ELSYS Note

Electric Machines in a Diesel-Electric Mining Haul Truck

A diesel-electric mining haul truck provides an illustrative example of different electrical-machine requirements within a single drivetrain. Estimated power ratings of an 850 kW generator and two 380 kW traction motors are used to examine their respective roles and operating characteristics. The example highlights the decoupling of engine and vehicle speed, the wide operating range of the traction motors, and the application of hairpin windings in high-power electrical machines.

Introduction

Mining haul trucks represent a demanding application for electric drive systems. High tractive effort is required at low vehicle speed, while long gradients impose substantial continuous power and thermal loads. A recently presented electric powertrain for a mining haul truck with a payload of 90 t provides an interesting example [1]. Based on the available information, the system is estimated to comprise an approximately 850 kW synchronous generator, two approximately 380 kW synchronous traction motors, five inverters, and separate cooling circuits for the electrical machines and power electronics.

Fig. 1 shows the principal components. Both the traction motors and the generator [2, 23:10] employ hairpin windings. Despite being part of the same drivetrain, however, the generator and traction motors have fundamentally different operating requirements.

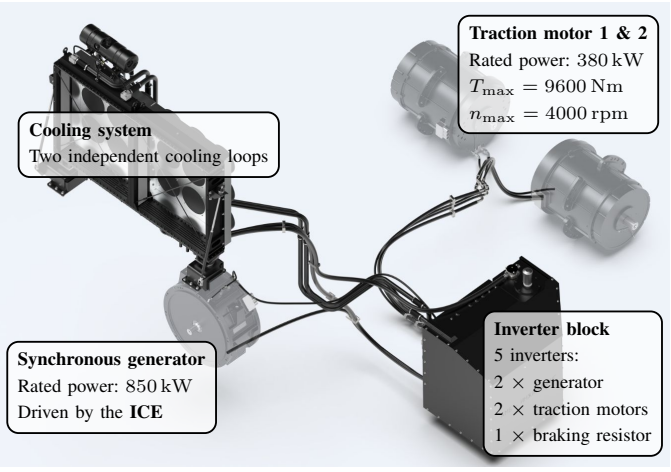


Figure 1. Overview of the electric powertrain for the 90 t mining haul truck based on the system information presented in [3].

Traction motor

Each traction motor is rated at 380 kW, with a reported maximum torque of 9.6 kNm and maximum speed of 4000 rpm [3]. These values already illustrate the demanding operating range of the traction machine.

The speed at which the maximum torque corresponds to the rated power follows from

$$n_{P,T} = \frac{60\,P_N}{2\pi\,T_{max}} \approx 378\,\text{rpm}. \tag{1}$$

Fig. 2 illustrates a possible torque–speed envelope by assuming maximum torque up to this point and constant power thereafter. The construction should not be interpreted as the actual motor characteristic: in particular, 378 rpm is not necessarily the field-weakening speed. For a permanent-magnet synchronous machine, field weakening starts when the available inverter voltage is reached and therefore depends on the machine parameters, current, and DC-link voltage.

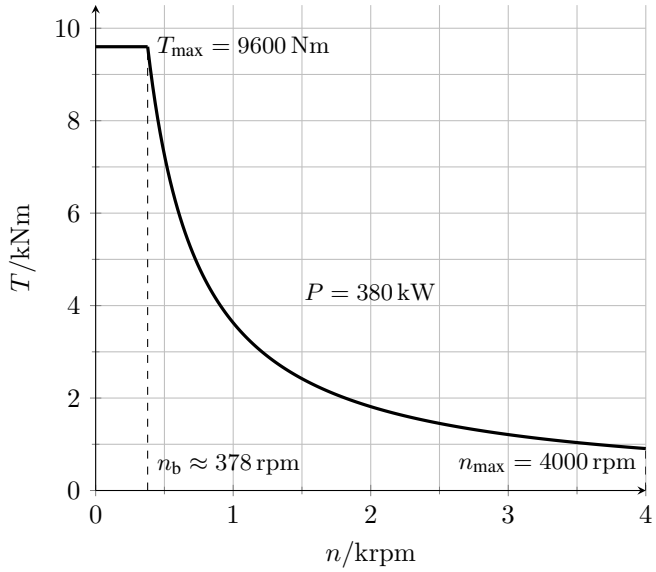


Figure 2. Estimated torque–speed envelope of the traction motor based on the published ratings of 380 kW, 9600 Nm maximum torque, and 4000 rpm maximum speed. Constant torque and constant power operation are assumed, with the transition between the assumed constant-torque and constant-power regions occurring at approximately 378 rpm.

The available video footage indicates a 16-pole V-shaped interior permanent-magnet rotor. If this interpretation is correct,

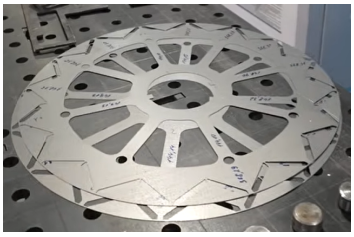
the electrical frequency at the reported maximum speed is

$$f_{\max} = 8\,\frac{4000}{60} \approx 533\,\mathrm{Hz}. \tag{2}$$

The traction machine must therefore combine high low-speed torque with operation at a comparatively high electrical frequency.



