

King of the HIL

Hardware-in-the-loop test of electrified dump trucks for surface mines



The Chinese SANY group's SET230 dump truck can move up to 230 tons of payload. Its diesel-electric drive and a dSPACE HIL simulator provide maximum efficiency — the first in heavy-duty transport, the latter in developing and validating the complex drive control.



Have you ever seen a multi-story apartment building climb up a 20-percent grade? If not, you should definitely go see a large open-pit mine. In today's mines, the dump trucks often reach the size of a small housing block and easily have a total weight of several hundred tons. Despite their enormous mass, these giants always move safely and, in comparison to the past, very efficiently over rough and steep terrain. One of the contributing factors is the diesel-electric drive, which has become the market standard for dump trucks of this magnitude. The diesel engine drives a generator that uses an electronic inverter to supply the two three-phase motors on the rear axle with electric power to generate the propulsion energy. Without a rigid driveshaft from the diesel motor to the drive axle, this design makes it possible to work completely without a manual transmission, mechanical couplings, differentials and drive shafts, which considerably reduces the weight and maintenance costs of the vehicle. However, to guarantee high efficiency and safety during heavy-duty use in the mine, this drive concept requires highly complex control strategies for the electrical components.

Model-Based to New Dimensions

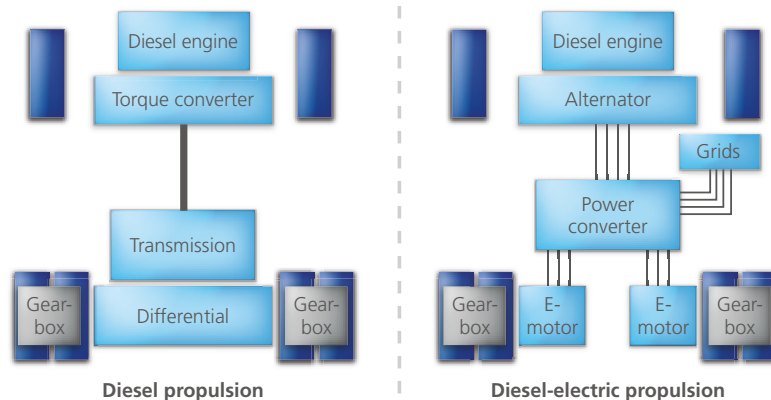
The engineers of the Chinese SANY group also had to face this challenge as they broke new ground while developing the SET230 dump truck (see the table for technical data), facing two issues at once. On the one hand, the truck's gigantic payload of 230 tons meant pressing forward into whole new dimensions for the company. On the other, the engineers only had rudimentary experience with diesel-electric drive technology. This is why SANY's goal was to use simulation to test and validate a large portion of the control development.

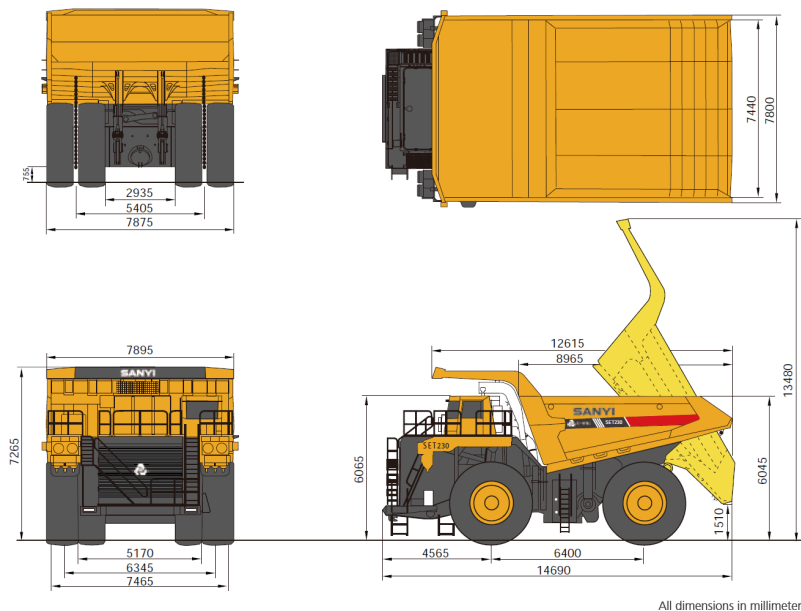
Turn-Key System for Virtual Vehicle Simulations

