Preliminary draft 13:42 30 August 2024

30 August 2024
arthur.constant.chevreau@cern.ch

SUMMER STUDENT PROJECT: Creation of a database of the electrical protection at CERN and how to maitain up to date

Arthur CHEVREAU
CERN, CH-1211 Geneva, Switzerland

Keywords: Circuit Breaker, Machine Learning, Electricity, DDO, Transformer,Data Bases

Summary

This report discusses a multifaceted project that combined database development with advanced machine learning applications. The primary goal was to create comprehensive Excel files dedicated to forming a database of Low Voltage (LV) circuit breaker settings, which is essential for streamlining the management and maintenance of CERN's complex electrical systems. Over time, the project expanded to include the development of an automated recognition system. This system leverages neural networks to enhance the accuracy and efficiency of data entry, using images of circuit breakers settings to automatically update CERN's database with the new tuning state of the protection. Additionally, valuable hands-on experience in transformer testing was gained, another critical component of electrical infrastructure. Under the guidance of experienced professionals, we explored both the theoretical and practical aspects of transformer testing, ensuring safety and precision in low-voltage scenarios. This project allowed us to bridge the gap between data management and electrical engineering, providing a well-rounded experience.

Contents

1 Acknowledgments

These past three months have been an incredible journey of learning and exploration. I have had the opportunity to work in highly advanced environments and become involved with the work of a crucial part of CERN's technical department. I would like to express our gratitude to the entire EN-EL-DDO Desk team for generously sharing their time and knowledge, offering us perspectives we had never experienced before. Although it was only three months, it has been the most rewarding and interesting summer of our lives. I hope that we have contributed positively to our coworkers' future endeavors. Thank you again to everyone; you have been a true source of inspiration for us, and we hope to meet again in future professional experiences.

2 Introduction

Understanding and managing the distribution network and its assets (such as cables, transformers, and circuit breakers) at CERN is crucial for ensuring the safety and efficiency of its operations. Circuit breakers are essential components in any electrical system, particularly in a complex environment like CERN, where the precise interruption of electricity under fault and load conditions is critical. These devices protect the electrical network from issues like short circuits, overloads, and differential faults by interrupting the flow of current when abnormal conditions are detected.

In this report, we will discuss the importance of electrical protection in a facility like CERN, their objectives, and how to properly configure them to ensure their correct operation. We will explore how machine learning can be utilized to recognize the settings of protective devices and store this information in a database for future analysis. Lastly, we will focus on transformers, analyzing their behavior to design a simulation model that can predict their performance in an operational state.

3 Circuit Breaker Databases

At its beginning, the project aimed to obtain the settings data for our circuit breakers using a series of pictures taken during the shutdown period imposed by the COVID-19 pandemic, as well as during various maintenance activities. These settings play a crucial role in determining the behavior of our protective devices. In this section, we will explore the types of faults that circuit breakers can prevent and how the different collected data help configure the device to trip only in necessary situations.

3.1 Electrical protection at CERN

At CERN, the importance of the electrical protection is magnified by the scale and precision required for its operations. Tripping an entire sector's electrical shutdown due to a fault would be catastrophic, potentially disrupting experiments, damaging equipment, and causing significant shut down time. Therefore, the circuit breaker network is designed to isolate only the affected parts of the system, ensuring that the rest of the network remains operational this ability of the distribution network is also called selectivity. It is vital to maintaining the integrity of the experiments and the safety of the facility.

Furthermore, CERN's reliance on high-speed particles, traveling near the speed of light, means that the delay before re-powering needed to be extremely short to ensure the well-being of the activity. To mitigate the risk of a complete electrical failure, CERN employs a robust backup system that includes multiple independent power sources from different electrical plants. In the event of a fault, the automatic transfer for medium voltage ($\geq$18KV) can immediately restore power to critical areas, minimizing downtime.

In addition, a strong UPS (Uninterruptible Power Supply) network is in place to ensure that even a brief power outage does not affect the operations. The UPS network acts as a bridge, providing power during the transition between a fault and the restoration of the electrical supply, thus ensuring that experiments continue without interruption.

3.2 The different type of Protection

- Short Circuit Protection: Short circuits occur when electrical currents bypass the normal load, creating an uncontrolled surge of electricity that can cause severe damage to equipment and pose serious safety risks. Circuit breakers detect these surges and immediately disconnect the faulty section to prevent widespread damage.Their are typically caused by insulation failure.

- Overload Circuit: Overloads happen when a circuit carries more current than it is designed to handle, which can overheat wires and cause fires. Circuit breakers protect against this by shutting off the circuit when they detect sustained excessive current.

- Differential Protection: This type of protection ensures that the current entering a circuit matches the current leaving it. If there is a difference, it may indicate a leak to earth or other fault, prompting the circuit breaker to trip and isolate the fault.

3.3 The Database Project

By meticulously scavenging through the 71,000 images of circuit breakers and documenting their states and configurations. This deep knowledge is essential not only for maintenance and troubleshooting but also for optimizing the network's reliability and efficiency. The ability to quickly identify and address issues within the circuit breaker network can make the difference between a minor hiccup and a major catastrophe in an environment where precision and continuity are paramount.

