

Balance of Power

To balance performance and cost, Hyundai Heavy Industries Co. Bulgaria uses ANSYS multiphysics solutions to design power transformers and associated equipment.

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Designing power transformers and associated equipment is complicated by a range of conflicting requirements that reach across physics and engineering disciplines. Heat generated by current flow may produce elevated temperatures that have a negative impact on the performance of tap changer contacts. A further concern is reducing stray eddy current losses in clamping plates, tie plates and other power transformer components that can generate losses and excessive loading on the structural components. Engineers also must address the potential for short circuit in a power transformer to produce electromagnetic forces that may generate excessive loading on winding conductors.

A tap changer is a connection point selection mechanism along a power

transformer winding that allows a variable number of turns to be selected in discrete steps. By varying the turn ratio of the transformer, its output voltage can be controlled. Hyundai Heavy Industries Co. Bulgaria (Hyundai) builds tap changers for its own and others' transformers. The company manufactures oil-immersed power transformers and tap changers for power substations, thermal power plants, hydro-electric power plants and industrial enterprises throughout the world. Its products have been validated consistently in tests by independent laboratories. Hyundai's compact design and dependable technical parameters reduce transformer weight and cost. The company is among the world's leading producers of tap changers, with more than 50,000 units produced so far.

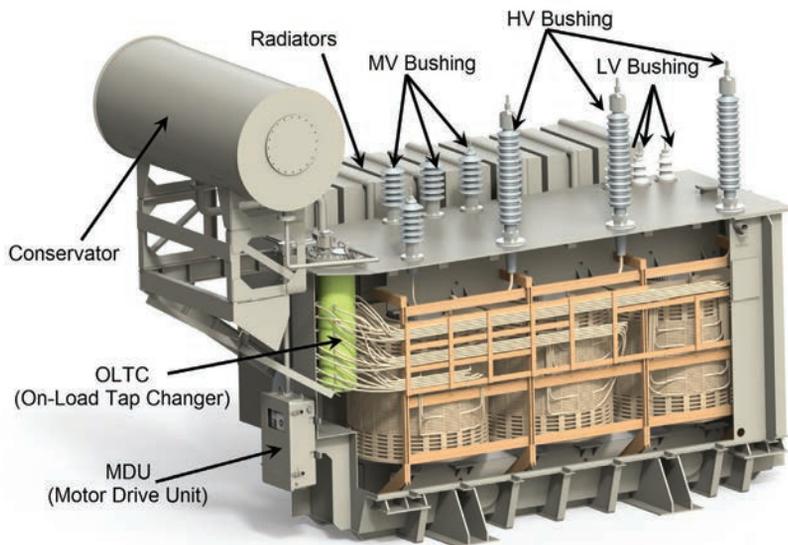


▲ Transient analysis showing equivalent stress on main shaft of tap changer

Parameterization is performed within ANSYS Workbench, which provides a single environment for design optimization across physics.

DESIGN METHODS

In the past, Hyundai engineers used a combination of stand-alone analysis tools and physical testing to design transformers and tap changers. Engineers applied simulation tools to analyze various aspects of the equipment's electrical, thermal and structural design. However, they performed each type of analysis separately without considering interrelated effects. For example, the electromagnetic simulation was not tied to the thermal and structural analysis; it was not possible, for example, to determine thermal



▲ Three winding power transformer

Hyundai reduced engineering costs by up to 5 percent. It expects to achieve up to 15 percent cost reduction in the future through multiphysics simulation.

stresses caused by eddy currents. The time required to perform tests in multiple simulation environments meant that only very limited amounts of simulation could be performed. This made it difficult to optimize first-pass design performance; it also meant that expensive modifications often had to be made during the trialing process.

