IEEE VTS Motor Vehicle Challenge 2026 – Design of Powertrain and Energy Management Strategy for a Refrigerated Lorry

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***Abstract*—The topic proposed for the IEEE VTS Motor Vehicle Challenge 2026 (MVC 2026) consists of two tasks. Firstly, the participants are required to design a powertrain for a dual-motor refrigerated lorry, which is able to transport 10 tons of frozen food. The lorry must be equipped with a refrigeration system that can maintain the temperature of the cargo at -18 °C. The second task consists of developing the lorry's energy management strategy. The motor and battery pack must be selected to maximize efficiency and reduce the time to complete the task. The battery pack can be charged in three different ways: wireless charging, plug-in charging, and regenerative braking. The MVC 2026 participants should also consider the impact of the lorry's weight as well as road slope, traffic, and wind on its performance and energy consumption.**

I. Introduction

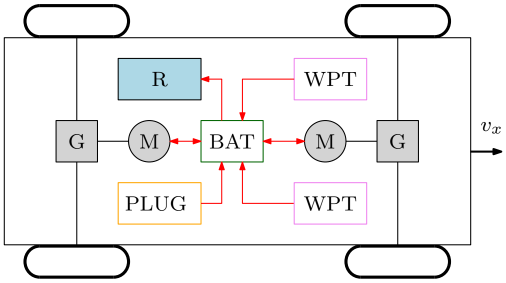
The electrification of heavy-duty vehicles is a key enabler for reducing greenhouse gas emissions and improving the sustainability of road freight transport [1]. Among these vehicles, refrigerated lorries play a crucial role in the cold chain logistics sector, ensuring the safe and efficient delivery of perishable goods. However, the integration of electric powertrains and advanced energy management strategies in such vehicles presents unique challenges due to their high payload, stringent temperature requirements, and variable operating conditions.

The IEEE VTS Motor Vehicle Challenge 2026 (MVC 2026) addresses these challenges by proposing a comprehensive design and optimization task. Participants are required to develop a powertrain for a refrigerated lorry capable of transporting 10 tons of frozen food while maintaining the cargo temperature at $-18\,^{\circ}$C. MVC2026 distinguishes itself from previous editions by its more transdisciplinary nature. It introduces new elements such as wireless power transfer and allows for strategy integration across multiple levels: motor control, energy management, battery selection, and charging strategy.

A central aspect of the challenge is the selection and sizing of the electric motor and battery pack. The chosen components must not only meet the performance requirements of the lorry but also maximize overall efficiency and minimize the time required to complete the delivery mission. The lorry is powered by means of two motors, one in the front axis and one in the rear axis. This is a useful electric vehicle powertrain topology that has given rise to various motion control and energy optimization problem [2], [3]. The battery pack can be recharged through multiple methods: wireless charging [4], plug-in charging [5], and regenerative braking. Each charging method introduces distinct constraints and opportunities for optimizing the vehicle's operational strategy. However, the regenerative braking is actually incentivised by the MVC 2026, and it is not weighted negatively in the scoring function.

In addition to the technical aspects of powertrain design, the MVC 2026 emphasizes the importance of energy management. An effective energy management strategy must consider the actual scenario where lorrys operate, including factors such as road slope, traffic conditions, and wind resistance, that is the weather. The interplay between these factors directly influences the vehicle's energy consumption, range, and operational cost [6].

In order to complete the mission profile, an emergency charging is provided, which allows the lorry to recharge its battery pack in case of emergency. The MVC 2026 tasks are designed to encourage participants to explore innovative solutions for the electrification of refrigerated lorries, with a focus on integrated design and control methodologies.



M: motor, G: gear, R: refrigerator, BAT: battery,
WPT: wireless power transfer

Fig. 1. System overview of the refrigerated lorry powertrain.

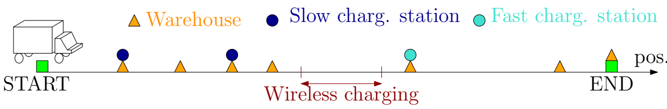


Fig. 2. Example of possible circuit for the refrigerated lorry mission profile.

