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Electric Vehicle PowerBox and electrical harness with Vehicle Management Unit

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If They stand behind you, learn from them
and protect them,
If They stand beside you, learn from them
and respect them,
If They stand against you, learn from them
and then defeat them.

Abstract

Widespread adoption of Electric and Hybrid Vehicles is often seen as a necessary step in the decarbonization process, because it enables relocating and concentrating carbon emission sources away from densely inhabited locations to energy production facilities, which are more efficient in terms of energy conversion and well equipped for flue gas treatement.

Altough favourable for emission reduction, Electric Vehicles are not as popular yet, mainly due to their higher intial cost: one solution to this problem is the electrification of Internal Combustion Engine Vehicles through so called “Retrofit Kits”, which allows owners to convert the vehicle(s) they already own for a fraction of the cost.

This paper details the development of an electric vehicle retrofit kit system, particularly the integration of a programmable VMU (Vehicle Management Unit) with the end goal of providing greater flexibility in the implementation and enabling higher-end features to be added with little effort and low engineering cost.

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Objectives

Current trends in the reduction of the environmental impact of human activities are seeking to improve efficiency of the most impactful contributions to energy consumption: Electric Vehicles (EVs) might represent the answer to efficient use of electricity to reduce pollution concentration in urban areas, by constraining fossil fuel usage to electricity production facilities, which are better equipped for effluent treatment and usually optimized for energy recuperation, while providing short-term improvement during renewable energy facility development and construction.

Although not in its infancy, electrification of vehicles still suffers from some economical and psychological concerns set forth by consumers over high cost, access to the grid and charge anxiety (fear of complete battery drainage far from charging stations), which are limiting widespread adoption of EVs by the general public. Moreover, customers expect all features and conveniences of internal combustion engine (ICE) vehicles to be seamlessly transferred to EVs, thereby risking negative publicity to spread from early adopters of unpolished implementations.

It is then of the utmost importance to deliver results that exceeds expectations (such as lower cost, comparable range to ICE vehicles) and products that can leverage emotions to influence consumers decisions, like iconic models restyling or money-saving retrofit kits to convert customer-owned vehicles, in order to promote widespread adoption of EVs.

Introduction

A possible solution to the high entry barrier in the Electric Vehicle market is the electrification of Internal Combustion Engine Vehicles through so called “Retrofit Kits”, which allows owners to convert the vehicle they already own for a fraction of the cost of a new vehicle.

This paper details the development of an electric vehicle retrofit kit system, particularly the integration of a programmable VMU (Vehicle Management Unit) into a simpler system (Panda G1), already developed by Prof. S. Carabelli and his Team, in conjunction with several private companies.

To introduce the reader to the scope of the project, some background will be made available about the current state of Panda G1 project and its specifications, then some limitations of current implementation will be highlighted to justify the additional cost and effort needed to integrate the VMU into the system.

After a brief review of prior art, the methodology used in the system development process will be described, followed by the actual implementation and integration of system components.

Finally, the documentation and review framework used to record advancements, issues and milestones of system development will be presented, along with some key open points which will not be covered in this thesis and will be considered as the starting point for future design upgrades.

2.1. Context

The starting point for the retrofit kit described in this thesis is the retrofit kit developed in Panda G1 project by Prof. S. Carabelli and his Team, in conjunction with several private companies. This kit consists of a custom battery pack, a brushless motor and motor controller and some accessories such as a dashboard to control vehicle functions and an electric heater to keep the passengers warm in cold climates.

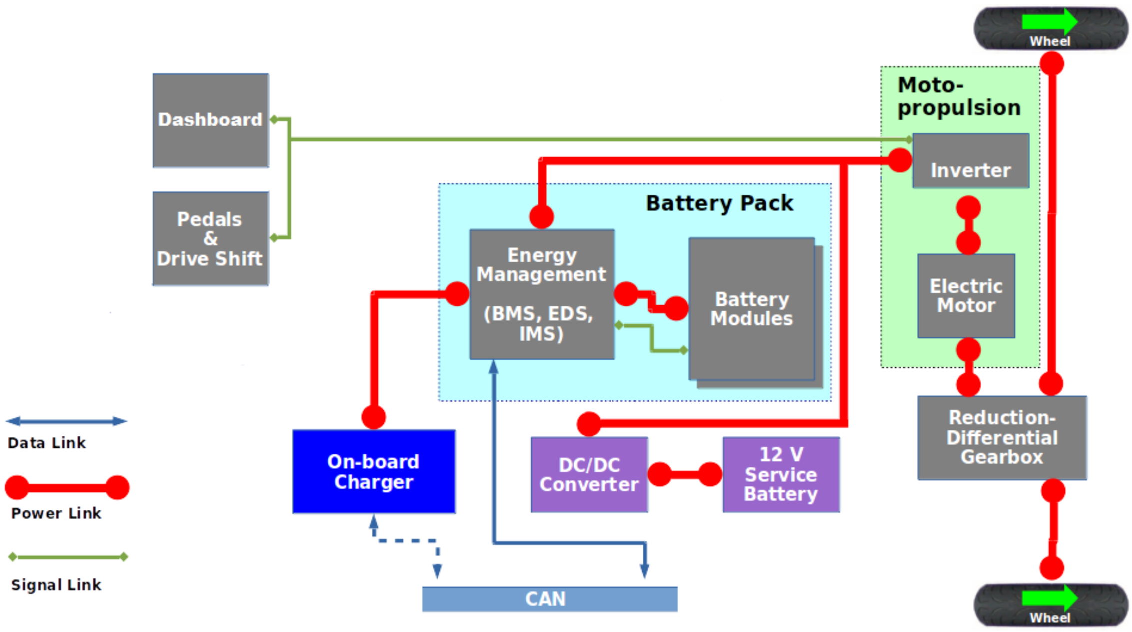


Figure 1 : Panda G1 block schematic

The Panda G1 project aimed for the electrification of a Panda Prima Serie gasoline vehicle, with an expected maximum driving distance of 100km on a full charge and providing basic functions such as forward/reverse drive, battery charging and management, vehicle heating, vacuum-assisted braking (by means of an electric vacuum pump).

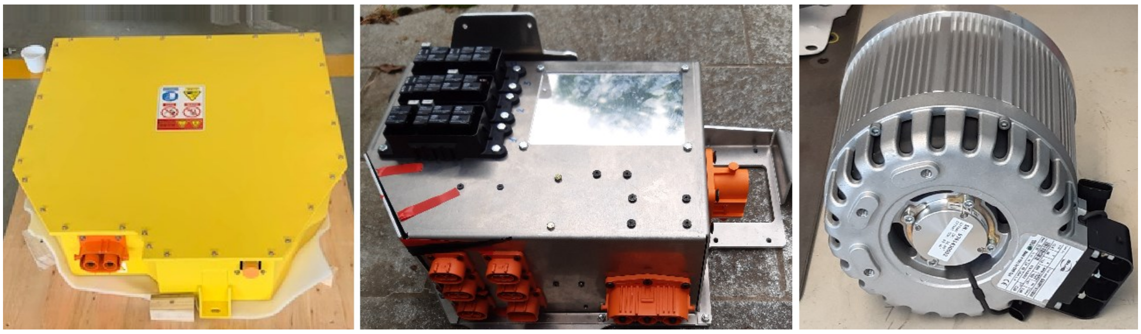


Figure 2 : Panda G1 powertrain (HV Battery, PowerBox, Motor)

Panda G1 retrofit kit will be used as a starting point for the power electronic section, while the control logic will be implemented in software inside the VMU programmable control unit, that will be integrated in the retrofit hardware design.

2.2. Motivation

While providing all functions needed to drive the vehicle and monitor the battery pack and electric motor, the architecture of the Panda G1 retrofit kit is implemented using discrete hardware components, a solution that is simple yet expensive and not easily adaptable to evolving customer needs. Moreover, the lack of serial communication interfaces and even basic add-ons present in today's vehicles relegates the use of this kit to vintage cars that do not rely on some form of in-vehicle communication network for their operation.

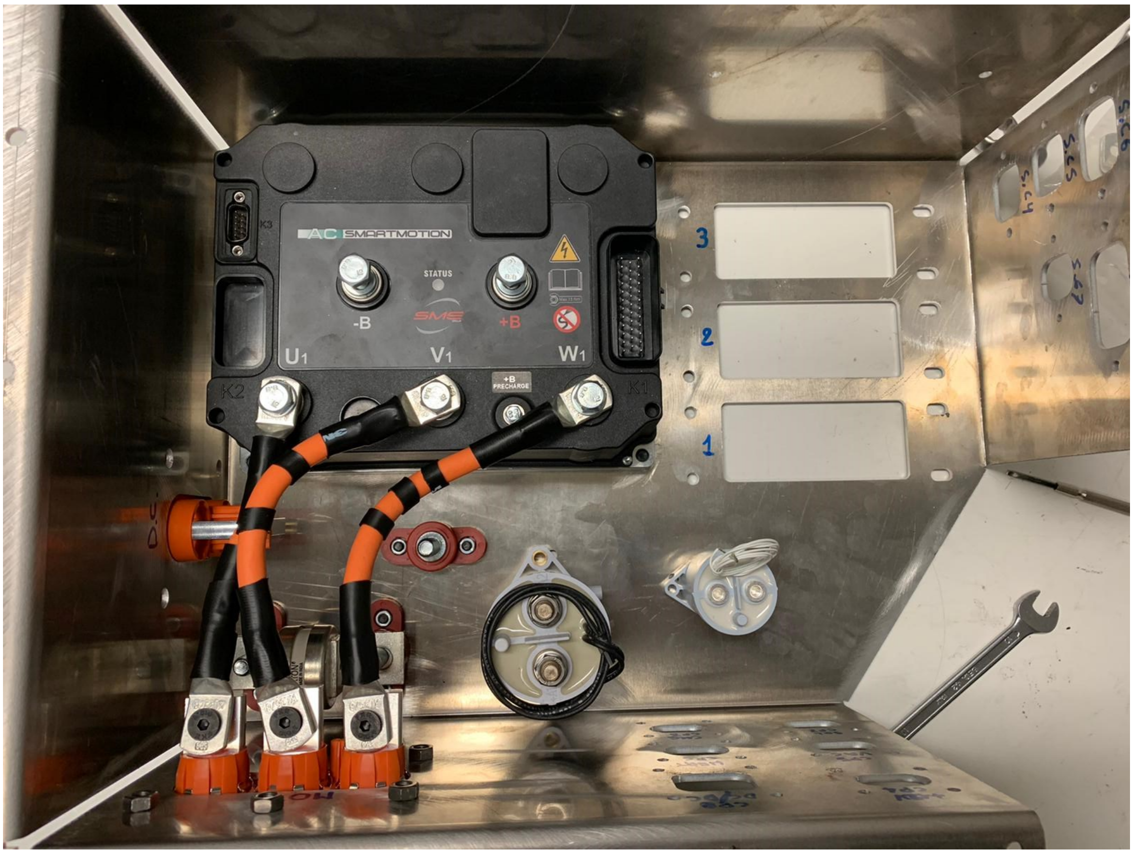


Figure 3 : Panda G1 PowerBox with high voltage motor cables

The design of the G1 retrofit kit contains some key concepts that will be carried over to the new implementation: one of these ideas is the fact that all high voltage connections will be grouped inside a metal box (PowerBox), that will protect the user and any technician performing repairs on the vehicle from being electrocuted by the high voltage output DC lines that deliver power to all components in the vehicle powertrain.

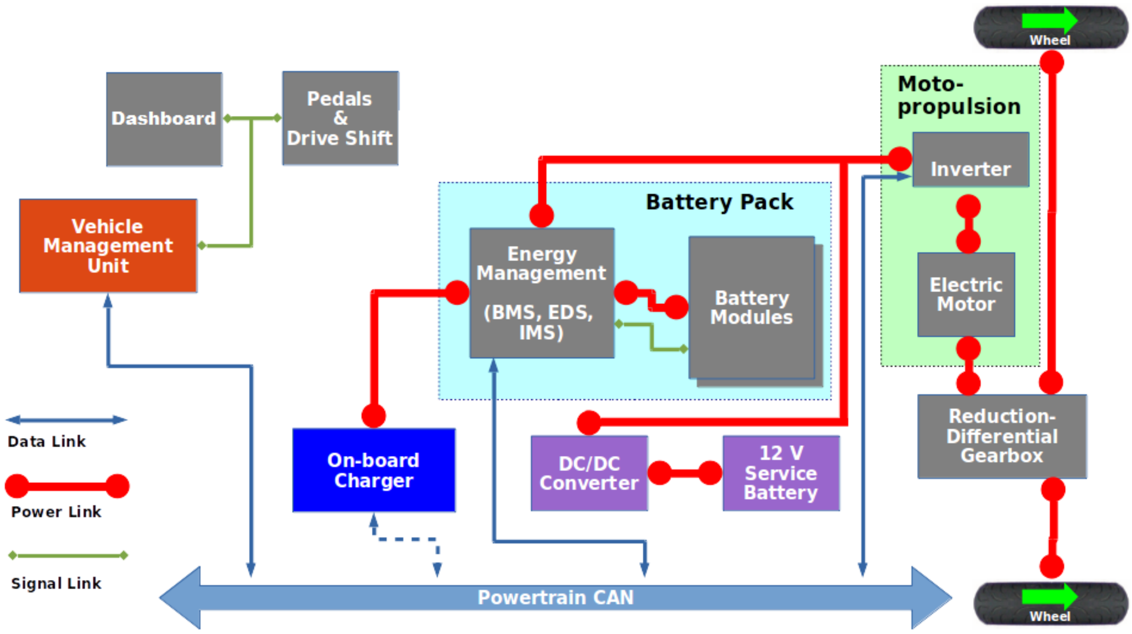


Figure 4 : New retrofit kit block schematic (with VMU)

The new retrofit kit will however be targeted to owners of newer vehicles, that will most probably integrate some kind of Electronic Control Unit and communication bus, such as Local Interconnect Network (LIN) and/or Controller Area Network (CAN). The integration of a VMU in the new system will simplify the hardware architecture, thereby reducing cost, complexity and assembling/testability issues of the design, while allowing for core complex features to be integrated into the control logic of the vehicle (such as hill-assist, battery management and critical safety checks).