To ensure that this crucial information is readily accessible and useful across CERN's technical departments, we have compiled all of these parameters into a comprehensive database. This database will be available to all relevant teams, significantly speeding up the decision-making process for planning new intervention on the distribution network or monitoring the availability of the install circuit. It provides a centralized resource for the design office to easily access detailed information about the circuit breakers, allowing them to efficiently order and calculate replacements for any parts that are nearing the end of their life cycle. This streamlined approach not only enhances operational efficiency but also ensures that the electrical network remains robust and reliable, supporting CERN's critical work without interruption.

The settings are configured on the circuit breaker using a dial or DIP switch, which can be directly implemented on the circuit breaker itself, although most require a side module with a specific adjustable range. To achieve the project's objectives, we need to identify the type of circuit breaker being used, the type of side module it employs, and the different settings applied to it. We must also consider other side modules, such as differential protection, which may not be adjusted on the circuit breaker itself but rather through a secondary device downstream of our protection. Once all this data has been gathered, we can input it into our Excel file, including all the information collected in the first part and the signaling code of the circuit breaker, which consists of two parts: the cubicle name and the device number within it. All the parameters collected can be used to create a curve that effectively and quickly describes the behavior of the circuit breaker.

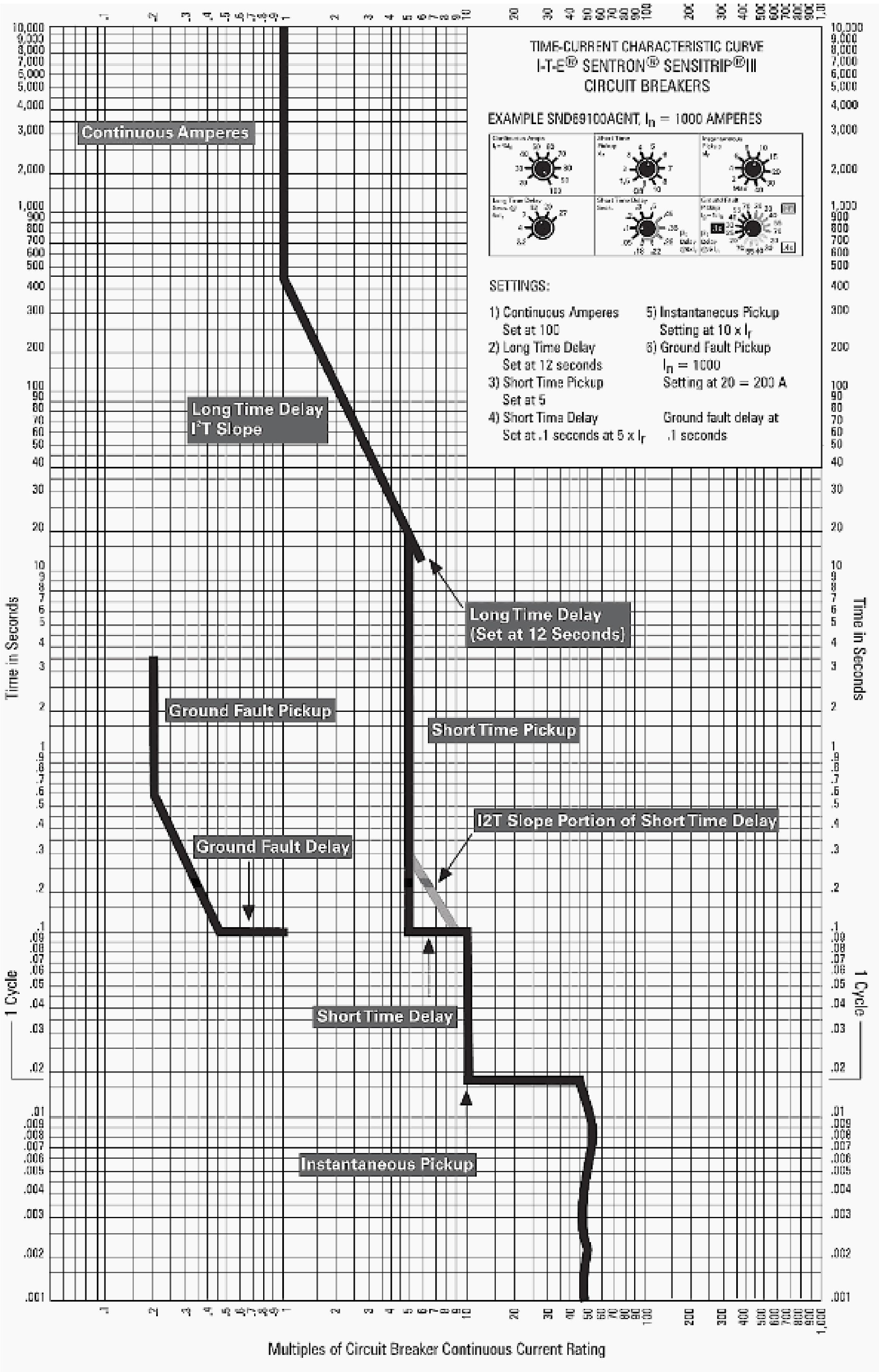

Figure 1: Multiples of Circuit Breaker Continuous Current Rating

The circuit breaker curve illustrates its behavior over time and current. The x-axis represents the current flowing through the circuit breaker, while the y-axis indicates the time required to trigger a specific protection mechanism. Here is the major region

