MoTeC

Electric Vehicle Application Note

ELECTRIC VEHICLE
APPLICATION NOTE

INTRODUCTION

This document sets out the application of MoTeC M1 series Vehicle Control Units (VCUs) as controllers in Electric Vehicle (EV) solutions, including for different EV driveline configurations. Application of other MoTeC products to these EV solutions is also covered. An example EV application is discussed as a case study; while keeping in mind that MoTeC product capabilities allow and enable a very wide and large variety of customisation and EV solutions applications. This document also provides some easy to use guidelines to help customers to identify their EV project key elements, and application of MoTeC products.

EV DRIVELINE

For the purpose of this document the term ‘EV Driveline’ is defined as the power transmission system from the battery pack to the wheels, including all sub-systems that are required for driving the vehicle; while the ‘EV Drivetrain’ is considered as the propulsion system which includes the electric motor, and associated gearbox(es) and/or differentials. The EV Driveline sub-system types are mainly dependant on the type of EV application, Energy Storage System (ESS) and Drivetrain configuration. Figure 1 below shows examples of EV driveline sub-systems for passenger cars.

Typically an EV Driveline includes the following sub-systems and main components:

Energy Storage System (ESS)

This supplies the required energy to power and run the vehicle. This is typically made up of multiple Li-Ion cells packaged into suitably sized modules, which then are assembled into a single or multiple battery power packs, depending on the vehicle solution requirements.

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 available in the market have control algorithms for various electric motor types such as IPM, SPM and ACIM, and in some cases can be partly parameterised by the customer. Except for the required hardware protections, the MCs also have software safety features to ensure avoiding potential electric faults (these are usually controlled over CAN).

Figure 1. EV Driveline Sub-systems Overview

Electric Drivetrain

This includes the electric motor(s) system, reduction gearbox(es)/differential(s) and the physical connections to the drive wheels. There are many different Drivetrain configurations examples currently in use in EV applications.

Battery Management System (BMS)

Li-Ion cells need protection against overcharging and excessive discharge, and from high and low operating temperatures. The BMS is a unit that reads and monitors the individual cell voltages, their temperature and the battery pack current. The BMS uses this information to calculate battery parameters such as State of Charge (SoC), State of Health (SoH), and Max and Min cell voltage / temperature values.

High Voltage (HV) Power Distribution Module (HV-PDM)

This unit includes HV contactors and all the required protection and safety measurements such as DC bus bar - voltage, current, temperature and isolation measurement. In some EV applications, these functions are embedded in the ESS, and in others HV-PDM applications it is an independent unit (more in heavy-duty EV applications). Dependant on the EV design topology, the HV-PDM can be controlled by the BMS or the VCU.

DC/DC converter

This is used to charge the Low Voltage (LV) (12/24 V) battery system from the existing HV battery pack. This is usually a CAN controlled unit.

Liquid Cooling System for the HV Sub-systems and Components

Most HV sub-systems including electric motors, MCs, DC/DC converters and others, require liquid cooling to optimise their performance.

Vehicle Control Unit (VCU)

This is the central or master supervisory controller which acts as the vehicle's brain, controlling and monitoring the EV's Driveline, and including all HV sub-systems.

Of the above EV sub-systems and key components, main three items exist in all EV applications, while other items may be part of an EV driveline depending on the specific application, sub-systems, and EV design topology. Other vehicle sub-systems and components shown at Figure 1, such as vehicle displays, LV power management, etc, are similar in application to EVs as they are for traditional Internal Combustion Engine (ICE) vehicles.

MOTEC PRODUCTS

All MoTeC hardware and software products can be utilised in the design and development of EV solutions; however, this application reference document will primarily focus on the EV application of the fully programmable MoTeC M1 VCUs, and in particular the M150EV VCU. Key features of the M150EV VCU are set out below. For additional and more detailed product information refer to the documents on the MoTeC website.