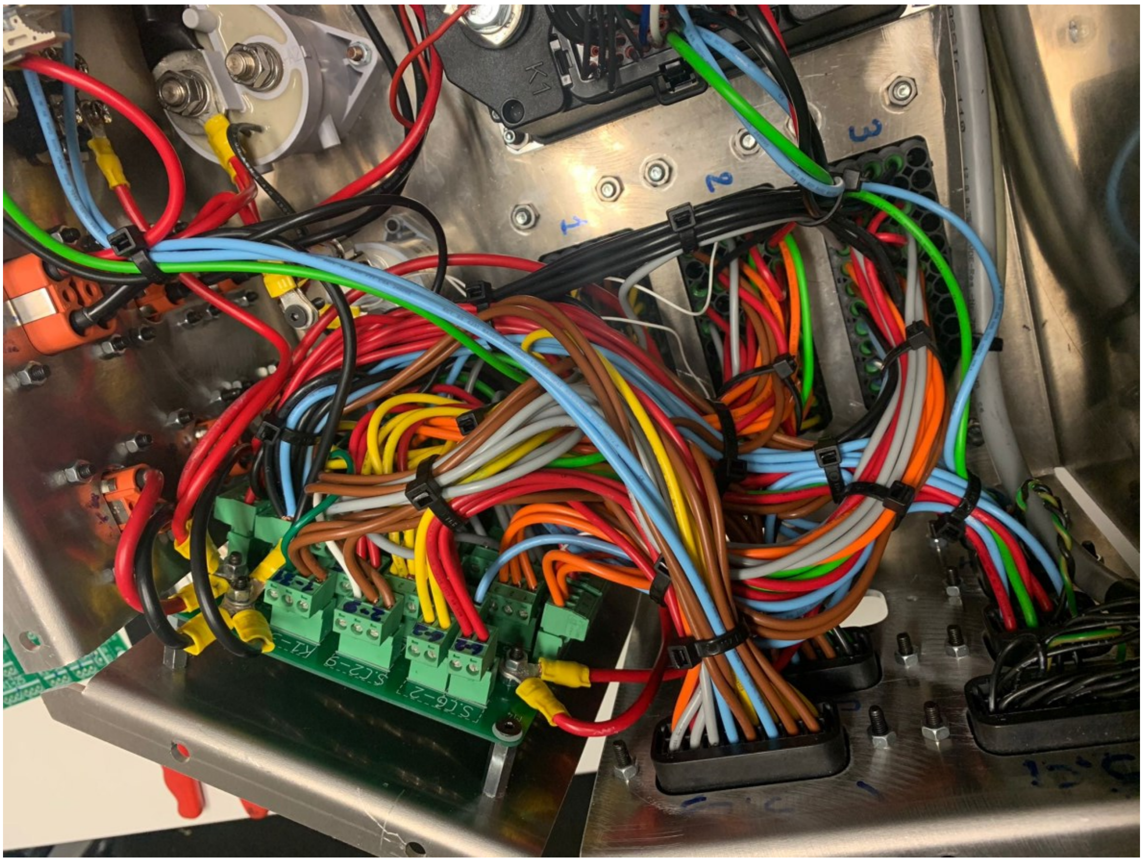


Figure 5 : Panda G1 fuseholders connections

The reduction in the number of wires needed to connect devices inside the PowerBox and the removal of almost all relays and all diodes will reduce the PowerBox assembling time significantly (the final number of connections is less than half of the harness inside the old design), leading to a less expensive product that will better cope with customer expectations (feature-wise) in this price range.

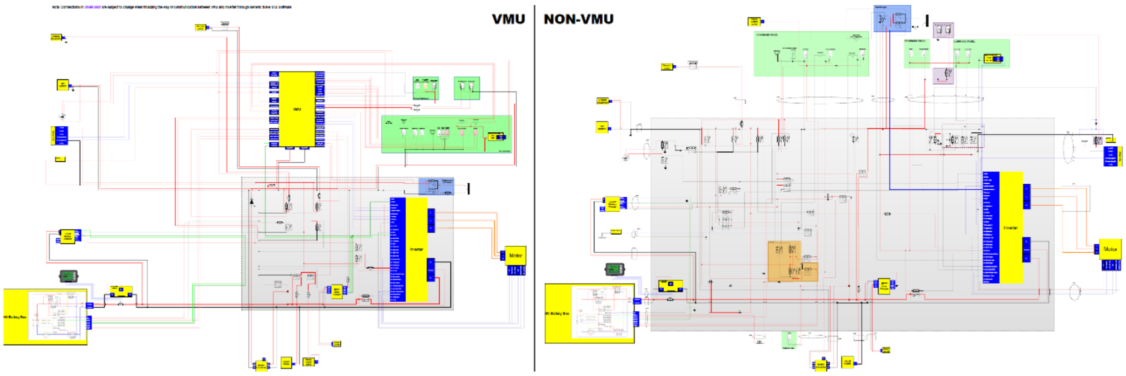


Figure 6 : Retrofit kits electrical schematic comparison

(new kit on the left, Panda G1 on the right)

In conclusion, the key aspects of power electronics hardware design that are already present in Panda G1 retrofit kit will be also considered as guidelines in the development of the new retrofit kit, and the hardware logic and many of the hardwired connections present inside the PowerBox will be replaced by a VMU, connected to its related harness and programmed to control the entire vehicle powertrain.

System Design

The retrofit kit developed in Panda G1 project will be used as a reference design, since it contains all the basic building block necessary to at least drive the converted vehicle by means of an electric motor.

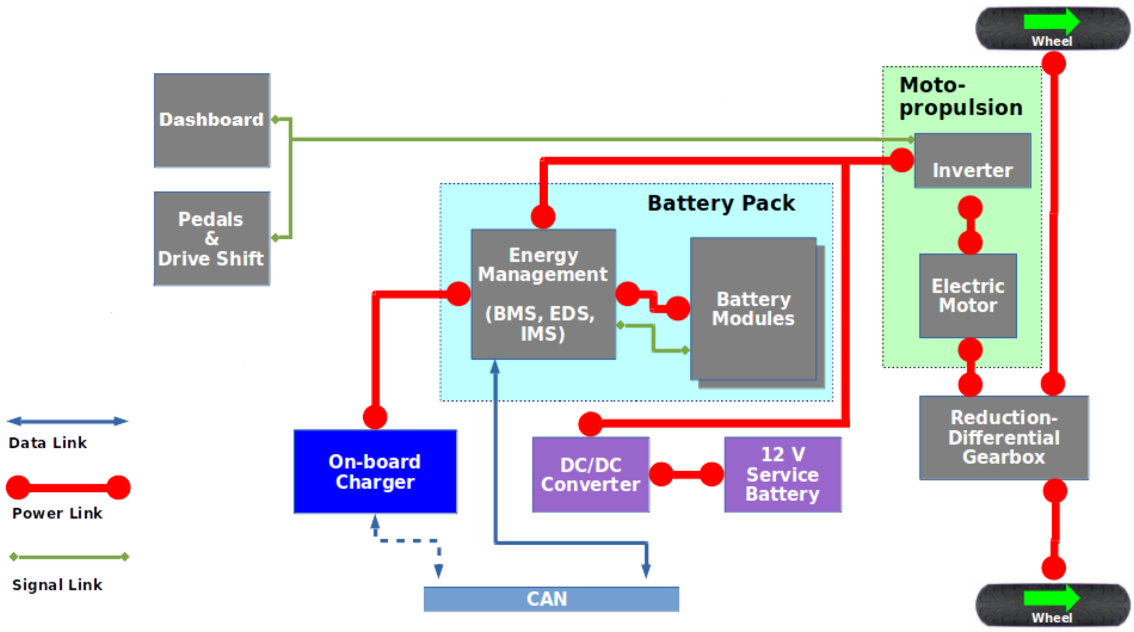


Figure 7 : Panda G1 block schematic

(a dedicated powertrain network is not implemented)

(Note that a CAN line is present even in the G1 system; however, this communication line is used by the charger to monitor the status of the HV battery and is not related to other powertrain functions, nor it is feasible to use it for any other purpose)

The original G1 design consist of three main parts, which are the battery pack with associated charger, the motor and the PowerBox assembly.

Figure 8 : HV Battery and matched AC Charger

The battery pack and charger are matched and were supplied by the same company, which built the subsystem according to custom specifications. The traction battery is a 96V, 10kWh pack, bolted under the rear axle and can be charged from a normal wall socket by the charger at the maximum continuous rate of 1/5 C.

Figure 9 : 10kW IPM Brushless electric motor with flange

The motor chosen for the project is a 10kW (20kW$_{peak}$) IPM brushless motor, capable of reaching a maximum speed of 6500rpm, providing an average torque of 50Nm and mechanically coupled to the vehicle transmission assembly.

Figure 10 : Panda G1 system

(additional dashboard, PowerBox with relay logic and inverter, DC/DC converter)

The PowerBox assembly contains the inverter (supplied in conjunction with the motor), the relay logic used to control the main functions of the vehicle and to respond to user actions on the dashboard and some accessory components, like the DC/DC converter that charges the 12V battery from the main battery pack.

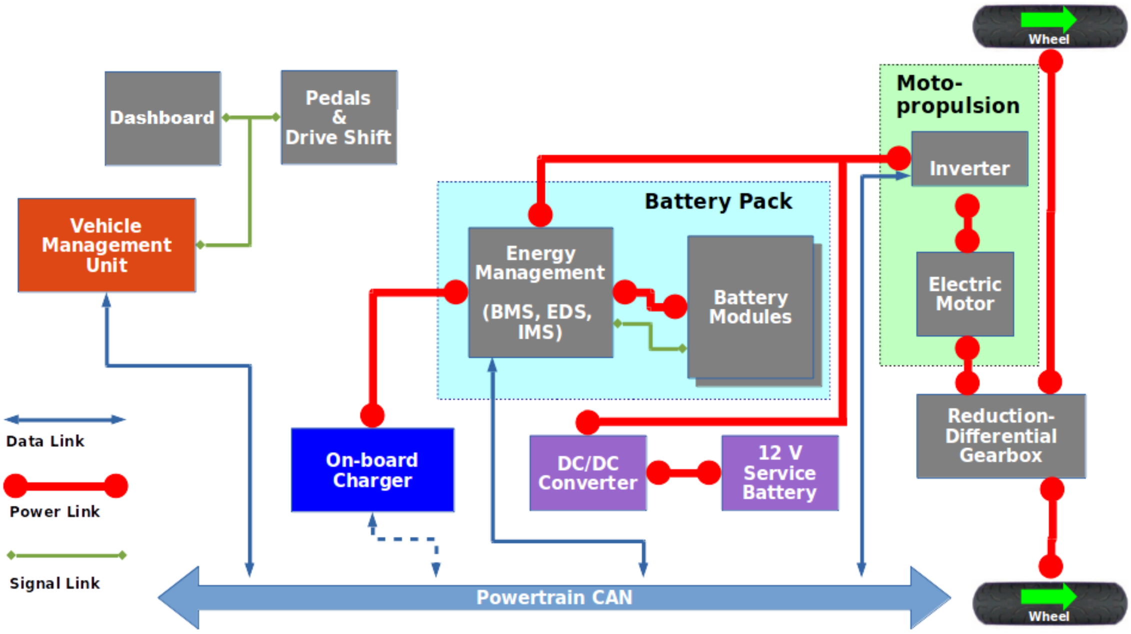


Figure 11 : New retrofit kit block schematic

(a dedicated powertrain CAN network is now implemented)

The new powertrain design will take advantage of the same basic blocks as the G1 project, but some modifications will be needed to adapt the kit to newer vehicle models and provide flexibility and configurability.

The traction battery, battery charger, inverter, motor and DC/DC converter used will be the same as for the G1 design.

Figure 12 : Comparison between Panda G1 and the new kit (main components):

Panda G1 with dashboard and relay logic on top, new kit with VMU and display on the bottom

The modifications needed to adapt the system to work in conjunction with a VMU will mainly affect the PowerBox, because the wired logic that controls the vehicle will be replaced by the VMU (apart from some additional safety systems). A digital display might then be used in place of the dashboard.

3.1. Methodology

The methodology used to tackle the complex task of designing and developing the new vehicle powertrain has been the hierarchical decomposition of the complete systems into different layers at different levels of complexity, namely the System level, the Hardware level, the Software level, the Mechanical level (non reviewed in this document).

This choice in system partitioning has then been coupled with a validation process, to confirm the correctness of the system elements concurrently designed and, at the end of the development phase, integrated into a single working system.

The most natural (and widely adopted) technique, used to standardize this delevopment scheme, is the V-cycle.

