American Journal of Science, Engineering and Technology
2022; 7(3): 77-86
http://www.sciencepublishinggroup.com/j/ajset
doi: 10.11648/j.ajset.20220703.13
ISSN: 2578-8345 (Print); ISSN: 2578-8353 (Online)

Digitalization of Air Insulated High Voltage Disconnectors and Earthing Switches

Mariusz Rohmann[1], Dirk Schraeder[2]

[1]Research and Development Queretaro, Siemens Energy S. de R. L. de C. V., Queretaro, Mexico
[2]Research and Development Mechanical Engineering and Testing, Siemens Energy Global GmbH & Co. KG, Berlin, Germany

Email address:
mariusz.rohmann@siemens-energy.com (M. Rohmann), dirk.schraeder@siemens-energy.com (D. Schraeder)

To cite this article:
Mariusz Rohmann, Dirk Schraeder. Digitalization of Air Insulated High Voltage Disconnectors and Earthing Switches. *American Journal of Science, Engineering and Technology*. Vol. 7, No. 3, 2022, pp. 77-86. doi: 10.11648/j.ajset.20220703.13

Received: June 23, 2022; **Accepted**: July 13, 2022; **Published**: August 4, 2022

Abstract: The product digitalization is nowadays part of almost any product development, so that the digitalization of air insulated high voltage disconnectors and earthing switches will be introduced. The motivation by consequences for the product installation and maintenance are given and necessary considerations for the different available and required operation methods of the product are included. Possible data sources within the product are categorized and applied use cases are explained. The possible use cases are covering the switching position, counted operations including forecasting and the monitoring of the anti-condensation heating, as simple use cases. Those are complemented by highly beneficial use cases, as the more known and expectable motor current monitoring and the overcurrent allowance, which is driven by the indirect proportionality of a temperature rise at one current value to a temperature rise of a second current value and the resulting quotient of both currents to the same potency, as per IEC TR 62271-306. The overcurrent allowance use case may not be as expectable, since the IEC reference is not directly related to disconnector and earthing switches, and therefore its underlying calculation methodology is explained and elaborated in detail with boundary conditions and its visualization by a case example. The calculated temperature rise factor is introduced and different safety margins are highlighted. Further use cases with information about realization complexity and potential benefits are complementing the product digitalization possibilities and opportunities. Finally, the applied use cases are illustrated by an executed example of a digitalized center break disconnector.

Keywords: Disconnector, Current Path, Digitalization, Use Cases, Switching Position, Motor Current, Overcurrent, Temperature Rise

1. Introduction

Air insulated high voltage disconnectors are occurring in high quantities within substation compared to other equipment. For example, there will be a minimum of two disconnectors for each circuit breaker in the substation with a single busbar installation. This minimum quantity per bay will be increased by additional equipment like e.g., current transformers and additionally by e.g., more complex layouts like a double busbar arrangement. The disconnector quantity reflects of course the efforts to be considered in regards of installation and maintenance activities. The fact, that disconnectors are needed for isolating other products within a substation, so that provision of a save state for maintenance activities is given, is essential and drives the disconnectors quantity need within a substation [8-12].

The installation activities as such for the product set-up are not tackled here, but if it comes to the operating mechanism for the product and its control, the installation activities contain a cabling effort for each device dependent on the complexity of the control features incorporated in the operating mechanism. The right digitalization concepts will allow a significant reduction of those efforts.

The efforts for maintenance activities will be significantly reduced if predictive maintenance is achieved. The digitalization has as one main goal the application of measurements and data provision to achieve the predictive maintenance. On the other hand, the given product quantities within a substation directly drive the investment efforts for the product digitalization, so that simplest digitalization solutions are critical. This implies the challenge of simple and ready-to-use measurement solutions still adequate for the necessary data achievement and lowest wiring efforts. Complex and relatively sophisticated solutions, even though well available on the market and known to the common literature, are consequently not suitable.

Finally, enhancements of the product performance will be possible with the right measurements and data analysis.

2. Disconnector Operation

The operation of disconnectors and earthing switches can be realized with one operating mechanism operating all three poles or with one operating mechanisms for each pole individually. As this is having significant implications on any digitalization solution, it needs specific consideration.

Measurements considering significantly or being highly dependent on the kinematic chain will have specific data details (e.g., distinctive appearance of a characteristic curve). Beside influences by size (rated voltage) or rated continuous current (contact system size / contact finger quantity) or switching capability feature (secondary contact system) [1, 2, 7].

2.1. Triple Pole Applications (Mechanically Ganged)

In cases where the operating mechanism is operating 3 poles of a disconnector or earthing switch at once, the poles need to be mechanically ganged (mechanical linkage between the poles, extended kinematic chain). Consequently, any measurement used for data collection located and applied within the operating mechanism directly is needed only be the quantity one.

2.2. Single Pole Applications (Electrically Ganged)

In cases where the operating mechanism is operating 1 pole of a disconnector or earthing switch at once, the 3 poles need to be electrically ganged. This implies whether cabling between the operating mechanisms or consideration for the cabling towards and within the control unit (house) of the substation. Any measurement used for data collection located and applied within the operating mechanism directly is tripled in quantity.

