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Artificial Intelligence in the Distribution Grid of Stuttgart Netze

Detecting Faults with Advanced Measurement Technology and Data Science

Low-voltage grids can be monitored and optimized automatically using advanced measurement technology and data science. This is demonstrated by a joint project of Stuttgart Netze, Smight, and Omega-LambdaTec. Among other things, the project investigated how grid anomalies, such as cable breaks, can be detected before a critical grid failure occurs and thus addressed proactively.

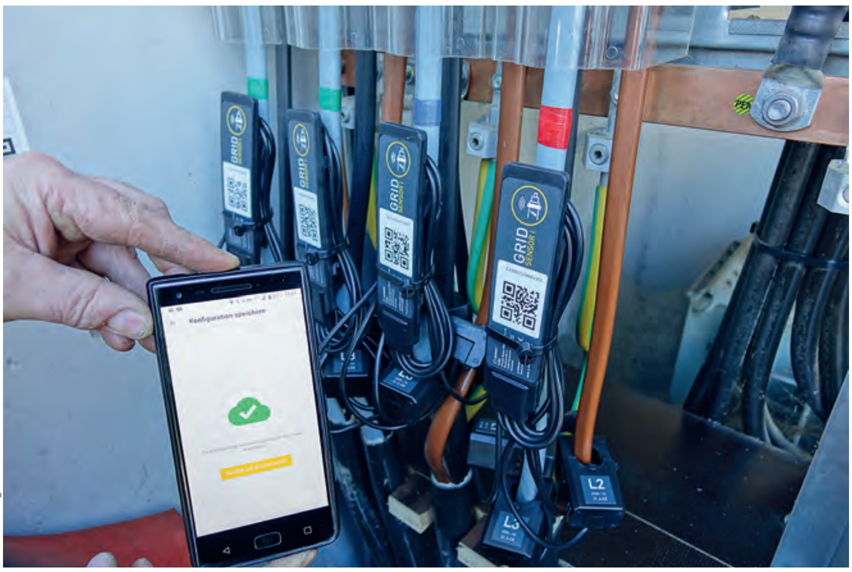
Distribution grid operators today face new challenges. Grids are subject to high volatility due to the increasing direct feed-in from renewable energies and the dynamic energy demand of electric vehicles. This requires a better understanding of load conditions, data-driven optimization, and continuous monitoring of low-voltage grids. The use of modern sensor technology enables new IoT-based applications for grid operators, foremost among them continuous monitoring and optimization of the power grid.

Quelle: Stuttgart Netze

Figure 1. Stuttgart Netze field technician installing Smight sensors in cable distribution cabinets

Challenge: Meshed Grid

Stuttgart Netze, Smight, and Omega-LambdaTec have therefore launched a joint project. Within this framework, the aim is to examine whether and how grid anomalies—such as cable breaks—can be detected in the low-voltage grid before a critical grid failure occurs and thus addressed proactively. This is particularly relevant for Stuttgart's meshed low-voltage grid, as consumers are typically supplied with electricity from two separate feeder connections. If a cable fails due to a fault, the customer is usually unaware. Faulty cables can therefore remain undetected for a long time, compromising the integrity of the grid. If the more heavily loaded second feeder also fails, many consumers lose power at once. Subsequent fault detection and restoration of supply are both time- and labor-intensive for the grid operator.



Quelle: Smight

Figure 2. Data transmission to an IoT platform begins immediately after sensor installation, which is supported by an app.

To prevent this in the future, robust measurement technology that reliably delivers data is required, along with suitable analysis methods and virtual grid models.

