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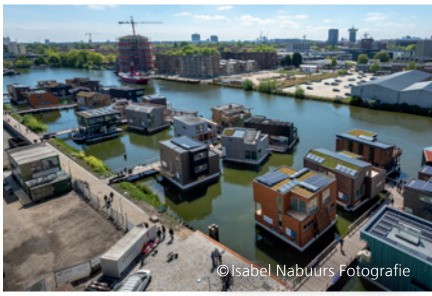
Energy

Our focus is on renewable energies, efficiency technologies, smart grids and the digitization of the energy industry. Small and medium-sized enterprises, as well as industry and the energy sector, have access to a wide range of research and development services. The focus is always on secure, sustainable, economical and socially equitable supply.

Smart Software for Managing Fluctuating Energy Production

In the "High Performance Computing" department, sustainability and the smart use of energy have had a high priority from the very beginning – as can be seen in the "Green by IT" group formed back in 2009. The commitment has resulted in a coporate spin-off, Wendeware AG, in 2019. Matthias Klein-Schlößl, head of the "Green by IT" group, outlines some of the highlights:



Floating residential and energy community with ITWM technology: Amperix controls the energy flows in Schoonschip.

We have been researching software and hardware solutions for the energy transition for many years. This has resulted in the energy manager Amperix and the platform myPowerGrid, which coordinates many decentralized energy managers as a combined virtual unit. Wendeware AG is now marketing our products and further develops these technologies. Since mid-2020, Wendeware has been partnering with an anchor customer: a leading German battery system manufacturer. They use our energy management system to record and monitor energy flows in plants and to intelligently control the storage system and other generators and consumers in a property.

Good winter for Schoonschip

"Green by IT" has been accompanying Schoonschip, a floating residential quarter in Amsterdam North, for quite some time. The energy community did really well over its first winter. To understand what we have achieved, you first need to know that 30 houses (47 residential units) share a very small electricity grid connection with a maximum output rating of around 150 kilowatts while being heated with heat pumps. This means that in winter, a high power consumption is to be expected, and at peak times this consumption would actually be too high for the grid connection.

All houses are equipped with battery storage. Our energy community control system uses these storage units for coordinated support of the grid connection, a process we call "peak shaving". At peak times, the storage systems supplied a total of up to 63 kilowatts of electricity. The shared grid connection was held close to its maximum due to the power consumption of the heat pumps, while the battery storage systems protected it from overload. During sunny periods, the storage systems are used for day-night buffering.

The technology is being used in another residential project: "Wohnen mit Freu[n]den" in Oggersheim. In addition to the main meters, we have equipped an apartment building (which also forms an energy community) with all kinds of technology for measuring electricity, water and heat, a practice known as submetering. This provides energy transparency for the residents and serves as a basis for billing. An evaluation of the key figures shows that "Wohnen mit Freu[n]den" already covers about 60 percent of its electrical energy requirement from its own combined heat and power plant (CHP) and, on balance, generates more than twice as much electricity as the residents consume. For this reason, it may make sense to couple the CHP with a battery storage system to further increase self-sufficiency.