3. Data Sources

Data collection is only possible based on measurements and/or signaling, so that digital and/or analogue input will be generated for further data processing.

Basically 3 sources as locations for measurements can be differentiated for disconnectors and earthing switches. The most obvious one is the operating mechanism itself and provides already interesting and useful possibilities. Additionally, this would be the place (if space is sufficient) to apply any type of item or device for data collection and data transfer (wired or wireless). Further locations are than the substructure (with the kinematic chain) and the current path (with the insulators) [1, 2, 7].

3.1. Operating Mechanism

The operating mechanism provides generally already contacts for indicating the closed and open position of the disconnector or earthing switch. Access is easy to the power supply of the motor (motor drive cases), where current measurements can be taken (reflecting torque) and an inner temperature would be a simple measurement possibility to monitor the heater functionality (always incorporated, as necessary ingress protections may cause humidity issues inside in dependence on outside temperature and humidity).

3.2. Substructure (Kinematic Chain)

The substructure gives additional possibilities for measurements and again an easy option would be the temperature (outside), but consideration of the sun exposure will be necessary (a shadow position maybe required). Direct measurement taking on the kinematic chain must be driven by the use case, as the challenges for wired or wireless applications need to be satisfied.

3.3. Current Path

Measurements on the current path would lead to highly useful data for operational use not only of the disconnector or earthing switch, but for the substation. However, identifying measurement solutions suitable for the application within electromagnetic fields is a challenge or would need special investigation. Also, for this location, the challenges for wired or wireless applications need specific consideration. A wire routing along an insulator (eventually one that is rotating while operation) may imply huge efforts for additional material (e.g., brackets and/or other routing items)

4. Applied Use Cases

The following use cases have been applied on test installations and being validated for its feasibility.

4.1. Switching Position and Counted Operations

The switching position is a standard need as a digital input to the customer, which is served with auxiliary switches (type and quantity as per customer requests). Considering digitalization needs, it is easy just to add accordingly contacts. This allows than easily the status indication (closed or open as real time operation state) and counting of the operations. The operations counting allows maintenance advice as per operating manual, but it will be important to trigger specifically lost connections. An indication for “lost connection”, an accordingly “time stamp” recording and a warning message for the application needs consideration.

The indication of the operation counting represents the mechanical lifetime of the device and is given by accumulated operations per year. An accordingly trend will give the possibility to indicate the remaining years of the lifetime based on the average number of operations per year. The maximum number, the mechanical lifetime, is contractually agreed (given on the rating plate) and a basis for the definition of warnings and alarms when being approached and/or exceeded.

Optionally and/or parallelly the remaining lifetime could be given with operation quantities, as well, if not sufficient with the indication on the y-axis. However, such details are surely a question of customization or features in a software application to be switched on/off as per current user wish or need.

Figure 1. *Visualization Example of Operation Quantities and Remaining Lifetime.*

4.2. Monitoring of the Anti-condensation Heating

This use case requires the ambient temperature and the inside temperature of the operating mechanism. By a difference definition and monitoring, the heater functionality can be judged and indicated.

First the ambient temperature measurement shall be situated in the shadow, so that there will be no misinterpretation because of sun exposure (extreme sun radiation) and accordingly consequences. Then, based on the availability of the ambient temperature, a judgement and indication of operating in the temperature range as per rating plate can and shall be done. Warning values can be defined for approaching the limits of the temperature range, and e.g., an alarm if reached or tends not to adhere anymore the temperature range specified.

With the additional inside temperature, a temperature difference can be calculated and the functionality (working/ non-working) of the anti-condensation heater can be judged. As the inside temperature shall always be higher than the ambient temperature to avoid inside condensation, a warning threshold can be defined e.g., when the inside (cubicle) temperature plus 3 Kelvin equals the ambient temperature (accordingly alarms are definable also). A little bit more sophisticated arrangement would allow to use these measurements to control the heater operation directly, as well.

Again, time series shall or can be recorded for future analysis.

4.3. Motor Current Monitoring (Online Trending)

For this use case a measurement of the current consumed by the motor is sufficient (reflects the output torque), so that the use case is very attractive in case of motor drives. If the operating mechanism is a manual drive, the measurement of the output torque directly is necessary, which is a more complicated case in regards of the instrument application (mounting/installation). The following explanations are based on the motor drive current but are directly transferable to output torques (of manual and motor drives).

The motor current measurement needs to be an online trending for identifying motor current changes within short durations of time, while device operation (total operation time for closing or open operation is below 15 seconds). Further the measurement of the current shall be triggered by a change of the position indication or by the direct commands for the motor operation, so that the online trending is done for operations specifically and not in e.g., extreme cases for long durations of non-operation (several months are not unlikely in case of disconnectors and earthing switches).