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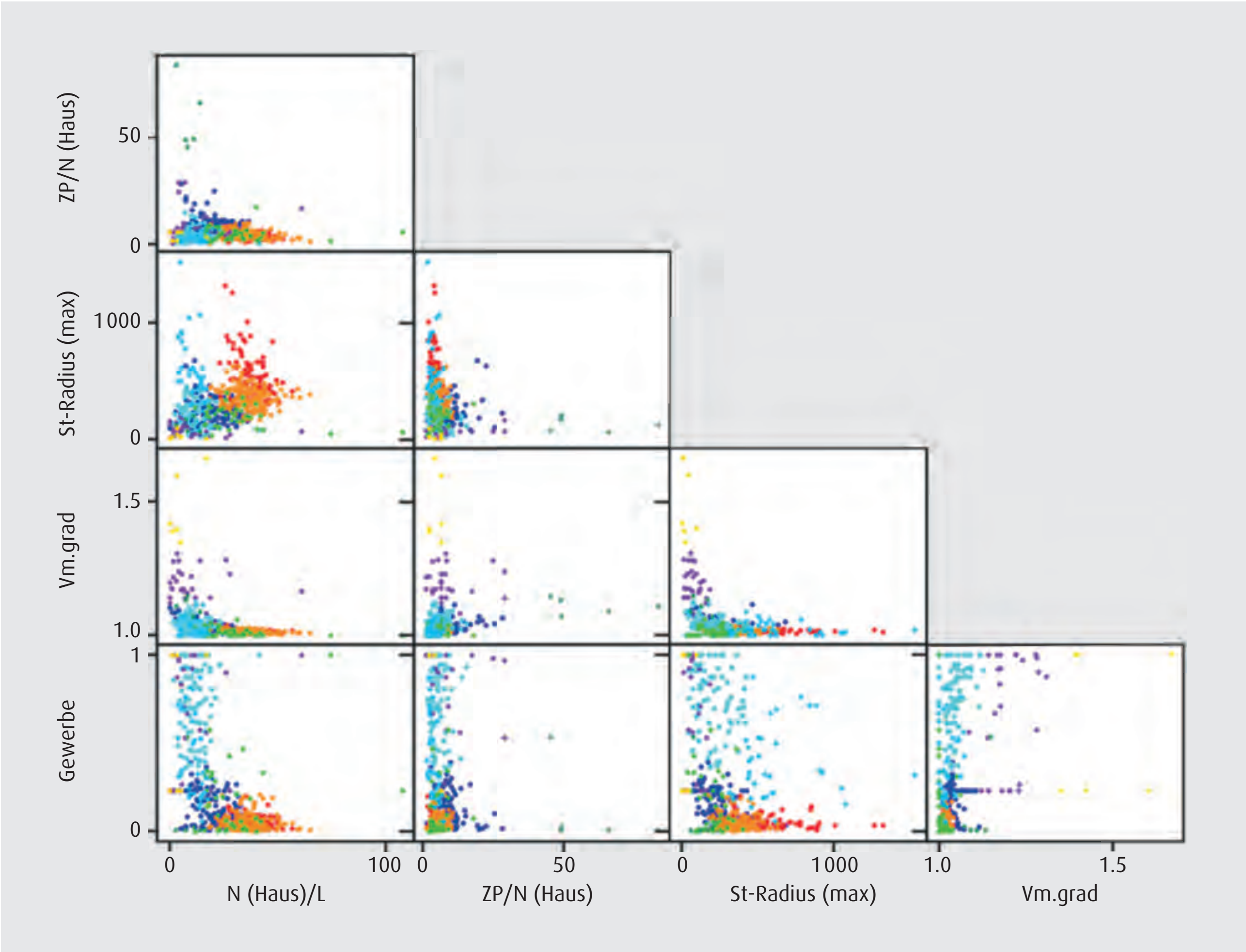

Quelle: OmegaLambdaTec

Bild 3. Clustering-Analyse: Alle 550 Stuttgarter Netzinseln wurden anhand ihrer Infrastruktur-Charakteristika (unter anderem Stationsradius, Anzahl Knoten, Vermaschungsgrad) ausgewertet und in die drei Hauptgruppen aus Wohnsiedlungen (rund 54 %), Gewerbegebiet (rund 21 %) und Industriegebiet (rund 25 %) sowie deren Unterklassen aufgeteilt und analysiert.

The partners also determined where and how much measurement technology needs to be installed to identify cable breaks with high accuracy, while keeping effort and costs as low as possible.

Measurement Technology Tailored for Grid Operators

“We had clear requirements for the operational use of the measurement technology: fast and simple. But the limited space in cable distribution cabinets could not be an obstacle either,” reports Christian Körner, Head of Plant Management at Stuttgart Netze. The choice quickly fell on Smight Grid, a sensor-IoT solution from EnBW subsidiary Smight. It was specifically developed for retrofit, i.e., subsequent installation in existing local substations (ONS). With minor adjustments, it can also be used in cable adjustments, it can also be used in cable distribution cabinets (KVS). Specifically, the power supply of the gateway for data transmission was optimized to equip defined measurement points with sensors (Figure 1).