3.2. V-cycle

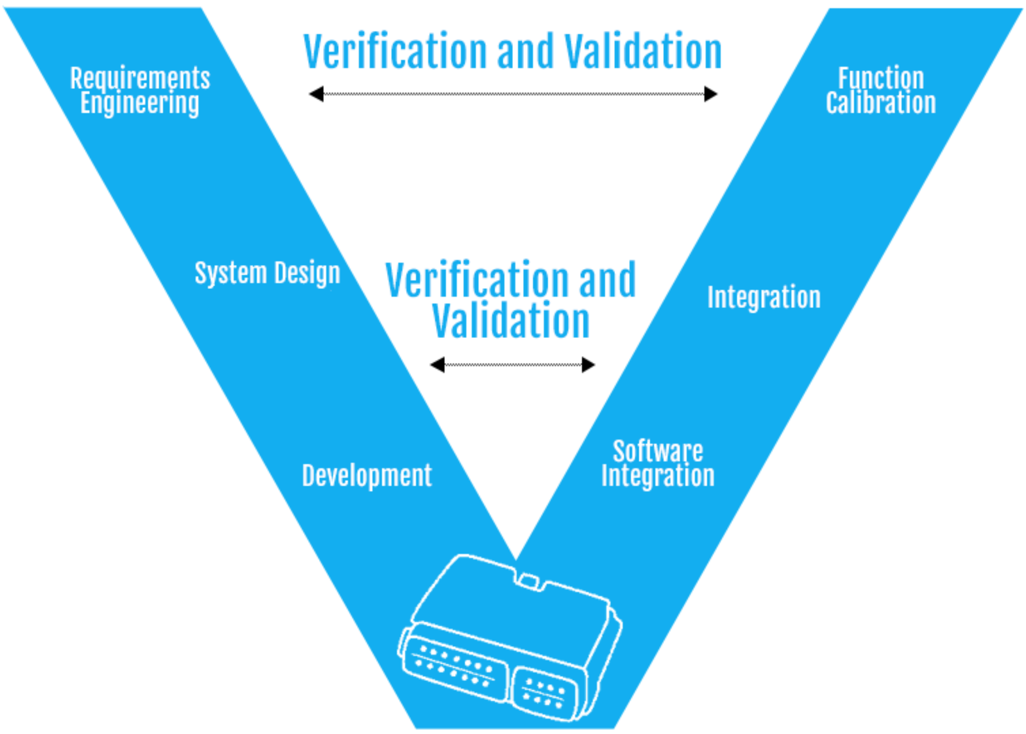


Figure 13 : Traditional V-cycle

The original V-cycle is composed by three sections:

-A design phase, in which the whole system is evaluated in terms of a single blackbox and work is distributed to various development groups;

-A development phase, in which the development groups will develop different parts of the system, based on the required functionality allocated to the subsystems;

-An integration phase, in which all components needed to build the system are integrated to produce the complete system.

For each subsystem development cycle, a verification process and a validation process has been used to verify the outcome of development against the requirements set during the design phase and to validate the system/subsystems at different stages of the integration phase.

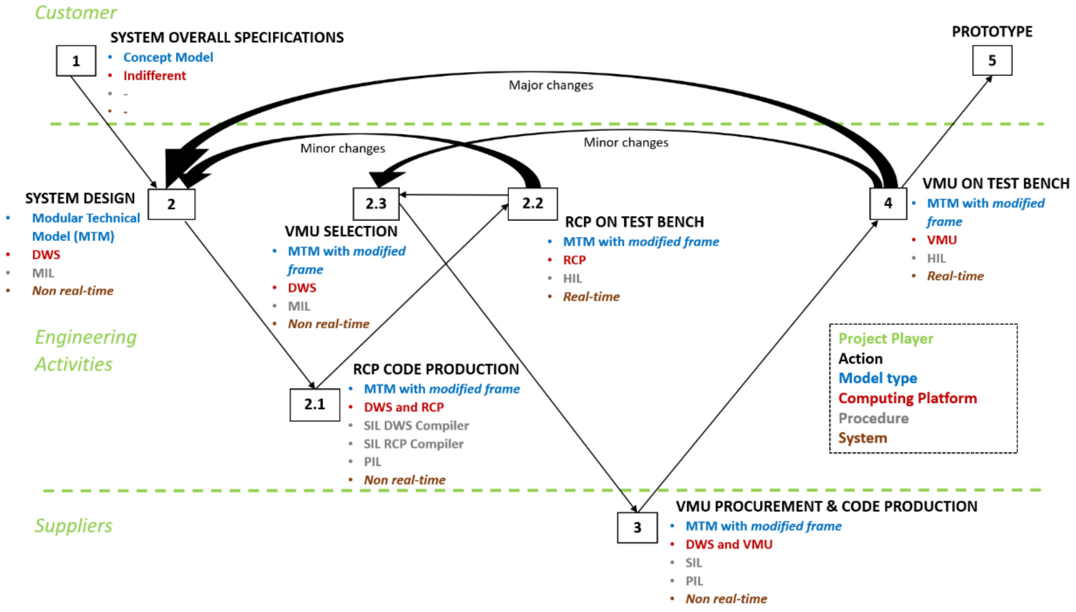


Figure 14 : Hybrid V-cycle

To better adapt the V-cycle to the development of the system described in this thesis, a modified version (called the Hybrid V-cycle) has been used instead of the original V-cycle, because it is taylored directly to the integration of a programmable control module and its firmware (Coletta, 2020).

This version of the V-cycle is particularly suited to this application because it clearly defines which design model and integration platform is used in each stage of the design, namely the whole control logic, the software written for the VMU or even a RCP (Rapid Control Prototyping) platform (a powerful hardware tool used to simulate the interactions with a real hardware device).

Figure 15 : MicroAutoBox RCP platform

As required by the Hybrid V-cycle, in addition to the overall system design and development, different validation loops have been implemented (one for each subsystem/model): in particular, validation cycles connected to step 2.2 and step 4 will be of great importance, because they will allow testing and evaluation of the behavior of the system and software when the real VMU is installed, by comparison with the behavior of the system with RCP platform installed.

3.3. Specifications Overview

The first step in the design process has been the collection of specifications and elicitation of requirements from all stakeholders (all entities involved or having claims or interest in the system, as per ISO/IEC/IEEE 29148:2011(E)).

Similarly to the Panda G1 design, some simple constraints has been considered to ease future work on the system, instead of producing detailed reports based on specific standards:

- The retrofit kit has to be compatible with the vehicles specified as compatible to the Panda G1 kit
- IP rating of system components must be appropriate with reference to the automotive environment (cautiously specified to at least IP67 for all assembled subsystems)

- Reasonable effort must be placed in avoiding unnecessary risk and providing failsafe system operation in case of faults (altough a complete Hazard Assessment and Risk Analysis has not been completed as per ISO26262)
- The system must be safe to use for the driver with regards to the electrical risks present in the powertrain
- The system must be easy to install and repair by trained personnel, when familiar with the implementation and adequately informed about procedures and methods for installation, diagnosis and repair
- All system components or subassemblies must be easily substituted as a single part during repairs, to reduce total repair time at customer premises /dealership.

3.4. Technical Requirements

The second step in the design process, as specified by the V-cycle, has been the derivation of system requirements and technical specifications from design specifications and a moltitude of lessons learnt from the Panda G1 project.

The main components and subsystems dimensions have been assessed and their placement on the vehicle has been specified, both in the front grade and the rear underbody. The placement of components has been roughly based on the G1 arrangement and has been modified as needed in case some upgrades would have required so.

Figure 16 : HV Battery placement under rear underbody (battery coloured in yellow)

The High Voltage battery has been placed under the rear carriage, taking into account the maximum displacement of the rear suspension assembly: this choice will allow quick access to the emergency battery disconnector from the rear side of the vehicle.


Figure 17 : HV Battery emergency disconnector

The PowerBox, DC/DC converter, accessories and motor has been placed in the engine compartment (in place of the internal combustion engine), by means of a custom baseplate and motor flange mount.

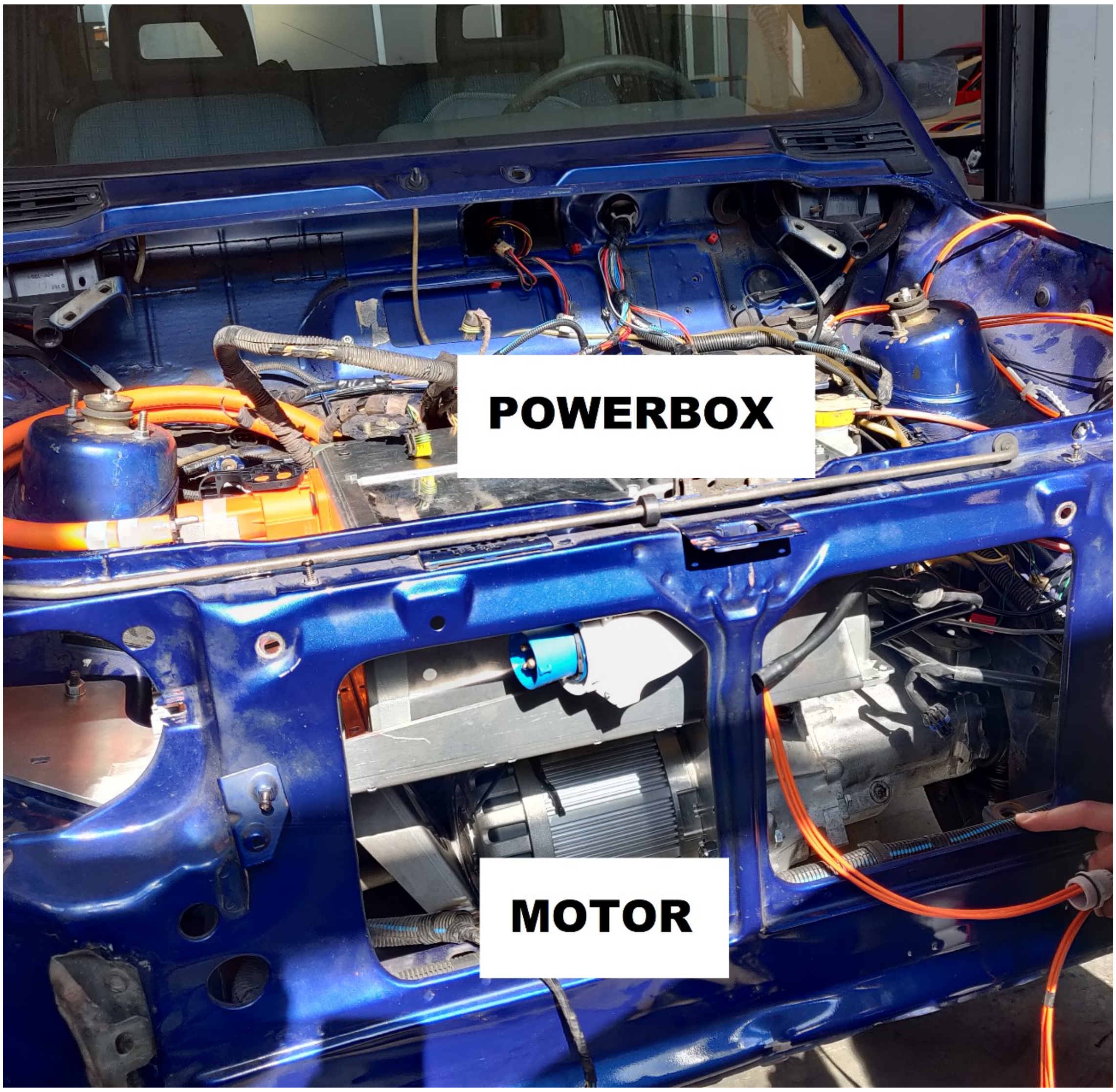


Figure 18 : PowerBox and motor installed in place of the internal combustion engine (toghether with other components)

The powertrain technical requirements in terms of power, speed and torque have been carried over from the Panda G1, since they were already optimized for this type of vehicle. The retrofit kit has been specified with a 96V, 10kWh battery pack and a 10kW (20kW_{peak}) IPM brushless motor, capable of providing a nominal torque of 50Nm and reaching a speed of 7000rpm, with a maximum current draw of 400A. This configuration will allow the vehicle to reach a maximum speed of 120km/h and to climb an 8% slope when loaded to the maximum capacity specified by the manufacturer. The maximum current draw of the system wil require 70-90mm^2 cables to connect the PowerBox to the traction battery and 35mm^2 cables to connect the PowerBox to the electric motor.

Contrary to what has been done for the Panda G1 project, the new design with VMU has seen almost all PowerBox relays sustituted by software functions programmed into the control unit (except for some safety-critical subsystems like the charging interlock or power relays).

A powertrain network has also been added to connect the main components in the system (VMU-ACcharger-Inverter). This digital network has been employed in lieu of simple voltage signal commands to exchange messages bidirectionally between the subsystems, thereby ensuring safety and system integrity and providing added flexibility in case of system updates.

System Development

The next step (and to some extent the longest part of the process) has been the development of the actual system, based on the technical requirements drafted during the activities completed in the previous sections and enhanced by the experience gained during the Panda G1 design activity.

The design has been decomposed hierarchically to allow a better understanding of each component function and promote a modular approach to development, in order to streamline the execution of each step in this phase.