M150 EV VCU Key Features

- High Side Outputs: 10 x 9 A - PWM 1 kHz
- Low Side Outputs: 40 (10 x 9 A + 30 x 2 A) - PWM 20 kHz
- Sensor Supply: 7 (6 x 5 V + 1 x 6.3 V)
- Universal Digital: 12 - PWM Input
- Digital: 4 - PWM Input
- Analogue Voltage: 23
- Analogue Temperature: 6
- CAN Bus: 3 (125, 250, 500, 1000 kbits/s)
- RS232: 1 (1.2 to 115 kbits/s)
- LIN: 1 (1.2 to 115 kbits/s)
- Logging Memory: 250 Mb
- Supply Voltage: 8V to 32V
- Dimensions: 162 x 127.5 x 40.5 mm
- Weight: 445 g
- Flexible Programming and Calibration Tools (M1 Build and M1 Tune)
- M1 Integration Tool for use with Simulink

SIMULINK Enabled
MathWorks Partner

EV APPLICATION CASE STUDY

This section covers an example EV project as a case study, covering the more common EV driveline design topologies; and potential control solutions that can be implemented using MoTeC M1 VCUs.

Case Study. The case study project objective is to design and develop an EV with a central electric motor that drives the rear wheels through a single ratio reduction gear and differential. Vehicle has a HV battery (400 V) and HV-PDM which distributes the power to the HV sub-systems such as motor controller, DC/DC converter and a HV inverter which powers and controls the steering system. The HV-PDM unit and the HV steering system are included in this case study to highlight the extensive capability of the M1 VCU controller for various EV applications. The vehicle also has an onboard battery charger which is connected to the battery via the HV-PDM. The EV Driveline block diagram is shown at Figure 2 below. The aim of this case study is to develop an EV control solution to run this vehicle.

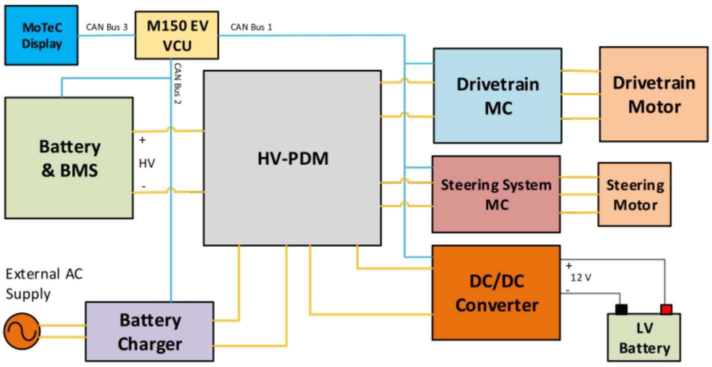

Figure 2. EV Driveline Sub-systems Block Diagram

The majority of the sub-systems at Figure 2 are CAN control based units; however, the overall integration and EV control solution requires considerable strategies to be developed, and diagnostics implementation to ensure safe vehicle operation. VCUs, such as the MoTeC M150EV unit, are required for managing overall vehicle performance, diagnostics and fault handling, and ensuring optimised safe performance of the EV.

A typical EV supervisory control system layout is shown at Figure 3. The HV sub-systems are used as local controllers of the MC and its sub-components, which need to be managed and monitored by the VCU from a higher system level. The respective sub-systems and associated control/diagnostics strategies are determined and customised to the requirements and uniqueness of each specific EV project. MoTeC's highly capable and flexible products, with software programming and calibration tools, enable much easier and faster EV development and customisation than other similar products in the market. Potential control solutions that the MoTeC M150EV VCU can offer for various EV Driveline components are discussed below.

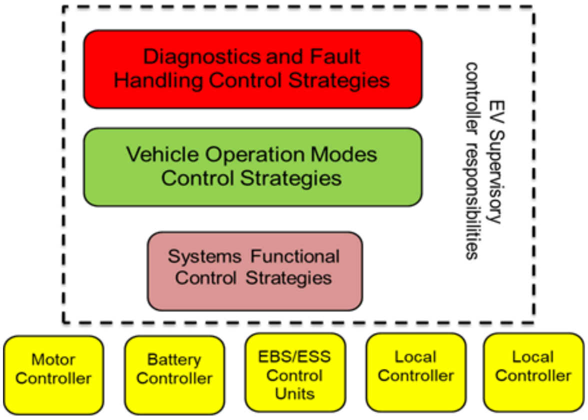

Figure 3. EV Supervisory Control System Typical Layout

Battery pack

EV batteries can be a single or multiple module configurations including number of cells per module, to achieve the required voltage and current for each specific EV solution. Typically each battery module or battery pack needs to have a BMS to monitor and control the charge and discharge of the battery pack. There are primarily two battery management topologies:

- A single unit BMS which directly reads and monitors the cell voltages, cell temperatures, and the battery pack current, and carries out the required calculations and implements the programmed control strategies.
- Multiple slave units that only read cell voltages and temperatures, and send the information to a master BMS unit using CAN communications. The master BMS interprets the information from the slave units does the required calculations and implements the programmed control strategies.