The opening and the closing operations of the device lead to distinctive motor current characteristic curves for the current consumption over the travelling time. A typical, representative curve shape would be as follows (torque is shown instead of motor current, but will have an accordingly occurrence):

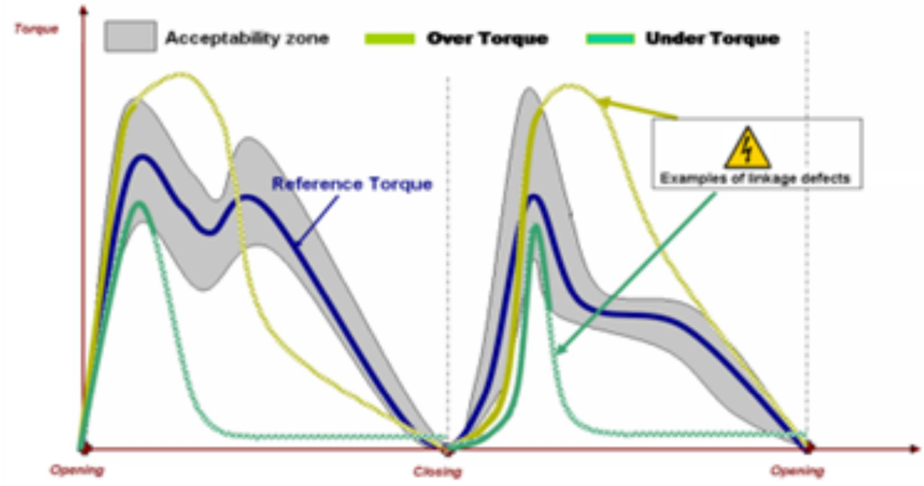

Figure 2. Representative Motor Current Curves for Opening and Closing Operation of Disconnectors.

For the closing operation, typically a first peak is observable to overcome the mass resistance (weight) and a second peak to overcome the friction resistance (contact system). For the opening operation, typically a first peak is observable to overcome the pressure resistance (contact system) and a second minor peak to overcome the mass resistance (weight) for moving to the end position [1, 2]. If the position indication (auxiliary switch) is used for the triggering, there will be a time delay (by the nature of the functionality of auxiliary switches), which will represent a missed first part of the motor current curve. Therefore, the direct motor operation commands (usually by relays) are recommended for triggering and ensuring the monitoring of the full motor current curve (without time delays).

With a minimum accuracy of the motor current characteristic curve, the comparison of two consecutives motor current characteristic curves will have than the potential to identify changes (matching of characteristic curves) and to evaluate a significance of an identified change, so that thresholds for warnings and alarms can be given based on change settings/definitions. The storage of characteristic curves and accordingly monitoring of variations of the characteristic curve with the quantity of operations is more important and gives the potential for predictive maintenance. Also, the influence of the ambient temperature in dependence of the installation location needs to be considered. The same device maybe be installed for ambient temperature ranges covering very low temperatures, which may even significantly influence the motor behavior and consequently the motor current curve by the cooling effect of very low ambient temperatures. This may lead to specific motor current characteristic curves.

Thresholds for warnings and alarms must be defined in dependency of the device type and ratings, which includes installation types. The device manufacturer needs to provide a definition for the acceptability zone of a specific motor current characteristic curve, as a mandatory basis for threshold definitions. Furthermore, a manufacturers definition of characteristic values within the motor current characteristic curve representing specific locations of the kinematic chain (substructure and current path locations) gives the potential not only for predictive maintenance in general, but also for definition of the location or items/parts relevant for the predicted maintenance.

This provides possibilities for highly optimized maintenance planning and the potential to save manual on-site checks (visual inspections for identifying the maintenance activities in regards of urgency and scope). Rarely but observable on the market accordingly data collection and monitoring are done based on the current drawn from motor drives from sources in control rooms (e.g., batteries). Such activity is then highly dependent on the operators experience and knowledge about specific devices installed, but without manufacturers input for motor current characteristic curves and their acceptability zones. Another behavior on the market is observable by requirements for motor current measurements while factory acceptance tests and a specified motor current difference limitation between the operations of +/-10 % (such cases require a minimum number of operations for a specimen while a factory acceptance test for a specific order, agreeing that the specimen will then be delivered with a reduced lifetime in regards of its mechanical endurance).

4.4. Overcurrent (-Power) Allowance

This use case indicates an allowable overcurrent against the rated continuous current (contractually agreed and given on the rating plate) based on the current ambient temperature.

4.4.1. Calculation Method

In fact, it is a calculation method using results/data of continuous current tests (formerly called temperature rise tests) of a specific current path with definitions for boundary conditions and based on the indirect proportionality of a temperature rise at one current value to a temperature rise of a second current value and the resulting quotient of both currents to the same potency (1), as per IEC TR 62271-306 [3]. The IEC TR 62271-306 [3] is basically an IEC technical report for circuit breakers, but as physical basic correlations are used and referenced, this technical report is taken as reference for other products being affected accordingly, as well. Specifically for disconnector and earthing switches there are known cases, where products installed in field were questioned for continuous current capacities, where the substation usage or requirements changed, and limited confirmations were possible only with the reference to the given IEC technical report and at least one additional continuous current test. The additional continuous current test is mandatory for the application of the given indirect proportionality (1), so that necessary inputs are delivered, and a formula can be provided to deliver the allowable overcurrent against the rated continuous current based on the current ambient temperature.