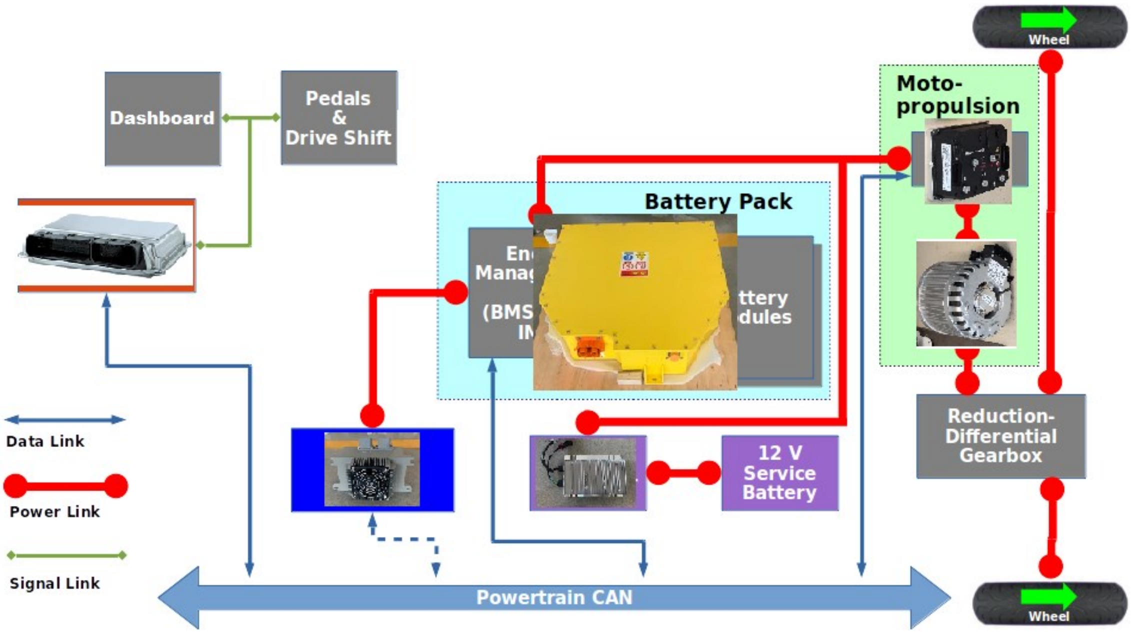


Figure 19 : Main components of the new retrofit kit

Expanding from the main architecture of the system, each block has been evaluated in terms of cost, procurement and impact on project outcome.

The main high voltage components (traction battery, inverter, motor, AC charger, DC/DC converter) have been procured as off the shelf parts, while control electronics (contained inside the PowerBox) has been designed from the ground up.

Lastly, the VMU has been purchased as a finished component but it will be flashed with custom code developed in-house (when completed).

4.1. PowerBox

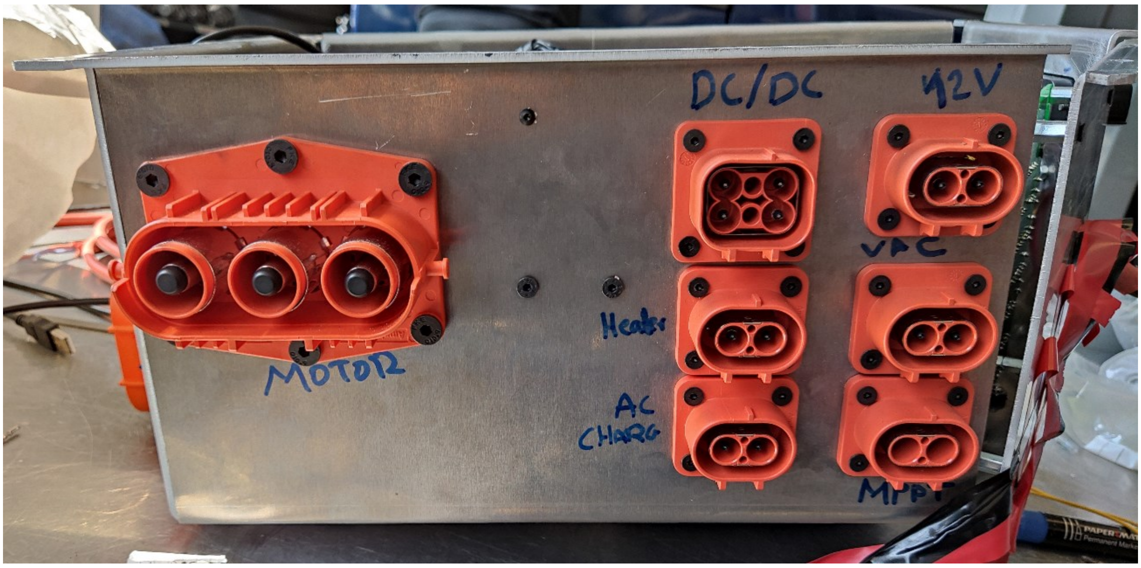


Figure 20 : New retrofit kit PowerBox

As done in the Panda G1 project, all control electronics has been housed inside a metal box, called PowerBox, toghether with the inverter, high voltage and low voltage connections.

Since the vehicles where the new retrofit kit will be installed might differ substantially from the original Panda Prima Serie, the mechanical mounting plate that support the PowerBox inside the engine compartment will be changed. However, there will be no need to change the actual PowerBox mechanical design and mounting strategy on the support plate (aside from differencies in the number and placement of connectors and internal components).

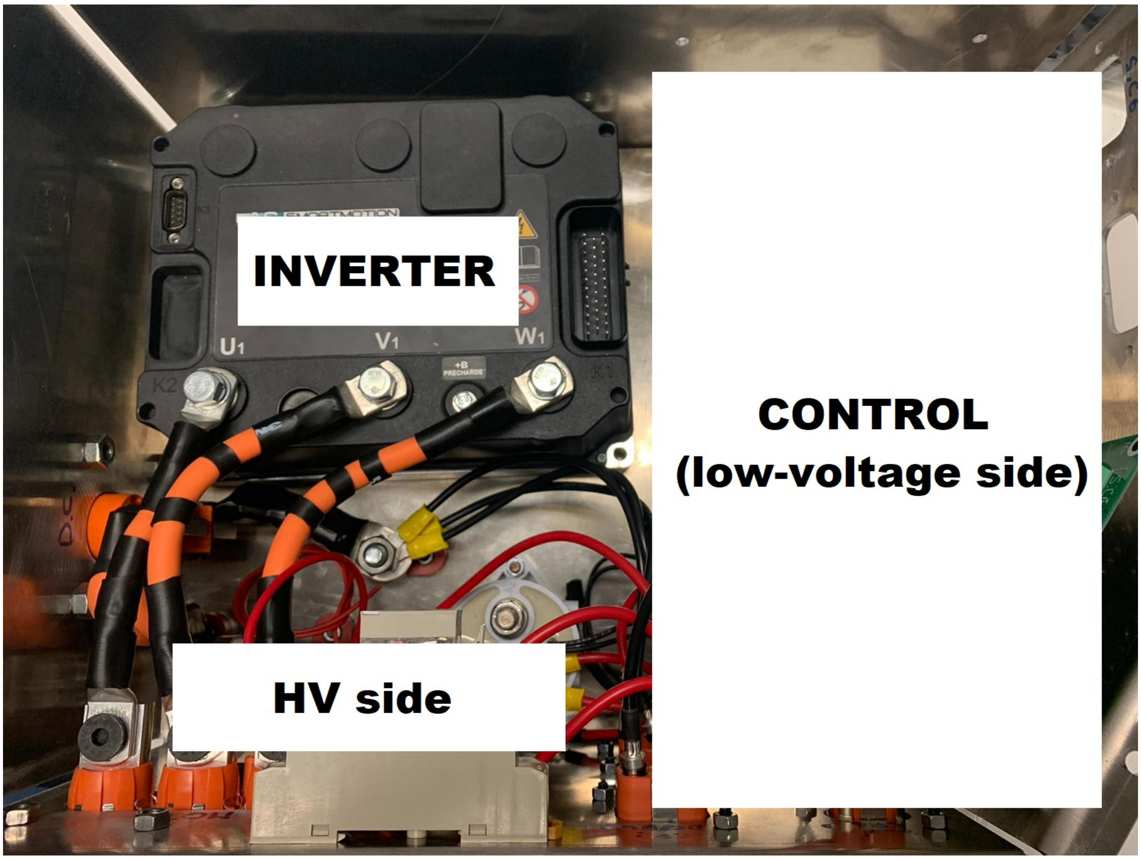


Figure 21 : Separation between the High Voltage side

and the Low Voltage side inside the PowerBox

The PowerBox has been designed to be the central part of the powertrain, which will control all aspects of traction and retrofitted vehicle accessories, protect the user/technician from high voltage connections and provide a single point where every component is electrically linked to the rest of the system.

The fact that every other component in the retrofit kit will be connected to the PowerBox will ease the assembly of the system: technicians whom are not familiar with the design will be able to assemble the kit just by following the instructions and connecting everything toghether in a simple and intuitive way.

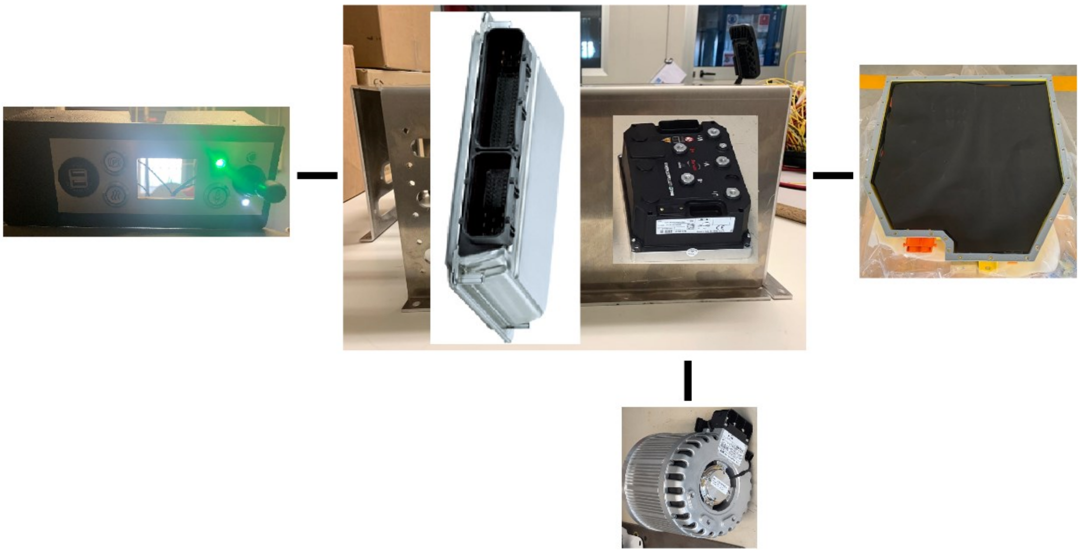


Figure 22 : The PowerBox is the central interconnection point in the powertrain

The PowerBox is the most important part of the system and it has been designed as a completely custom component (instead of procuring a commercially available part) in order to provide the flexibility needed to accommodate all components in a tight space and to better control the development phase for this subsystem.

Designing the PowerBox has also been an important step in learning how to assess the total cost of the subsystem and reduce its weight on total NRE cost (Non-Recurring Engineering cost): lessons learnt in this step will be applied also during the design and development of the other subsystems.

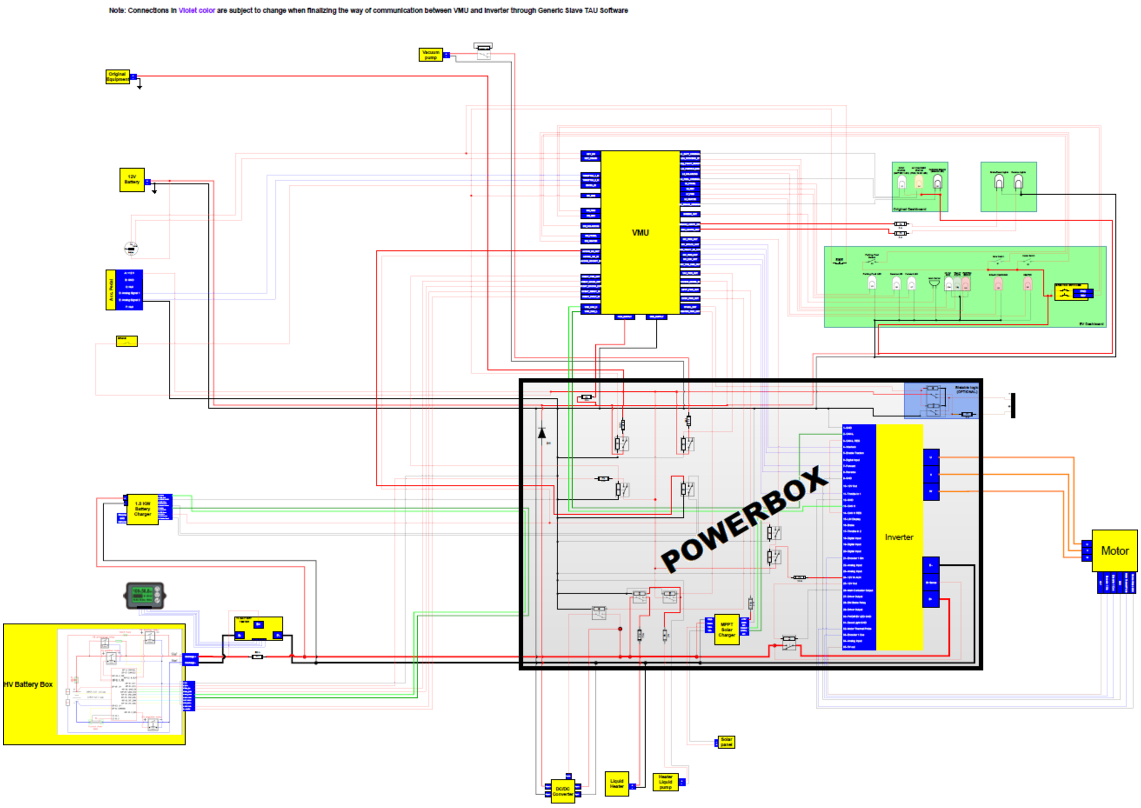


Figure 23 : The PowerBox contains most of the hardware components

As can be seen in the above image, most of the complexity (that will be reduced) will be located inside the PowerBox perimeter, while all other components in the system seem to be already connected to the logic using the smallest possible number of wires.

All wires that are not directly connected to components inside the PowerBox have been routed directly outside of this subsystem, since many of the most expensive components have been found to be IP67 connectors needed to get through the PowerBox wall.

The most important connections marked for installation inside the PowerBox (after placement of all procured components) have been the high voltage wires going from the battery and motor connectors to the inverter, due to their size and stiffness that have limited positioning of other components in the same area.