- Continuous Protection: The upper part of the curve, marked by a flat line, represents continuous protection. This section is designed to respond to faults lasting at least 500 milliseconds, allowing for brief high-current pulses needed for the startup of certain devices.
- Long-Time Delay: This part of the curve follows the continuous protection section and can vary in shape depending on the I^2T dial settings. It controls the delay time before tripping the breaker under sustained overcurrent conditions, such as those seen during motor startups.
- Short-Time Pickup and Delay: The short-time pickup sets the maximum current the breaker can carry for a brief period, allowing downstream devices to clear short circuits without tripping the upstream breaker. The short-time delay adjusts how long the breaker can handle this current before tripping.
- Instantaneous Pickup: This function trips the breaker immediately when the current exceeds a set threshold, ranging from 2 to 40 times the breaker's continuous ampere setting (Ir), to quickly disconnect the circuit in case of a severe fault.
- Ground Fault Pickup: This setting determines the current level at which the breaker will interrupt the circuit to protect against ground faults. The adjustment range is from 20% to 70% of the maximum breaker rating, with a maximum trip point setting of 1200 amps as per NEC® 230-95 (A) regulations.

The picture and the summarized comments on the different parts of the circuit breaker curve have been sourced from an article by EEP.[EEP - Electrical Engineering Portal(2023)]

4 How to maintain this database up-to-date ?

4.1 Introduction

In parallel with the database project, An automated system was developed to feed the database. For this, Python was used alongside several libraries to handle different aspects of the project.

- TensorFlow is a tool for building neural networks with numerous parameters and fine-tuning capabilities. The most challenging aspect of this project has been creating a recognition model for highly specific elements in images. I trained two models from scratch: one for detecting potentiometer orientation and another for predicting DIP switch positions. These tasks required intricate training processes.
- EasyOCR is an open-source OCR tool enhanced with comprehensive machine learning functions. I used it to better identify text on circuit breakers, even when images were partially blurred or overexposed.
- YoloV8 is an independent library for image recognition, using specialized neural networks to create robust recognition structures with minimal data. This component was crucial for the image recognition tasks in my project.

4.2 Image Rotation Function

Despite the power of these libraries, some parts of the code had to built from scratch. One of the most challenging was the image rotation function. This part of the program relies on the image editing library CV2. Since the pictures used to build the database often had issues with quality and orientation, specialized function to address this was developed. First, the program applies filters to create a mask of the image, highlighting color transitions where the picture is overexposed. This technique helps the program more easily identify relevant objects. The mask is then used to detect contours with an average pixel identifier, sorting them by size. Smaller contours, which aren't relevant for orientation prediction, are discarded. The remaining larger contours are analyzed using basic trigonometric formulas, and their orientations are stored in a table. This table is then averaged to determine the image's offset, and the picture is rotated accordingly.

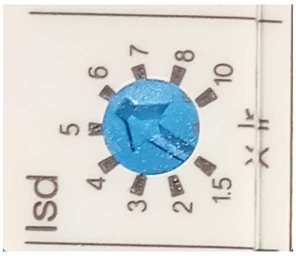

Figure 2: Input Image

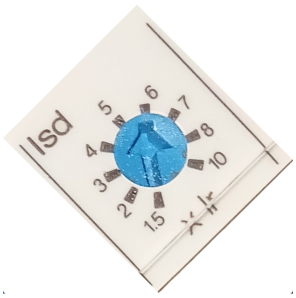

Figure 3: Image 45°

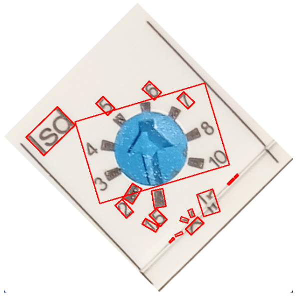

Figure 4: Rectangle Adjust

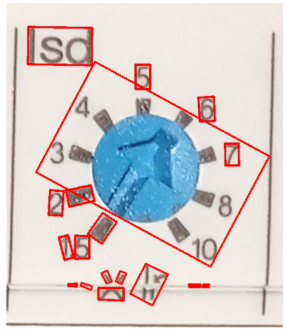

Figure 5: Output Image

When this program was first tested , the average error was around 80 percent. This significant error was due to the program's inability to handle flipped images, as it would rotate the picture without recognizing that it was upside down or sideways. To fix this, a trust factor was added based on the larger sides of the contour rectangles: the wider a rectangle, the more weight its orientation carries in the program. Additionally, the image was tilted by 45 degrees upon entry, forcing the program to choose between the two sides of the picture. This adjustment is like how a cube settles on one side when released, rather than remaining in an unstable position. In this case, gravity is replaced by the orientation of the rectangles.

With these improvements, the average error was reduced to 1 in 15 pictures. While further reduction is possible, development was paused here to focus on the neural network.

4.3 Data Labeling and Neural Network Training

Before feeding data into YoloV8 [Ultralytics(2024)], a crucial step is "labelling" (The process of assigning meaningful tags or categories to data points, which helps algorithms learn to make accurate predictions or classifications based on that data.). This involves drawing boxes around objects of interest in each image and assigning a name to each box (called ROI: Region of Interest). This is essential for teaching the algorithm to distinguish between the background and the objects of interest in each image. One of the most impressive aspects of YoloV8 is its efficiency: it requires only 300 images to train a nearly perfect recognition model. In comparison, training the neural network to determine the position of a potentiometer or DIP switch required over 10,000 images. This difference is due to the complexity of teaching a computer to translate visual information into computable data.