For more information, visit www.itwm.fraunhofer.de/greenbyit_en

Our cooperations at www.wendeware.com/ueber-uns

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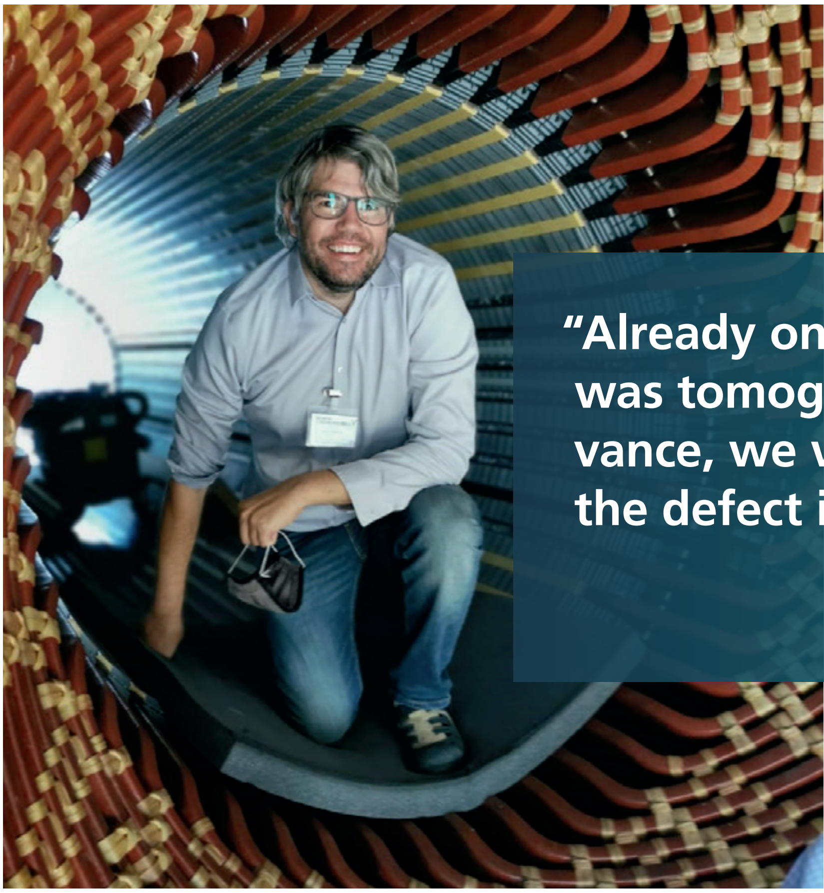
Keeping the Current Flowing: Non-destructive Testing of Power Plant Generator Rods



Preliminary examination: Dr. Friederich in the power plant generator, whose mica insulation, which is sometimes difficult to access, can be examined using terahertz technology.

The inspection of power plant generators is a complex undertaking, partly because of the sheer size of the generators and partly because of their structure. Not all locations are accessible and space for the use of measurement technology is often limited. In recent years, however, many terahertz and millimeter-wave technologies have evolved from scientific backgrounds into specific industrial applications, including non-destructive testing for defects below the surface in quality control and product maintenance. Together with Siemens Energy, we were able to prove the applicability of the new technology for the inspection of power plant turbines in several feasibility studies.

The mica insulation of current conductors in the generator was investigated. Early detection of defects and cracks in the insulation is crucial for the functionality and running time of the generators. The goal was to detect internal defects before the surface material ruptures. Camera-based inspection methods only detect defects on the surface and are therefore not an option on their own. This is because it is too late for maintenance and timely repair. The defects must be detected before they are visible from the outside.

> **"Already on the first specimen, which was tomographically recorded in advance, we were able to recognize the defect in the terahertz image."**
>
> **Dr. Andrey Mashkin**
> Siemens Energy

Radar-based measurement technology combined with terahertz waves

"Imaging-based terahertz testing is particularly well suited for this purpose," says project manager Dr. Fabian Friederich from the "Materials Characterization and Testing" department. "Radar-based approaches, in fact, enable the acquisition of depth information and simplify the differentiation of individual features of the measured object." Corresponding terahertz imaging systems are often based on quasi-optical lens systems that offer a certain degree of flexibility, e.g., with regard to the choice of focal length and thus working distance. The quasi-optical components for the terahertz range are usually quite large and are therefore not suitable for the inspection of generator rods. The remedy here is a combination of radar-based measurement technology and the use of a type of endoscope, which is guided between the generator rods. This consists of a plastic waveguide as a near-field antenna in conjunction with a terahertz radar sensor.