$$\frac{\Delta T1}{\Delta T2} = \frac{I1^{v}}{I2^{v}} \quad (1)$$

The capability of a distinct current path to carry the rated continuous current is proven by the continuous current test (as per IEC 62271-1/102 [4, 5], which is the case for all high-voltage products tested or validated as per IEC's 62271 [3-6]). This validation is done for a defined maximum ambient temperature, which is usually 40°C (50°C in extended cases). For the 60Hz applications the permitted temperature rise is reduced as per IEC 62271-1/102 [4, 5] and a factor of 0.95 must be applied (95 %). The validated current carrying capacity will be a rated continuous current as per IEC 62271-1/102 [4, 5]. Consequently, there are different scenarios where the distinct current path will not be fully used in regards of its capabilities. E.g., in the case of ambient temperatures below 40°C (respectively 50°C).

However, the case requires a measured ambient temperature as input for the calculation method. As the formerly given temperature measurement for the use case of the monitoring of the anti-condensation heating is located in the shadow for its specific purpose, here it seems not to be adequate, as it may provide a risk for a falsified low ambient temperature. An ambient temperature measurement exposed to the sun appears to be reliable, so that a separate location and measurement is foreseen. Of course, also the current path could obtain specific shadow, but this would be considered as safety margin. An agreed location of the current path in the shadow, may allow the preference for the usage of the available temperature measurement by the anti-condensation heater monitoring use case. Furthermore, upon user/customer agreement any ambient temperature measurement available in the substation would be useable.

4.4.2. Boundary Conditions and Calculated Temperature Rise Factor

The absolute temperature rise (1) can be substituted by the difference of a maximum allowed temperature measurement at a measurement point (as per worst scenario, the point of the temperature rise test with the most critical temperature rise against the permitted temperature rise as per IEC 62271-1 [5] must be chosen) and the current ambient temperature. The following definitions and boundary conditions will allow to convert (1), so that the use case is served.

v: ranges between 1.8 and 2.0 (IEC TR 62271-306 [3]), depending on the thermal radiation and other factors. IEC TR 62271-306 [3] recommends 1.8 if there is no specified value by the manufacturer. Presumed value could be 2.0 in a first step, based on a worst-case scenario. For higher accuracy and consequently higher overcurrent possibility by calculation the potency v shall be determined by two or more temperature rise tests on the same current path with different continuous currents, where once the rated continuous current is chosen and additionally a potentially permissible higher current or different ones and/or lower ones as well. Finally, the use case requires this value as a product property.

I_r: rated normal/continuous current (as applied for the respective temperature rise test).

I_a: permissible current, calculated based on the current ambient temperature measured, but limited as per IEC TR 62271-306 [3] to $I_{a,max} = 2\ I_r$. The limitation is very high and unlikely to be reached, so that any manufacturer may strictly consider this fact or if preferred, specify individually.

T_{am}: ambient temperature (currently measured). The current ambient temperature must be measured in proximity of the current path and with similar sun exposure and/or other external heat and/or cooling sources, so that a minimum accuracy of measurement in comparison to the current path location can be achieved (this may be negligible, as long as v is chosen relatively high, but not if v is determined accurately).

$T_{am,t}$: ambient temperature measured as per temperature rise test of the concerned current path. For the occurring ambient temperature above this value, the permitted current (overcurrent) must not be changed or calculated and be fixed to the rated normal/continuous current as per the respective temperature rise test.

$T_{a,max}$: temperature of the measurement point with the temperature rise most critical against the permitted temperature rise as per IEC 62271-1 [5] of the concerned current path at rated normal/continuous current (lowest margin of temperature rise measured against permitted temperature rise as per IEC 62271-1 [5]).

ΔTr: temperature rise of the measurement point with the temperature rise most critical against the permitted temperature rise as per IEC 62271-1 [5] of the concerned current path at rated normal/continuous current (lowest margin of temperature rise measured against permitted temperature rise as per IEC 62271-1 [5]). This assumes for any ambient temperature the same temperature rise and highest temperature at the chosen measurement point and includes a safety margin in the methodology – in fact the temperature rise is lower for lower ambient temperatures and accordingly measurement series (temperature rise tests at different ambient temperatures would allow to determine different ranges of ambient temperatures where different temperature rise values will be valid and the overcurrent permission would be even more optimized). Additionally, achieved applications for 60 Hz and/or maximum ambient temperature of 50°C will be covered or need specific consideration by reducing this temperature rise value accordingly.

Replacements in the equation (1) to use values as per continuous current test reports and conversion are possible, as follows:

$$\frac{(T_{a,max} - T_{am})}{\Delta T_r} = \frac{I_a^2}{I_r^2} \quad (2)$$

$$I_a = I_r \sqrt{\frac{(T_{a,max} - T_{am})}{\Delta T_r}} \quad (3)$$

The possibility for a definition of a "calculated temperature rise factor" occurs and is as follows:

$$I_a = I_r * \tau \quad (4)$$

$$\boldsymbol{\tau} = \sqrt{\frac{(T_{a,max} - T_{am})}{\Delta T_r}} \quad (5)$$

This defined "calculated temperature rise factor" (5) requires boundary conditions, which is applicability for $T_{am} < T_{am,t}$, but $\tau_{min} = 1$ and $\tau = 1$, if $T_{am} \geq T_{am,t}$.