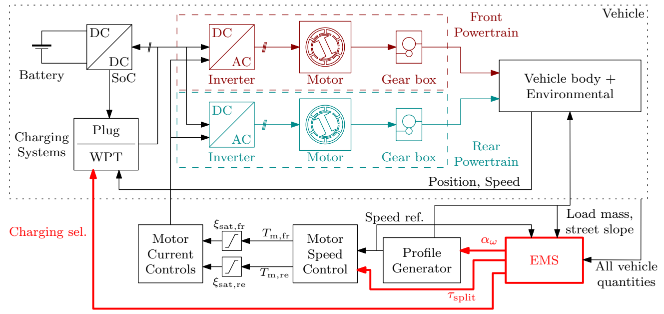


Fig. 3. Schematic of the simulation. Bold-red arrows represent the signals available to the participants for designing an energy management system.

II. System Overview

The powertrain of the refrigerated lorry consists of the following components:

- Front- and rear-axis motor
- Battery pack
- Refrigeration system
- Charging system

The front- and rear-axis motors are responsible for propelling the lorry, while the battery pack stores the energy required for the operation of the motors and the refrigeration system. The refrigeration system is responsible for maintaining the temperature of the cargo at $-18\,°\mathrm{C}$ during the mission profile. The charging system allows the battery pack to be recharged through different methods, such as wireless charging, plug-in charging, and regenerative braking. The system overview is illustrated in Fig.1. An example of mission profile is shown in Fig.2, where the speed, position, and state of charge (SoC) of the battery are plotted over time.

The simulation project available for the MVC 2026 is based on the MATLAB/Simulink environment, which allows participants to design and test their powertrain and energy management strategies. The simulation environment provides a realistic representation of the lorry's dynamics, including the effects of road slope, traffic conditions, and wind resistance. Several mission profiles are available for the participants to test their designs and strategies. The position of charging stations, warehouses, and other relevant elements of the mission profile changes for each mission profile, so the participants will have to adapt their strategies accordingly. The final evaluation will be based on new mission profiles that will not be available to the participants before the final evaluation. For the sake of time computation, the actual time is scaled down by a factor n_{scale}, so the simulation time is n_{scale} times shorter than the actual time. The value of n_{scale} is available for the participants and it will not be changed for the final evaluation.

The participants will have access to all the measurement regarding the simulation. The competition is divided in two parts: the first part is the design of the powertrain, where participants will have to select the motor and battery pack sizes, and the second part is the development of the energy management strategy, where participants will have to develop a control strategy that optimizes the energy consumption and performance of the lorry during the mission profile. The powertrain and battery pack design is discussed in Sect. III-A and III-B. To ease the comprehension, the complete schematic of the simulation is reported in Figure 3. For the sake of continuity, the simulation files are structured as in the 2025 MVC challenge, see [7].

III. Powertrain Design and Energy Management

A. Electric powertrain

The front- and rear-axis motors should be selected based on the required power and torque to propel the lorry under various operating conditions. The motor selection should consider the efficiency, weight, and cost of the motor. In particular, permanent magnet synchronous motors (PMSMs) are often preferred for their high efficiency and power density, making them suitable for heavy-duty applications like refrigerated lorries. Interior permanent magnet synchronous motors (IPMSMs) are particularly advantageous due to their high torque density and efficiency across a wide range of speeds [8], which is crucial for the variable load conditions of refrigerated lorries [9]. The availability of both electromagnetic and reluctance torque in IPMSMs allows for better performance under different operating conditions, enhancing the overall efficiency of the powertrain [10]. *Participants will have to develop an energy management strategy that selects the current references for the motors, which will be used to control the motors and achieve the desired torque and speed.*

The electric motors considered for this challenge are IPMSMs with parameters as reported in Table I. The rated power of the motors $P_{\text{m,r}}$ is a parameter that can be selected by the participants, but with a maximum limit of $250\,\mathrm{kW}$ for the front motor and $450\,\mathrm{kW}$ for the rear motor. The weight of the motor m_{m} is a function of the power size as:

$$m_{\text{m}} = k_{\text{m}} \cdot P_{\text{m}} \tag{1}$$

TABLE I
ELECTRIC MOTOR POWERTRAIN SPECIFICATIONS.