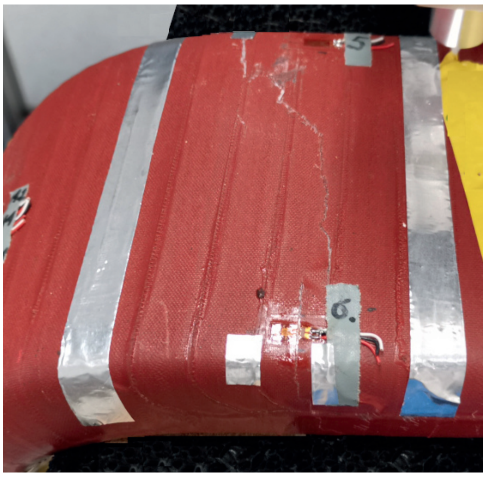
Promising test measurements

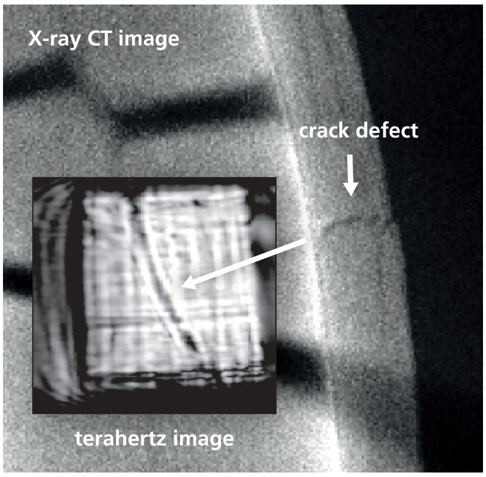
The measuring tip was first tested on a defective generator rod in the laboratory. It was guided over the surface in the area of the defect and the surface of the generator rod was scanned point by point to generate a volumetric image of the area. Comparative images with X-ray CT were used to detect and rule out the defect characteristics. The investigations led to very promising results, so that in the next step, specific approaches for the application of the method in typical interstices of the generator rods were tested.

For this purpose, the ITWM experts first investigated suitable materials for the guidance and influences due to bending of the measuring tip, in the form of further comparative measurements on the generator sample taken. On the basis of these findings, adapted measuring tips were subsequently worked out on plastic plates and combined to form an endoscope. Finally, exemplary measurements were carried out on assembled generator bars to validate their suitability for use.

What is next?

In the next steps, other aspects of the measurement geometry are investigated; for example: What is the influence of the angle of incidence on the measurement signal? Other approaches to solving the problem of the measuring tip in the field are also being examined. “We want to realize a fully adapted measurement system that can be used routinely to check generator rods on this basis,” says Dr. Fabian Friederich.





The photo on the left shows a section of a generator rod. The X-ray CT image of the sample cross-section shown in the background on the right shows a crack inside the insulation. The embedded terahertz image has a different perspective that shows that the crack extends over the entire width of the generator.

More information at www.itwm.fraunhofer.de/terahertz-testing

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FlexEuro: Flexible and Smart Management Wins in the Energy Market

The manufacturing industry needs a lot of electricity. Energy and electricity usage are therefore often decisive cost factors in the industrial sector. At the same time, flexibility in the power supply system has become the slogan of the day. After all, those who respond smartly to fluctuations on the market and manage their power consumption benefit from it. In the BMWi-funded FlexEuro project, researchers from the "Financial Mathematics" and "Optimization" departments are developing models and methods for the optimal marketing of load flexibilities in various electricity markets.

So-called supply-dependent power generation was unimportant in the past for nuclear and coal-fired power plants, but is now crucial for the price in the electricity mix. This means that due to renewable energies, such as wind and solar power, electricity production is increasingly dependent on the weather and also fluctuates over the course of a day, sometimes every hour or even every second. However, it is not just generation that has an impact on markets and prices, but also varying levels of demand. Companies that respond to such flexibility when purchasing electricity are going to have decisive advantages in the future, especially energy-intensive companies. At the same time, they relieve the burden on the energy network.