4.4.3. Illustration

The following illustration of the methodology was done based on the indicated example of a disconnector current path to test and visualize the methodology:

For the visualization different scenarios of the potency v have been chosen, so that the influence of the accuracy of the same is transparent. Further, the lowest ambient temperature chosen is reflecting the fact in the case of disconnector and earthing switches that mainly the steel properties (ordinary standard steel applied for insulator flanges and substructures) are a limiting factor for low temperature applications, as steel will change the properties below -24°C and specific steel variants may be chosen – beside of this, the general released temperature value for low temperature applications of the product must limit the permitted application of the methodology in regards of a minimum ambient temperature (consequently the limitation as per IEC TR 62271-306 [3] with $I_{a,max} = 2\ I_r$ is not visible).

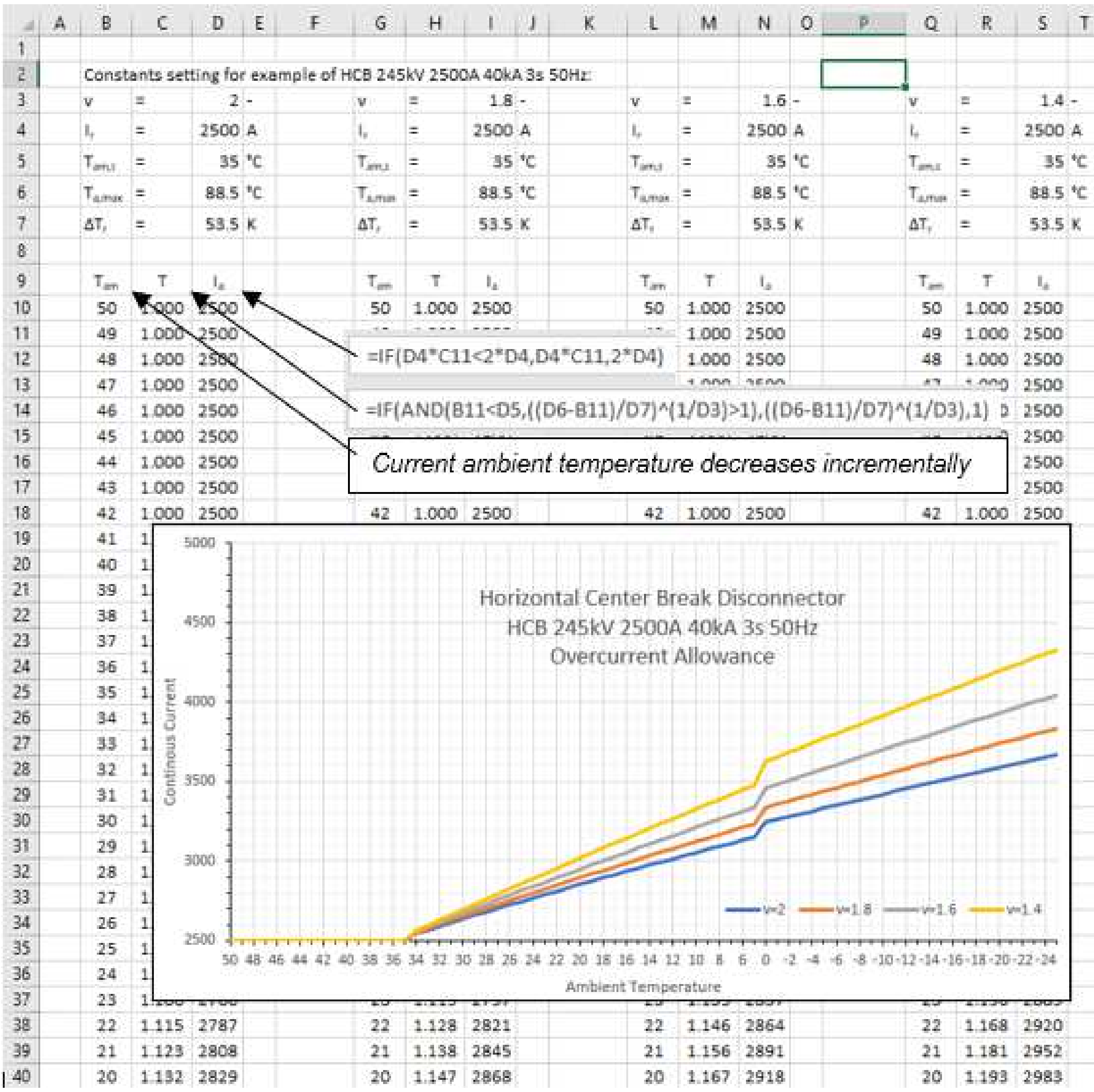

Figure 3. *Visualization of Overcurrent (-power) Allowance.*

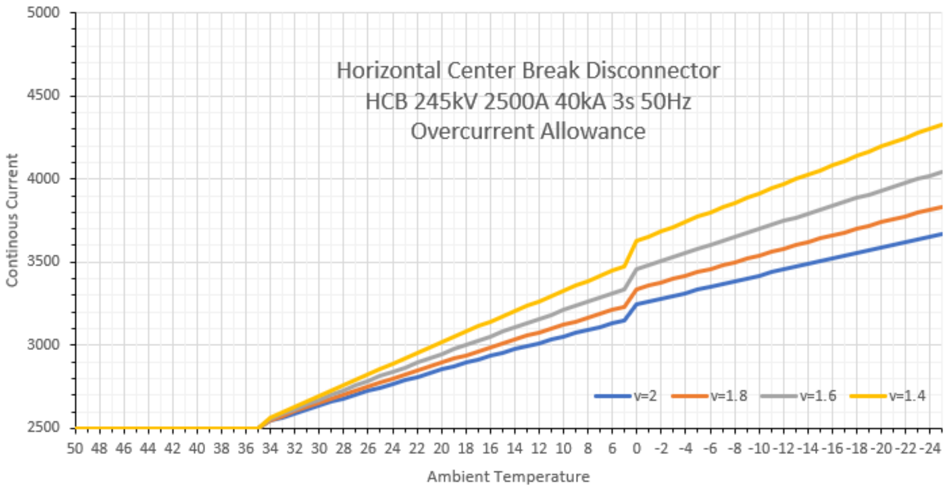

Figure 4. *Visualization Detail of Overcurrent (-power) Allowance.*

The underlying data of accordingly continuous current test (temperature rise test):