In the first BMS topology above, the BMS is an independent unit that is monitored/controlled by the VCU (e.g. M150EV) via CAN Bus. The BMS internal control features vary between different BMS manufacturers. In the second BMS topology above the MoTeC M150EV can be used as the master BMS, while simultaneously being used as the vehicle VCU. Figure 4 schematic below shows an example of an M1

VCU being used as a master BMS. The MoTeC M1 series controllers are capable of performing calculations up to 1000 Hz, which is sufficient for SoC calculations using coulomb counting techniques.

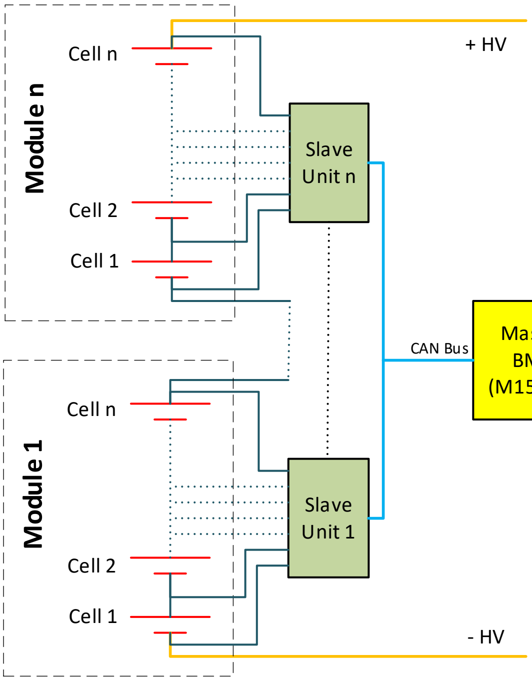

Figure 4. M1 application as a master BMS

As an example, the main BMS control functions that can be calculated when using an M150EV VCU solution in the second BMS topology above, includes:

- SoC and SoH Calculations;
- 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.

HV-PDM

In most OEM passenger car EV solutions the HV contactors are embedded inside the battery pack, while in heavy-duty EVs and custom and retrofit EV solutions the HV contactors are normally in a separate unit. In both cases, a controller is needed to control activation of the HV connection/disconnection, as well as the required diagnostics and safety checks. The battery charger (whether onboard or external) is also connected to the battery by the HV-PDM.

In some applications, the BMS performs all the above functions; and in that configuration the MoTeC M150EV VCU can also act as the master BMS and control the HV-PDM. In this configuration the main control functions that can be done by the M1 VCUs can 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.

EV Supervisory Controller

As shown at Figure 3 above, the EV supervisory controller responsibilities can be defined in the following three main categories:

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

In an optimised EV design solution a central vehicle control unit, as the ‘central brain’ of the vehicle, should perform all functions associated with the above three categories. Each of these control layers is briefly explained below, along with the M1 VCU capabilities which enable optimised solutions for each of these functional categories.

System Functional Control

This category includes two main functions; these being 1- controlling each individual local controller to perform its required specific functions, and 2- manage the required and defined functional relationships and interactions between these local controllers. Therefore, the main objective is to achieve the best performance from the sub-system, while making sure that these sub-systems do not create conflicting functional issues for the vehicle system as whole. One example of this type of potential system degradation due to functional mis-alignment between sub-systems is reduced drivetrain performance during torque mapping strategies, as a result of battery pack and motor condition not being optimally managed. Other examples of this system functional mis-alignment include electric regenerative braking management, and maintaining efficient motor performance under varying load demands. These are areas that the MoTeC M1 VCU solution can provide significant improved solution benefits, through MoTeC's highly flexible programming (M1 Build) and calibration (M1 Tune) software tools. M1 Build and Tune provide a highly effective and dynamic programming and tuning environment and platform to achieve maximum sustainable performance from an EV Driveline. Key functional control strategies that can be implemented using the M150EV VCU, include:

- CAN control of the HV sub-systems such as MCs, DC/DC converter, battery charger, HV-PDM, etc;
- Torque mapping/vectoring strategies for multiple drivetrain configurations, including central motor(s), 2WD and 4WD, etc;
- Regen control under various vehicle control condition;
- 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, etc.