A major advantage from the technicians’ perspective: the sensors are powered via clamp-on transformers and the transmission to the gateway occurs wirelessly, eliminating complex wiring. “From the very beginning, concrete requirements from grid operations were incorporated into the development of Smight Grid,” explains Oliver Deuschle, CEO of Smight. “Installation can therefore also be carried out by in-house personnel.”The installation is supported by an app, which scans QR codes on the hardware components and assigns them to the cable distribution cabinet (KVS) on an IoT platform (Figure 2). Once this pairing is complete, data transmission begins (1- to 15-minute averages, current in amperes). “Data recording and transmission is very robust. We receive complete and time-synchronized datasets. This provides a solid foundation for the planned analyses,” says Körner. This laid the groundwork for further use of the measurement data by the analytics experts at Omega-LambdaTec.

Selection of Suitable Grid Islands

Based on the Stuttgart grid, which comprises 550 grid islands with around 170 potential measurement points per island, thorough planning of the analyses is necessary. Equipping all measurement points in the Stuttgart power grid with sensors, however, would—besides high

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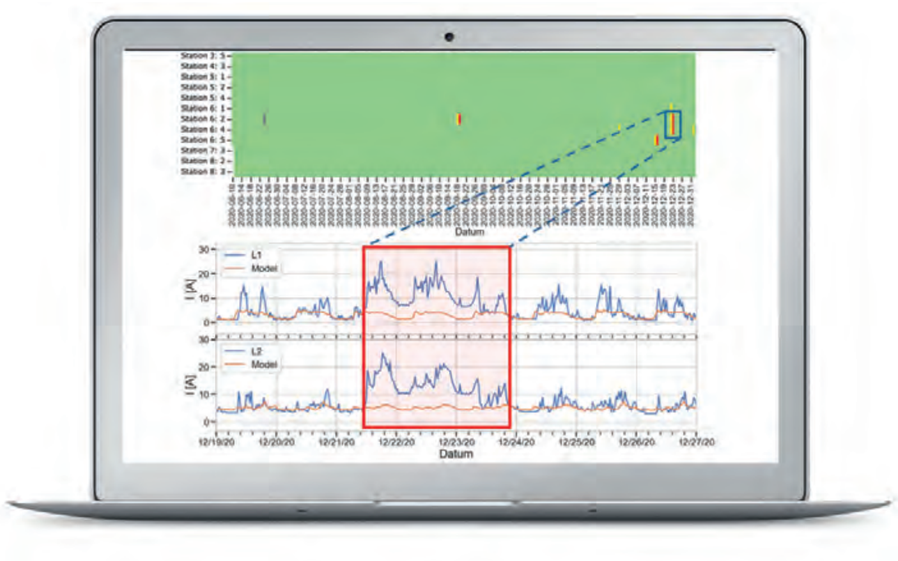

Quelle: OmegaLambdaTec

Figure 4. Dashboard visualization with automated detection and localization of a cable break in a grid island. The manually induced cable break was successfully detected spatially in Substation 6 (blue rectangle) and temporally constrained in the signal (red rectangle) using OmegaLambdaTec's AI algorithms. The cable break can be identified from the differing current profiles between the digital twin simulation model (orange) and the measured current signal (blue).

investments would also entail significant personnel effort. Therefore, the experts determined in advance how many sensors are required at which positions to ensure a high level of comprehensive detectability of grid anomalies. At the same time, economic efficiency and technical feasibility were also taken into account.

The starting point was the construction of a realistic digital twin simulation environment of representative low-voltage grid islands based on shapefiles and GIS reports. To decide which grid islands should be equipped with measurement technology, various relevant grid parameters (e.g., maximum substation radius, share of commercial load) and graph parameters (e.g., number of nodes, meshing degree, failure rate) were determined for each grid island. Based on these parameters, a detailed, high-dimensional clustering analysis was carried out in just one week (Figure 3). This enables automatic, data-driven characterization of all grid islands using machine learning. "With these results, grid islands with high potential for optimizing grid structure and ideal for sensor deployment can be identified," explains Rene Fassbender, CEO of OmegaLambdaTec.