Figure 6: Wall Fresco example

The neural network uses a technique called ”wall fresco” to greatly expand the dataset: each photo is placed alongside others, with some images overlapping. YoloV8 training forces the neural network to identify the positions of all elements, even when the images are geometrically modified, ensuring a thorough understanding of the object’s features. This method can generate an infinite number of training images, which are used dynamically to train the model with high precision.

The confusion matrix displayed in the image represents the performance of the recognition model trained to identify three distinct components: circuit breakers, signalization plates, and potentiometers, with an additional category for background elements. The matrix is normalized, meaning that the values represent proportions rather than absolute

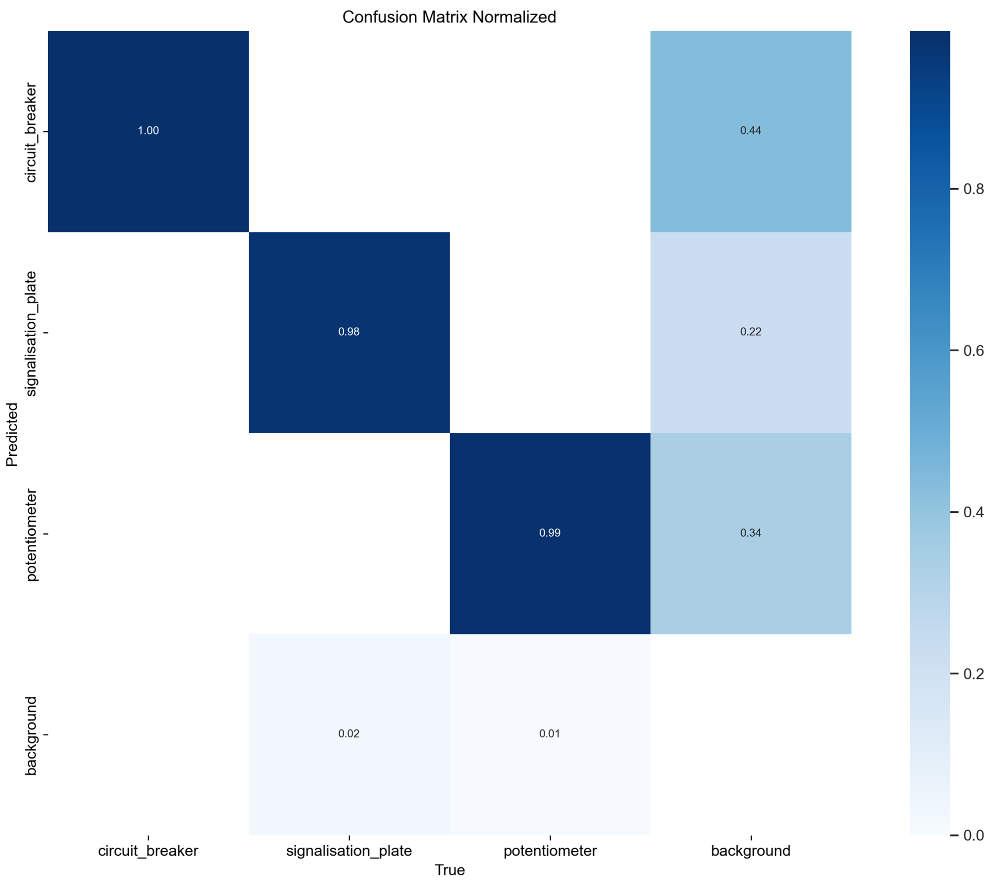

Figure 7: Confusion matrix of the YoloV8 Training

counts, allowing for easier interpretation of accuracy across the different classes. In the matrix, the diagonal values show the true positive rates for each class, where the model correctly identified the component. Notably, the model has achieved perfect accuracy (1.00) in recognizing circuit breakers, indicating that all instances of circuit breakers were correctly classified. Similarly, high accuracy is observed for potentiometers (0.99) and signalization plates (0.98), with minimal misclassifications. However, some confusion is evident in the off-diagonal values, particularly where signalization plates and potentiometers are sometimes mistaken for background elements, and vice versa. For instance, 0.44 of the time, the background was incorrectly classified as a circuit breaker, and in 0.34 of the cases, it was misidentified as a potentiometer. This suggests that while the model is highly effective, there are areas, particularly in distinguishing between actual components and background noise, where further refinement could improve overall accuracy. This matrix highlights the strengths of the recognition model in identifying the main components while also pointing out specific areas where the model could be enhanced to reduce misclassifications, especially in differentiating between background and actual elements.

4.3.1 Training the Neural Network for DIP-Switch and Potentiometer parameter recognition

As previously mentioned in the section 3.3, training the DIP switch and potentiometer prediction models required a substantial amount of data. Fortunately, the images didn't have to be label manually. To assist with this, a Python program was developed that takes thousands of manually labelled images and applies various transformations to expand the dataset, thereby improving the training process. The transformations are relatively straightforward:

- For the potentiometer, the image orientation was changed multiple times to simulate different positions of the potentiometer, enhancing detection and recognition, especially in highly deteriorated images. Some images were also subjected to predefined filters, such as contrast, colour exposure, and noise, with the labels adjusted accordingly to match the transformations.