Smart control of aluminum production

These industrial processes with particularly high energy consumption include, for example, the production of aluminum or, more precisely, aluminum electrolysis. TRIMET Aluminium is on board as an application partner in the FlexEuro project. Everything revolves around light metal products in the medium-sized family business. "At the kick-off to the project, we were also shown the impressive manufacturing processes in the electrolysis furnaces during a tour of the plant. That definitely increased our understanding. They have to run 24/7 so that in the end the output does not suffer," says Dr. Neele Leithäuser. That takes a lot of energy. Some of the furnaces are already designed to compensate for deviations in power input by controllable heat exchangers without interrupting production.

"TRIMET also calls these flexible furnaces a virtual battery," explains the deputy head of the "Optimization – Operations Research" department. The special feature: In the converted cells, production can be ramped up and down depending on the weather. When the sun is shining and the wind is blowing, the furnaces can melt up to 25 percent more with surplus green electricity. If it is dark or there is no wind, they ramp down production by up to 25 percent. This is highly complex, because electrolysis requires a constant operating temperature of 960 °C. Even 10 degrees above or below that is not good for the end product. The aim of the project is to control electricity consumption in such a way that the electricity required on the market can be used as efficiently as possible.

Mathematics keeps an eye on short-term marketing options

"Here, we focus on short-term marketing options for flexibility," explains Elias Röger, ITWM expert in financial mathematics. Röger cites the so-called day-ahead-market as an example. "Always at noon of each day, the stock

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Flexible electrolysis furnace at TRIMET Aluminium SE.

Short-term Marketing Options

- The balancing power market: Balancing power, also referred to as reserve power, ensures supply in the event of unforeseen events in the power grid. It is provided by certified market participants and remunerated by the grid operators.
- The day-ahead auction: trading of electricity for the following day. There is one price for each of the different delivery periods, which becomes known at the end of the auction.
- The intraday market: It refers to the continuous buying and selling of electricity that is delivered on the same day. Electricity can be traded back and forth until shortly before the delivery date, which allows speculation. Positions from the day-ahead auction can be changed again here.

market determines the electricity price for each hour of the following day. This result depends on the level of expected consumption and the forecast generation from renewable energy sources." The different characteristics and restrictions of the markets require an individual combination of mathematical models for each marketing option (see info box for differences between the markets). In TRIMET's practice, this can mean that the furnaces then use less electricity in a "more expensive hour" in the best case and continue to ramp up in less expensive hours. The project is now halfway completed and the researchers are drawing up an initial interim balance.

Leithäuser summarizes: "In the first one and a half years, we at ITWM dealt intensively with marketing on the day-ahead-market. For this purpose, the possibility of flexible consumption was modeled as a multicriteria optimization problem. Mathematical forecasts were then used to calculate optimal load schedules for the coming day. Here we were able to show that flexibility is very profitable economically."

FlexEuro will run until August 2022 and the end result should be specific recommendations for practical action. The plan is to bring the developed models and methods into use as software prototypes at the project partner.

More information at www.itwm.fraunhofer.de/flexeuro_en

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Industry 5G – Not Just Dreams of the Future Due to Mathematics Expertise

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Dr. Paulo Renato da Costa Mendes brings 5G and Industry 4.0 closer together in his team; especially when it comes to the topic of flexibility and renewable energies.

Slogans such as the Internet of Things (IoT) or Industry 4.0 are ubiquitous in the media. It seems clear that in the future, more and more machines, systems and devices will be networked with each other, especially in production. Everyone is also talking about 5G, which is considered the successor to 4G (LTE). But the fifth generation is much more than just a new mobile communications standard. 5G is opening up entirely new perspectives for Industry 4.0 as it is aimed specifically at communication between machines. The “5Gain” project, funded by the Federal Ministry for Economic Affairs and Energy, forms a core of the ITWM activities on the topic of 5G.

The team led by Dr. Paulo Renato da Costa Mendes and Dr. Christian Salzig is dealing with very practical problems and Industry 4.0 in the field of energy, more specifically with “5G infrastructures for cellular energy systems using artificial intelligence”. In the interview, Paulo Renato da Costa Mendes explains to us what the 5G developments mean:

5G is considered a future technology par excellence. Siemens and Handelsblatt are already talking about “Industrial 5G”. What advantages will 5G bring in the area of Industry 4.0? And when is that even foreseeable?