Parameter	Symbol	Front motor	Rear motor
Stator resistance	R_s	$0.5\,\mathrm{m\Omega}$	$0.5\,\mathrm{m\Omega}$
d-axis inductance	L_d	$0.1\,\mathrm{mH}$	$0.08\,\mathrm{mH}$
q-axis inductance	L_q	$0.35\,\mathrm{mH}$	$0.15\,\mathrm{mH}$
PM flux linkage	λ_m	$0.085\,\mathrm{Wb}$	$0.08\,\mathrm{Wb}$
Pole pairs	p	3	3
Rated speed	Ω_r	$10\,000\,\mathrm{rpm}$	$12\,000\,\mathrm{rpm}$
Max power	$P_\mathrm{m,r}$	$250\,\mathrm{kW}$	$450\,\mathrm{kW}$

where k_m is a constant, P_m is the power size of the motor in kW. The motors rated current is thus calculated as function of the selected power size by means of the following power equation [8]:

$$P_\mathrm{m,r} = \frac{3}{2} p \left[\left(\lambda_\mathrm{mg} + (L_d - L_q) \cos(\beta) \right) I_\mathrm{r} \sin(\beta) \right] \Omega_\mathrm{r} \quad (2)$$

where I_r is the rated current magnitude and β is the phase angle of the current vector in the dq reference frame at rated operations. The motor parameters are reported in Table I. *Participants can select the rated power of the rear motor differently from the front motor.*

An additional possibility for the participants is to decide which motor, i.e. front or rear, to use for the propulsion of the lorry. In turn, the total torque produced by the motors is the sum of the front and rear motor torques:

$$T_\mathrm{tot}(t) = T_\mathrm{m,front}(t) + T_\mathrm{m,rear}(t) \quad (3)$$

where $T_\mathrm{m,front}$ and $T_\mathrm{m,rear}$ are the front and rear motor torques, respectively. By using the variable $\tau_\mathrm{split} \in [0, 1]$, the torque split between the front and rear motors can be defined as:

$$T_\mathrm{m,front}(t) = \tau_\mathrm{split}(t) T_\mathrm{tot}(t), \quad T_\mathrm{m,rear}(t) = (1 - \tau_\mathrm{split}(t)) T_\mathrm{tot}(t) \quad (4)$$

Participants can select the torque split between the front and rear motors by means of the variable τ_{split}, and its value can change during the simulation.

B. Battery pack

The battery pack should be selected based on the required energy capacity and power output to meet the mission profile requirements. The battery pack choice should be carried out also considering the weight of the battery: the higher the energy capacity, the heavier the battery pack. The possible choices are usually among several sizes of lithium-ion batteries, which are commonly used in electric vehicles due to their high energy density and efficiency, [11]. The participants can select the battery pack size based on the required energy capacity and power output to meet the mission profile requirements. The weight of the battery pack m_batt is a function of the energy capacity as:

$$m_\mathrm{batt} = k_\mathrm{batt} \cdot E_\mathrm{batt} \quad (5)$$

where k_batt is a constant, and E_batt is the energy capacity of the battery pack in $\mathrm{kW\,h}$. *Participants will have to select the battery pack can be selected among four different sizes, that is* $\{50, 100, 150, 200\}$ $\mathrm{kW\,h}$.

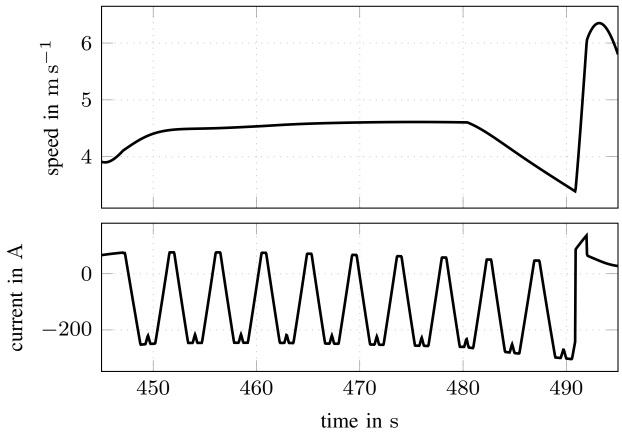


Fig. 4. Wireless charging current as a function of the lorry's speed and position.