- For the DIP switch, a similar process was applied, but with a 180-degree rotation to artificially flip the switch in the opposite direction.

This technique generated a large dataset, but a way to train the model was still needed to ensure accuracy. Machine learning, as a tool, learns from a dataset, but this learning process is governed by rules and limitations. For each training session, we set several epochs, which define the number of generations of our neural network. The goal is to continually generate new neural networks based on the previous one, with small changes in the architecture of nodes and links—a process known as mutation. After each epoch, the model is tested to evaluate its performance on the desired task using indicators like Loss and MAE. If the results are satisfactory, the model serves as the basis for further training. This cycle describes the life of one epoch, but to create a model capable of accurately determining the position of the potentiometer or DIP switch, we needed to fine-tune the hyper-parameters to reduce the Loss and Mean Absolute Error (MAE) to acceptable levels:

- Loss refers to a function that measures the difference between predicted and actual values. Minimizing the loss function is central to improving model accuracy. Different types of loss functions are used depending on the problem type (e.g., regression or classification).

- Mean Absolute Error (MAE) is a specific loss function used mainly in regression tasks. It calculates the average absolute differences between predicted and actual values.

To better understand and optimize these parameters, I attended several lectures at CERN on machine learning and hyper-parameter tuning. Some key aspects include:

- Learning Rate: This parameter determines the extent of mutation applied to the neural network between epochs. It dictates how much the network changes between generations. High learning rates are useful in early training stages but should be decreased in later epochs to help the model converge to a lower Loss value.

- Batch Size: This is a subset of the training data processed in one iteration, offering benefits like improved memory efficiency, faster computation, reduced overfitting, and enabling parallelization for quicker training with multiple processors or GPUs. This approach balances computational efficiency, memory usage, and training speed, which is crucial for effectively training large models.

With these parameters optimized, two predictive models were successfully trained : one with an average precision of 25 percent for the potentiometer and an 70 percent accuracy rate for the DIP switch. Despite potential for further improvement, the automatic Circuit Breaker Reader was prioritized.

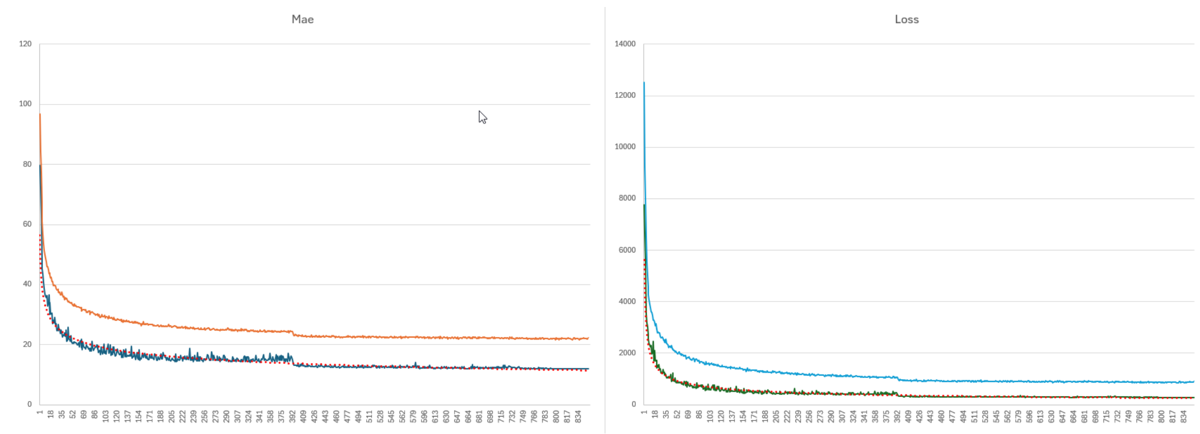

Figure 8: Summary of a training for the potentiometer recognition neural network

4.4 System Operation

The final system allows users to upload many images to the program, which then starts its recognition process. The first step is to extract the Regions of Interest (ROI) from the images—two ROIs are relevant in our case: the signalling plate of the circuit breaker and the setting devices (DIP switch, potentiometer). After extracting this data, the orientation module independently reorients the different ROIs within the same image, which is necessary due to the varying orientations of the setting devices and plates on some circuit breakers. The program then interprets the ROIs using two different approaches:

- Signalling Plate: The ROI is processed through the EasyOCR program to extract most of the readable text. The extracted text blocks are then combined into a single string, starting with the first word in the upper right corner of the ROI. Using this strategy, we obtain a rough guess of the circuit breaker type, which is then refined by a string comparator that matches the text with a pre-made database of circuit breaker names. This data enables us to extract additional information from the database.

- Potentiometer and DIP Switch: These ROIs are passed through a simplifier to facilitate accurate predictions by the trained neural network. After analysis, the system returns a prediction of the device's position.

Finally, the program generates an Excel file summarizing the results: circuit breaker type, image name, date of the image, and settings of the circuit breaker.