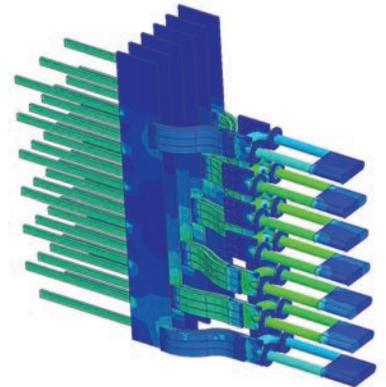
MULTIPHYSICS SIMULATION

Hyundai engineers made the decision to utilize ANSYS simulation software because it provides industry-standard multiphysics capabilities combined with data and process management, reduced-order modeling and cosimulation via a single technology platform. ANSYS Workbench provides a collaborative environment for engineering teams to work together in developing multiphysics solutions. By coupling ANSYS simulations based on electromagnetic, thermal and structural models, Hyundai engineers can evaluate design alternatives within multiple domains, conduct what-if studies, and optimize final designs in a rapid, cost-effective manner.

Optimizing the contact system of tap changers is one of several critical areas for which Hyundai engineers utilize multiphysics analysis. The contacts operate at elevated temperatures due to the large values of electrical current passing through them. The team runs electrical analysis with ANSYS Maxwell low-frequency electromagnetic software

to simulate the flow of current through the tap changers and determine losses in the contacts. An engineer enters material properties for tap changer components and then specifies excitations and boundary conditions based on a voltage distribution designed to stress the components. These losses provide loads for steady-state thermal analysis with ANSYS software to determine the temperature distribution throughout the contacts. Engineers check to make sure the temperatures do not exceed the limits specified in the IEC 60214 tap changer standard. On some tap changer components, the Hyundai Heavy Industries team uses ANSYS Maxwell and the transient thermal capabilities in ANSYS Mechanical to determine temperature distribution, then couple the results within ANSYS Mechanical's static-structural simulation solver to calculate the stresses and deformations due to thermal expansion. All of this is performed within the ANSYS Workbench environment, so data can be easily transferred.

Engineers use multiphysics analysis on the clamping plates and tie plates used in the active parts of power transformers. They apply current in the windings, and Maxwell predicts the eddy current losses in the plates and metal structure of the transformer. These losses provide loads for transient thermal analysis in ANSYS Mechanical to determine the temperature distribution throughout the plates

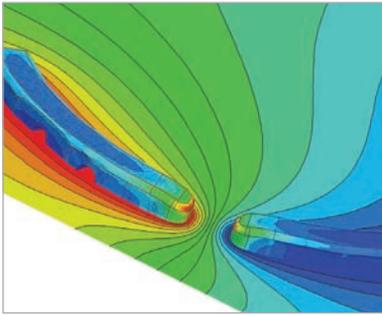


▲ Current density in bus bars, flexible connections and bushings of transformer

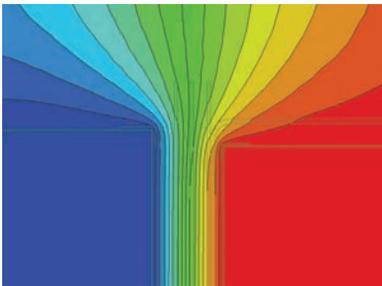


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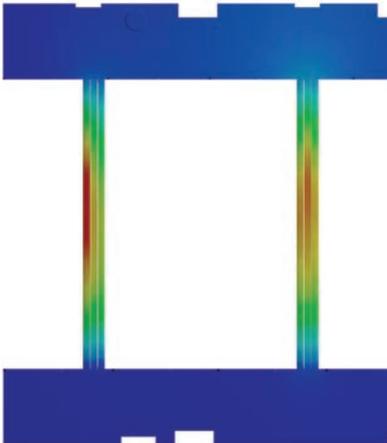
and metal structure. Engineers go one step further in analyzing the bus bars in the power transformer: They use Maxwell to determine eddy current losses in the bus bars and ANSYS Mechanical to perform transient thermal analysis to predict temperature distribution. This temperature distribution data is used as input to a static structural simulation to predict stresses and deformations due to thermal expansion caused by electromagnetic forces.