C. Charging system

The charging system allows the battery pack to be recharged through different methods, such as wireless charging, plug-in charging, and regenerative braking. The wireless charging system is based on inductive power transfer technology, which allows the battery pack to be recharged without physical connections. The plug-in charging system allows the battery pack to be recharged through a standard AC or DC charging station. In particular, the plug-in charging system can be either a fast or a slow charging station, depending on the available infrastructure. One fast and two slow charging stations are available along the mission profile in an a priori known positions. The plug-in charging is available only when the vehicle is at zero speed.

The wireless charging allows both static and dynamic charging, where the lorry can be charged while moving or stationary. Of course, the amount of charging power available depends on the charging infrastructure and the lorry's speed. The wireless charging is not available along the entire mission profile, but only in the sections where the wireless charging stations are located. The wireless station position is known a priori before starting the mission profile. In particular, the wireless charging power P_W is a function of the lorry's speed and the position, [2], [3], see Fig.4. The wireless charging is available till a maximum speed $v_\mathrm{max,W}$ of the vehicle.

Participants can select the charging technology to be used by means of enable flags, which can be set to true or false. The flags are a necessary, but not sufficient, condition to enable the charging technology. All the conditions described in this section must be satisfied in order to enable the charging technology.

D. Mechanics of the lorry

The motors are connected to the wheels through a gearbox, which allows the motors to operate at their optimal speed and torque range. The gearbox ratios of the front and rear motors, and the tire radius are reported in Table II. The total weight of

TABLE II
LORRY SPECIFICATIONS.

Parameter	Symbol	Value
Maximum speed	V_{max}	$110\,\text{km}\,\text{h}^{-1}$
Maximum load	m_{load}	$10\,000\,\text{kg}$
Refrigeration power	P_{refrig}	$3\,\text{kW}$
Empty lorry weight	$m_{\text{lorry,empty}}$	$12\,000\,\text{kg}$
Tire radius	r_{tire}	$0.3\,\text{m}$
Gearbox ratio (front)	n	1:6
Gearbox ratio (rear)	n	1:8

the lorry m_{lorry} is a function of the weight of the components as:

$$m_{\text{TOT}} = m_{\text{m,front}} + m_{\text{m,rear}} + m_{\text{batt}} + m_{\text{load}} + m_{\text{lorry,empty}} \quad (6)$$

where $m_{\text{m,front}}$ and $m_{\text{m,rear}}$ are the weights of the front and rear motors, respectively, m_{batt} is the weight of the battery pack, m_{load} is the weight of the goods, and $m_{\text{lorry,empty}}$ is the weight of the empty lorry. The weight of the empty lorry $m_{\text{lorry,empty}}$ is reported in TableII it does not count for motors and battery pack weights.

The refrigeration system is responsible for maintaining the temperature of the cargo at $-18\,°\text{C}$ during the mission profile. For the sake of simplicity, the refrigeration system is assumed to be a constant power load, which consumes a certain amount of energy per hour. The power consumption of the refrigeration system is imposed at $3\,\text{kW}$.

E. Emergency charging

In case of emergency, the lorry can be recharged through an emergency charging station. The emergency charging station is assumed to provide a constant power of $50\,\text{kW}$. The emergency charging starts automatically when the battery state of charge (SoC) drops below a certain threshold, which is set to $5\,\%$, and it restore the SoC to a predetermined value of $50\,\%$. In order to recharge the battery pack, the lorry must be stationary, so the speed will be forced to zero during the emergency charging phase.

F. Mission profile

The circuit consists of a closed loop with several warehouses for loading and unloading of the goods, as well as charging stations. Along the circuit, the road slope, traffic conditions, and wind resistance vary, which affects the energy consumption and performance of the lorry.