CURRENT PASSED IN AMPS	TIME	AMB TEMP IN °C	Temperature Measured at various points					
			1(M.Stem)	2(M.Arm)	3(M.C)	4(FC Jaw)	5(F.M Arm)	6(F.M Stem)
2500	9:45	31.0	31.0	31.2	31.1	31.4	31.2	31.5
2500	10:15	33.5	51.9	60.5	59.9	57.4	50.5	42.5
2500	10:45	33.7	62.0	71.3	71.8	69.6	60.5	51.5
2500	11:15	33.7	66.4	76.3	74.9	72.8	69.5	56.5
2500	11:45	34.6	68.9	80.4	77.8	77.8	74.9	60.9
2500	12:15	35.0	69.6	83.8	82.7	81.9	78.7	64.7
2500	12:45	35.6	71.9	86.1	85.1	85.5	81.8	68.8
2500	13:15	35.0	74.4	88.4	87.9	87.1	84.9	73.9
2500	13:45	35.0	75.0	88.9	88.3	87.3	84.8	74.3
2500	14:15	35.0	75.1	88.5	88.7	87.9	85.5	74.6
Actual temp.rise measured at various points			39.2	52.6	52.8	52	49.6	38.6
Max permissible temp.rise as per IEC over an ambient of 40°C			65	65	75	75	65	65

Figure 5. *Example of Continuous Current Test Data.*

The visualization of the underlying data of accordingly continuous current test (temperature rise test):

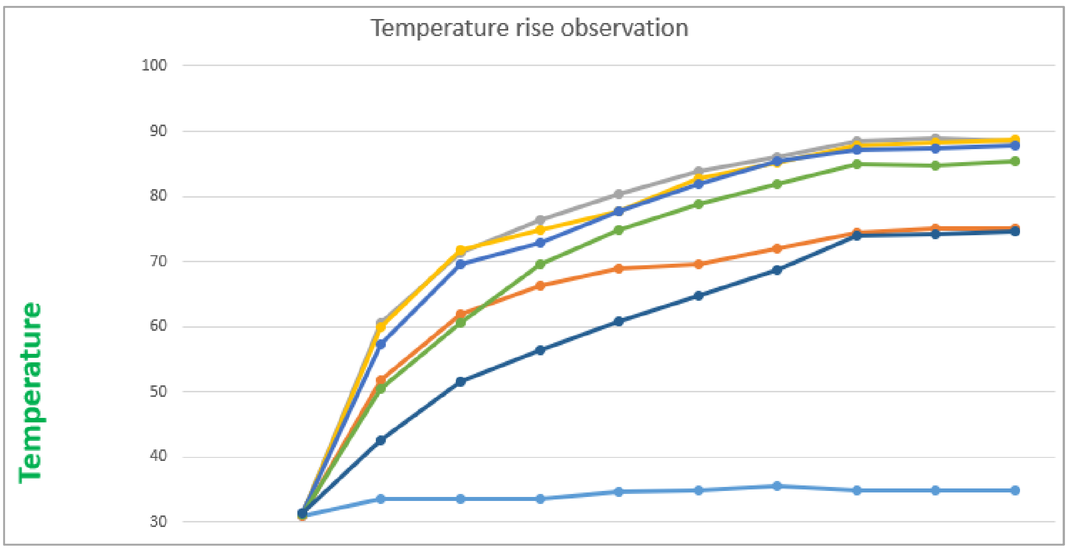

Figure 6. *Example of Continuous Current Test Data Visualized.*

The difference between the actual temperature rises at the given measurement points and the maximum permissible temperature rise as per IEC 62271-1 [3] quickly indicate the applicability for an ambient temperature of 50°C or 60 Hz – or with more use case relation, the part of the safety margins mentioned before.

