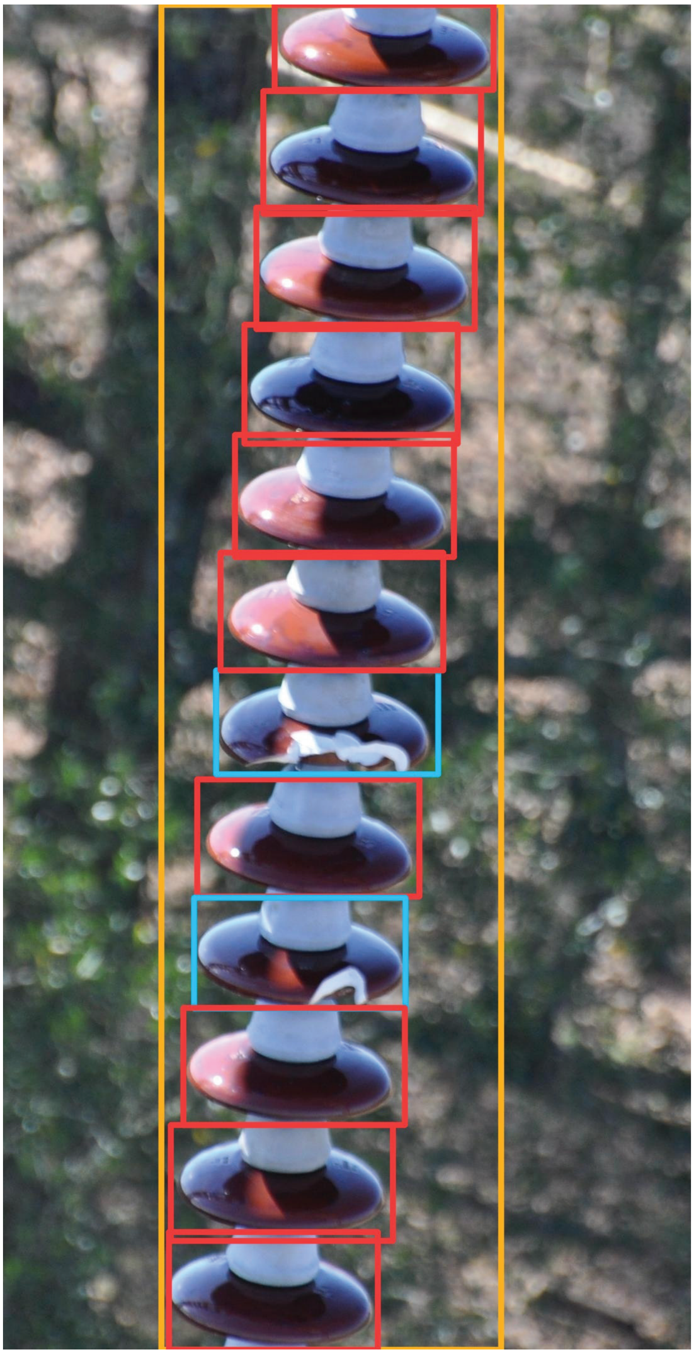
PREDICTIVE MAINTENANCE OF THE POWER GRID ASSETS

Infrastructure systems such as the electricity grid are regularly maintained to ensure reliable operation. Wear and damage must be recognised at an early stage. A team of scientists from the Swiss Federal Institute of Technology (ETH) in Zurich, in collaboration with the national grid operator Swissgrid, has investigated the possibilities of predictive maintenance of the electricity grid. The aim is to auto-mate fault detection and classification with the help of machine learning models.

The backbone of the Swiss electricity grid is the nationwide transmission network. High-voltage lines transport the electricity from the large power plants to the finely meshed distribution grids in towns and municipalities and ensure the exchange of electricity with neighbouring countries. 6700 kilometres of lines run across the country on about 12,000 pylons. Beside the lines the transmission network incloses 147 switchyards.

Two thirds of the Swiss transmission grid dates back to before 1980. Swissgrid, the operator of the very-high voltage power grid, carries out 12,000 inspections every year to ensure reliable operation. Not only age-related wear and tear, but also lightning strikes, storms, heat, rains, and debris flows put a strain on the systems. Maintenance work includes among others the application of corrosion protection, the replacement of faulty insulators, or the renovation of defective pylons and concrete bases, as well as tree trimming and



The researchers at ETH Zurich analysed drone images of insulators taken by the US Electric Power Research Institute (EPRI), among others. The object recognition programme distinguishes the entire insulator (yellow frame) from the individual, intact discs (red frame) and the faulty discs (blue frame). Photo: EPRI

A technical report about the results of a research project in the field of grids, which is financially supported by the Swiss Federal Office of Energy. The report has been published in the technical magazine ET Elektrotechnik (issue August 2024).