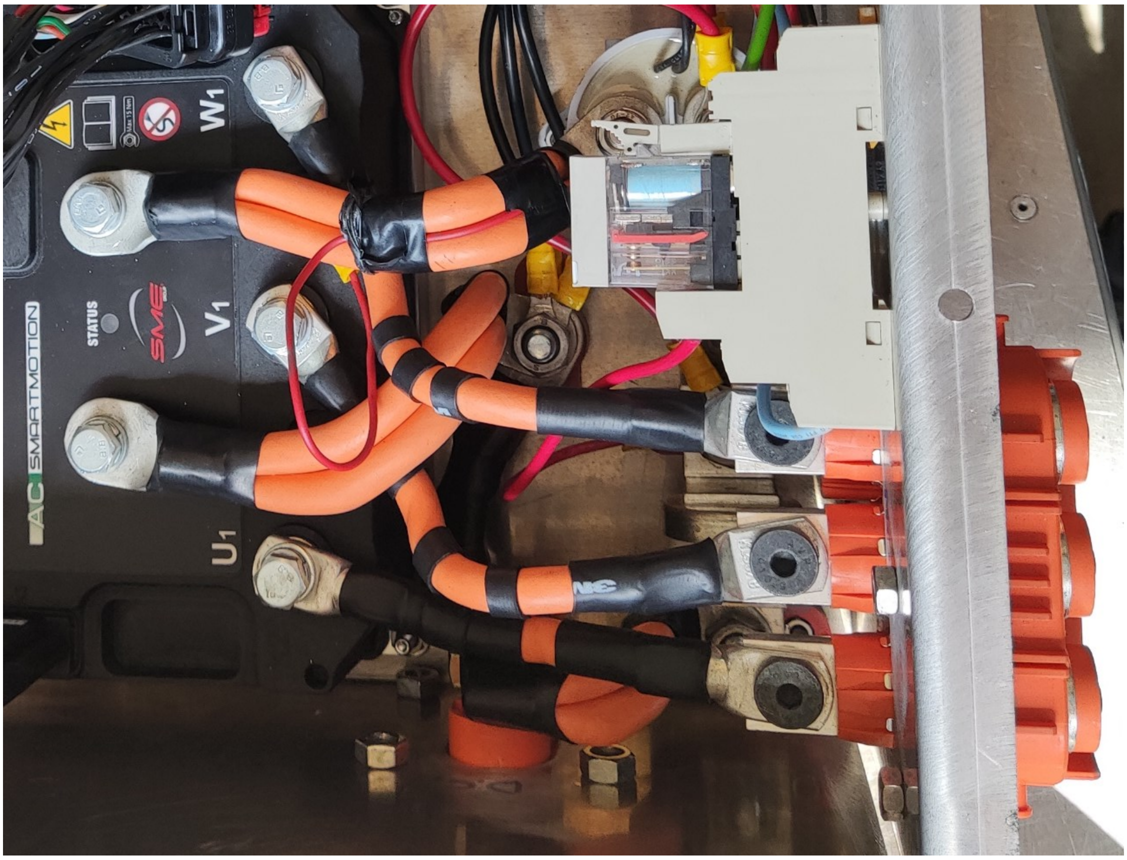


Figure 24 : High Voltage connections between HV Battery, inverter and motor

Due to the high current flowing in the high voltage connections (around 400A), the same wire size as the one in high voltage connections in Panda G1 project has been selected (70-90mm^2 cables to connect the PowerBox to the traction battery and 35mm^2 cables to connect the PowerBox to the electric motor).

Copper busbars have been considered at the start of the design phase, but have been rejected after a brief analysis because of the added complexity of the insulated support brakets needed to secure them in place and avoid movement due to vibrations. Flexible, appropriately rated cables have been selected to connect high voltage components.

Figure 25 : HV cable ring termination

Cable lugs have been crimped to the ends of the wires for connection to bolt-on terminals and cables ends have been protected using automotive-rated heatshrink tubing.

Since most functions of the powertrain will be controlled by Firmware tasks inside the VMU, the control unit might become a single point of failure in case of faults, leading to unexpected (and probably dangerous) behavior.

Although no countermeasures have been selected to actively monitor the VMU from outside of it’s casing, the use of a safety-certifiable platform, Realtime Operating System with task scheduling and watchdog has been proposed as a starting point in assuring safety for the end user.

The only external safety measure devised (to date) has resulted in the addition of an hardware interlock to selectively inhibit the inverter when the vehicle is connected to a charging station, even in case of complete VMU failure.

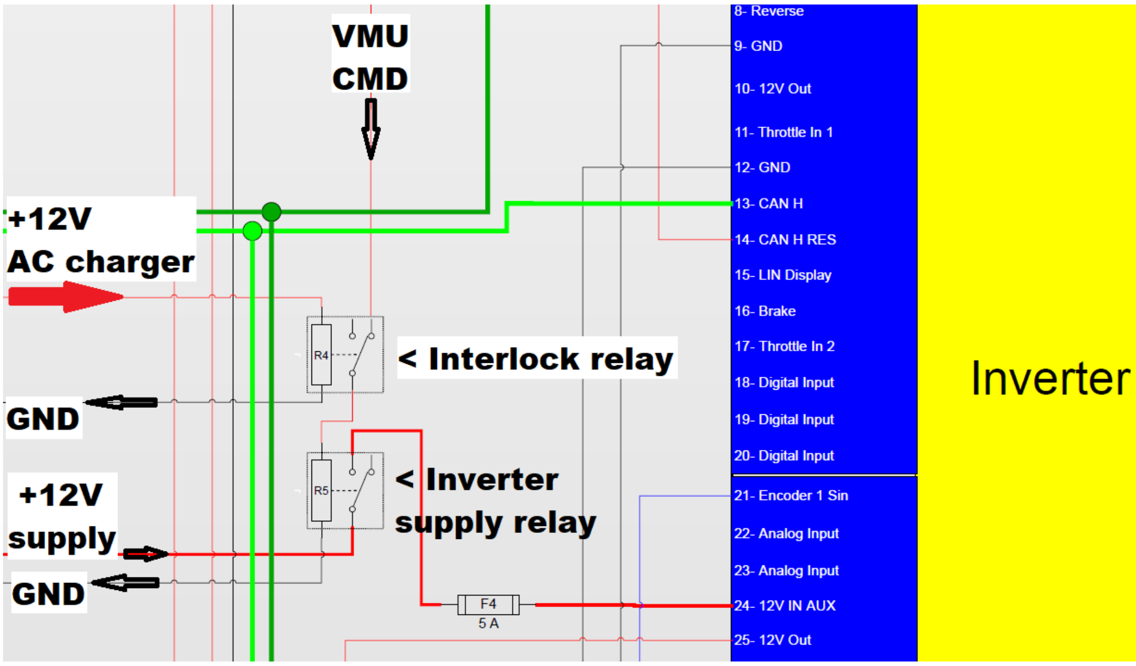


Figure 26 : Hardware interlock circuit to disable inverter during charging

The HW interlock has been designed to disconnect the related VMU power output from the inverter positive supply wire when a 12V signal is generated by the AC charger (present whenever the charging plug is connected to a wall socket).

A couple of proposed features have been marked as "optional" for the retrofit kit to reduce cost and complexity, namely the parking pawl (bistable magnetic brake) and a solar charging subsystem.

These features are listed for completeness and briefly discussed but will not be included in the final design.

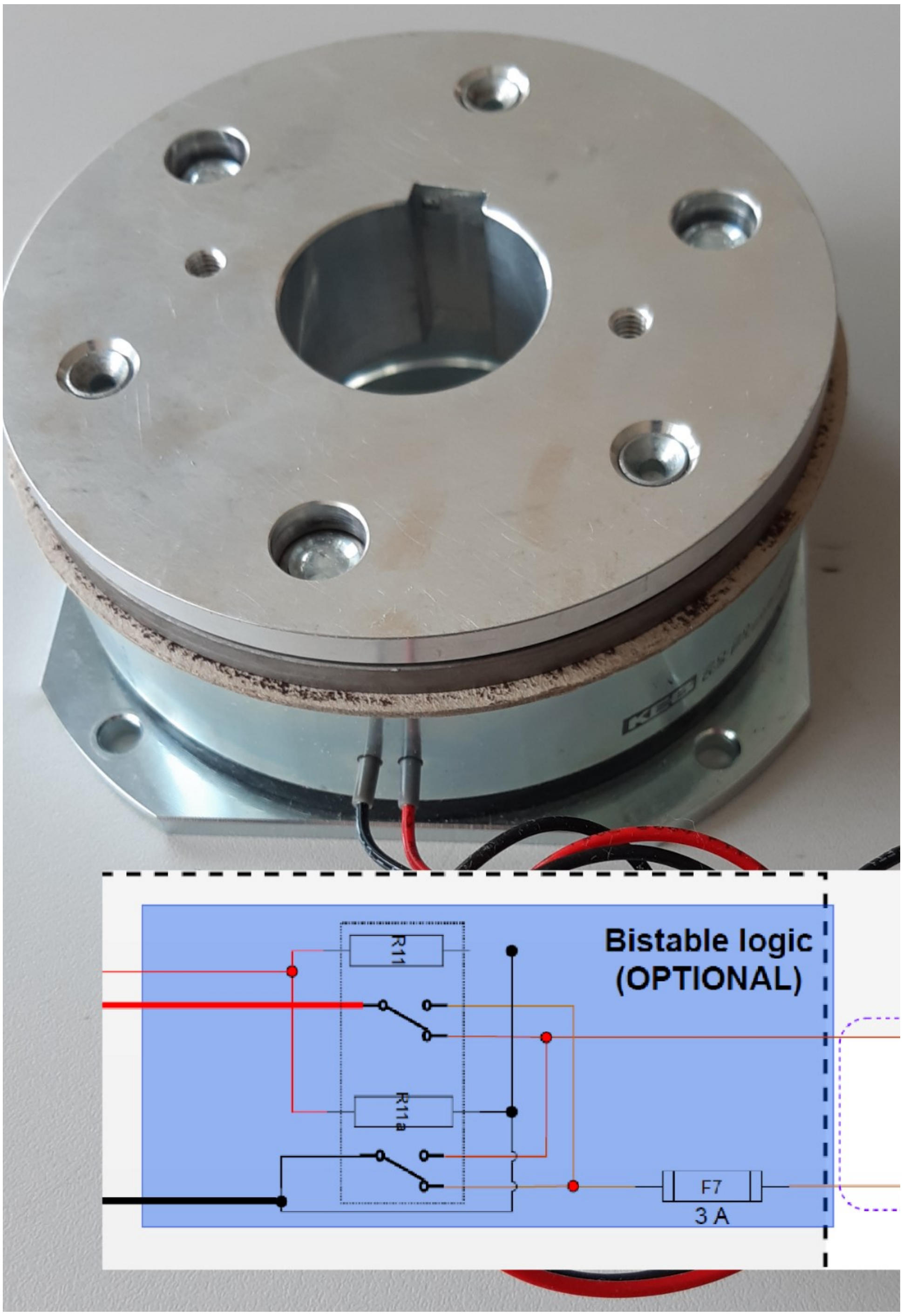


Figure 27 : Magnetic parking brake and relays driving circuit

A bistable magnetic brake might be added to prevent the retrofitted vehicle from rolling downhill when the parking brake is not enabled. This subsystem requires its own control relays that can be omitted in the standard design.

Figure 28 : Example of solar panel mounting and MPPT controller

A second optional subsystem, requiring more extensive modifications to both the vehicle and the PowerBox, has been devised a solar charging addon kit, similar to the one already implemented in the Panda Saver project (an earlier project developed by Prof. Carabelli team). This addition consist in a solar panel installed on the vehicle roof and an MPPT (Maximum Power Point Tracking) solar controller placed inside the PowerBox, to regulate current going to the traction battery, plus some dedicated control logic.

After all features located inside the PowerBox have been developed according to the requirements, a completed schematic has been drafted for the whole system. Even if not required by the VMU datasheet, flyback diodes have been added in parallel to all relay coils for the prototype, in case a non-protected control unit is ever used.

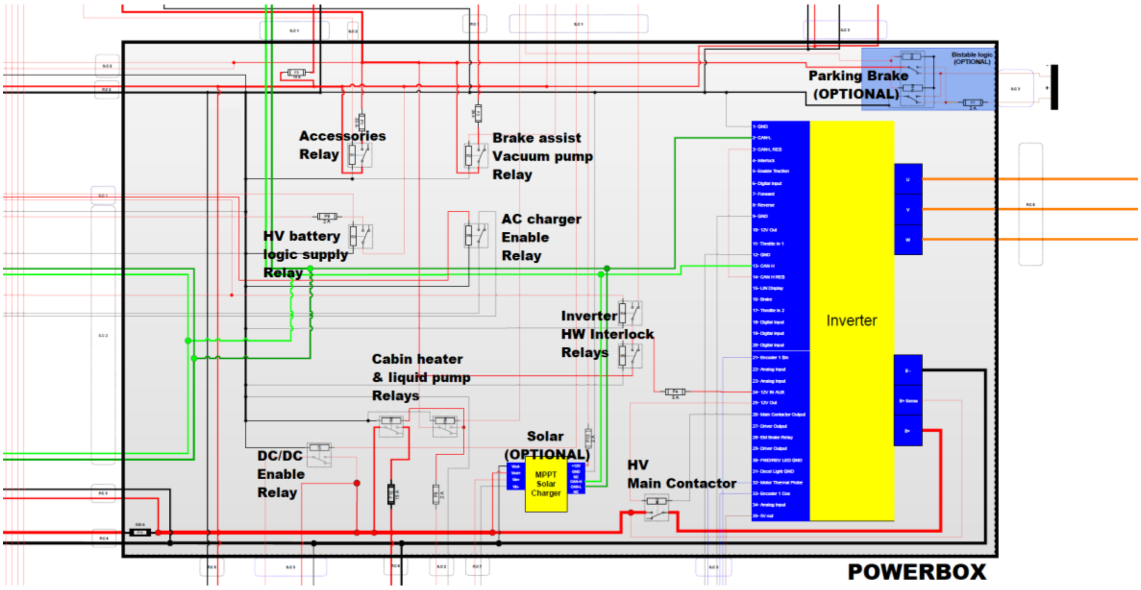


Figure 29 : Reduction in complexity in the PowerBox hardware of the new retrofit kit

One noticeable difference, with reference to the Panda G1 schematic, is the overall lower complexity and reduction in the number of wires inside the PowerBox, obtained by removing most of the relays of the old logic and substituting them with VMU software functions.