"For us, this comprehensive analysis provides fundamentally new perspectives. Previously, this was only possible for small sections of the grid. Now we can fully observe and assess our entire grid structure," emphasizes Körner.

In addition to determining which grid islands are particularly relevant for measurements, the question of how many measurement points need to be equipped with Smight sensors to detect faulty cables with high probability was also addressed. Analyses by OmegaLambdaTec showed that equipping only 15–30% of the ONS feeders and 10–20% of the KVS feeders can guarantee a detectability of over 80%. Accordingly, in the Stuttgart district of Bergheim (Weilimdorf), twenty measurement points were equipped with Smight sensors across several KVS and ONS in a typical residential area.

Automated Detection of Anomalies

To derive insights from the sensor data and actually detect and locate cable breaks, intelligent, automatic analysis algorithms from OmegaLambdaTec are employed. The sensor data stream from Smight is first ingested into an OmegaLambdaTec cloud solution and prepared for further analysis. A continuously adapting forecast model for the power measurement data is then created using AI techniques (artificial intelligence). By comparing the measurement data with the forecast model, anomalies exhibiting the characteristics of a cable break can be identified in the data stream and reported to the grid operator via email.

During the proof-of-concept phase, this analytics solution was put to a practical test. Since cable breaks are fortunately rare in the grid, several artificial cable breaks were manually induced in the Stuttgart grid by disconnecting a cable for a few days. Using load flow calculations, the software successfully detected all induced cable breaks (Figure 4). "Our automated AI anomaly detection pipeline enables continuous monitoring of all power fluctuations in the low-voltage grid, precise temporal and spatial detection and localization, as well as load flow analyses of potential cable breaks," explains Alexander Fritz, COO & CISO at OmegaLambdaTec. Comparing the measurements with the simulation dataset allows the signal strength of detectable faults to be determined and visualized using a heatmap (Figure 5).

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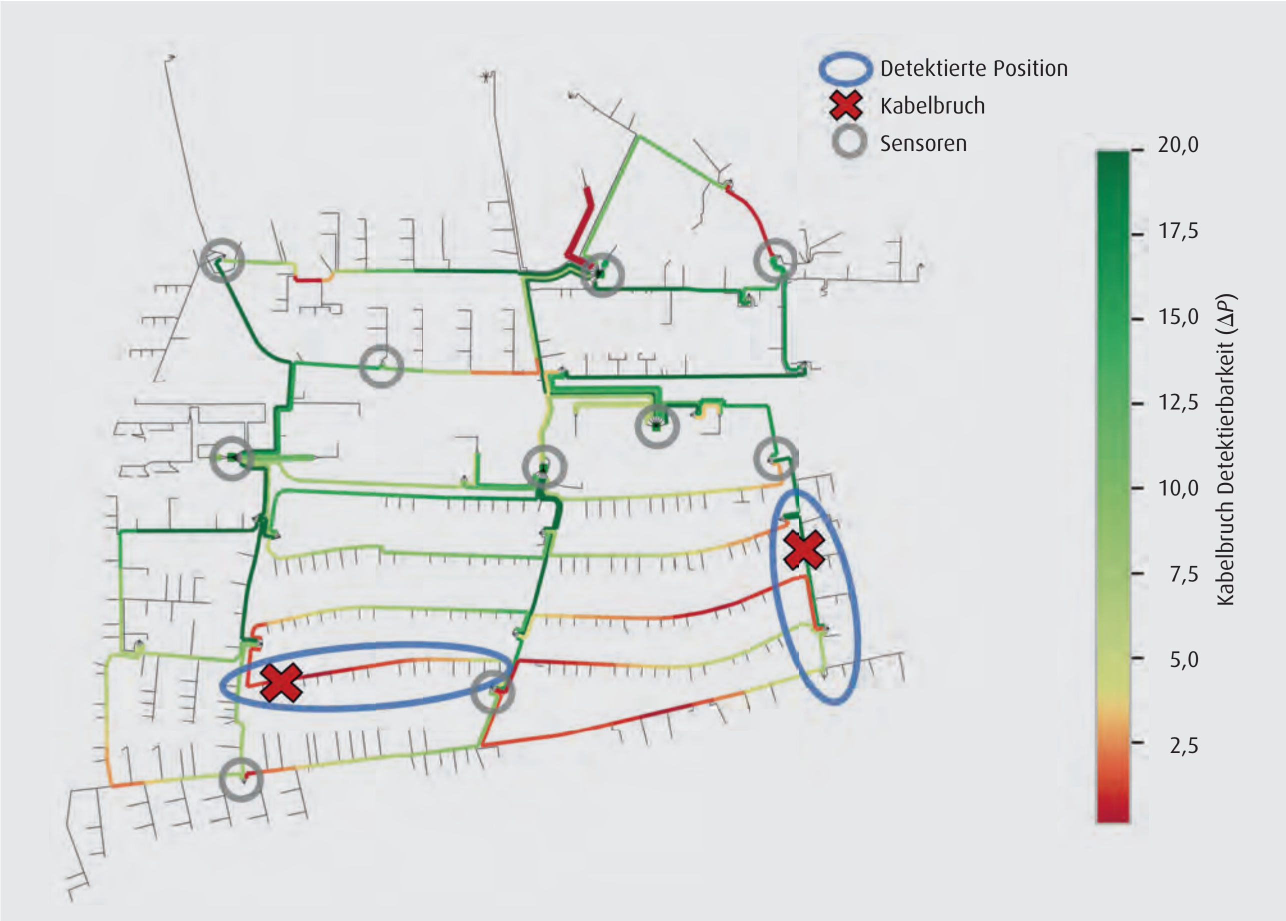

