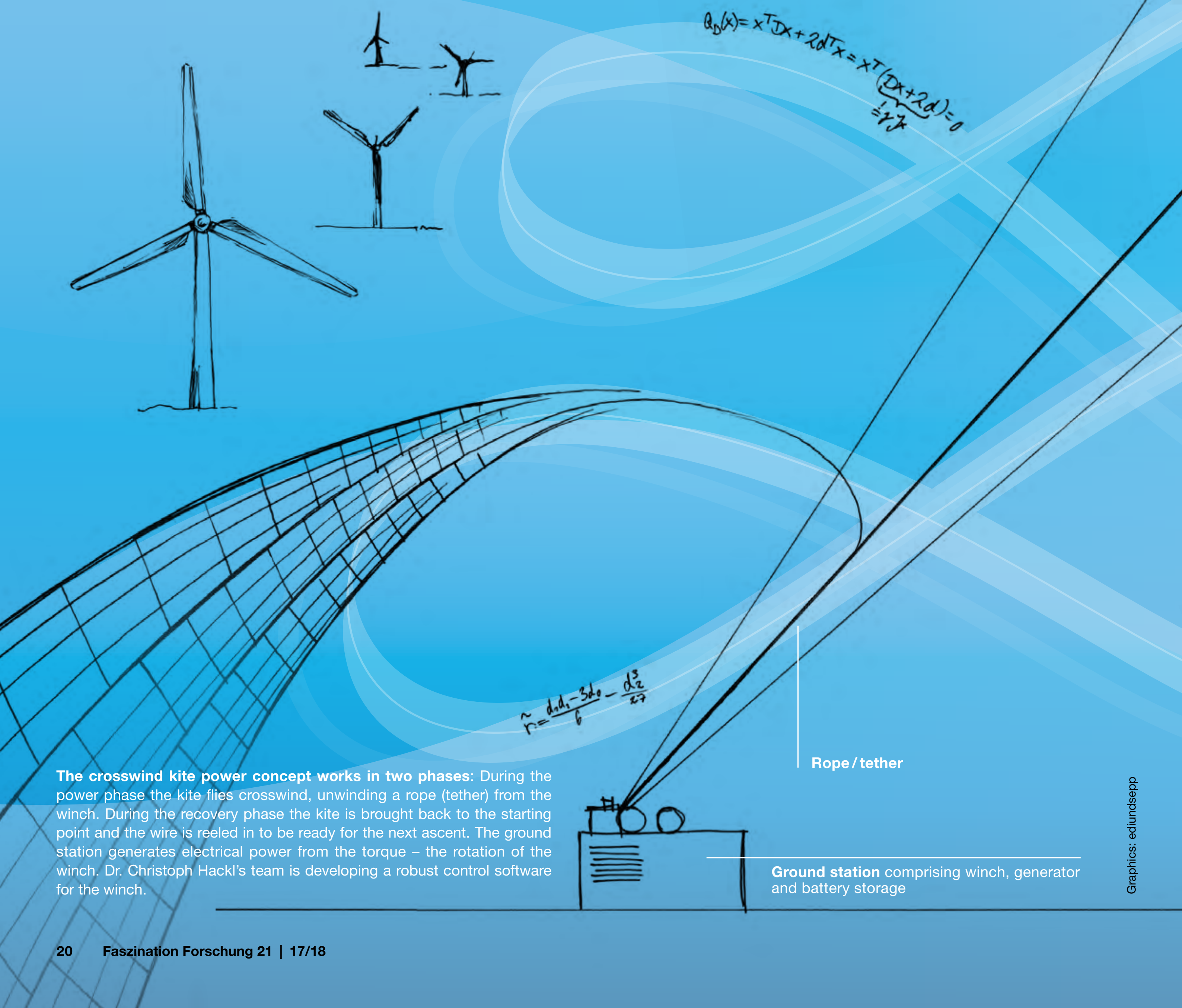
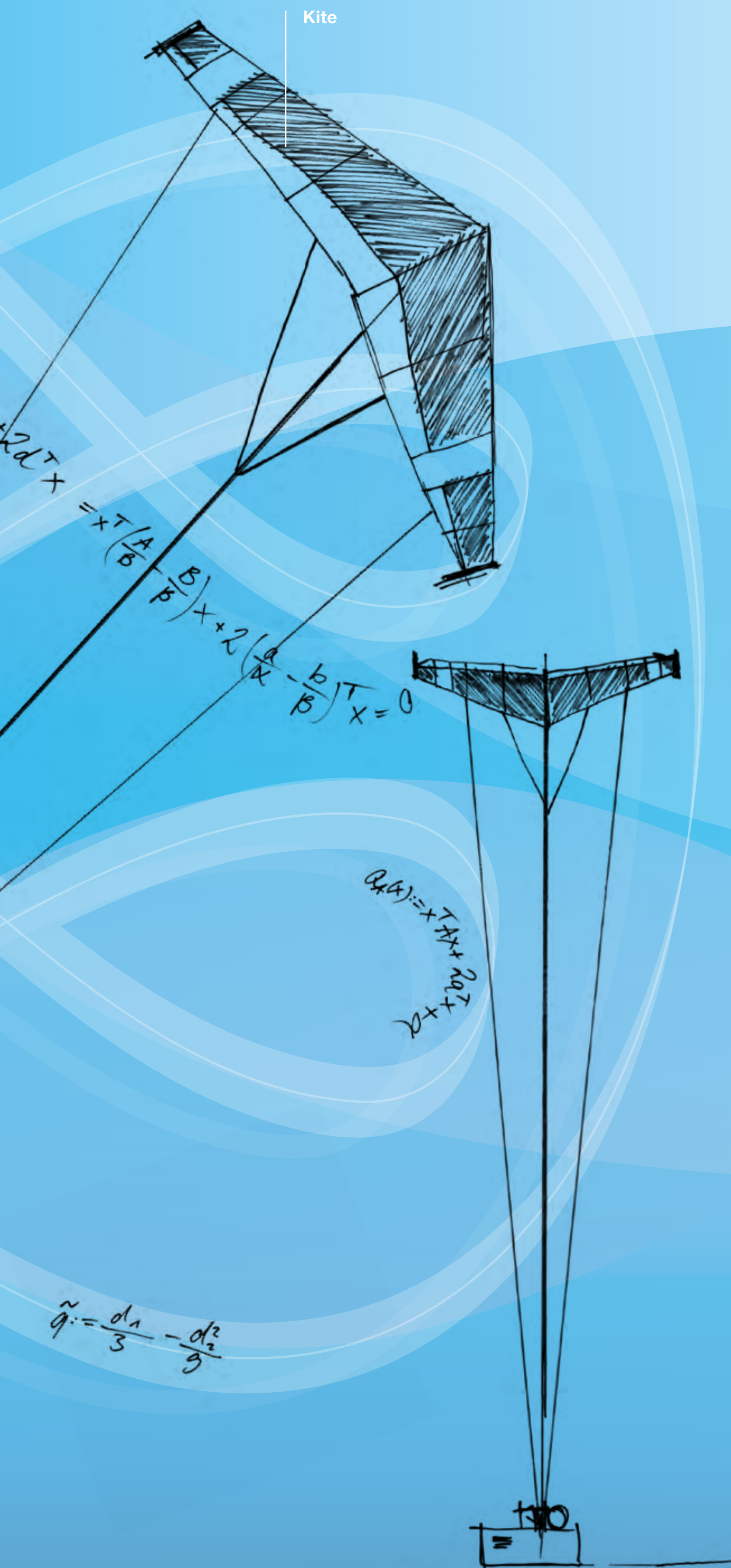
Energy Transition – **Efficiency Gains through Mathematics**

