

Interpreting the results of circuit breaker analysis?

Important tests during circuit breaker analysis and the interpretation of the measured results - coil current, dynamic contact resistance and motion analysis

1 Introduction

Circuit breakers are like insurances for every energy distribution network. They are there in case something bad happens. And if it happens, they have to do their duty and prevent any further damage. Therefore circuit breakers need to be inspected regularly to assure that they are operating as specified. Cutting-edge circuit breaker-analyzing devices provide methods which help identify malfunctions or worn parts of a circuit breaker.

In order to achieve a condition assessment in a time-efficient manner an analysis must be done, preferably without disassembling the circuit breaker.

2 Different measurements and their interpretation

For a reliable condition assessment of a circuit breaker it is of vital importance to have a correct interpretation of the results obtained during an analysis. As the interpretation of a timing analysis is pretty straight forward it will not be discussed any further in this article. However, to draw the right conclusions from

- coil current analysis,
- dynamic contact resistance measurements, and
- motion analysis,

more background knowledge about what is going on inside a circuit breaker is required.

These three methods are widely used worldwide for a successful condition assessment of circuit breakers. However, our daily work reveals that there are usually a lot of open questions when it comes to the interpretation of the measured results.

The **coil current analysis** of the trip coil gives you a deeper understanding on what is going on during the closing or opening sequence of the main contacts. By taking a closer look at the coil current a lot of useful information can be revealed. For instance:

- the electrical properties of the coils, such as the time constant,
- the force, i.e. current which is proportional to that force, and must be applied in order to trigger the loaded spring,
- the correct timing sequence of the auxiliary contacts 52a and 52b.

Measuring the **dynamic contact resistance** combined with a motion analysis is an approach that is commonly used for determining the length and the condition of the arcing contact without disassembling the main contacts of the circuit breaker. That contact underlies a natural abrasion, because each time a circuit breaker is tripped during load, an arc is created which vaporizes parts of the arcing contact. Due to this process-related abrasion the contact must be inspected regularly in order to avoid any malfunctions. When the contact length goes below a reference value given by the manufacturer, the correct functionality of the circuit breaker cannot be guaranteed any longer and the breaker must undergo maintenance.

A **motion analysis** can detect weak mechanical components of a circuit breaker. This, for example, can be worn out damping units, problems with storing the energy (a worn spring or leaking pressure system) for tripping or closing, and contacts which have already reached the end of their life cycle.

By detecting these problems at an early stage, counteractions can be applied to guarantee a safe circuit breaker operation and ensure reliable distribution of electrical energy throughout the grid.

3 Interpretation of coil current analysis

During a coil current analysis the current flow in the trip or close coil during the closing or opening sequence of the main contacts is measured and displayed in a diagram over time. Resulting curve deviations from the electrical coil properties that are expected (time constant), the necessary driving force (proportional current), and the correct timing sequence of the auxiliary contacts are indicators for electrical or mechanical problems within the trip and close mechanism of the circuit breaker. An interpretation of the different curve sections is given in the following diagram.