(a) Stator [2, 28:38]



(b) Rotor [2, 30:42]

Figure 3. Stator and rotor of the traction motor identified from the available video footage [2], [3].

Why a generator?

The role of the generator is easily overlooked when considering the traction motors alone. In a diesel-electric drivetrain, the internal combustion engine (ICE) does not mechanically drive the wheels. Instead, the principal power flow is shown in Fig. 4.

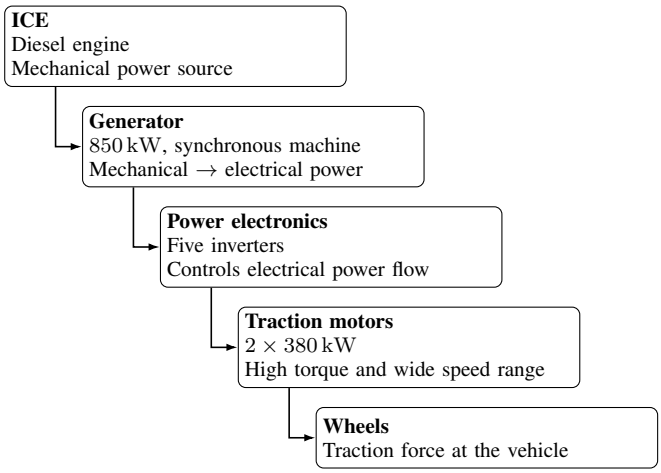


Figure 4. Power flow in a diesel-electric mining haul truck.

The important consequence is that vehicle speed and ICE speed are largely decoupled. The generator and traction motors must transmit approximately the same power, apart from losses and auxiliary loads, but they need not operate at the same speed or torque. A slowly moving truck can therefore develop high wheel torque while the ICE operates at a speed and load selected with regard to fuel consumption and efficiency.

A typical maximum ICE speed for this class of application is approximately $1900\,\mathrm{rpm}$. Assuming the generator is directly coupled to the ICE, the generator operates at the same mechanical speed. For an estimated generator power of $850\,\mathrm{kW}$, the corresponding torque at this speed is

$$T_{\mathrm{G}} = \frac{60\,P_{\mathrm{G}}}{2\pi\,n_{\mathrm{G}}} = \frac{60 \cdot 850\,\mathrm{kW}}{2\pi \cdot 1900\,\mathrm{rpm}} \approx 4.27\,\mathrm{kNm}. \tag{3}$$

Thus, although the generator has more than twice the rated power of one traction motor, its torque at this operating point is less than half the reported maximum traction-motor torque of $9.6\,\mathrm{kNm}$. This illustrates why power alone is insufficient for comparing electrical-machine size.

The difference between the estimated generator power of $850\,\mathrm{kW}$ and the combined traction-motor power of $760\,\mathrm{kW}$ can account for conversion losses and auxiliary electrical loads within the drivetrain.

Hairpin Windings

Hairpin windings provide a high copper fill factor and are well suited to automated manufacturing. Their discrete conductor arrangement, however, restricts the available number of turns and winding configurations.

The number of slots per pole and phase q of the machines considered here is not known. As a general example, [4] discusses a fractional-slot hairpin winding with

$$q = \frac{Q}{2p\,m} = 1.5, \tag{4}$$

illustrating a possible configuration for permanent-magnet synchronous machines. Hairpin technology therefore requires the electromagnetic winding layout and manufacturing process to be considered together.

Conclusion

The example illustrates two distinctly different electrical-machine tasks within the same drivetrain. The traction motor must provide high torque over a wide speed range, whereas the generator converts the mechanical power supplied by the ICE and operates within the speed range imposed by the combustion engine. The generator also decouples ICE speed from vehicle speed, allowing the engine operating point to be selected largely independently of wheel speed.

References

[1] L. I. Trukhnov and A. M. Naskovets, “New line of BELAZ-7558 mine dump trucks with electromechanic transmission of alternating current and carrying capacity of 90 t,” *Gornyi Zhurnal*, no. 5, pp. 91–93, 2014.

[2] AMB-Engineering. “Amb-engineering: Electric machines and production.” Video, Accessed: Sep. 18, 2026. [Online]. Available: https://www.youtube.com/watch?v=n1kO7_uN1hI

[3] AMB-Engineering. “Cooling and thermal management systems.” Product LFMYa.435000-40.13.000, Accessed: Sep. 18, 2026. [Online]. Available: https://amb-engineering.by/products

[4] M. Carbonieri, G. Venturini, and M. Popescu, “A practical approach to hairpin winding design: Patterns investigation, feasibility verification and fractional slot solutions,” *2022 IEEE Energy Conversion Congress and Exposition (ECCE)*, 2022, pp. 1–8. DOI: 10.1109/ECCE50734.2022.9947875