vehicle applications.



MoTeC EV Products: M150EV VCU, Display, Data Logger and LV-PDM

The hardware product lines applied to EV solutions are:

- M1 Series Vehicle Control Units (VCUs)
- PDMs as LV power distribution units
- Displays as a Human-Machine Interface (HMI) for communication to the driver
- Data Loggers – dedicated logging units or integrated display loggers

[Click here to find more information about these products](#)

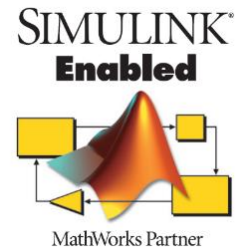
These products are supported with a suite of software tools particularly useful for EV developments:

- M1 Build - Programming Platform
- M1 Integration Tool for use with Simulink®
- M1 Tune - Calibration Platform
- i2 - Data Analysis Software

[Click here to find more information about the software](#)

M1 Series VCUs

These units deliver extensive capability for EV supervisory control and, with their ability to control modern combustion engines, they are equally suited for HEV applications.



M150EV VCU with M1 Integration Tool for use with Simulink®

Feature highlights:

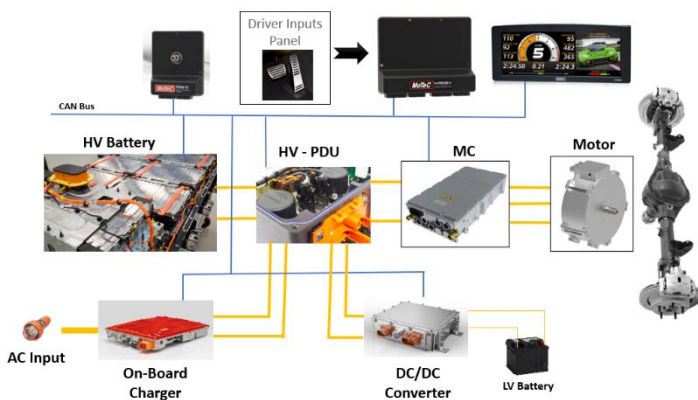
- Latest generation high performance processor
- Extremely compact and lightweight
- Large logging memory with Ethernet for fast downloads
- Compatible with 12 V and 24 V systems
- Multiple High Side and Low Side outputs with PWM capability, fully programmable in software
- Multiple digital, PWM, analogue and temperature inputs, fully programmable in software with diagnostics
- Multiple communication ports (CAN, RS232 and LIN)
- Robust and comprehensive security features

The range consists of several units, catering for a range of applications. Detailed specifications for each unit can be found in the datasheets [M130EV](#), [M150EV](#) and [M190EV](#).

► AN EXAMPLE PROJECT

The objective of this example project is to develop an EV control solution to run a vehicle with the following configuration:

- A central electric motor that drives the rear wheels through a single ratio reduction gear and differential
- A HV battery and HV-PDU which distributes the power to the HV sub-systems
- A motor controller
- A DC/DC converter
- An onboard battery charger which is connected to the battery via the HV-PDU
- CAN communication to control most sub-system units

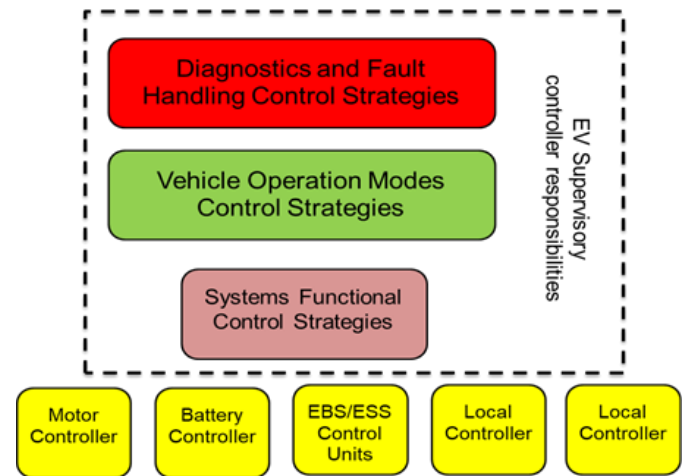


EV Driveline Sub-systems Block Diagram

To ensure safe vehicle operation, the overall HV electrical and the supervisory control integration requires considerable development of strategies and implementation of diagnostics for all HV subsystems.