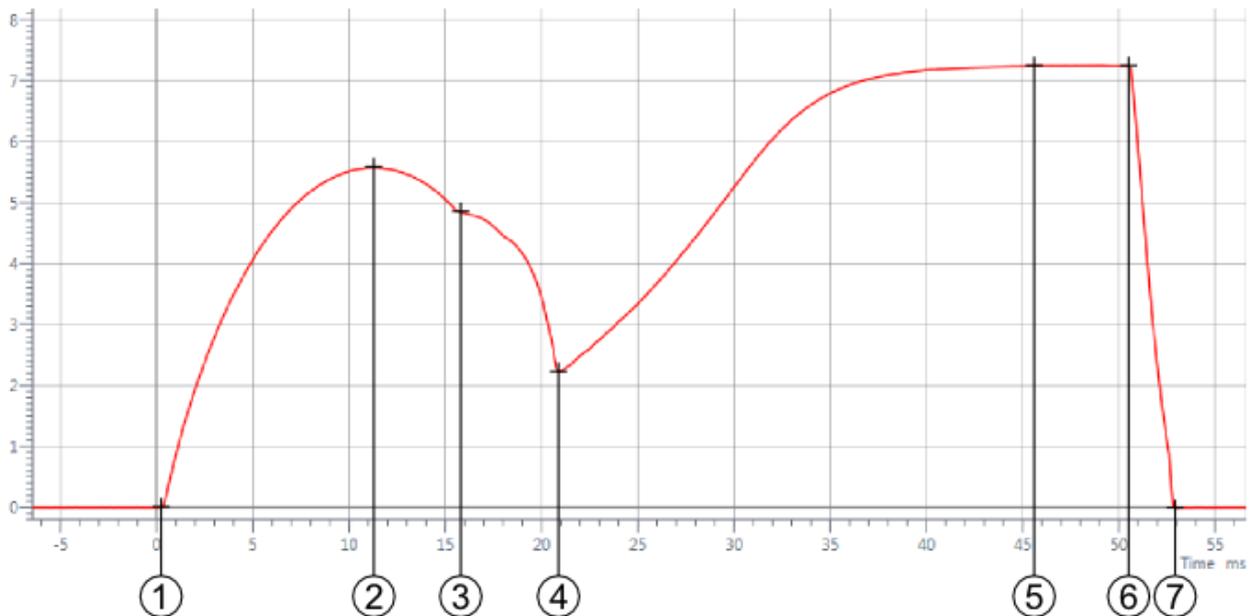


Figure 1: Typical curve of coil current flow

Curve section 1 to 2

After the coil has been energized the current starts to flow. The speed of the current rise depends on the coil impedance. That impedance depends on the position of the armature, which is still static between point 1 and 2 of the curve (see Figure 2). After point 2 the armature starts to move out of the coil.



Figure 2: Coil at Point 1

Any current flow deviation in this section indicates a problem with the electrical coil properties and the voltage supply. Here it is important to make sure that the coil even trips at an undervoltage condition.

The time constant (L/R) of the coil can be calculated by measuring the time between point 1 and point 2 and the peak current at point 2. If the time constant of the coil deviates from the reference value it indicates that a coil is damaged (e.g. short-circuited windings).

Curve section 2 to 3

The moving armature induces a back e.m.f. which causes a reduction of the coil current. A slow movement of the armature is an indicator that lubricant has entered the wrong area.

Point 3



Figure 3: Coil at Point 3

Here the armature hits the trigger which up to this point kept the charged spring from moving (see Figure 3). The armature must have sufficient power to overcome the mechanical resistance of the trip mechanism.

Any deviations here are usually an indicator of oil or grease within the coil area which causes a damping effect on the movement.

With the help of the coil current diagram in that section a poorly aligned armature-trigger configuration or obstacles blocking the trip mechanism can also be identified.

Curve section 3 to 4



Figure 4: Coil between 3 and 4

The armature releases the charged spring and keeps moving until it reaches its end position (see Figure 4). The current level decreases until the armature comes to a stop. A deviation from the lowest current value indicates that the armature did not reach its designated end position due to a mechanical issue.

Curve section 4 to 5



Figure 5: Coil between 4 and 5

Now that the armature has come to a stop, back e.m.f is no longer generated to reduce the current flow (see Figure 5). Therefore the current level increases again. However, this time the current value reaches a higher level, because the coil inductance has changed due to the displacement of the armature. A deviation from the expected time constant indicates once again that there is electrical damage in the coil windings.

Point 5

At this time the current has overcome the coil inductance and stays constant until the auxiliary contact opens and interrupts the current flow. An early or delayed interruption indicates that the timing between the main and auxiliary contacts (52a and 52b) needs to be adjusted.

Point 6

Between the release of the charged spring at point 3 and point 6 the main contact and (with a short delay) the auxiliary contacts change their state and open.

Curve section 6 to 7

The changing state of the auxiliary contact interrupts the voltage supply to the coil and therefore the armature starts to move back into the coil until it reaches its starting position again. A slower current decrease or even short current increase may show that the movement of the armature has been decelerated. A strong deviation from the reference value indicates mechanical friction or a damaged recovery diode.