Instead of testing the real electrical components in a large laboratory, SANY decided to simulate the SET230's entire drive system with the help of a turn-key dSPACE Simulator Full-Size. This allowed the newly developed controls to be tested and validated together with an entire "virtual" vehicle immediately after implementation on the electronic control unit (ECU). Thus, the engineers were able to optimize their control strategies already on the test bench. Without having to compromise safety at all,

>>

Compared to conventional diesel-powered mining trucks (left figure), diesel-electric vehicles like the SET230 do not require a rigid driveshaft from the diesel engine to the drive axle (right figure). Thus, both vehicle weight and maintenance effort are reduced significantly.





All dimensions in millimeters

Maximum grade ability	24%
Continuous grade ability	12.5%
Maximum downhill ability	-14%
Continuous downhill ability	-13%
Maximum vehicle speed	64 km/h
Weight of the electric drive system	45 t
Maximum payload	230 t
Maximum allowed gross weight	400 t

Technical data of the SANY SET230: For a vehicle weighing up to 400 t, the diesel-electric dump truck delivers impressive driving performance, even in rough terrain.

this reduces the need for expensive track tests with a real truck prototype.

Powerful and Flexible Simulator

The HIL simulator at SANY uses a DS1006 Processor Board, which can calculate even the most complex simulation models in real time, thanks to the high performance of its quad-

core processor. The processor also provides the ability to distribute different calculation tasks onto its individual cores during the various function tests. For the signal processing and processor-based electric motor simulation at signal level, SANY relies on the dSPACE Electric Motor HIL (EMH) Solution, based on two DS5202

FPGA Base Boards. On the one hand, this solution measures the fast, electromotor-specific signals of the ECUs, such as the pulse-width-modulated control signals of the power electronics. On the other hand, it generates the rotary encoder signals for controlling the electric motors. dSPACE adjusted the signal conditioning exactly to SANY's specific requirements so that the sensors could be simulated at a current output with feedback signals of up to ± 600 mA. To test the CAN-bus communication with the other vehicle systems, SANY uses two DS2202 HIL I/O Boards that allow its engineers to conveniently perform restbus simulation with the RTI CAN MultiMessage Blockset.

Modeling to the Last Detail

Besides powerful and flexible hardware for the simulation, SANY also focused on creating the most exact model of its dump truck and replicating its unusually harsh work environment as closely as possible. Since offline simulation with MATLAB®/ Simulink® needed to be possible for both of these aspects, SANY decided to also implement an extensive range of dSPACE Automotive Simulation Models (ASM). These models either already seamlessly covered all of the dump truck's technological areas, or could be adapted to meet them without great time and effort. To simulate the diesel-electric system, one of the components used is the ASM Engine Basic model that already replicates all the necessary parameters for the diesel engine. For the various electrical components of the drive, in addition to a few customized models SANY mainly relied on the ASM Electric Components (ASM EC) Library, with some components individually adapted to match the special application. Among others, these components included the generator's separately excited synchronous motor (modified ASM EC), the inverter (ASM EC), the rectifiers, the intermediate circuit (ASM EC), the

“Because of our good experiences with the HIL simulator and the ASM tool suite, we are going to integrate more dSPACE tools into our tool chain.”

Lu Liling, Project Engineer, SANY Group

braking resistors, and the two asynchronous squirrel cage traction motors (ASM EC). The simulation models were parameterized almost completely with the ASM Vehicle Dynamics Library, which replicated all the longitudinal and transverse dynamic influence factors from the reduction gears, to the tires, steering system, brakes, and suspension. The only aspects that needed to be integrated additionally in the modeling and parameterization were the influences of the dump truck’s various payload states, from empty trips up to maximum utilization of the full 230-ton payload. The environment models already included in ASM Vehicle Dynamics also allowed an accurate replication of the challen-

ging terrain profiles that the dump truck travels through. This covered the widely diverse range of demands on the SET230’s drive system, from short upward drives, to steep inclines, to continuous operation on long declining slopes.