The overall performance of this application is reasonable, providing predictions with a certain level of confidence. However, errors still occur, particularly when images are too deteriorated for the neural network to interpret, leading to erratic behaviour and high error rates. This issue is unfortunately too common to fully delegate the identification work and database feeding to the program. However, the model seems to remain insensitive to these new modifications, raising a complex problem in machine learning: Are we sure the neural network is learning the correct properties? After all, a neural network is driven by its goal to match labelled data, and it often develops complex methodologies that don't always align with human logic.

4.4.1 Performance and Ongoing Improvements

The application performs reasonably well, though errors occur with deteriorated images. Ongoing improvements include training with new methods to expand the dataset and addressing potential issues with the neural network's learning process.

5 Evaluating Transformer Performance: Testing Methods and Results

An experiment was conducted with my supervisor on a transformer. This equipment is one of the most important tools electricians use to manage powerful electrical currents and provide electricity at usable voltages. Like all electrical components, understanding and studying transformers is crucial to comprehending their electrical parameters. These parameters can further be implemented in a standard model, which can be found in the reference.

A transformer is an electrical device designed to transfer energy between circuits through electromagnetic induction. It consists of a laminated silicon steel core to minimize energy losses, primary and secondary winding made of insulated copper or aluminium wire, and terminals for external connections. Larger transformers are housed in oil-filled metal tanks with cooling systems to dissipate heat and may feature tap changers for voltage adjustment. Insulation materials and bushings ensure safe operation, while protection and monitoring devices, such as pressure relief valves and temperature gauges, maintain reliability and safety[Glover and Sarma(2002)].

To test a transformer, a power supply was required capable of delivering high currents and voltages, this device is called the "Raptor." [rap(2017)] This transformer can boost current to high voltage levels (e.g., 1000V for the NCF-15-100) and is equipped with various measurement tools to carefully analyse and monitor the data output by the transformer. The Raptor also features a touchscreen interface for controlling the transformer's operation during the test and can calculate large amounts of data collected by its sensors.

Before starting any test, the operation was meticulously planned by using the equipment manuals. The aim of the test was to evaluate the percentage impedance (%Z), which indicates the voltage drop within the transformer when delivering full load current, as well as the iron and copper losses. These losses affect transformer efficiency and performance. Fortunately, thanks to the transformer documentation it was known what the expected values should be,

Two common tests used to obtain these values are the Short Circuit Test and the Open Circuit Test. In both cases, applying current or voltage at the transformer's nominal settings can be hazardous, so several precautions were taken:

- Secondary measurement tools were used to ensure the transformer's settings were not exceeded and to protect against potential sensor faults.
- The transformer was placed on an insulation plate to prevent any current leakage during testing.
- The Raptor was programmed with the transformer's limit data to trigger an automatic safety stop in case of a fault.

During the Short Circuit Test, the output coils of the transformer were securely short circuited using a WAGO connector, allowing us to neglect shunt admittance. For the Open Circuit Test, the coils were left disconnected, and the conductive parts of the coil were carefully taped to prevent any unwanted current leaks. Finally, a resistivity test was conducted on the coils using an ohmmeter. This test ensured the transformer's integrity and helped validate the data obtained in the earlier tests.

5.1 Simplified model of a transformer

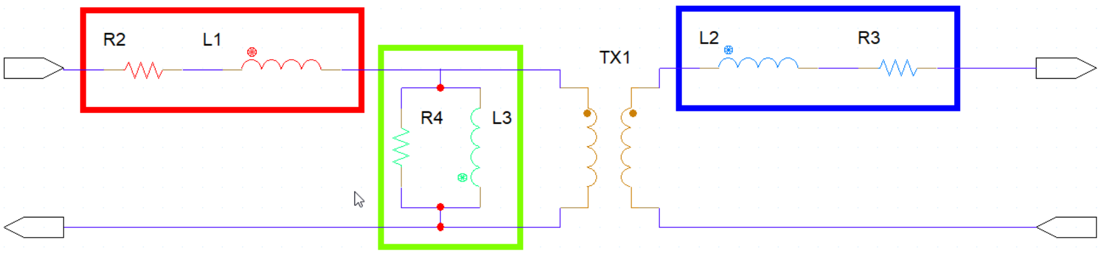

Figure 9: Equivalent circuit of a Transformer

The image depicts a simplified electrical model of a transformer, illustrating key components associated with its primary and secondary circuits. The red rectangle on the left represents an RL series circuit consisting of a resistor (R2) and an inductor (L1), which model the primary winding resistance and leakage inductance of the transformer. The green rectangle in the center shows an RL parallel circuit with a resistor (R4) and an inductor (L3), representing the core loss resistance and magnetizing inductance, which are crucial for modeling the transformer's core behavior. On the right, the blue rectangle displays another RL series circuit with an inductor (L2) and a resistor (R3), corresponding to the secondary winding resistance and leakage inductance. These components together provide a comprehensive representation of the transformer's electrical characteristics, including losses and magnetic properties:

- Red Rectangle: Primary winding resistance and leakage inductance (RL series circuit).
- Green Rectangle: Core loss resistance and magnetizing inductance (RL parallel circuit).

- Blue Rectangle: Secondary winding resistance and leakage inductance (RL series circuit).

The goal of the experiment is to assign the correct resistivity values to all the components to ensure an accurate model of our transformer and enable effective simulation.