5. Further Use Cases

Further use cases possible and frequently pointed-out by technicians generally, but foremost product end users, are given in the following chapters. However, those have not been installed or practically validated.

5.1. General Use Cases

Mechanical stresses are easily requested, as those can have a high input value for predictive maintenance activities and are usually unproblematic for measurement solutions (strain gauges) and installations (substructure). If it comes to the current path, the electromagnetic field needs to be considered.

Vibration detection and acoustic measurements are also discussed. However, here the benefit potential is less obvious, so that this is less discussed and analyzed. But just to mention the radio interference voltage and lifetime influences, there will be a beneficial area for specific customers or installation areas.

5.2. Life Parts Related Use Cases

Life part related use cases or needed measurements will need to cope with the measurement location within an electromagnetic field and to withstand the same.

The current path temperature is of specific interest, so that by this temperature there can be a direct indication for allowed overcurrent (still this is related to specific measurement points as per continuous current test).

The current path resistance is of specific interest and even more complicated for a measurement possibility. Potential is given in regards of lifetime judgements or predictive maintenance specifically to the conductive joints of the current path.

The switching position verification directly on the current path (by light or laser beam) is of specific interest for highest safety requirements, as validation for the auxiliary switch signal of the operating mechanism ('out of'-choices will be logically possible).

The position or the timely moment (related to the operation start) of lightning interruption is of specific interest in cases of requested and provided switching capability (known lightning measurement solutions from e.g., circuit breaker applications, need verification for applicability).

The earthed current is also of certain interest in cases of earthing switches and maybe easier installed because of a possible substructure location.

5.3. Other Use Cases

In case of double motion devices, where one motion is linear, which is often the second motion generating the important insertion movement for a final contact position, a distance measurement would be of high interest. This would be an additional confirmation or verification for a final position reached, which in this case guarantees right contact position for carrying current. Limit switches do not appear to be sufficient (in regards of margin for a safe contact position). This measurement will be preferably on the current path, but is possible on the substructure, where an electromagnetically field would not need to be withstood.

In case of remote installations, the application of batteries and solar panels related to the operating mechanism may be of high interest. Especially, if remote access (mobile network) is given, it could be very effective in regards of saving visual inspections. This case is considering the digitalization of a product beyond measurements and data collection and integrates local energy supply or sources for operations, where needed.

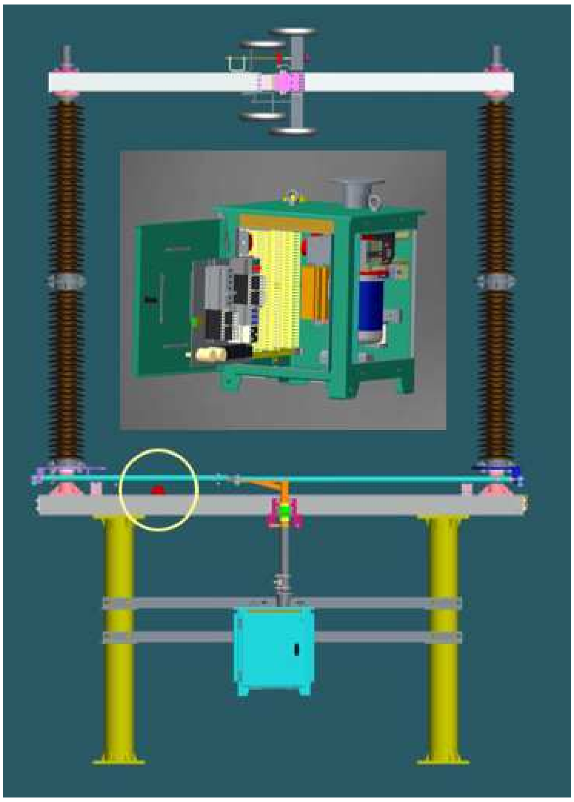

Figure 7. *Example of a Digitalized Center Break Disconnector.*

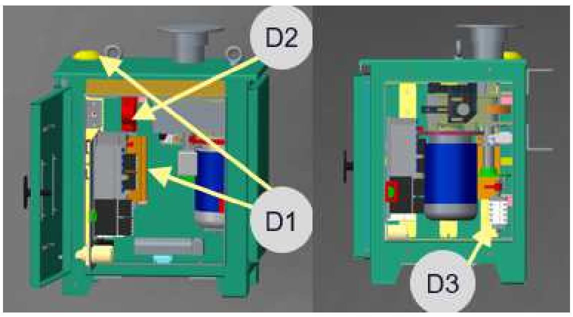

Figure 8. *Example of an Operating Mechanism (Motor Drive) of a Digitalized Center Break Disconnector.*

6. Example of a Digitalized Center Break Disconnector

The applied use cases are covered. The following illustrations will give a general impression, even though there is not much difference to be visually identified against a non-digitalized center break disconnector (as generally expected by digitalization). The temperature measurement on the substructure (base channels) are only partially visible (yellow circle in the following illustration, the shadow position is not possible), so that the focus will be with the operating mechanism.