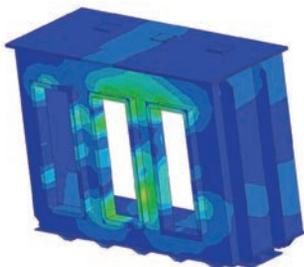
▲ Electrical field stress and voltage distribution between two contacts of tap changer



▲ Voltage distribution inside the insulation system of a power transformer



▲ Temperatures of the tie-plate, a power transformer component



▲ Distribution of flux density in tank, caused by high current in low-voltage side of furnace transformer

For each new power transformer design, engineers must verify that torsional forces produced in the event of a short circuit in the helical windings do not produce a catastrophic failure of the support structure. Hyundai engineers use ANSYS Maxwell 3-D electromagnetic analysis to predict the torsional electromagnetic forces based on the leakage magnetic field distribution. These electromagnetic forces are coupled to an ANSYS static structural simulation to determine the mechanical stress components and circumferential displacements of the conductors.

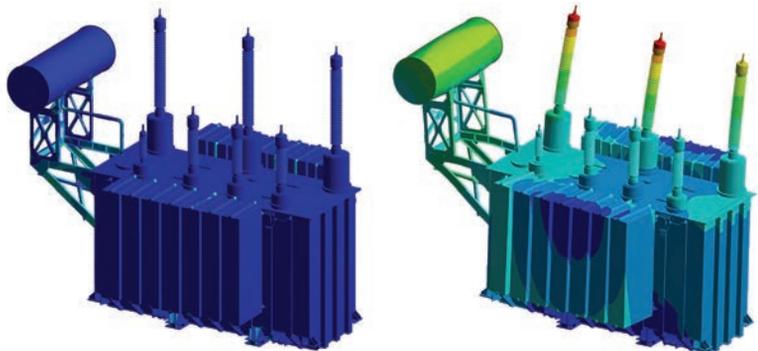
In addition, because Hyundai Heavy Industries Co. Bulgaria has clients all over the world in many seismic zones, the company's engineers perform static, modal and response spectrum simulation to verify that the transformer is able to withstand earthquakes.

Tap changers contain complex mechanisms with shafts, bearings, gears, hinges, springs and contact systems. Smooth and proper operation of the tap changer is vital to maintaining performance of the entire transformer. A problem with tap changer operation could potentially damage or even destroy the entire transformer. Hyundai engineers use ANSYS Mechanical to perform rigid/flexible transient simulation of the mechanism. The team can then determine tap changer performance and generate velocity, acceleration, deformation, and stress and strain data to verify smooth contact switching of the diverter switch. Loads on components are often used as input for fatigue analysis to predict operating life.

In most of these simulations, the team evaluates a number of iterations by trying different values for design parameters, such as winding clearances, insulation thickness and type of material. Engineers optimize the design to minimize material use and component size while maintaining required safety factors. They maximize the efficiency of a power transformer by removing material when possible in areas where eddy current losses are high. In some cases, power losses are reduced by using magnetic shunts to protect exposed metal parts from stray fields. Parameterization is performed within ANSYS Workbench, providing a single environment for design optimization across physics.

SAVING ENGINEERING COSTS

With electrical power demand growing rapidly, power transformer and tap changer performance must be continually improved. Hyundai Heavy Industries uses coupled ANSYS multiphysics systems in Workbench to evaluate 3-D conceptual designs. Simulation reduces the time and number of prototypes required to develop higher-performing products, reduce time to market, and minimize production costs. Hyundai estimates that engineering costs have been reduced by 3 percent to 5 percent; it expects to achieve a 10 percent to 15 percent cost reduction in the future through multiphysics simulation. ▲



▲ The company conducts seismic analysis of power transformers to ensure that equipment functions reliably in earthquake-prone areas. Equivalent stress in horizontal direction: response spectrum analysis (left) and modal analysis (right)