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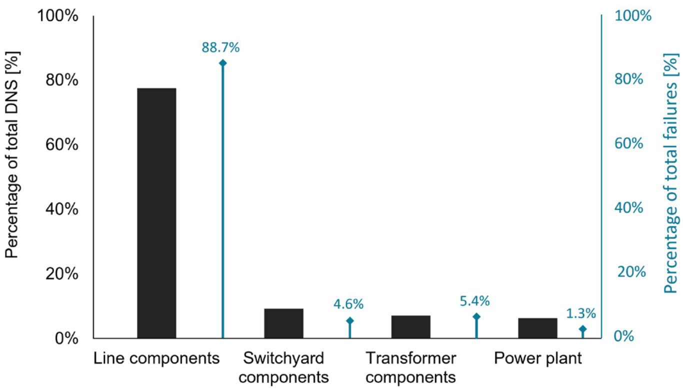
vegetation management. «The upcoming maintenance work is defined after the annual visual inspections,» writes Swissgrid on its website. In 2018, the grid company recreated all lines and substations in a digital 3D model based on aerial photographs. The model has since helped with the planning of maintenance work.

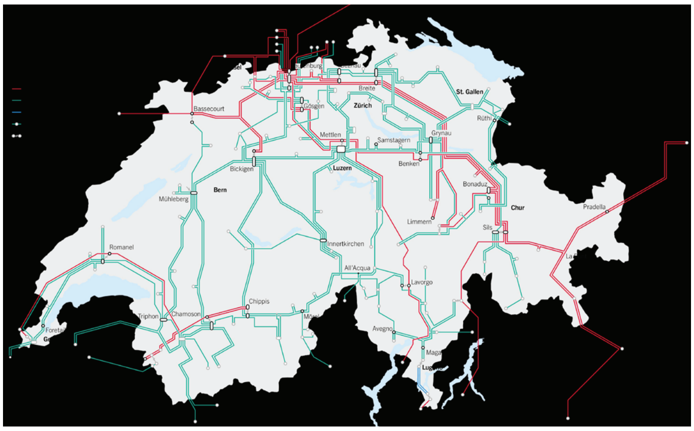
Automated detection of faults

Researchers at ETH Zurich have now investigated how Swissgrid could further improve the maintenance of the transmission grid in terms of predictive maintenance. ‹Predictive› in this context means that problem areas in the grid are recognised early and automatically. The focus was on overhead lines, insulators, and transformers. «The advantage of predictive maintenance is that it can also recognise unexpected problems, and maintenance work is not carried out in advance, which saves personnel and money,» says Laya Das. The postdoctoral researcher of Indian origin works at the ETH Laboratory for Reliability and Risk Engineering, which is headed by Prof. Giovanni Sansavini. The research project supported by the SFOE was completed at the end of 2023.

One approach is the identification of faults in the transmission grid by analysing drone images. The images were used to identify faulty insulators on the high-voltage pylons. The novel approach: flashed-over or broken insulator discs do not need to be detected by individual evaluation of the photos, but automatically by object recognition programmes, which are trained with machine learning models. The ETH researchers used more than 2000 drone images of high-voltage towers from Switzerland, the USA, and China. In the first



Data from the Italian transmission grid shows that power lines (including associated components) have the highest participation in the demand not supplied (DNS) to consumers and have the highest shares in total failures. In other words, they fail the most and have the highest impact. Graphic: RRE Lab, ETH Zürich



The Swiss transmission grid. Grafic: Swissgrid

step, they labeled the images. Then, they trained a machine learning model using YOLOv5 (You Only Look Once, version 5). The trained object recognition model automatically recognises the insulators in a given image and identifies the type of fault (flashed or broken).

Ready for use in the network

In the world of automated object recognition, the accuracy of an algorithm is expressed by the ‹mean average precision› (mAP). This is a number that can assume a value between 0 (not recognised) and 1 (reliably recognised). The programme ‹trained› by ETH recognises broken discs of an insulator with a mAP of 0.77, and flashed-over discs with a mAP of 0.18. The researchers attribute the comparatively poor recognition of flashed-over discs to the fact that only a few such discs are encountered in reality and therefore too few images are available to train the recognition algorithm sufficiently well.

To improve the prediction accuracy, a second analysis step was added in which the faulta are characterised utilizing an anomaly detection procedure. «Our object recognition tool for detection of faulty insulators works well and is ready for use by operators of high-voltage grids,» says Blazhe Gjorgiev, a native of Macedonia who was involved in the ETH project as a senior postdoctoral researcher.

Test with Ticino overhead line

A good database - this is also the key to a second approach that ETH researchers have investigated in order to recognise faults in transmission lines. In this case, the starting point is not drone images, but high-resolution measurements. At the centre of this study was a 26 km long 220 kV overhead line from Avegno (near Locarno) to Gorduno (near Bellinzona),

Broken porcelain of an insulator and its label used to train anomaly detection model. Photo: EPRI (left) and RRE Lab, ETH Zürich (right)

divided into 26 segments. At the begin-ning and end, the line is equipped with modern measuring devices (phasor measurement units/PMU) that can measure voltage and current 8,000 times per second.