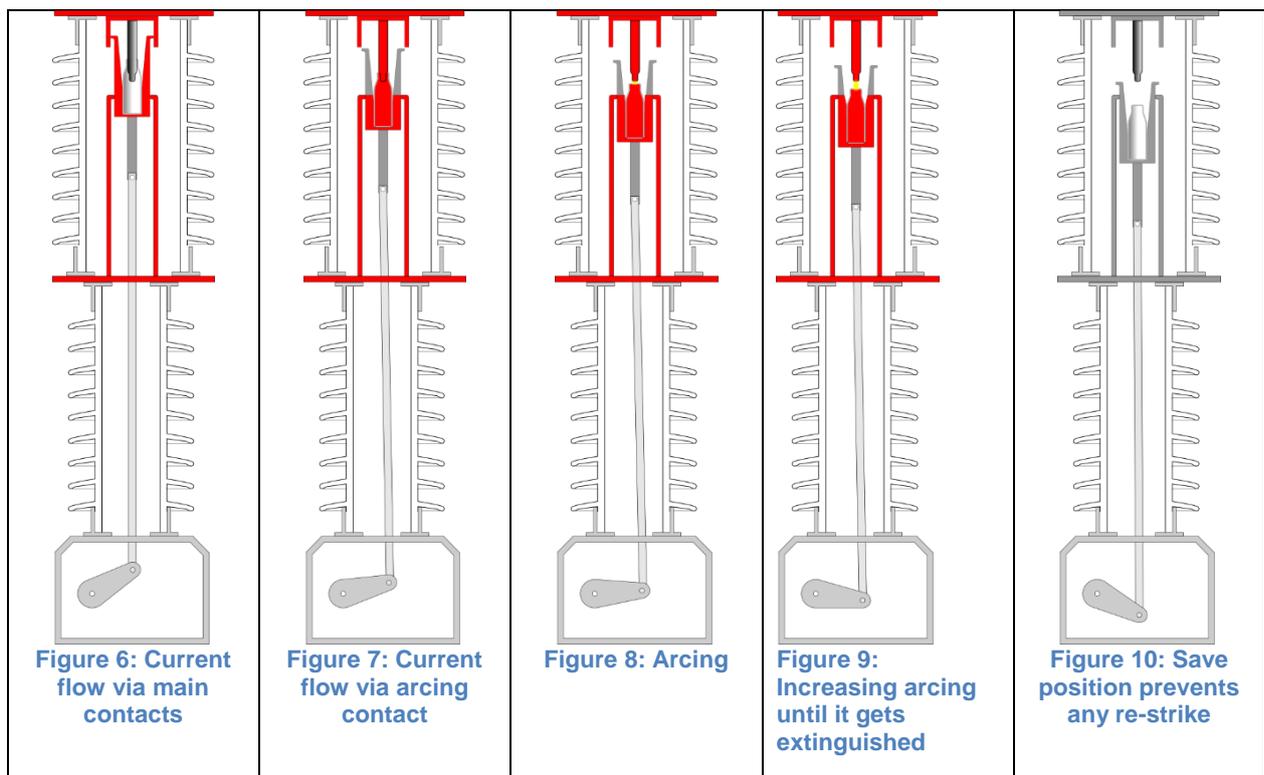
4 Interpretation of DRM results

Motivation for the dynamic contact resistance measurement

A dynamic contact resistance measurement is a commonly used method, because it determines the contact length without having to disassemble the circuit breaker.

When the arcing contact becomes shorter than the minimum requirement specified by the circuit breaker manufacturer, a safe operation can no longer be guaranteed and the interrupter unit needs to be maintained properly.

In order to apply that method it is important to know the components of an SF6 circuit breaker interrupter unit and how the current is interrupted during an open operation. Figure 6 through 10 show the different phases of an opening sequence.



Detailed description of an opening sequence

When the interrupter unit is closed, the current flows via the main and arcing contact of a circuit breaker (see Figure 6). As soon as the opening process starts, the main contacts are separated first and now the current flows only via the arcing contacts (see Figure 7). After a few milliseconds the arcing contacts also move apart but the current continues flowing, because the voltage across the contacts initiates an arc

(see Figure 8). As the sinus-shaped current crosses the zero point the dielectric strength between the contacts is sufficient enough to resist a re-initiation and the ionised gases are removed. At this point the arc is extinguished.

The contacts continue to separate, increasing the dielectric strength threshold as the voltage across the contacts increases, preventing any restrike (see Figure 10).

During each opening process the resulting arc destroys parts of the arcing contact material. The amount of wear depends on the current level. With higher currents more contact material is burned away. During the arcing stage the current is only limited by the supply circuit impedance.