5G is considered to be ten to 20 times faster than 4G, as well as more flexible, autonomous, secure and efficient. It enables higher data transmission rates and shorter latencies. Depending on the application, the advantages cannot be fully exploited simultaneously in one and the same network. The consumer sector may need rather high data rates to stream videos on the go, for example.

For industrial applications, reliability and lowest latency are important. Particularly where the level of industrial automation is already high, 5G offers rapid opportunities to turn Industry 4.0 into Industrial 5G. 5G is still largely a pipe dream. But we are talking about a relatively near future. In three to five years, some things will be realistically feasible.

How can mathematics, or we at Fraunhofer ITWM, support this in practice? What challenges arise in the project and what expertise do we bring to the table?

Especially our years of experience and methodological competences in the field of machine learning qualify us. We develop AI algorithms for a wide variety of areas. This paves the way for optimally exploiting the potential for 5G. In the "5Gain" project, this helps when coupled with our project experience in the monitoring and control of energy networks. AI methods for the distributed control of cellular energy systems are just as much in demand as forecasting models. These are to predict communication requirements based on demand. The solution path is mathematics with the goal of developing intelligent grid control.

It can be explained more precisely like this: Due to the decentralized expansion of renewable energy sources with controllable loads and storage (e.g. electric mobility), the control of energy systems is becoming increasingly complex. Most electricity from renewables is weather-dependent. It is produced independently of demand, when the wind blows or the sun shines. More flexible thinking is needed. At the same time, the power grid should be expanded as little as possible. Our solution approach: dividing the energy grid into regional cells. Each cell has different participants and characteristics and performs decentralized load management, feed-in management and marketing. We develop adaptive methods (e.g. reinforcement learning) that learn the control of such individually present energy grids.

That means AI and machine learning are used. And what does that mean for 5G in the end?

The regulation requires a communications infrastructure that provides the necessary data rates, response times and resources for different numbers of participants, and does so flexibly and quickly in every situation. All this lies dormant in the advantages of 5G. We are working on the further development of various system components and testing them with our partners, also in real environments. For example, in the real lab of the city of Dortmund and with partners from the consumer side or energy producers.

However, other areas in which 5G creates completely new opportunities are of course also exciting. Another application example in the near future could be the remote maintenance of plants via 5G networks, so that 5G will also play an important role in our predictive maintenance application field in the future. There will certainly be other exciting projects to research and develop in the future.

More information on our website at www.itwm.fraunhofer.de/5gain_en

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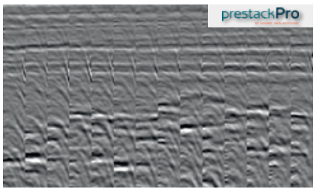
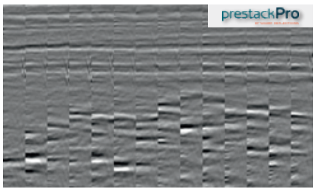
Deep Learning Speeds up Seismic Data Processing





Seismic gathers after prestack depth migration. Curved events (upper image) originate from multiple reflections and are recognized as such by the ML software and eliminated (lower image).

The energy supply of industrialized nations is increasingly based on a mix of different sources. Despite their diversity, they have one important feature in common: the nature of the earth's subsurface. Whether it is locating oil and gas fields, siting offshore wind farms, or identifying areas suitable for geothermal energy: Seismic data sets are measured, processed and interpreted to identify the geology of the subsurface. A research project of the "High Performance Computing" department investigates how Deep Learning methods can support this process.

Deep Learning (DL) has proven its usefulness in many application areas. For seismic data, however, the application is more difficult because the data originates from the unknown and inaccessible subsurface. DL methods that accelerate seismic interpretation are sought; most current methods are too complicated due to many parameters. The working group around Dr. Norman Ettrich has now achieved an important step: They have developed machine learning (ML) methods that do not require parameters. The subjectivity of human data interpretation is also eliminated.