The EV control system consists of several strategies for HV sub-systems, coordinated in various levels by a VCU to manage overall vehicle performance, diagnostics, and fault handling, and ensure optimised and safe performance of the vehicle under normal and fault conditions.

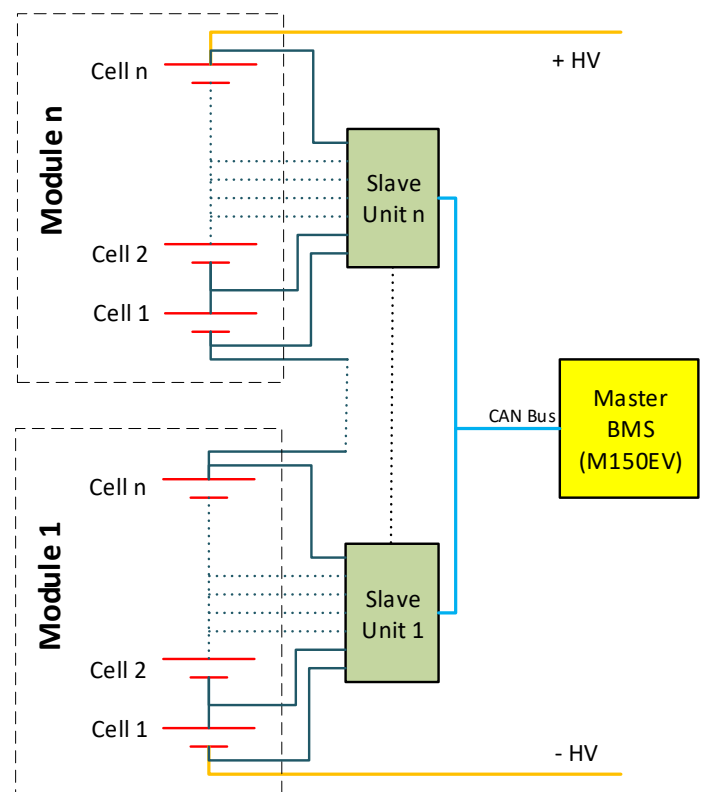
In this example, a MoTeC M150EV VCU is used both as the supervisory controller and the master BMS.



EV Control System Layout

Energy Storage System

In this example, the energy storage system has slave monitoring units for each module in the battery pack. These units read cell voltages and temperatures and send this information to the master BMS unit via CAN. These boards have cell balancing circuits as well that can be controlled over CAN during battery charging.



M1 application as a master BMS

The M150EV VCU acting as a master BMS calculates the following control functions:

- SoC* and SoH,
- max, min and average cell voltages,
- max, min and average cell temperatures,
- Discharge Current Limits (DCL),
- Charge Current Limits (CCL),
- cell voltage limits and SoC settings,
- diagnostics and fault settings,
- cell data logging.

* The M150 VCU performs calculations up to 1000 Hz, which allows SoC calculations using coulomb counting techniques.

HV-PDU

The M150EV VCU also controls the HV-PDU. The functions the M150EV VCU carries out include:

- Pre-charge circuit control and safe HV connection/disconnection
- Battery charger connection/disconnection and charging process control as required
- Safety checks such as monitoring current consumption and isolation measurement

Vehicle Control Unit

M150 VCU performs the master supervisory controller functionality on all three main categories:

- System Functional Control
- Vehicle Operation Modes Control
- Diagnostics and Fault Handling Strategies

System Functional Control

The main objective of the system functional control is to achieve the best performance from each sub-system, while ensuring they do not create conflicting issues for the complete vehicle system that could result in performance degradation.

For example, sub-optimal battery pack and motor condition managing can result in reduced drivetrain performance during torque mapping strategies. Another

example where conflicting issues can easily arise is electric regenerative braking management and maintaining efficient motor performance under varying load demands.