Determination of contact length

The dynamic contact resistance method measures the contact resistance continuously during the opening operation of the circuit breaker's interrupter unit. This is done with the breaker being isolated from the HV supply and performing a four wire resistance measurement test during the opening operation.

The dynamic contact resistance measurement goes through the phases shown in Figure 6 through 10. They show an increase in resistance as the contacts open. As soon as the main contact is open, a steep decrease can be seen.

Now the arcing contact is the only connection. The resistance level shows strong deviations. They are caused by the noise produced during the arcing process.

When the arcing contact movement comes to an end, the resistance increases again until it exceeds the measurable limit and becomes infinite (i.e. contact is open).

The arcing contact length is determined by measuring the time between Figure 7 and 8 (i.e. time of current flow via arcing contact until interruption). This time is used for calculating the actual contact travel (see Figure 11).

A closing operation is usually not used for dynamic contact resistance measurements, because the mechanical forces applied to the contact fingers would result in an extremely „noisy“ resistance measurement.

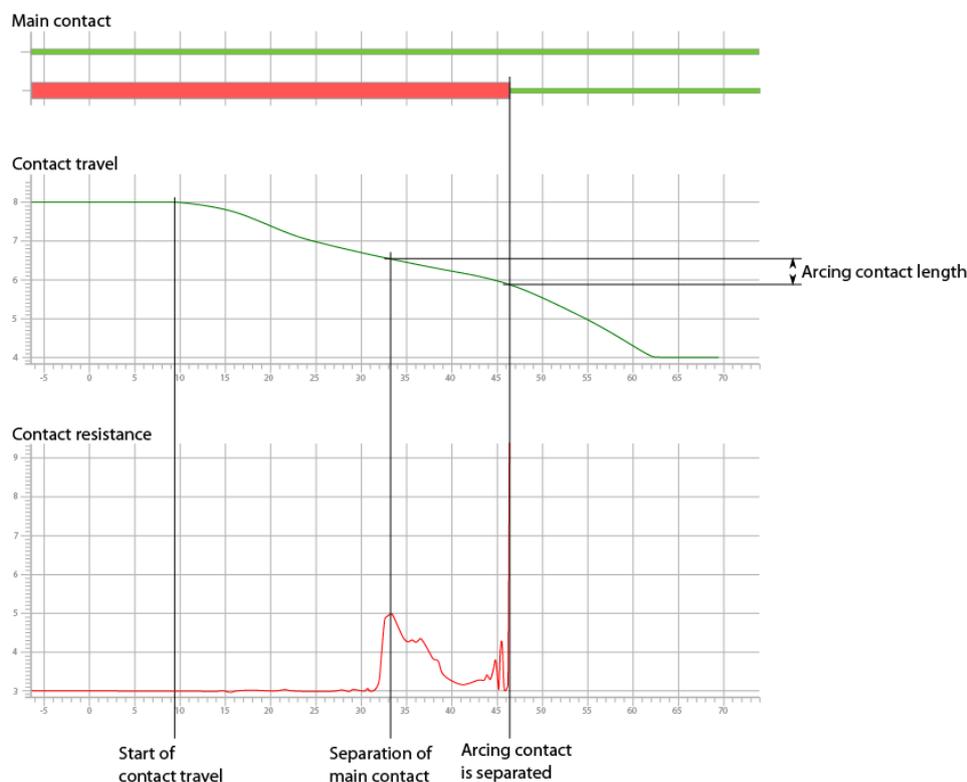


Figure 11: DRM curve interpretation

5 Interpretation of motion analysis

A motion sensor attached to the mechanical linkage of a circuit breaker reveals a lot of useful information. Therefore it is highly recommended to use this method for tracing the motion of the current interrupting mechanism.

In order to classify the condition of the damping units and mechanical issues of the circuit breaker's operating mechanism, the important performance parameters to take note of are the overtravel (amplitude, duration), total travel, and timing behaviour of the contacts.

Each motion analysis compares the reference data specified by the circuit breaker manufacturer with the measured values.

The following shows the measurement curves of the three performance parameters mentioned above and their interpretation.