Training through Supervised Learning

The basis is the training of deep neural networks. This is not uncommon, but so far the networks are trained on only part of the data and the learning steps are applied to the entire data set bit by bit. A neural network learns quickly what a cat looks like because it can be trained with photos of cats. This is completely different with seismic data: here there is no clear target image. That is why it trains on synthetic data that reflects the wide variety of real-world data.

"We train exclusively on synthetic data and transfer what we learn to arbitrary field data sets," says project leader Dr. Norman Ettrich. "This is successful because our data modeling excellently reflects the properties and diversity of real measured data. Our methods are used in processing. In simple terms, the input is data with interfering signals, the output is cleaned data. In other words, data without interfering signals, which makes interpretation much easier."

Enormous reduction in computing time

The newly developed methods simplify the seismic work chain. Above all they shorten the required working time by days and even weeks – in each case depending on the amount of data. And this can be huge, because areas of 1000 to 10,000 square kilometers are considered!

The new ML methods were integrated into the ALOMA software, which was also developed in the "High Performance Computing" department. The result is a software package for parallel ML-supported processing of seismic data.

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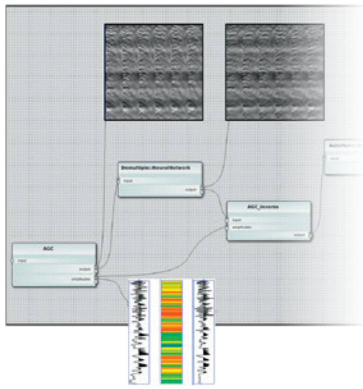
Further information on our website www.itwm.fraunhofer.de/seismic

ALOMA: A Parallelization Framework – Not Only for Seismic Applications

One of the challenges of Big Data is to correctly execute complex computing operations on growing volumes of data. It can only be mastered with the massive parallelization of computers and computing power.



Section of an exemplary workflow with ALOMA

Researchers in the High Performance Computing department have been using GPI-Space for years as a programming platform for high-performance systems. What makes GPI-Space so special is its user-friendliness: Customers do not need to acquire any special HPC knowledge, because the software system takes care of the efficient execution of the algorithms. This also applies to the specialized version ALOMA.

ALOMA detects data dependencies

The tool is primarily used in seismics. However, it is designed as a general framework for the execution of workflows on distributed systems, because ALOMA recognizes dependencies in the data sets that are supplied as input – regardless of the data source – and answers the following questions: How is the data distributed? Which data can be processed simultaneously and independently? Where can the data be processed?

"In order to identify dependencies and answer these questions, ALOMA must have or generate appropriate information about the individual modules and their combination in the workflow. For this workflow, we use a representation as a Petri net, which the internal workflow engine can analyze accordingly," explains project manager Dr. Dirk Merten. To do this, users only have to connect outputs of algorithmic modules with the inputs of further modules in a graphical workflow editor. Information about the individual modules is provided when they are integrated into ALOMA. This information includes the number and types of the modules' input and output data, as well as their granularity. These are values specific to seismic (e. g. "Seismic Data" or "Velocity Model") and the granularities "Trace", "Gather" or "Inline".

Traditional algorithms and ML

In addition to the granularities typical for seismics, ALOMA also supports data splits from pattern recognition and machine learning. This means that modules derived from Deep Learning can also be integrated. In an exemplary workflow, a volume of input data can be corrected multiple times, stacked into one volume, and analyzed for error patterns. Processing and analysis modules for traditional algorithms and neural network inference are easily combined in one workflow. ALOMA automatically handles the parallelization of all modules within the workflow.

With ALOMA, seismic experts can integrate new traditional or machine learning-based algorithms and prototypes within a very short time, combine them with existing algorithms in workflows, and test them in parallel on realistic data sets and under everyday conditions.

Further information on our website www.itwm.fraunhofer.de/aloma_en

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