With the help of advanced mathematical methods, Christoph Hackl develops control technology for energy systems. His aim is to enhance the efficiency and robustness of power electronics in electric vehicles and renewables, such as wind energy systems.



The crosswind kite power concept works in two phases: During the power phase the kite flies crosswind, unwinding a rope (tether) from the winch. During the recovery phase the kite is brought back to the starting point and the wire is reeled in to be ready for the next ascent. The ground station generates electrical power from the torque – the rotation of the winch. Dr. Christoph Hackl's team is developing a robust control software for the winch.

Graphics: ediundsepp



Jan Oliver Löfken

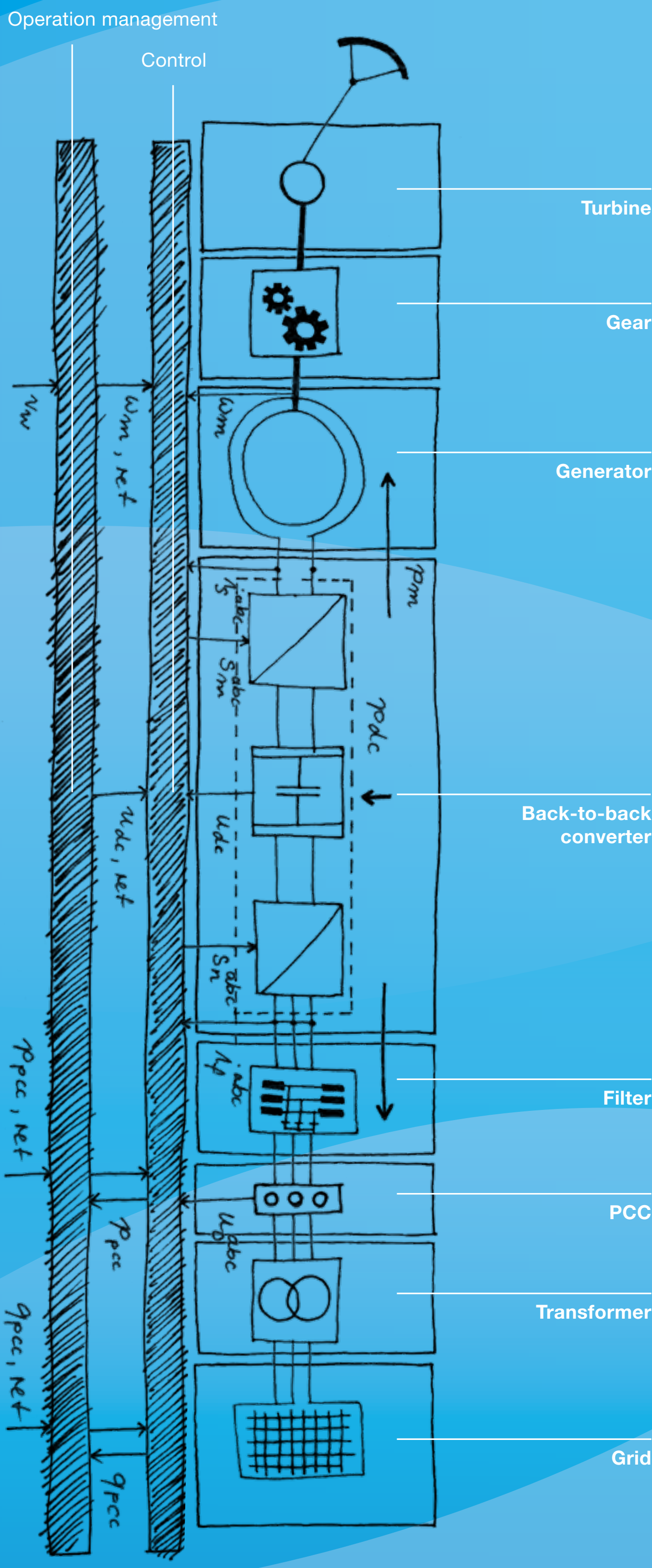
Energiewende – Effizienzschub durch Mathematik

Der Systemtheoretiker Dr. Christoph Hackl reizt bisher ungenutztes Potenzial von erneuerbaren Energiesystemen und Elektroautos aus. Allein mit intelligent gesteuerter Leistungselektronik und komplexer Regelungstechnik will der 39-Jährige die Effizienz von Kraftwerken um mehrere Prozentpunkte steigern. Erste Resultate erzielte die Forschungsgruppe „Control of Renewable Energy Systems“, die Hackl an der Munich School of Engineering der TUM leitet, bereits bei einer Störfallregelung von Flugdrachenkraftwerken und bei der Steuerung klassischer Windkraftwerke, Elektroautos oder Geothermiekraftwerke.

In all diesen Anlagen stecken elektrische Maschinen und elektronische Module wie beispielsweise Umrichter. Diese Bauelemente der Leistungselektronik bereiten die elektrische Energie etwa für die Einspeisung in ein Stromnetz vor. Zum einen entwickelt Hackl dafür eine auch bei Störfällen robuste Regeltechnik. Zum anderen analysiert er das komplexe Eigenleben dieser Energiesysteme. Denn lange Kabel und leistungselektronische Bauteile führen zu Schalt- und Leitungsverlusten, metallische Bauteile in elektrischen Maschinen werden magnetisiert oder die Leistung von Generatoren und Pumpen schwankt. „Um das Potenzial eines Kraftwerks voll auszuschöpfen, müssen wir die Physik der Anlage mit möglichst all diesen nicht-linearen Effekten komplett verstehen“, sagt Hackl.