The actual speed reference $\omega^*_{\text{m}}(t)$ of the lorry is calculated from the mission profile, that is $\vartheta^*_{\text{profile}}$, as follows

$$\omega^*_{\text{m}}(t) = \frac{d}{dt}\vartheta^*_{\text{profile}}(\tau) \quad \text{with} \quad \tau = \int_0^T \alpha_\omega dt \quad (7)$$

where $\alpha_\omega \in [0, 1]$ is a parameter that can be tuned by the participants. The position reference $\vartheta^*_{\text{profile}}$ is provided by the task. *Participants will have to design the value of the parameter α_ω to achieve the mission profile based on the energy management strategy.*

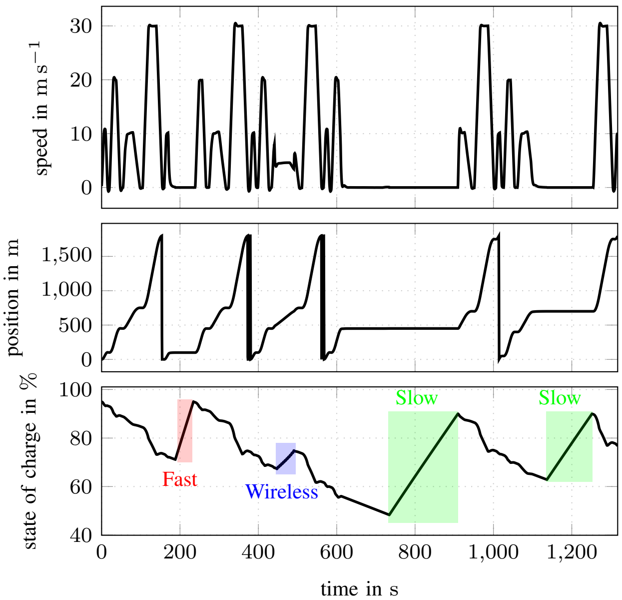


Fig. 5. Speed, position and SoC of the battery during the mission profile.

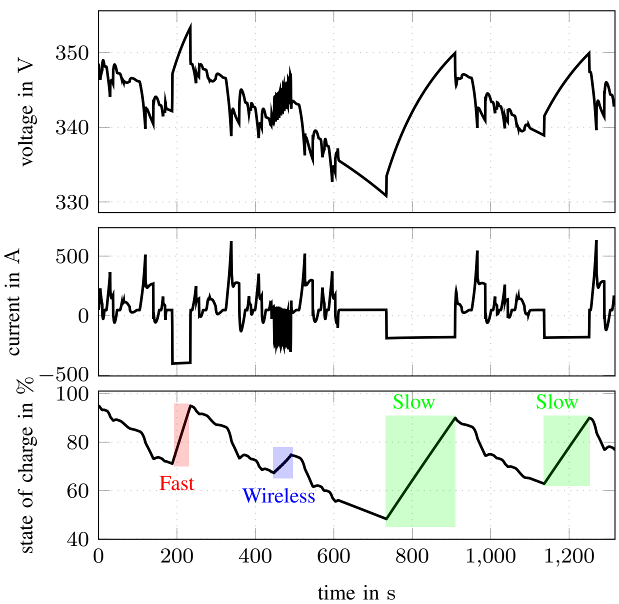


Fig. 6. Battery quantities during the mission profile.

IV. SIMULATION AND SCORING

The scoring function consists of the following terms:

- Energy consumption: the total energy consumed by the lorry during the mission profile.
- Time to complete the mission: the time taken to complete the mission profile.
- Powertrain sizing: the powertrain cannot be eavily under-sized for reducing weigth.
- Charging typology: plug-in charging can be fast or slow, and wireless charging can be static or dynamic.
- Battery current fluctuation: the battery current should be

kept as constant as possible to avoid high current peaks. Each term is weighted according to its importance in the overall performance of the lorry.

The scoring function is defined as follows:

$$\Phi_{\text{tot}} = w_1 \cdot \Phi_{\text{E}} + w_2 \cdot \Phi_{\text{cost}} + w_3 \cdot \Phi_{\text{tau}} + w_4 \cdot \Phi_{\text{time}} + w_5 \cdot \Phi_{\text{batt}} \quad (8)$$

where w_1, w_2, w_3, w_4, w_5 are the weights assigned to each term in the scoring function. In particular, w_3 and Φ_{cost} are vectors and they are discussed in Section IV-A.