Overtravel curve

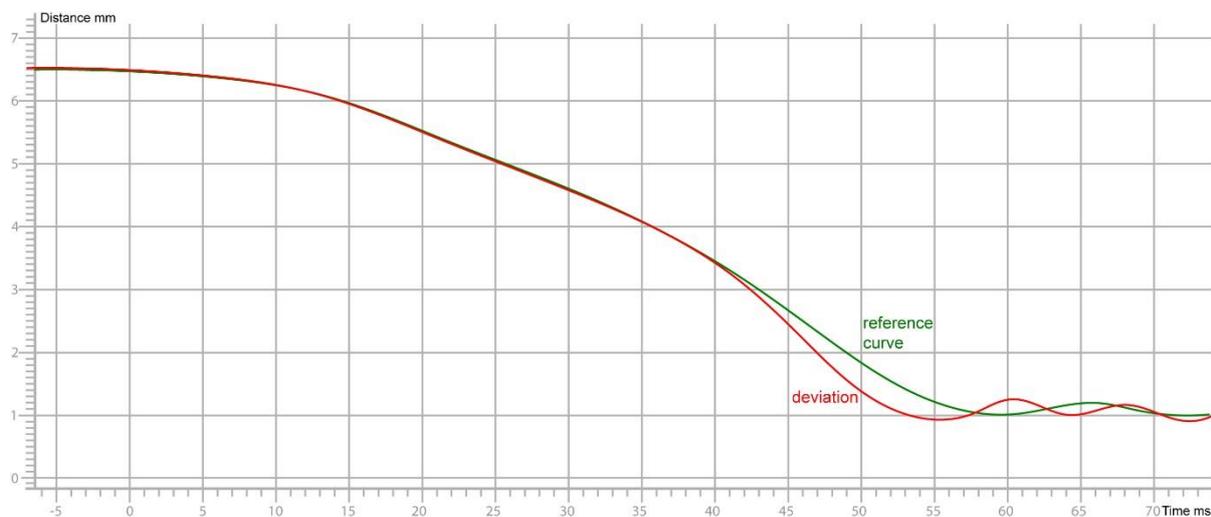


Figure 12: Overtravel curve

The overtravel curve displays the motion of the main contacts over time. An excessive oscillation at the end of the curve indicates a defective damping system.

The purpose of the damping system is to be able to avoid any damage to the mechanical components by slowing down the motion of the contacts after they have reached a safe position.

Quite often dash pot-based systems are used which have the same functional principle as the suspension systems found in cars.

As seen here in the motion trace, the damping effect of these components is velocity dependent and they are designed to slow down the moving contacts before they reach the end position.

Total travel curve

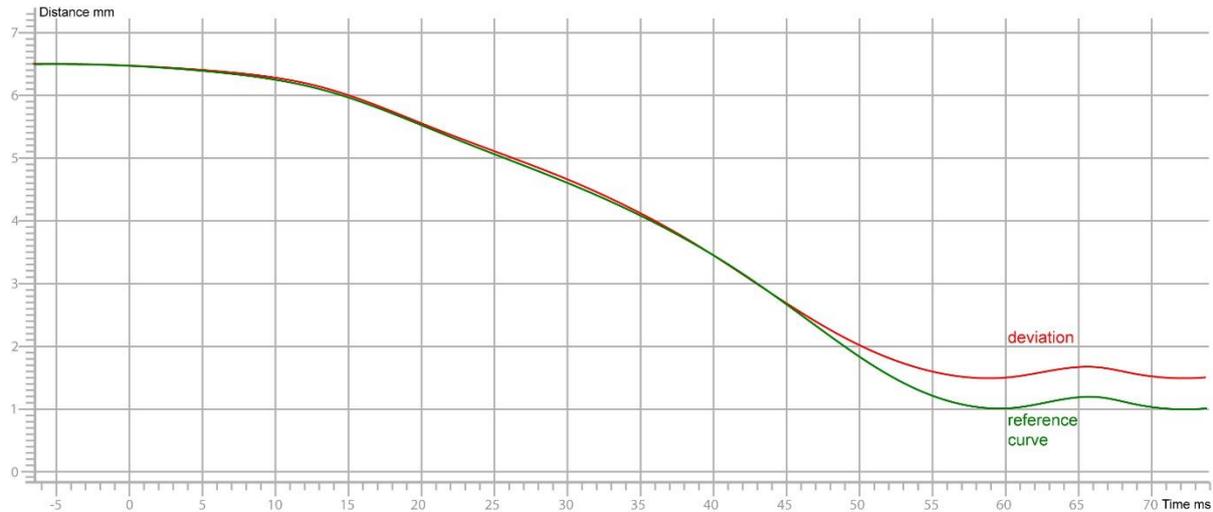


Figure 13: Total travel curve

The total travel curve shows the difference between the start and end position of the main contacts over time. If the total travel varies from one measurement to the next this might be an indication of the fact that there was not enough energy stored (a worn spring or leaking pressure system) or the energy consumed by the motion itself has increased because of higher friction forces (corrosion at circuit breaker or mechanical parts).