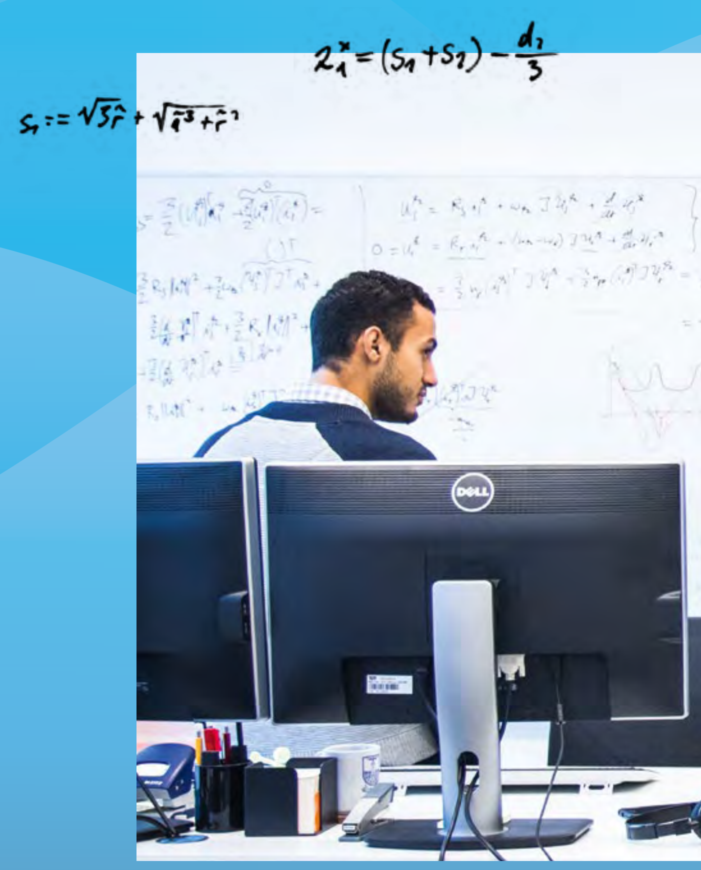
Nicht-lineare Effekte verlangen auch nach nicht-linearen mathematischen Verfahren. So lassen sich mit komplizierten Gleichungssystemen am Computer relevante Zustandsänderungen wie Temperatur, Leitfähigkeit oder Magnetisierung berechnen. Es folgt die Simulation einer Anlage am Computer, auf der dann eine Regelungssoftware aufbaut. „Je nach Anlage können wir die Effizienz um mehrere Prozentpunkte steigern und so die Gewinnmargen entsprechend erhöhen“, sagt Hackl. Seinen Ansatz – die Verknüpfung von Energietechnik mit Systemtheorie – bringt er mit Projektpartnern wie BMW, Volkswagen und den Stadtwerken München in die Praxis. □

Research group “Control of renewable energy systems”
www.cres.mse.tum.de



“We have to overcome our fear of complex mathematics.”

Christoph Hackl



The scheme shows the electronic components of airborne wind energy systems. By optimizing for instance the electric currents within the generator, Christoph Hackl is able to minimize power losses.

Within seconds the kite is spiralling in a tight figure-eight pattern up to 300 meters above a field near Pritzwalk in the German state of Brandenburg. As it soars, it unwinds a rope, a so-called tether, from a winch below. Linked to a generator and battery storage, the winch and kite form an unusual power plant: As the kite rises higher, the rotation of the winch is converted to electrical power. After a controlled descent, the kite loses altitude and the rope is reeled in to be ready for the next ascent. The prototype automatically repeats this maneuver at one-minute intervals. It utilizes the steady and strong winds at higher altitudes. With this concept for airborne wind energy systems – still in its infancy – the start-up company Enerkite plans to start supplying electric power to remote areas by 2019. That would eliminate the need for the diesel generators often used in such locations.

Dr. Christoph Hackl heads the “Control of Renewable Energy Systems” research group at TUM’s Munich School of Engineering. A partner of Enerkite within a European research project, he fosters the development of airborne wind energy systems. His aim: to develop a robust and intelligent control concept for the winch system. The concept has to be flexible enough to reel in the tether and permit a safe and controlled landing of the kite even in case of malfunctions such as short circuits or a partial disruption of the electronics. His tools: a well-founded knowledge of power electronics and mechatronics combined with complex mathematics.