However, it is worth to mention that the set-up and its documentation do indeed consider and describe the sun exposure and shadowing situation, so that even the cardinal points are clearly indicated, and the sun travelling can be understood (hours of sun exposure for the device).

The positions marked with D1 indicate a connectivity device (gateway) with an antenna (mobile network) and an inclusive PT100 item for the inner temperature measurement. The position D2 indicates the current transformer (transducer, converting into standard analog signals) for the motor current measurement (supply wire). The position D3 indicates the auxiliary switch (manufacturer's standard) providing the position input to the gateway (based on the provision of sufficient outputs).

Overall, a simple installation effort without any demand for a changed operating mechanism (a motor drive in this case). A differently driven minimum size of the housing usually provides sufficient space and possibility for a gateway and a current transformer.

7. Conclusion

The given applied uses cases are providing already an initial digitalization of disconnectors and earthing switches with significant potential for an increased product lifetime, reduced maintenance efforts and optimized maintenance activities. Even though the use cases of the switching position / counted operations and the anti-condensation heater monitoring are appearing with smaller benefits, the use cases of the motor current monitoring and the overcurrent allowance provide huge benefits – where the motor current monitoring is of specific importance for predictive maintenance and the overcurrent allowance for enhanced product performance. The benefits of a predictive maintenance may easily cover the investment of operators for this digitalization aspect. The benefits of allowed overcurrent operation may allow the operator to provide increased energy supplies and therefore judging the invest for such digitalization aspect [8, 10-12].

Within the further use cases options is foreseeable, which will be of great benefit for operators. However, those use cases may not have such general benefits, but be more specific for certain operators or regions of product applications (e.g., with specific demand for switching capabilities or seismic qualification).

Finally, it can be stated, that with relatively low efforts big benefits can be generated by the digitalization of the product. This even in the given case with products, the disconnectors and earthing switches, which are often understood as low-cost products with hesitations or avoidance of such investments. Therefore, it is worth to implement digitalized disconnectors and earthing switches, to investigate and collaborate for further use cases and to standardize the same.

Acknowledgements

M. R. thanks his wife Nallely Dzib Soto for her patience and continuous support while his professional efforts and specifically responsibilities and commitments abroad on delegations apart and on long distance from his family. Further he thanks Gurumoorthy Kurra, Subba Challa and Sateeswara Mogatala for the teamwork and the enrichment of experience and knowledge about air insulated high voltage disconnectors and earthing switches designs. He thanks Dr. Reno Reinhold, Dr. Joerg Teichmann, Dr. Stefan Giere and Oliver Dohnke specifically for their general guidance and support in regards of his professional development and utilization of his expertise.

References

[1] M. Rohmann, D. Schraeder, „Swicthing Capability of Air-Insulated High Voltage Disconnectors by Active Add-On Features", ASTESJ Volume 6, Issue 1, Page No 43-48, 2021, ISSN 2415-6698.

[2] M. Rohmann, S. Challa, G. Kurra, S. Mogatala and D. Schraeder, "Switching Capability of Air Insulated High Voltage Disconnectors," 2019 International Conference on High Voltage Engineering and Technology (ICHVET), 2019, pp. 1-4, doi: 10.1109/ICHVET.2019.8724315.

[3] IEC TR 62271-306, Guide to IEC 62271-100, IEC 62271-1 and other IEC standards related to alternating current circuit-breakers, Edition 1.1, 2018.

[4] IEC 62271-102, High-voltage switchgear and controlgear – Part 102: Alternating current disconnectors and earthing switches, Edition 2.0, 2018.

[5] IEC 62271-1, High-voltage switchgear and controlgear – Part 1: Common specifications for alternating current switchgear and controlgear, Edition 2.0, 2017.

[6] IEC 17025, General requirements for the competence of testing and calibration laboratories, 3rd Edition, 2017.

[7] CIGRE Technical Brochure No. 511: Final Report of the 2004 – 2007 International Enquiry on Reliability of High Voltage Equipment, Part 3 – Disconnectors and Earthing Switches, 2012.

[8] Sunil S Rao, "Switchgear Protection and Power Systems (Theory, Practive and Solved Problems)", Khanna Publishers, 2008.

[9] M. Rohmann, "Analysis of Assembly Times for a Gas-Insulated High Voltage Switchgear on the Level of Components", M. Sc. Thesis with Siemens AG at FernUniversitaet Hagen, 2008.

[10] E. Kuffel, W. S. Zaengl and J. Kuffel, "High Voltage Engineering Fundamentals", published by Butterworth-Heinemann, Great Britain, 2000, ISBN 978-0-7506-3634-6.

[11] Helmut Lindner, Dr. Harry Brauer, Prof. Dr. Constants Lehmann, "Pocket Book of Electro-Technics and Electronics", Fachbuchverlag Leipzig, 1999, ISBN 3-446-21056-3.

[12] Gerd Balzer, Bernhard Boehle, Kurt Haneke, Hans Georg Kaiser, Rolf Pöhlmann, Wolfgang Tettenborn, Gerhard Voß, "Substations", 9th ed., Cornelsen Verlag Schwann-Giradet Duesseldorf, 1992, ISBN 3-464-48233-2.