Intuitive Parameterization, Clear Visualization

To adjust the model parameterization intuitively and manage its extensive parameter sets, including the tailored components, SANY relies on the graphical user interface of dSPACE ModelDesk. A visualization software, dSPACE MotionDesk, also comes into play. MotionDesk illustrates all of the results, including the various simulated

maneuvers and scenarios, in a vivid 3-D online animation that makes the effects of parameter changes visible in real time. SANY’s engineers carry out the entire operation and record test data in dSPACE ControlDesk.

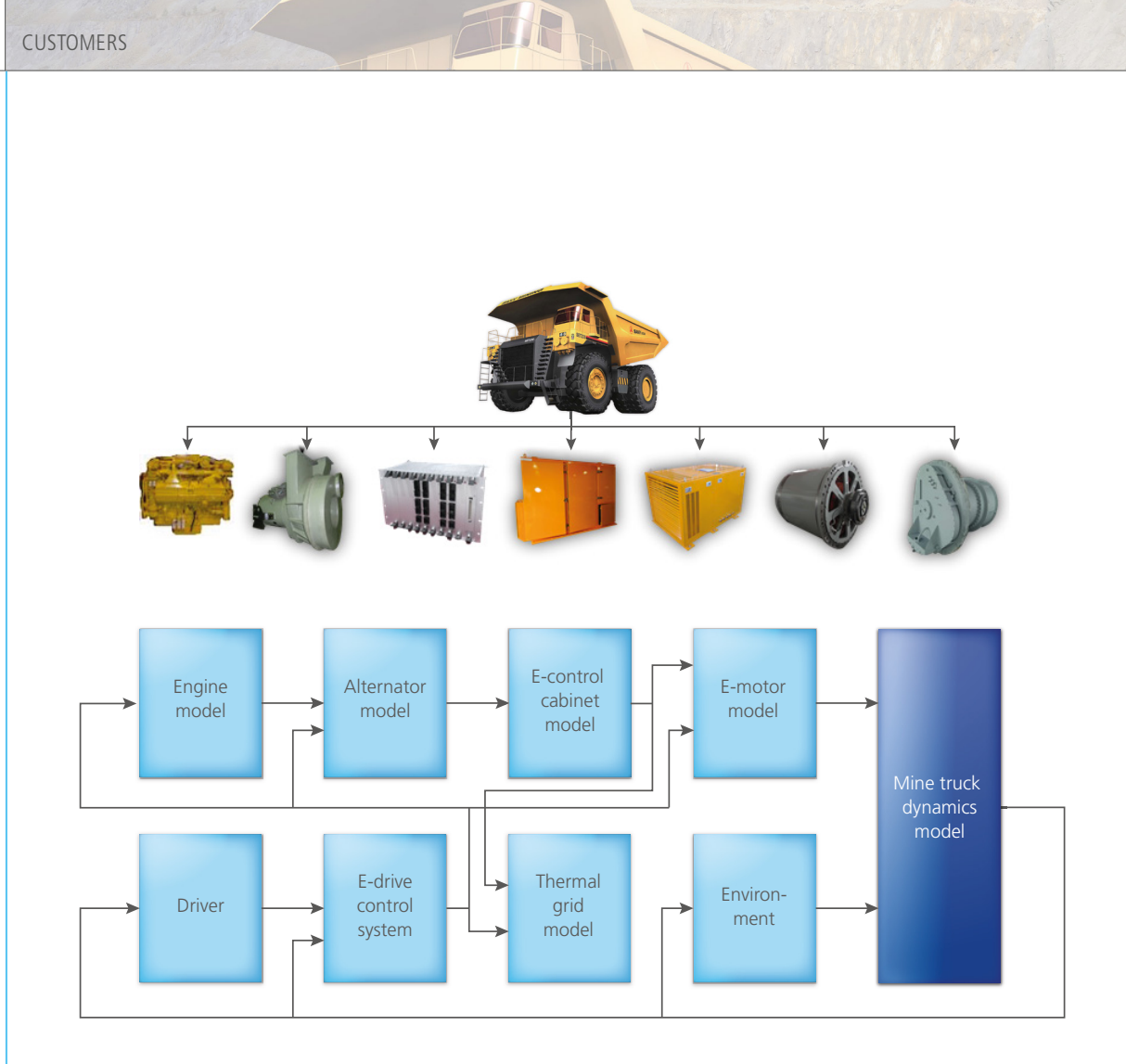
Quickly Ready for Operation

The HIL simulator for the SET230 was developed by the dSPACE Engineering team, along with all its hardware and software components. Together with SANY, they modified, implemented, programmed, and tested the simulator and delivered it turn-key for operation on-site in Shanghai. Only eight months passed between receiving the order and commissioning the system, so SANY was able to start

>>

Virtual vehicle: The turn-key dSPACE Simulator Full-Size replicates the SET230’s entire sensor system (on the right) and actuator components (on the left). This lets the engineers at SANY test the basic control strategies together with the other vehicle components at an early stage, without any expensive test drives with a real dump truck.





A wide range of model parameters: From the diesel motor to the components of the electric drive, the operator, and the environment, numerous factors flow into in the vehicle dynamics model of the dump truck.

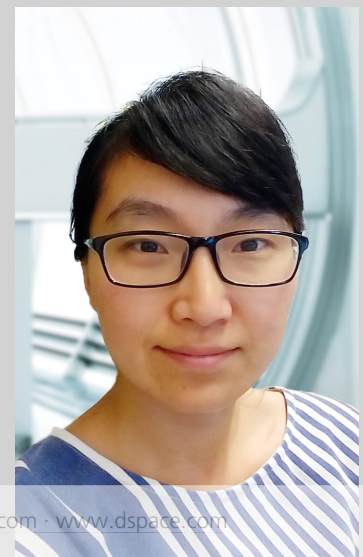
developing the e-motor control of the SRET230 within schedule. By using the model-based approach and dSPACE's efficient as well as versatile tools, the engineers succeeded in staying on schedule while implementing all the development steps, testing the fundamental control strategies, and validating