A. Energy consumption

The energy consumption is calculated as the total energy consumed by the lorry during the mission profile. It includes the integral of the power given by the battery and the energy delivered by the charging systems. Thus, the term Φ_{E} in the scoring function is defined as:

$$\Phi_{\text{E}} = \int_0^T P_{\text{batt}}\, dt + \int_0^T P_{\text{charging}}\, dt \quad (9)$$

where P_{batt} is the power consumed by the battery during the mission profile, and T is the total time of the mission profile. The power delivered by the charging systems is the sum of the power delivered by the plug-in charging, wireless charging, and emergency charging systems:

$$P_{\text{charging}} = P_{\text{plug-in}} + P_{\text{wireless}} + P_{\text{emergency}} \quad (10)$$

Each term of (10) is calculated as the product of voltage and current of the respective charging system.

The charging typology chosen by the participants affects the final cost of (8), too. The energy cost will be calculated by considering the following ascending order of costs: slow plug-in charging, wireless charging, fast plug-in charging, emergency charging. Therefore, the term Φ_{cost} accounts for the amount of energy spent by each charging typology, and it is defined as:

$$\Phi_{\text{cost}} = [E_{\text{fast}},\ E_{\text{slow}},\ E_{\text{W}},\ E_{\text{emer}}]^\top \quad (11)$$

where E_{fast}, E_{slow}, E_{W}, and E_{emer} are the energy consumed by the fast plug-in charging, slow plug-in charging, wireless charging, and emergency charging, respectively. The weight w_3 is a vector of weights that assigns a cost to each charging typology, and it is defined as:

$$w_3 = [w_{\text{fast}},\ w_{\text{slow}},\ w_{\text{W}},\ w_{\text{emer}}] \quad (12)$$

B. Time to complete the mission

The time to complete the mission is calculated as the total time taken to complete the mission profile. The mission consists of several laps, thus the time to complete the mission is calculated as the sum of the time taken to complete each lap. The mission is completed when the lorry reaches the end position of Fig.2. Therefore, the term Φ_{time} in the scoring function is defined as:

$$\Phi_{\text{time}} = T \quad (13)$$

where T is the total time of the mission profile.

C. Powertrain sizing

The overloading of one or both motors is penalized in the scoring function. The time spent while requesting the maximum torque to one or both motors is thus penalized in the scoring function. In particular, the term Φ_{tau} in the scoring function is defined as:

$$\Phi_{\text{tau}} = \int_0^T (\xi_{\text{sat,front}} + \xi_{\text{sat,rear}}) dt \quad (14)$$

where $\xi_{\text{sat,front}}$ and $\xi_{\text{sat,rear}}$ are indicator functions defined as:

$$\xi_{\text{sat},x} \begin{cases} 1 & \text{if } |T_{\text{m},x}| = T_{\text{r},x} \\ 0 & \text{otherwise} \end{cases} \quad (15)$$

where x is front or rear, alternatively, and T_{r} is the rated torque of the motor.

D. Battery current fluctuation

The current fluctuation of the battery is calculated as the standard deviation of the battery current over the entire mission profile. The root-mean-square value of BP current time derivative has been thus selected as the most suitable index to this purpose, leading to:

$$\Phi_{\text{batt}}^2 = \frac{1}{T} \int_0^T \left(\frac{dI_{\text{batt}}}{dt} \right)^2 dt \quad (16)$$

V. Conclusion

In this paper, the design and optimization framework for the IEEE VTS Motor Vehicle Challenge 2026 has been presented, focusing on the electrification of refrigerated lorries. The challenge encompasses both the selection and sizing of key powertrain components—such as electric motors and battery packs—and the development of advanced energy management strategies. The simulation environment, based on MATLAB/Simulink, provides a realistic testbed for evaluating the impact of various operational factors, including road slope, traffic, and wind. The proposed scoring function balances energy efficiency, mission completion time, powertrain sizing, charging strategies, and battery current fluctuations. This comprehensive approach aims to foster innovative solutions for sustainable and efficient cold chain logistics, encouraging participants to address real-world constraints and optimize overall vehicle performance. All the materials for the participants can be found in the GitHub page (link) of the 2026 MVC competition.

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