Vehicle Operation Mode Control

Refers to managing the mode of operation and hence performance of an EV. The Vehicle Operation Mode Control is a layer above the functional control which can override the strategies within the functional control layer. Respective EV operation modes are highly dependent on the specific system design and type of application. Figure 5 shows a generic EV operation modes model.

The sub-systems functional control strategies are specific for each operation mode type, and these are defined through and by the supervisory controller. The supervisory controller is responsible for defining the correct state of operation of the EV according to the driver demands, EV driveline status and diagnostics reporting.

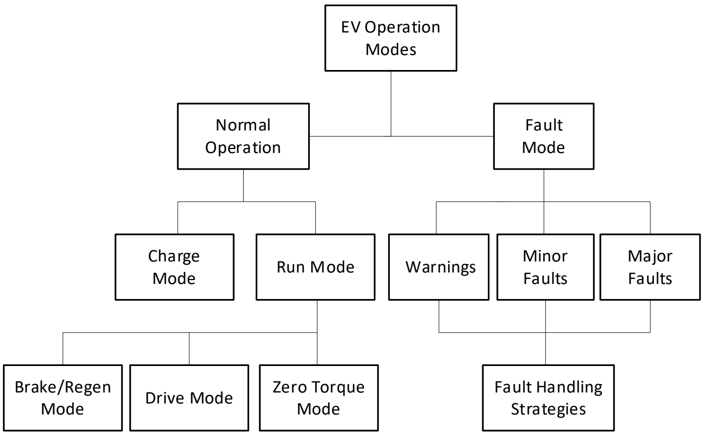

Figure 5. Generic EV Operation Modes Model

For example, in Charge Mode the vehicle cannot be driven as the drivetrain is deactivated while the LV battery is charging from the DC/DC converter. A Finite State Machine (FSM) is usually used for implementing EV operation mode control strategies. The M1 Build programming environment provides an ideal platform to implement complex control algorithms required for various EV applications.

Diagnostics and Fault Handling Strategies

These strategies are some of the most critical functions of the supervisory controllers due to EV systems being high voltage and high power and energy sources. In the automotive industry voltages above 60 V are considered as high voltage applications, and relevant regulations need to be followed in the system electrical design. Additionally, extensive diagnostics must be carried out in the supervisory controller software, and the control system must be able to implement required fault handling strategies to maintain safe operation of the vehicle.

Diagnostics must be performed continuously in the background, and include checking of all safety critical parameters of the HV sub-systems and other conventional sub-systems of the vehicle. Most of the HV sub-systems communicate their operation status, including internal faults and warnings, over CAN Bus. The main objective of these continual communications is to make sure the safety critical parameters are within the accepted limits; and ensure any out of limits states are actioned accordingly and communicated to the vehicle driver. However, fault handling strategies will be highly dependent on the fault severity, local controllers' internal safety features, and the system electrical design. 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 YOUR EV PROJECT WITH MOTEC PRODUCTS

MoTeC has wide range of product types and models that can be used in enabling and integrating an EV system design. The main MoTeC product lines and those being applied to EV solutions, include:

- M150EV VCU
- M190EV VCU
- M130EV VCU
- PDM30 and
- PDM 15
- C1212 Display
- C127 Display
- C125 Display
- L180 Data Loggers

There are three main approaches to engaging with MoTeC and utilising MoTeC products for EV applications, in particular using the M1 ECUs, these being:

1. The Client's engineers develop the full EV solution, including all M1 ECU supervisory controllers programming, with MoTeC primarily providing training on the MoTeC products and software development environment, and technical support.
2. The Client and MoTeC collaborate on the development of the required EV control solution. This arrangement is normally covered with an 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, including all system functional requirements. This is typically covered by a documented contract arrangement between the parties.

Contact MoTeC to discuss your EV project requirements, and to get initial technical guidance on how MoTeC products can enable your EV application solution. As an initial step MoTeC will provide an '**Electric Vehicle Project Start-Up Requirements Questionnaire'** which will assist in the initial definition of your EV requirements, and assist MoTeC to provide the best initial advice and guidance. This Questionnaire covers following main areas of your EV project:

- EV Project General Information;
- Vehicle Specifications & Operation Requirements;
- Battery Pack Requirements Information;
- Drivetrain Configuration and Requirements Information;
- Integration and Build requirements Information.

For further information please contact MoTeC

MoTeC Pty Ltd

121 Merrindale Drive,

Croydon South
Victoria 3136, Australia

T: +61 3 97615050
F: +61 3 9761 5051
Email: evapplications@motec.com.au
Web: www.motec.com