them on-site in Shanghai. The result at the end of the process, was an e-motor control with the maximum possible efficiency and reliability. By using dSPACE tools, the development times in the laboratory and the calibration times in the vehicle were reduced considerably, which also cut costs significantly. In addition, SANY was able to enormously expand its range of experience in electrified powertrains. Their new experience was used to establish a new, highly

motivated team of developers. After the successful start with the HIL simulator and ASM models, SANY is planning to integrate more dSPACE tools in its tool chain, including products such as the test automation software AutomationDesk, the production code generator TargetLink®, and the data management tool SYNECT®. Now that SANY's SET230 has broken ground in the market segment of heavy, diesel-electrically driven dump trucks, they also plan to expand their position with even larger models in the future. Thus, it's a good possibility that the "moveable apartment buildings" are soon going to grow by another few floors. ■

Lu Liling, Qi Lie, SANY Group

Lu Liling

Lu Liling is an engineer in the development team of the SET230 mining truck at SANY Group in Shanghai, China.





Clear visuals: In dSPACE MotionDesk, SANY engineers can replicate the driving maneuvers and scenarios simulated on the HIL system in a clear 3-D online animation. This lets them visualize the effects of parameter changes in real time.

Qi Lie

Qi Lie is an engineer in the development team of the SET230 mining truck at SANY Group in Shanghai, China.



Developers with pride: The intuitive dSPACE tools not only helped SANY significantly simplify and speed up the development and testing of the dump truck. The tools also helped them gain a better overall understanding of the technology behind electrified powertrains. Their new experience will be used to establish a highly qualified team of developers.