5.2 Short Circuit Test

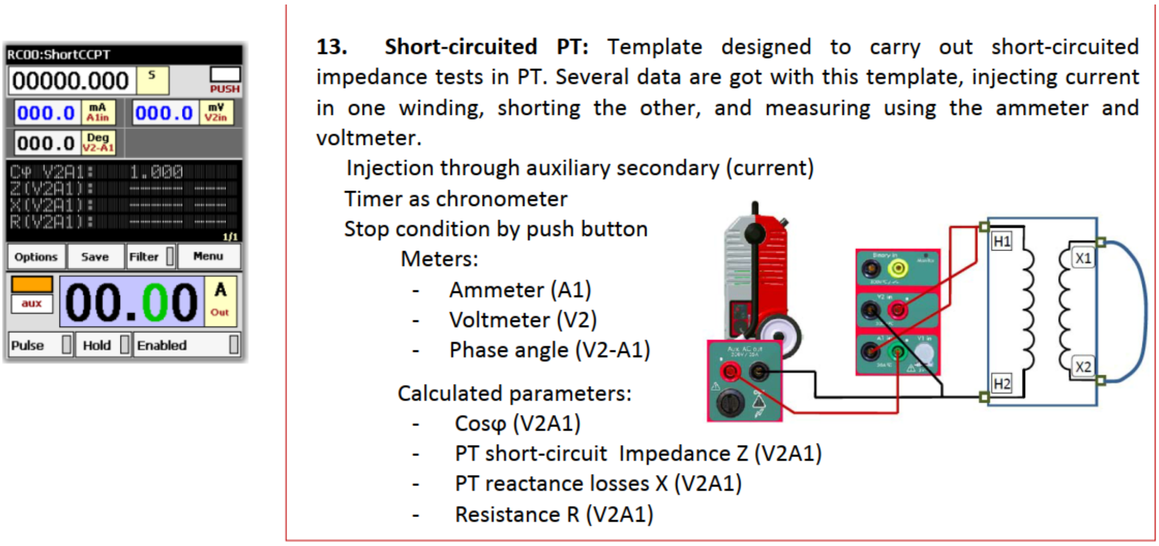

Figure 10: Schematics use for the wiring of the Transformer and the Raptor [rap(2017)]

The Short Circuit Test aims to measure impedance, reactance, and copper loss of the transformer. This test is crucial for understanding how the transformer behaves under high current conditions.

5.2.1 Test Setup

For the settings of the Raptor, the premade template No. 13 was used which performs the following measurements/calculations:

- Primary voltage measurement
- Primary amperage measurement
- Reactive/Active power angle
- Cos (Phi) - Calculated
- Impedance - Calculated
- Reactance - Calculated
- Loss - Calculated

To conduct this test, two WAGO connectors were used to create the short circuit between the secondary coils. In total, three tests were performed: one for the first secondary coil, one for the second secondary coil, and one with both coils in short circuit.

The estimated current on the primary side has been defined by the formula:

$$I_{\text{nom}} = \frac{P_{\text{nom}}}{V_{\text{nom}}} = \frac{1\,\text{KVA}}{230\,\text{V}} = 4.35\,\text{A}$$

This estimated current on the primary side was divided by two when the single coil tests were performed (First & Second Test).

5.2.2 Results

The following results were obtained for three different configurations:

	1st Test: UCC12 (Orange-Yellow)	2nd Test: UCC13 (Red-Black)	3rd Test: UCC123 (Orange-Yellow & Red-Black)
A1in (A)	2.28 A	2.30 A	4.68 A
V2in (V)	7.21 V	7.47 V	10.09 V
Deg [V2-A1]	2.20°	3.10°	3.50°
Power Loss (W)	16.43 W	17.16 W	47.13 W
Cos(ϕ) [V2-A1]	0.999	0.999	0.998
Z (Impedance) [V2-A1]	3.16 Ω	3.25 Ω	2.16 Ω
X (Reactance) [V2-A1]	121.39 mΩ	175.64 mΩ	131.90 mΩ
R (Loss) [V2-A1]	3.16 Ω	3.24 Ω	2.15 Ω
Asec (Orange-Yellow)	11.10 A	11.10 A	11.10 A & 11.30 A
Aout (A)	2.35 A	2.37 A	4.73 A
Z%	3.13%	3.25%	4.39%

Table 1: Results of the Short Circuit Test using Raptor and Transformer 1000P1-2-045

Finally, a dummy model was created of our transformer to verify the impedance of the general model and our hypothesis. This model was made using a scholarly electrical simulation tool called CrocoClip, which is a very good tool for test measurement in low-voltage simulations. The schematics were reproduced with actual values from the tests conducted. The leakage inductance was 131 milliohms, and the copper loss resistance was 2.15 ohms. The average voltage for this circuit was very close to the actual voltage, 10.7 V compared to 11.0 V, and the current nearly matched the input current of the actual transformer, with a value of 4.70 A compared to the desired 4.68 A. As the model closely matched the values of the actual transformer the model is assumed to be correct.