The number of connections inside the PowerBox has been reduced considerably, but the space occupied by all relays (mounted on suitable holders) and the time needed to connect and install them have been deemed as not acceptable. Therefore, a more compact solution has been developed in the form of a printed circuit board (PCB), used to mount all relays and fuses and to route all wires of the connections between all components in the form of copper tracks.

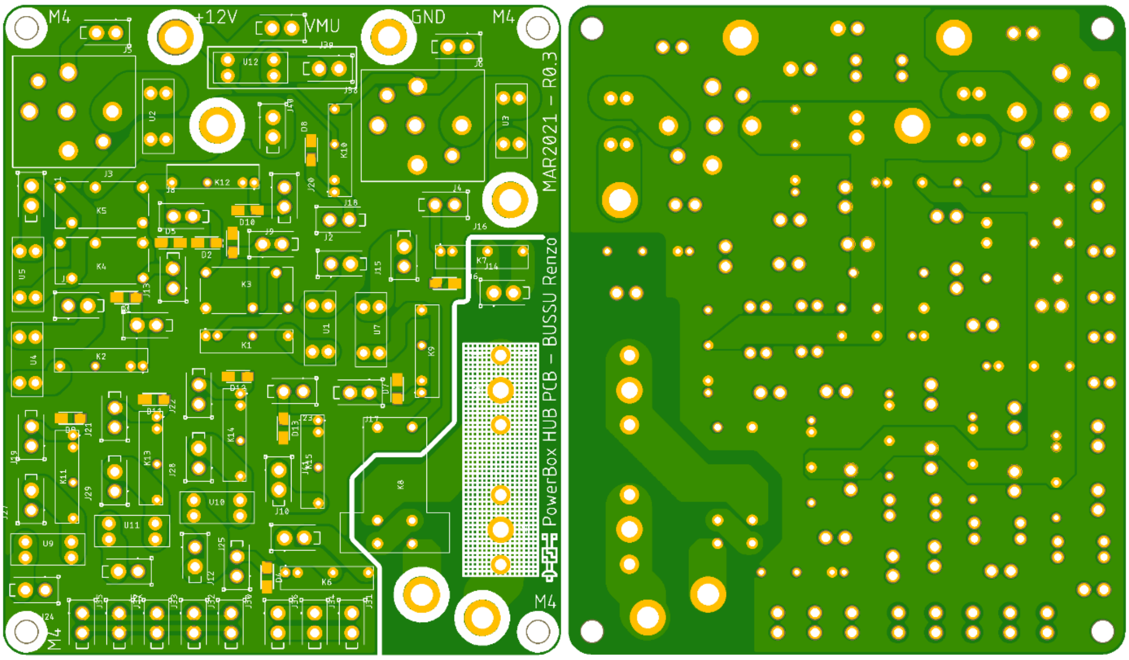


Figure 30 : New retrofit kit PCB

All flyback diodes have been placed on the PCB as small surface mount devices (SMD), and the connections between relays, diodes and fuses have been routed on the top and bottom faces, toghether with the tracks going to all connectors, to link the PCB with the other components through the PowerBox harness.

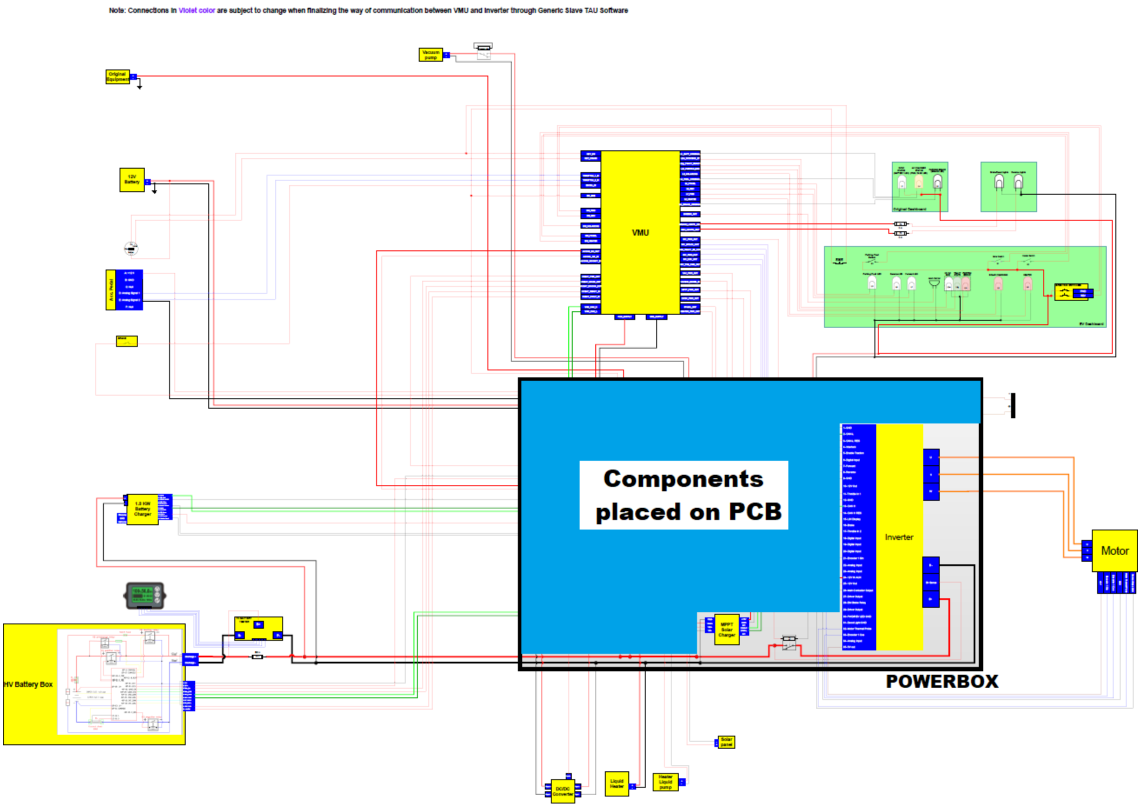


Figure 31 : Portion of components mounted on PCB

The addition of the PCB have allowed for the inclusion af almost all connections into a mass-produced, small and inexpensive subassembly, that can be manufactured, assembled and tested automatically without human intervention, thereby providing a great reduction in the overall material and assembly cost for the PowerBox subsystem.

The second addition that have been used to reduce cost and provide upgreadability features to the design has been the digital network that connects the main PowerBox components.

As protocol and speed are supported by all devices, a 250kbps bus based on CANopen specifications have been implemented: the network will allow the VMU to control the inverter by means of CAN messages instead of using different wires for critical signals, like traction enable, interlock (and analog voltage torque request), ensuring correct information transfer and allowing the inverter to provide periodic status feedback messages.

To verify proper communication between the VMU and the inverter, the network has been split into two branches at first, one section connecting the inverter to the VMU and another section connecting the AC charger to the traction battery.

After proper operation of the isolated sections has been assured, all CAN network branches have been reunited into one common network and tested again, proving to be reliable in all common automotive environments.

The complete network has been terminated at the farthest components from the PowerBox (the traction battery) and at the inverter, since these two components conveniently provide a switchable termination at their sockets.

Testing

The last step before the construction of a demonstrator, and one of the most delicate parts of the development process has been testing and validation of the system against requirements, with special attention placed to the challenging task of in-depth scrutiny of the VMU firmware and its behavior.

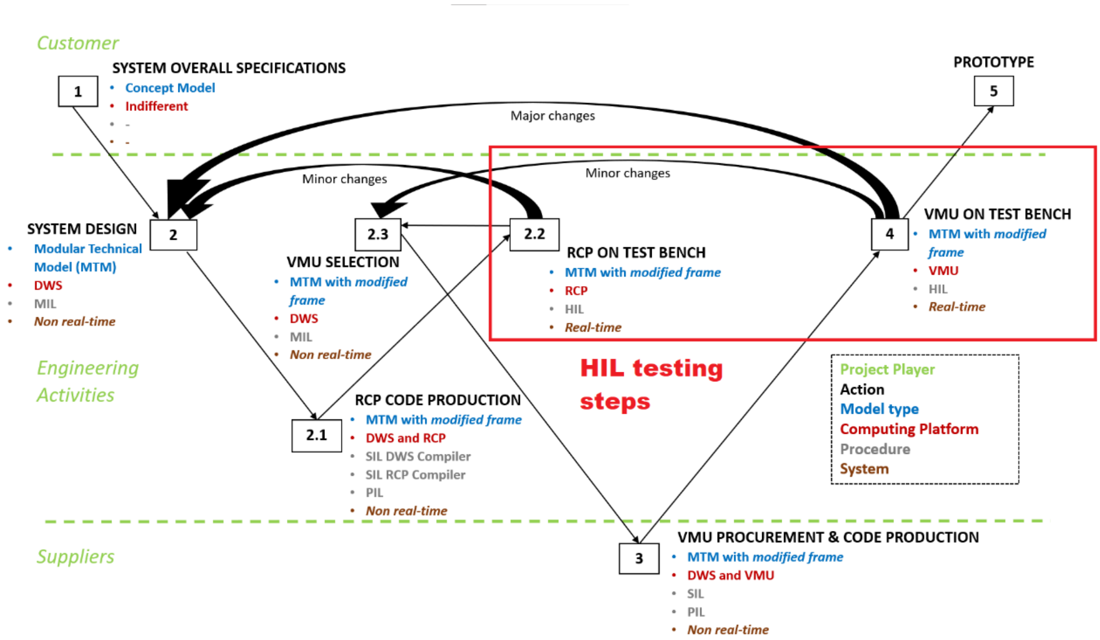


Figure 32 : Hybrid V-cycle HIL (Hardware in the Loop) steps

As specified in the hybrid V-cycle, two different steps has been exploited in the validation process, with different expected outcomes: in step 2.2, each task of the firmware VMU code has been tested using a RCP platform, while in step 4, the actual VMU has been installed.

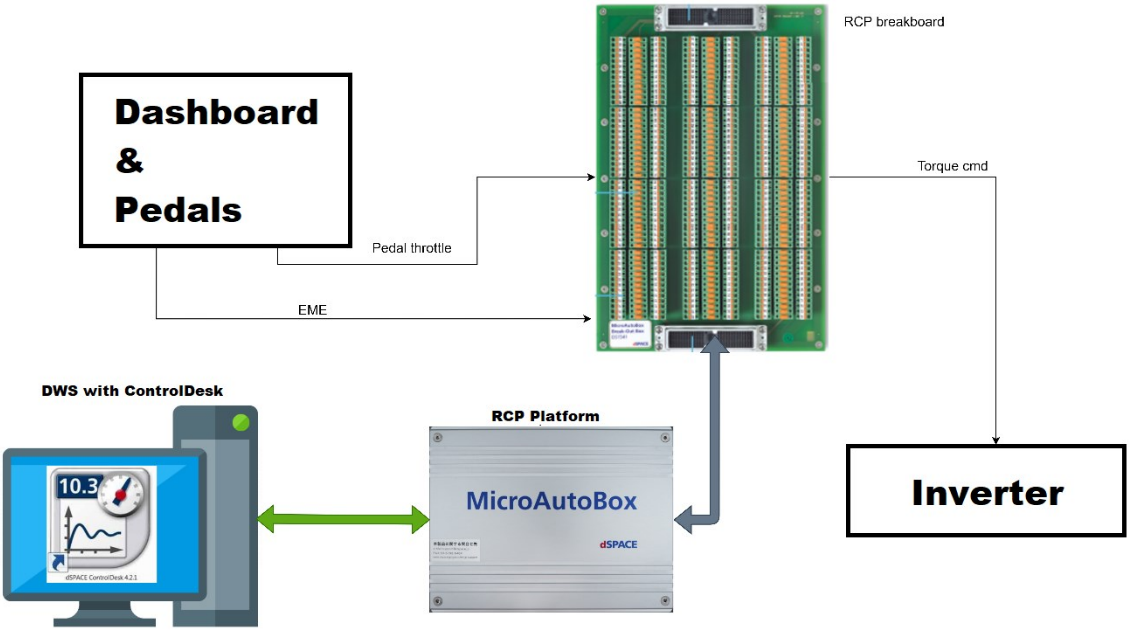


Figure 33 : RCP testbench setup

The RCP platform is a generic hardware control platform, capable of providing a great number of inputs and outputs and relatively high computational performance, and it is used to test the control part of a system while connected to actual hardware, because it can be programmed and monitored directly from a computer, allowing the validation of the control algorithm behavior early in the process, before procurement of the VMU.