The M150 VCU provides significant benefits in developing the best solutions for these issues through MoTeC's flexible programming (M1 Build) and calibration (M1 Tune) software tools. Together they provide a platform to achieve maximum sustainable performance from the EV driveline.

The key system functional control strategies to implement using the M150 VCU are:

- CAN control of the HV sub-systems such as MCs, DC/DC converter, battery charger, HV-PDU, etc.
- Torque mapping/vectoring strategies for multiple drivetrain configurations, including central motor(s), 2WD and 4WD etc.
- Regenerate control under various vehicle conditions
- Torque limiting and drivetrain degradation strategies aligned with HV sub-systems status
- HV sub-systems liquid cooling systems control
- HV steering system control
- DC/DC converter output control based on LV power demand

Vehicle Operation Modes Control

The VCU determines the mode of operation of the EV according to the driver demands, EV driveline status and diagnostics reporting.

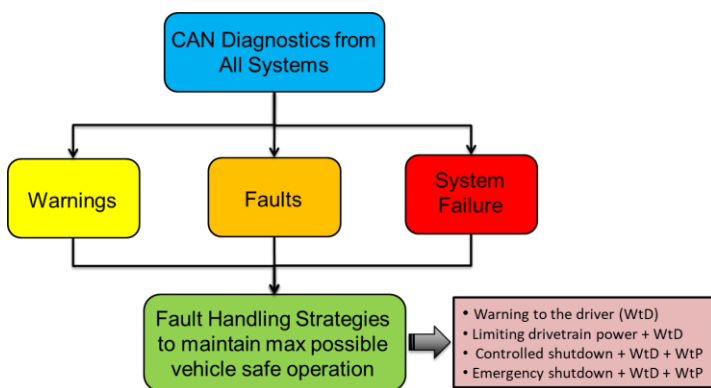
Vehicle Operation Modes Control can override the strategies within the System Functional Control layer. For example, in Charge Mode the vehicle cannot be driven as the drivetrain is deactivated while the LV battery is charged via the DC/DC converter.

A Finite State Machine (FSM) is used to determine the modes and transitions, while complex control algorithms are required to ensure correct EV operation under all circumstances.

MoTeC's M1 Build with the M1 Integration Tool for use with Simulink® provides the programming platform to facilitate implementation of the complex state machines and control algorithms.

Diagnostics and Fault Handling Strategies

Most HV sub-systems communicate their operation status, including any internal faults and warnings over CAN. The M150 VCU must implement the required fault handling strategies to maintain safe operation of the vehicle. This requires extensive diagnostics to be continuously performed in the background in the VCU software. Fault handling strategies are highly dependent on the fault severity, the internal safety features of the local controllers and the system electrical design.



Generic EV Fault Handling Strategies

All safety critical parameters of the HV and conventional sub-systems of the vehicle are continuously monitored to ensure they are within the accepted limits.

If any safety critical parameter is out of accepted limits, immediate action is required and communicated to the vehicle driver.

MoTeC's advanced CAN based programmable digital displays can provide a flexible platform to set up an effective Human-Machine Interface (HMI) for efficient communication to the driver.

► INITIATING A NEW EV PROJECT

There are three main approaches to engaging with MoTeC for EV applications:

1. MoTeC provides technical support and training on their products and the software development environment (if needed); while the client develops the full EV solution, including all M1 VCU supervisory control programming.

2. The client and MoTeC collaborate on the development of the EV control solution. This arrangement is normally covered with a MoA between the parties to ensure all objectives, roles and responsibilities, project milestones, deliverables, and business and IP sharing arrangements are clearly defined.
3. MoTeC develops the EV integration and control solution for the client in accordance with a client defined system specification. This is typically covered by a contract arrangement between the parties.

Contact MoTeC to discuss your EV project, and to get initial technical guidance on how MoTeC products can enable your EV application.

MoTeC will provide an '**Electric Vehicle Project Start-Up Requirements Questionnaire**' which will help in defining the EV requirements specification. The Questionnaire covers the following subjects:

- EV project general information;
- Vehicle specifications & operation requirements;
- Battery pack requirements;
- Drivetrain configuration and requirements;
- Integration and build requirements.

For further information please contact MoTeC.



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