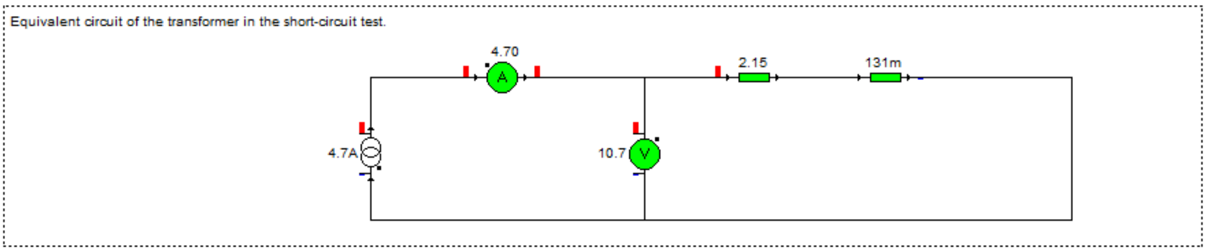

Figure 11: CrocoClip: Simplified Transformer schematic

5.3 Open Circuit Test

The Open Circuit Test evaluates iron losses of the transformer when no load is connected to the secondary coil.

5.3.1 Test Setup

A homemade template was used for the Raptor settings, which included:

- Primary voltage measurement [Measured]
- Primary amperage measurement [Measured]
- Reactive/Active power angle [Measured]
- Cos (Phi) [Calculated]

Application of Tests: the coil was secured with some Wago connectors to prevent the conductive part from coming into contact with anything, and the input voltage was increased to estimate the difference between the input and output current."

5.3.2 Results

The following results were recorded:

Table 2: Open Circuit Test Results

Measurement	Value	Unit
A1in	0.02	A
V2in	228.80	V
Power Loss	4.19	W
Cos(phi)	0.974	
Vout	230.00	V

The circuit used for this test is the same as the one used for the first test.

5.4 Resistivity Test

The Resistivity Test measures the copper losses by evaluating the resistivity of the coils.

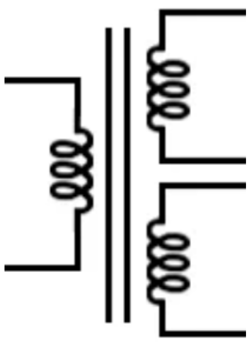

Figure 12: Schematics of a one primary, two secondary windings transformer [All About Circuits()]

Three test is required to fulfill this task :

- The primary on the left side of the picture
- The first secondary coils on the upper right of the picture
- The second secondary coils on the down right of the picture for each of them a ohmeter was used to test the average resistivity of the coils

5.4.1 Test Setup

A multi-meter was used in series with the coils to measure resistivity. The small resistivity of the multi-meter's cable was subtracted from the measurements.

5.4.2 Results

The following resistivity measurements were obtained:

Table 3: Resistivity Test Results

Measurement	Error	Measure	Real
R-B	$0.30\,\Omega$	$0.40\,\Omega$	$0.10\,\Omega$
B-B	$0.30\,\Omega$	$1.40\,\Omega$	$1.10\,\Omega$
O-Y	$0.30\,\Omega$	$0.40\,\Omega$	$0.10\,\Omega$

5.5 Test Result

The results from the transformer testing closely matched the documented values, though slight discrepancies were observed. These differences can be attributed to ambient temperature effects on resistance. The transformer's copper resistance should have increased with heat generated during operation, but was not significantly observed during our short-duration tests. As mentioned earlier in this document, the goal of the experiment was to model the simplified circuit of a transformer. The test results were:

- Primary resistance: 2.15 ohms
- Primary leakage inductance: 131 milliohms
- Combined resistance and inductance of the secondary coil: 100 ohms

Unfortunately, due to time constraints the core loss resistances were unable to be measured. However, with the data collected, a robust model for simulating our transformer was still created.

6 Conclusion

To conclude, the database built through the manual scavenging of pictures can improve the way the DDO team plans their work by adding a new piece of information to their library regarding the devices installed. This work needs to be kept up to date to ensure the validity of the data. As discussed in Section 3, the development of the tools is not yet complete, but the goal remains valuable due to the significant number of devices installed at the CERN site. This can save a considerable amount of time despite some weaknesses in the algorithms, as there is still room for improvement in the program to fully achieve its objectives. Finally, the tests conducted on the transformer helped us understand the internal workings of the device and confirmed predictions based on construction data. Although this is not a guarantee of success for the installation of the device, the tests conducted assist in planning for future installations, such as the circuit breaker settings, and provide a preliminary fail-safe approach to the circuit.

References

[rap(2017)] *Primary Injection Testing System User's Guide: Raptor*, October 2017. Raptor Reference: KAXVMV02, Version 4.

[All About Circuits()] All About Circuits. Winding configurations. URL https://www.allaboutcircuits.com/textbook/alternating-current/chpt-9/winding-configurations/. Accessed: 2024-08-30.

[EEP - Electrical Engineering Portal(2023)] EEP - Electrical Engineering Portal. 6 adjustable tripping settings of a circuit breaker you must understand, 2023. URL https://electrical-engineering-portal.com/6-adjustable-tripping-settings-circuit-breaker#ground-fault-pickup. Accessed: 2024-08-28.

[Glover and Sarma(2002)] J. Duncan Glover and Mulukutla S. Sarma. *Power System Analysis and Design*. Brooks/Cole, Thomson Learning, 3rd edition, 2002.

[Ultralytics(2024)] Ultralytics. *YOLOv8 Online Documentation*, 2024. Available on GitHub.