Smart control despite breakdowns

“When faults occur, conventional control systems can easily fail, resulting in a loss of control,” he explains. Hackl, who earned his doctorate in system theory, wants to gain a detailed understanding of these faults, simulate them with computers and make them tangible with complex formulas. These will be used as the basis for control software developed by his team for the flexible and above all secure operation of power plants. “But the applications for this approach are certainly not limited to kite-based high-altitude wind power,” says Hackl. The list of projects pursued by his research group includes conventional wind power, electric cars, geothermal power stations, solar energy and biogas systems. They all use power electronic modules such as rectifiers and converters. These power electronics components convert the electric energy before being fed into a power grid, for example. They can be actively controlled and optimized using Hackl’s expertise. ▷

Christoph Hackl (second from the right) and his team work on a wide variety of energy systems, from geothermal power stations and wind power facilities to electric cars.

Graphics: ediundsepp; Picture credit: ediundsepp/TUM

But possible malfunctions are only one aspect. The energy systems under consideration lead complex and dynamic lives of their own: Long wires combined with power electronics components result in critical resonances as well as switching and conduction losses. Metal components in electric machines become magnetized to greater or lesser degrees, and the performance of generators or pumps can vary depending on their operating point or external influences. “Those are only a few examples of complex, non-linear behavior with a direct impact on the operation of a power station or an electric drive,” says Hackl. Non-linear means that these effects are difficult to predict and cannot be calculated using simple mathematical formulas.

Using the full potential of power stations

“Equipment manufacturers and engineers are aware of these non-linear effects,” says Christoph Hackl. “However, they are rarely exploited in detail.” Instead it is standard practice to make more or less rough guesses of their possible impact. To avoid unpleasant surprises when operating electric equipment, the customary approach is to exceed the required performance parameters or to use additional cooling to prevent overheating. This safety buffer is where Hackl sees the potential for greater efficiency.

“To exploit this efficiency potential, we need to understand a system completely, including having the best possible understanding of all non-linear effects. And we have to overcome our fear of complex mathematics,” says Hackl. Non-linear effects call for non-linear mathematical processes. In some cases this requires highly complicated systems of equations. However, these can be worked out using computers, taking into account all of the relevant changes in state such as temperature, conductivity and magnetization.

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Christoph Hackl

Industry showing interest in complex mathematics

Once the physics is understood and systems of equations are formulated and solved, a power system can be simulated on a computer. This serves as the basis for the control software that Christoph Hackl and his team are testing in their own laboratory on small converters and electric machines. He never loses sight of practical applications. “With a supercomputer we can generally take into account any effect that might arise, for example in wind power generators, no matter how small,” says Hackl. But that would simply be too costly. He therefore scales the control software back to cover only the most important effects. The computer power needed for the electronic control of a system – whether airborne wind energy, a solar park or a geothermal power station – should not greatly exceed that provided by a cheap industrial computer.

“With our intelligent control of the power electronics and the electric machines, we can boost the efficiency of power production by several percentage points, depending on the system, and thus greatly improve profit margins,” says Hackl. And that is possible without making costly adjustments to the system itself. It’s hardly surprising that his research approach is meeting with growing interest not only for new developments such as the wind kite, but also among established companies. Other project partners include BMW, Volkswagen and the municipal utilities provider Stadtwerke München. His methodology – combining energy technology with system theory – could thus become a competitive advantage. “At the international level, our work is rather unique,” says Christoph Hackl, not without a hint of pride. *Jan Oliver Löfken*

Dr.-Ing. Christoph Hackl

Striking a balance between energy and mathematics

Christoph Hackl has taken an unusual route in pushing the development of power electronics with the help of complex mathematical models. The electrical engineer completed his doctorate at TUM in 2012. In his doctoral thesis on the control of mechatronic systems, mathematical methods of system theory played an essential role.

In 2014 Hackl established the research group “Control of Renewable Energy Systems”. The group works within the Munich School of Engineering – an Integrative Research Center at TUM that engages in interdisciplinary research and teaching.

His 10-member team works on a wide variety of energy systems, from geothermal power stations and wind power facilities to electric cars. Hackl is a senior member of the Institute of Electrical and Electronics Engineers (IEEE).

The 39-year-old sees himself as a scientist conducting fundamental research with clear links to real-world applications. When teaching up-and-coming engineers about the opportunities opened up when straddling those two worlds, his enthusiasm is very much in evidence. Christoph Hackl’s goal: For all of his students to acquire comprehensive interdisciplinary knowledge of drive technology, mechatronics and, of course, system theory.