Quelle: OmegaLambdaTec

Figure 5. Detection heatmap of the Stuttgart grid island equipped with Smight sensors (gray circles). The manually induced cable breaks (red crosses) were successfully detected and spatially constrained using OmegaLambdaTec's algorithms (blue ovals). The color of the lines indicates the detectability of cable breaks, from low (red) to high (green), based on a digital twin of the power grid created by OmegaLambdaTec..

New Potentials through Artificial Intelligence

The developed data analysis and anomaly detection pipeline can thus automatically monitor and maintain the low-voltage grid. "Detected and evaluated cable breaks can be reported directly to the grid operator via email. Staff therefore do not need to analyze measurement data around the clock to avoid missing anything," explains Deuschle. The results of the anomaly detection can also be displayed in a dashboard and evaluated in more detail. This enables the grid operator to continuously monitor the network. Currently, the partners Smight and OmegaLambdaTec are working on further optimizing the data visualization, making it possible, among other things, to generate monthly and annual reports for each grid island.

With the measurements and analyses in the low-voltage grid, Stuttgart Netze is among the pioneers in Germany.

"The combined use of AI opens up new ways for us to optimize the low-voltage grid in a targeted, data-driven manner. This allows us to fully exploit the potential of equipping the grid with modern sensors," comments Arvid Blume, CEO of Stuttgart Netze. Currently, the deployment of sensors in additional areas of the Stuttgart power grid is being planned. In doing so, the company aims to proactively consider where growth in e-mobility and renewable feed-ins is expected in the coming years. Such grid areas are highly dynamic and more prone to faults, allowing Stuttgart Netze to respond more quickly. With the available grid condition data, the subsidiary of Stadtwerke Stuttgart can also prioritize construction measures based on actual needs, process grid connection requests faster, and ensure long-term supply security.

All these aspects ultimately lead to higher customer satisfaction—and pay off in the long term in the concession competition.

> Dr. **Anja Martin**,
Manager Marketing & Kommunikation, Smight, Karlsruhe
Dr. **Andreas Schulze**,
Data Scientist,
OmegaLambdaTec GmbH, Garching
Dr. **Alexander Fritz**,
COO & Data Scientist,
OmegaLambdaTec GmbH, Garching
Dr. **Rene Fassbender**,
Geschäftsführer,
OmegaLambdaTec GmbH, Garching
Christian Körner,
Teamleiter Anlagenmanagement,
Stuttgart Netze GmbH, Stuttgart

> a.martin@enbw.com
info@omegalambdatec.com
c.koerner@stuttgart-netze.de

> www.smight.com
www.omegalambdatec.com
www.stuttgart-netze.de