The scientists now wanted to find out whether it would be possible to determine whether or in which of the 26 segments on the 26 kilometre-long line leakage currents occur simply by comparing the current measured values at both ends of the line. The occurrence of leakage currents is an indication of faulty insulators.

Lack of faulty grid data

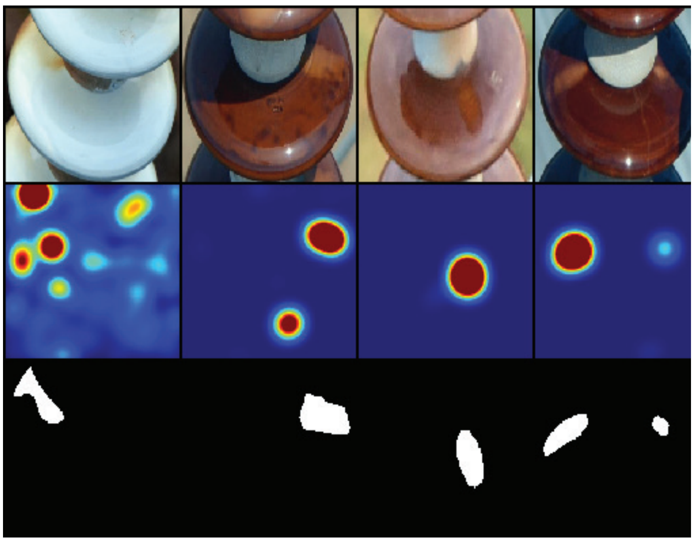
As a means to an end, the researchers modelled the Ticino transmission line with a physics-based model (simplified digital twin) using MATLAB Simulink software, which uses parameters such as resistance, capacitance, and inductance. The model was trained with synthetic data that contained healthy and faulty sections. Using simulations and machine learning models, they succeeded in identifying and localising defective insulators via leakage currents. This was achieved with three machine-learning models (Feed forward neural network/FNN, Recursive neural network/RNN, Convolutional neural network/CNN) with a prediction quality of 98 percent and more. This means that at least 98 of 100 defective areas with leakage currents are recognised automatically.

An astonishing result, but one that ETH researcher Gjorgiev is not happy with: «At first glance, this result looks great. However, our model is still not suitable for practical applications, as our physics-based model is based on data from a functioning power grid.» Unfortunately, the project team was unable to include any measured data that indicates faults in their investigation, says Blazhe Gjorgiev. Thus, the team had no way of validating whether the fault localization model is actually correct in practice. For the team, this exercise provided "proof of concept" that such an approach can be used given sufficient data for model development.

Troubleshooting transformers

The ETH project team has also investigated the idea of predictive maintenance for transformers. The latter are technically more complex than overhead lines and insulators. The DGA method (Dissolved Gas Analysis) has been used for many years to assess the functionality of transformers. This involves chemically analysing the oil that acts as an insulator and a coolant in the transformer. The determined gas residues allow conclusions to be drawn about thermal and electrical faults in the transformer.

Here too, the ETH researchers aimed to automate fault detection by using machine learning models. Swissgrid and the Fachkommission für Hochspannungsfragen (FKH) provided a dataset of several thousand DGA samples. By automatically analysing the samples statistical (conventional) and machine-learning models, the scientists were able to identify conspicuous DGA samples that indicate faults in the transformer



The FCDD anomaly detection programme automatically detects faulty insulators: The middle row shows thermal images in which the intact areas are shown in blue and the faulty areas in red. The bottom row shows the shape of the fault. Photo: EPRI (top row) and RRE Lab, ETH Zürich (middle and bottom row) with an estimated accuracy of 70 to 90 %. For methodological reasons, the researchers must leave open whether the inclusion of machine learning actually brings an advantage here.


In addition to insulators, fault detection programmes can also detect stockbridge dampers (green) and bird nests (yellow). Photo: Swissgrid

Planning tool for maintenance work

As a result of their project, the ETH researchers have provided the project partner Swissgrid with three tools: a deep learning model for detecting defective insulators based on drone images; an algorithm that helps with the evaluation of DGA data for transformers; and finally, a trained machine learning model for diagnosing transformer faults from DGA data.

According to ETH researcher Blaze Gjorgiev, the latest findings could also be important for the Swiss distribution grid operators that operate their high-voltage grids. Medium- and low-voltage grids may also benefit from advanced machine learning methods for fault detection, Gjorgiev says. The applicability of the findings in this project for the assets from different grid voltage levels requires further investigation.

- The **final report** on the research project ‹IMAGE - Intelligent Maintainance of Transmission Grid Assets› is available at: www.aramis.admin.ch/Grunddaten/?ProjectID=48027.

- **Information** on the project is available from Michael Moser (michael.moser@bfe.admin.ch), Head of the SFOEs ‹Grids› research programme.

- Further **specialised articles** on research, pilot, demonstration and lighthouse projects in the field of electricity can be found at www.bfe.admin.ch/ec-strom.

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