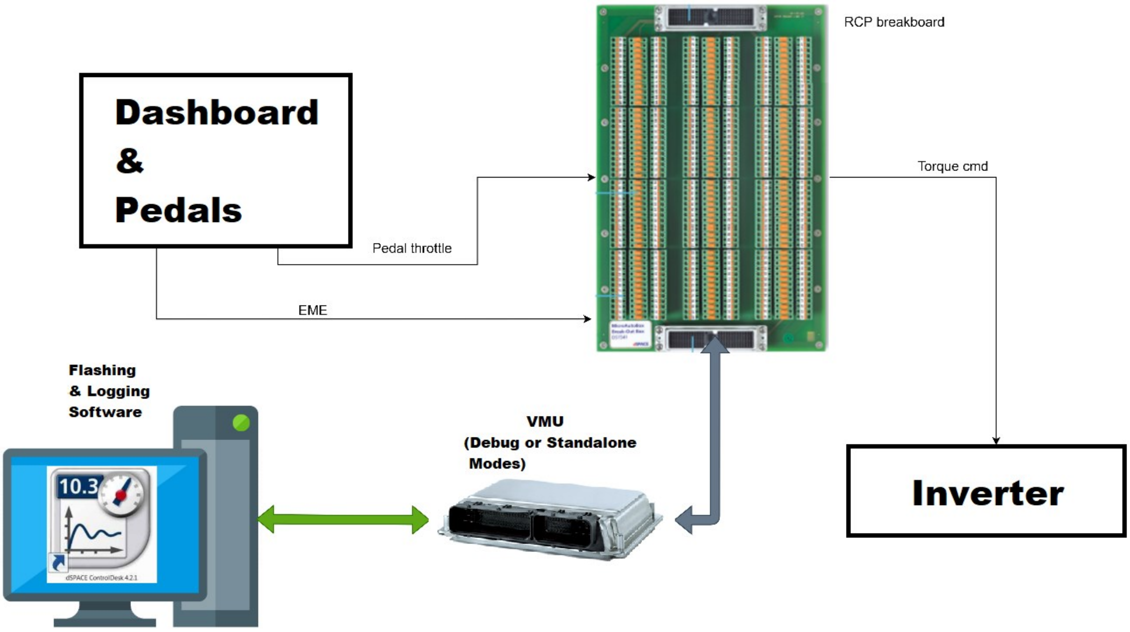


Figure 34 : VMU testbench setup

After the actual control unit has been procured, the code has been integrated within the VMU firmware and tested again, to verify that customization and parametrization of tasks code and variables (and, to some extent, code production from modeling tools) have not introduced any error or hidden bug in the firmware.

A VMU often features a lower number of inputs and outputs and lower computational performance, with reference to the RPC platform, because of tradeoffs with cost and complexity. Therefore ensuring reliable execution of the control algorithm can present some challenges when the code is ported to the final hardware subsystem.

Documentation

The management of the design, development and validation process presented some organizational challenges regarding information access and control. This problem has been solved by means of a somewhat simple but cleanly constructed collection of design documents, aimed at providing all information needed to the entities involved without cluttering the overall view on the project.

5.1. Flowcharts

The specifications supplied by project stakeholders have been collected and outlined in flowcharts, to establish a baseline from which the requirements have been derived. Flowcharts have been used for this purpose because they can be exported to different file formats that can be opened without the need for specific software, and are the easiest type of document to understand for stakeholders that are not particularly technically-inclined.

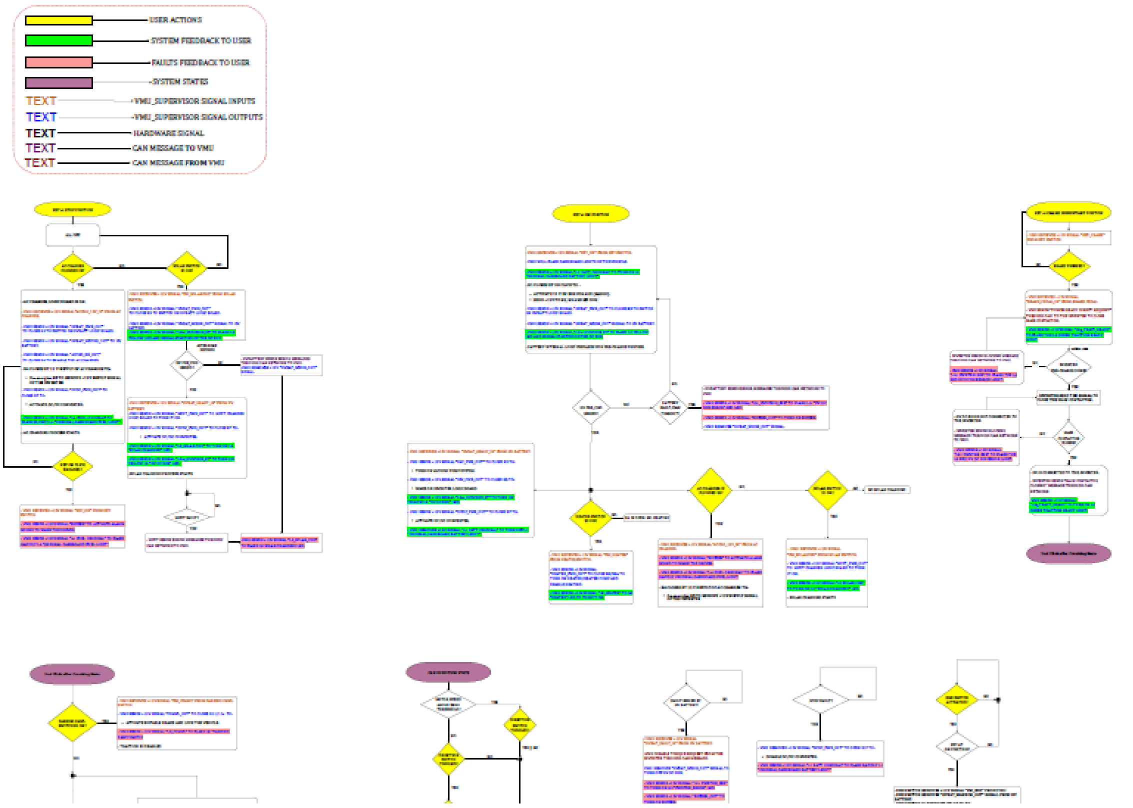


Figure 35 : Specifications flowcharts

The flowcharts have been used to detail the behavior the stakeholders expect from the completed system and to provide a reference point in time when specifications have been baselined (frozen) before requirements drafting.

5.2. MTM

The requirements related to the development of the control system have been utilized to model the control system algorithms inside a MTM (Modular Technical Model), in which the control logic was integrated with basic models of the other subsystems and the environment (Serrano Andres, 2020), to simulate and verify the behavior of the system against requirements (and in doing so, indirectly, against stakeholder specifications).

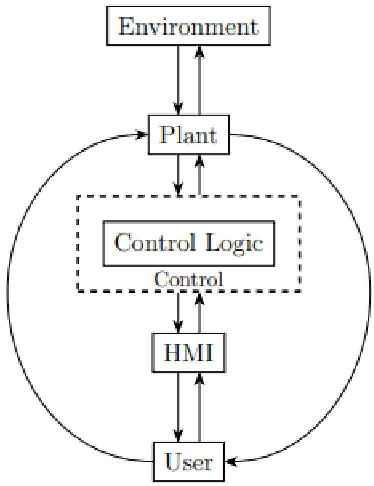


Figure 36 : MTM (Modular Technical Model)

The MTM has provided a common platform for all designers to subdivide development efforts on different part of the system and then collect the results inside a single structure.

5.3. Electrical Schematic

The requirements related to system architecture (specifically to the hardware design) have been applied to draft a hardware schematic, in which the VMU input and output interfaces have been connected with the other hardware components.

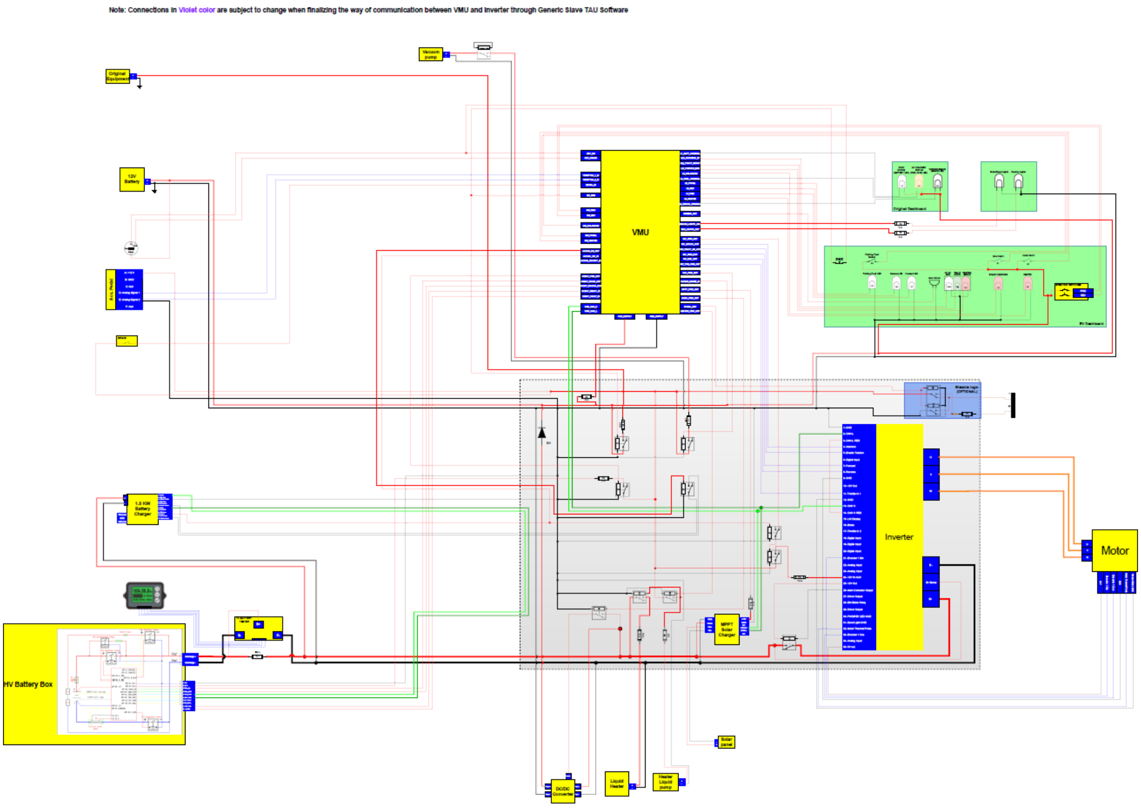


Figure 37 : Retrofit kit electrical schematic

The schematic has been arranged to reflect the physical placement of the different subsystems: this strategy has allowed designers to specify which hardware components have been placed inside the PowerBox and which have been connected directly to the harness.

5.4.Versioning and Reviews

Tracking of all changes and modifications to documents is vital to ensure that no detail is lost due to improper handling of files and folders. All files related to the project have been saved saved both in the cloud and locally on each developer's computer, using a version control tool.

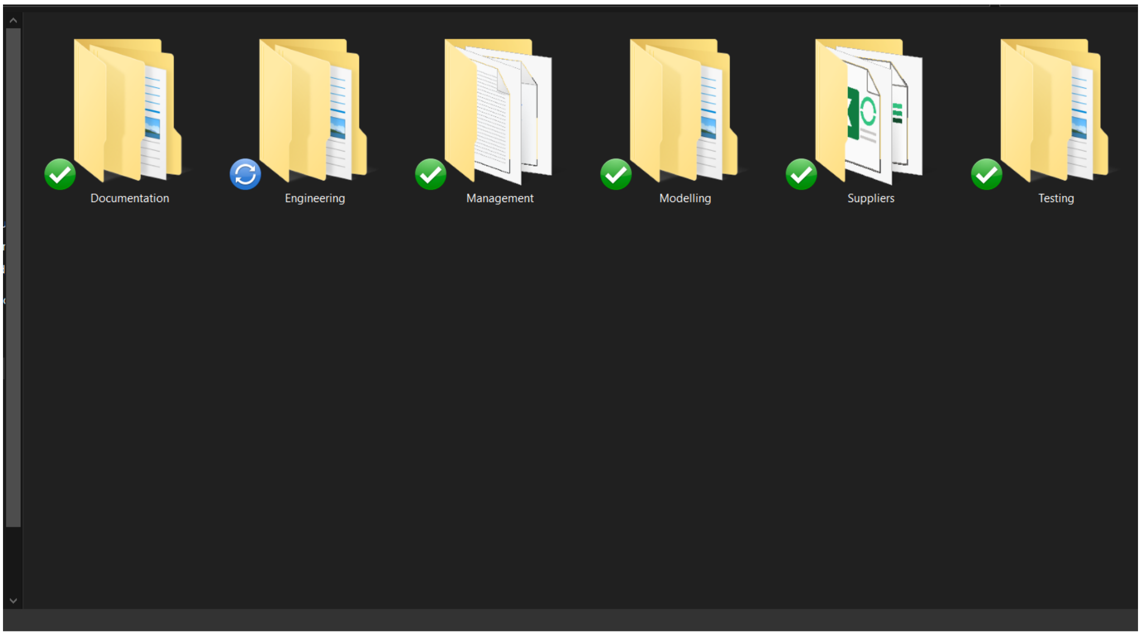


Figure 38 : Project folders with active syncronization using versioning and backup software

As an added safety measure and to provide folder usage metrics, a small script has been written to provide a list of all files and subfolders of the directory in which it is executed. By executing the script on the repository folder, the directory list will be saved on each computer as well.