Timing behaviour curve

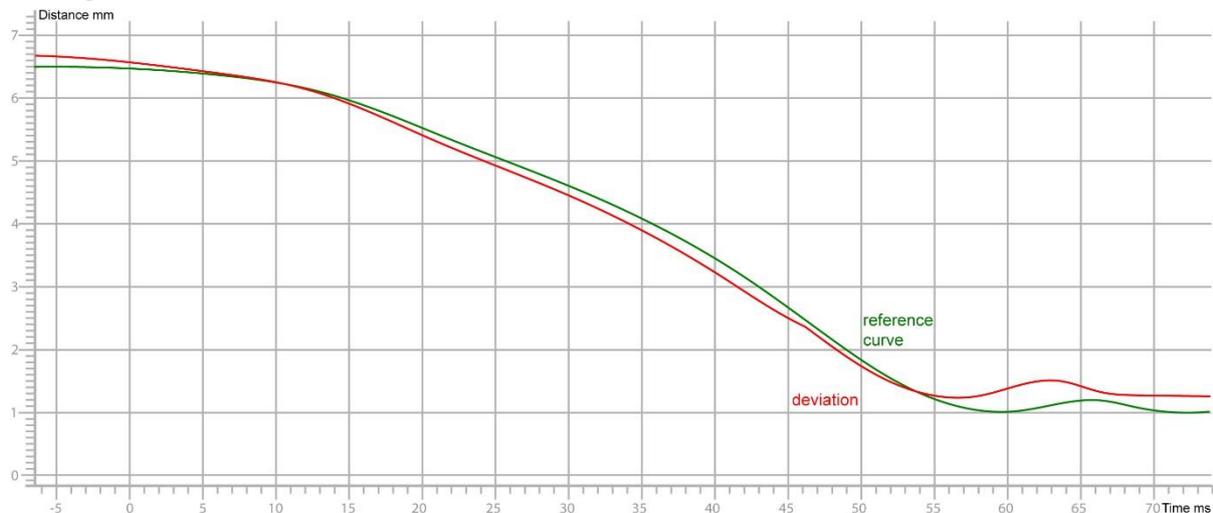


Figure 14: Timing behavior curve

The timing behaviour curve displays the motion of the contacts over time.

When the motion starts earlier than it has in previous measurements this might indicate that the contacts are worn.

When the motion in previous measurements starts at the same time but finishes earlier this indicates a change in energy balance. This means that during the last measurement more energy was stored (higher pressure in pressure system) or the contact movement itself has consumed less energy than it has during the previous measurement (contact which is too short).

Anyway, it is important to state that the contacts must be within their minimum and maximum opening time as specified by the manufacturer. Otherwise the breaker must undergo maintenance.

Contacts must not open too quickly, because they would not be able to deal with a transient short-circuit current. On the other hand, they must not open too slowly in order to avoid a restrike of an arc that has already been extinguished.

6 Summary:

In a conclusion it can be said that with a proper interpretation of the results obtained by the coil current analysis, dynamic contact resistance measurements and motion analysis an overall assessment of the circuit breaker's most important electrical and mechanical properties can be given. This gives the user additional information about the results already obtained through standard methods such as static contact resistance and general timing measurements. With this information it is much easier to decide whether the circuit breaker must undergo any maintenance or if it is still fit for operation.



Andreas Nening has a degree in automation engineering and mechatronics obtained by the university of applied science in Dornbirn, Austria. Since September 2013 he has been product manager of OMICRON's new circuit breaker test set CIBANO 500. He started his professional career with an apprenticeship at the municipal utilities of Feldkirch, Austria. Later he graduated as Master of Science at the university of applied science in Dornbirn, Austria. After that he spent several years abroad working as application engineer and project leader before finally returning to Austria working as product manager in the field of decentralized renewable energy. Andreas is member of the Cigré Working Group A2.32 (Non-intrusive methods for condition assessment of circuit breakers).

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