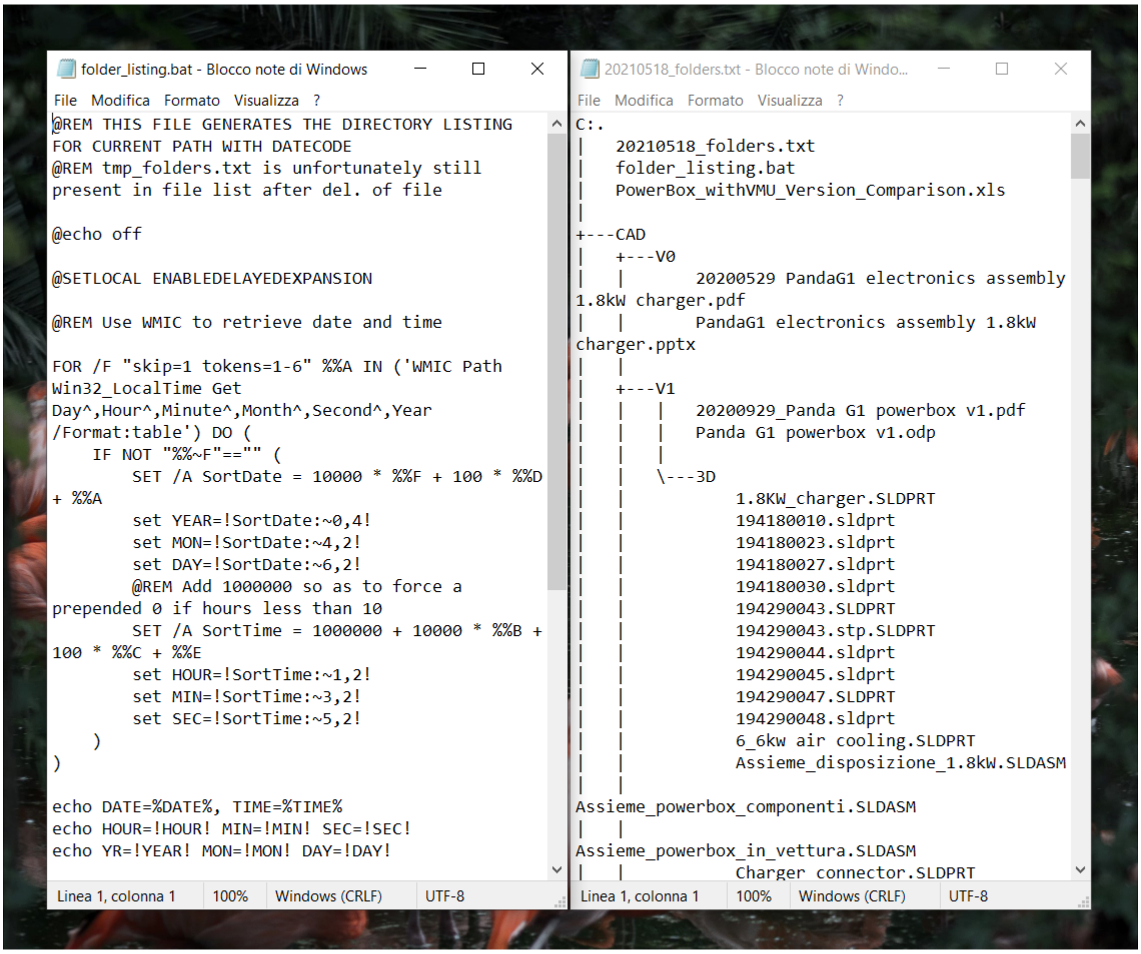


Figure 39 : Folder list script and resulting report file

5.5. Rollout Plan and Changelog

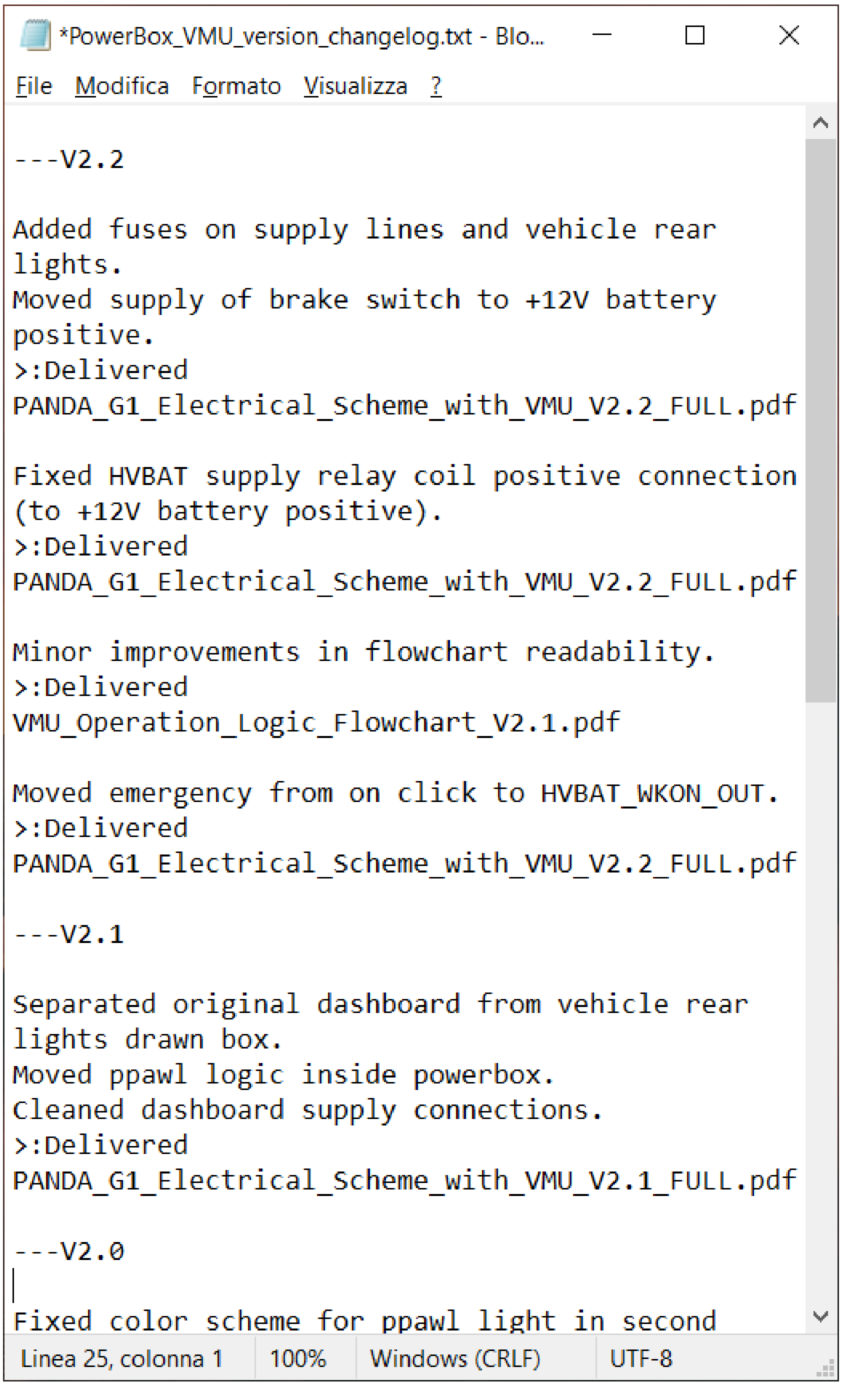
Since all features would not have been reasonably implemented in a short amount of time, the development has been completed incrementally by subdividing the features into work packages, to be completed before the release of subsequent versions. This behavior has been documented in the Rollout Plan, which contains a list of all features, their state related to project versions and any open issue that might prevent the team from implementing a particular portion of the design.

LABEL	>	TYPE	STATE
X	>	FEATURE	Implemented
X	>	FEATURE	Implemented, issue present on this subject
-	>	FEATURE	Not implemented
-	>	FEATURE	Not implemented, issue is preventing implementation
TBD	>	FEATURE	Will be implemented in a future version
	>	ISSUE	Issue present
	>	ISSUE	Issue solved

		Version		
		V2.0	V2.1	V2.2
NOTES				
	CAN1 – CAN2 interconnected	-	-	-
	CAN0 (ONLY ONE BUS)	TBD	TBD	TBD
	VMU supply always active	X	X	X
	Dashboard supply always active	X	X	X
	FUSES on main components	X	X	X
	FUSES on main outputs	-	-	X
	EME. SW VMU input	X	X	X
	EME. SW on main 12V relay coil (HW)	X	X	-
	EME. SW on HVBATT wakeon (HW)	-	-	X
ISSUES	HVBATT supply only when KEY ON active			
	Check CAN standards on all devices			
DEPENCENCIES	Operation Logic Flowchart VERSION	**2.0**	**2.0**	**2.1**

Figure 40 : Rollout plan

To record all changes pertaining to each released version, a Changelog has been kept updated by documenting modifications applied (in the form of a summary) and the work products delivered (e.g. flowcharts in pdf form), toghether with the related version number.




```
---V2.2

Added fuses on supply lines and vehicle rear
lights.
Moved supply of brake switch to +12V battery
positive.
>:Delivered
PANDA_G1_Electrical_Scheme_with_VMU_V2.2_FULL.pdf

Fixed HVBAT supply relay coil positive connection
(to +12V battery positive).
>:Delivered
PANDA_G1_Electrical_Scheme_with_VMU_V2.2_FULL.pdf

Minor improvements in flowchart readability.
>:Delivered
VMU_Operation_Logic_Flowchart_V2.1.pdf

Moved emergency from on click to HVBAT_WKON_OUT.
>:Delivered
PANDA_G1_Electrical_Scheme_with_VMU_V2.2_FULL.pdf

---V2.1

Separated original dashboard from vehicle rear
lights drawn box.
Moved ppawl logic inside powerbox.
Cleaned dashboard supply connections.
>:Delivered
PANDA_G1_Electrical_Scheme_with_VMU_V2.1_FULL.pdf

---V2.0

Fixed color scheme for ppawl light in second
```


Figure 41 : Version ChangeLog

Conclusion and Future Work

The main objective of the project described in this paper has been reached: the VMU has been integrated into the existing Panda G1 design, which has also been updated to cope with this addition and has been optimized (to some extent) in order to reduce production cost and time spent to implement future upgrades.

Since the framework used to manage the evolution of the project has been detailed, the features that still need to be implemented will benefit from a reduction in the development time needed to reach a new milestone due to this upgraded process. Although part of the control system algorithm has been implemented, other tasks still need to be reworked and exported as code from the modeling environment to be integrated into the external VMU firmware codebase.

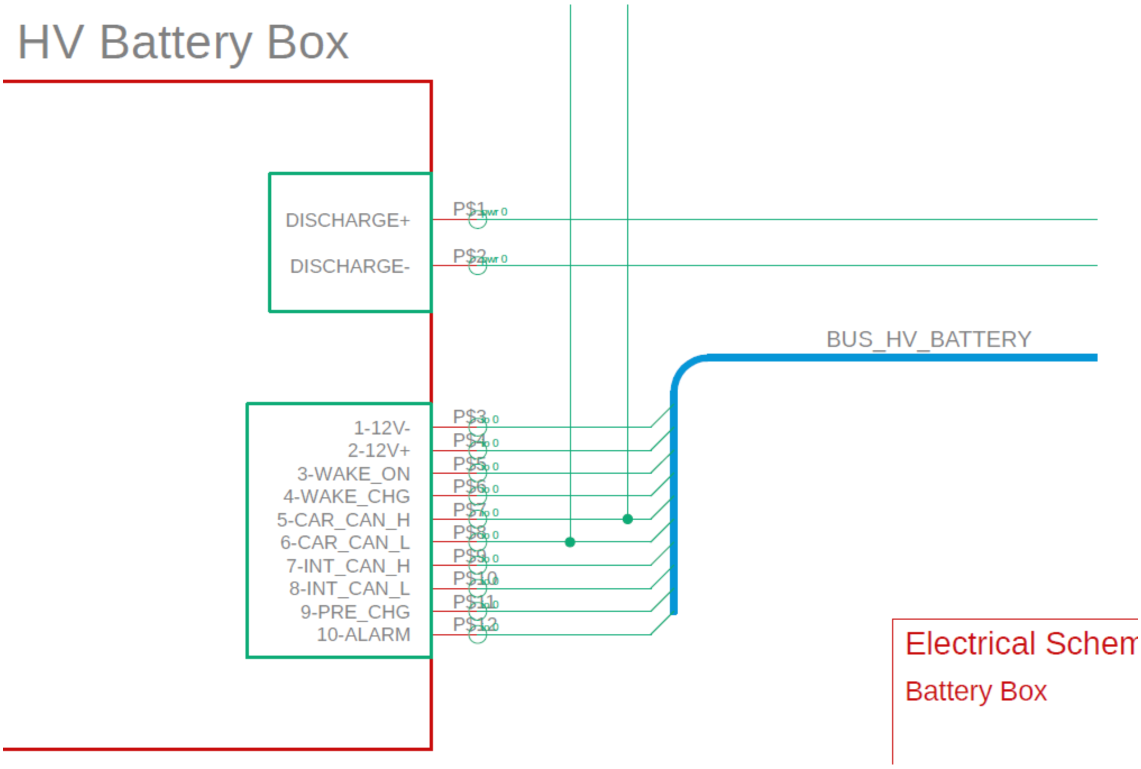


Figure 42 : Retrofit kit improved schematic (preview)

Finally, as this project might quickly become of great interest (following plans for the electrification of most privately-owned vehicles in the near future), a decision has been made to extend the scope of the project to vehicles newer that the Panda Prima Serie. The use of a newer vehicle as the platform for the retrofit kit described in this paper will pose new challenges, such as the integration of the kit into the existing vehicle CAN network and many more. To this extent, a new and improved electrical schematic is being drafted to include all new devices found in a modern vehicle, and to asses the feasibility of this new proposal.

Bibliography

Coletta, M. (2020). *Model-based Design of an Automotive Control Code with a modified V-cycle and Modular Model approach.*

Serrano Andres, J. D. (2020). *Project for the implementation and validation of the Vehicle Management Unit (VMU) code of a hybrid car following the V-Cycle development strategies described in ISO 26262.*