CONTAMINANTS EFFECTS ON ROTATING ELECTRICAL MACHINES WINDINGS

WALTER EVALDO KUCHENBECKER[1], DANIEL RODRIGO MORETTI[2]

[1]Collaborating Doctor Researcher of the Postgraduation Program in ENERGY - UFABC, walterk@weg.net
[2]External Services Analyst - WEG Equipamentos Elétricos SA, morettid@weg.net

SUMMARY

A significant portion of the insulation failures in rotating electrical machines is directly related to environmental factors, which cause contamination of the equipment. Usually, they are inherent to the production process where the equipment is installed and consequently submitted.
The effects of contaminants on the electrical machines insulating materials are evidenced by measurements applied to the insulation systems. These assessments can be done by trend curves from various measurements in scheduled shutdowns, either from continuous monitoring. The incipient identification of changes in the insulators dielectric characteristics by contaminants, and corrective maintenance, will prevent a possible unexpected and premature failure.
This article presents the cause and effect relation of the environmental contaminating factors that progressively reduce the equipment lifetime, taking it out of operation prematurely.

KEY WORDS: dielectrics, contaminants, aging, leakage path (tracking).

1. INTRODUCTION

The failures occurrence in rotating electrical machines windings has been reduced by the introduction of the Vacuum Pressure Impregnation (VPI) in the mid-1960s. The technological evolution of insulating materials and epoxy resins have also been constant since the implantation of the VPI system.
With the increase in insulating materials thermal resistance, it was possible to reduce the areas consumed by this material, during the manufacture of rotating electrical machines and consequently helped to make them more compact, increasing efficiency, thermal capacity and even improving the power factor. In addition, modern materials resistant to the corona effect, applied to the windings, reduce the impact to the rapid voltage surges submitted during the vacuum circuit breaker maneuver and semiconductor pulses used in frequency converters.
However, contaminated winding surfaces tend to cause intense discharges and possible leakage paths. These contaminated surfaces can lead the windings to premature failure, acting from the surface into the coil. Contaminants on the windings surface create leakage paths, through chemical reactions, abrasives in the insulation (either by moving the coils or suspended particles), mechanical damage in general, improper cleaning and drying of the windings, oil mist, moisture, cleaning solvents, condensation of process contaminants.
The failure cycle basically consists of four factors: electrical, thermal, mechanical stress either the contamination from the environment. These factors can interact with the insulation system components in order to cause premature aging and, consequently, equipment failure. Stress factors can contribute to the aging of the insulation system individually or in combination.
Contaminants from the environment are directly related to the process of modifying the materials dielectric properties, causing the appearance of corrosive by-products, increasing the conductivity of the insulation, causing conditions to increase partial discharge activities and as an inevitable consequence, the premature rupture of the high voltage stator.
Contamination usually occurs on the stators' coils heads. If the contamination has any conductive properties, then a current flow is established, as long as there is a potential difference.

The Figure 1 presents the failure cycle of the insulation system according to the IEC 60505 Standard and in it, you can determine which the stress factors the insulation system is subjected to.

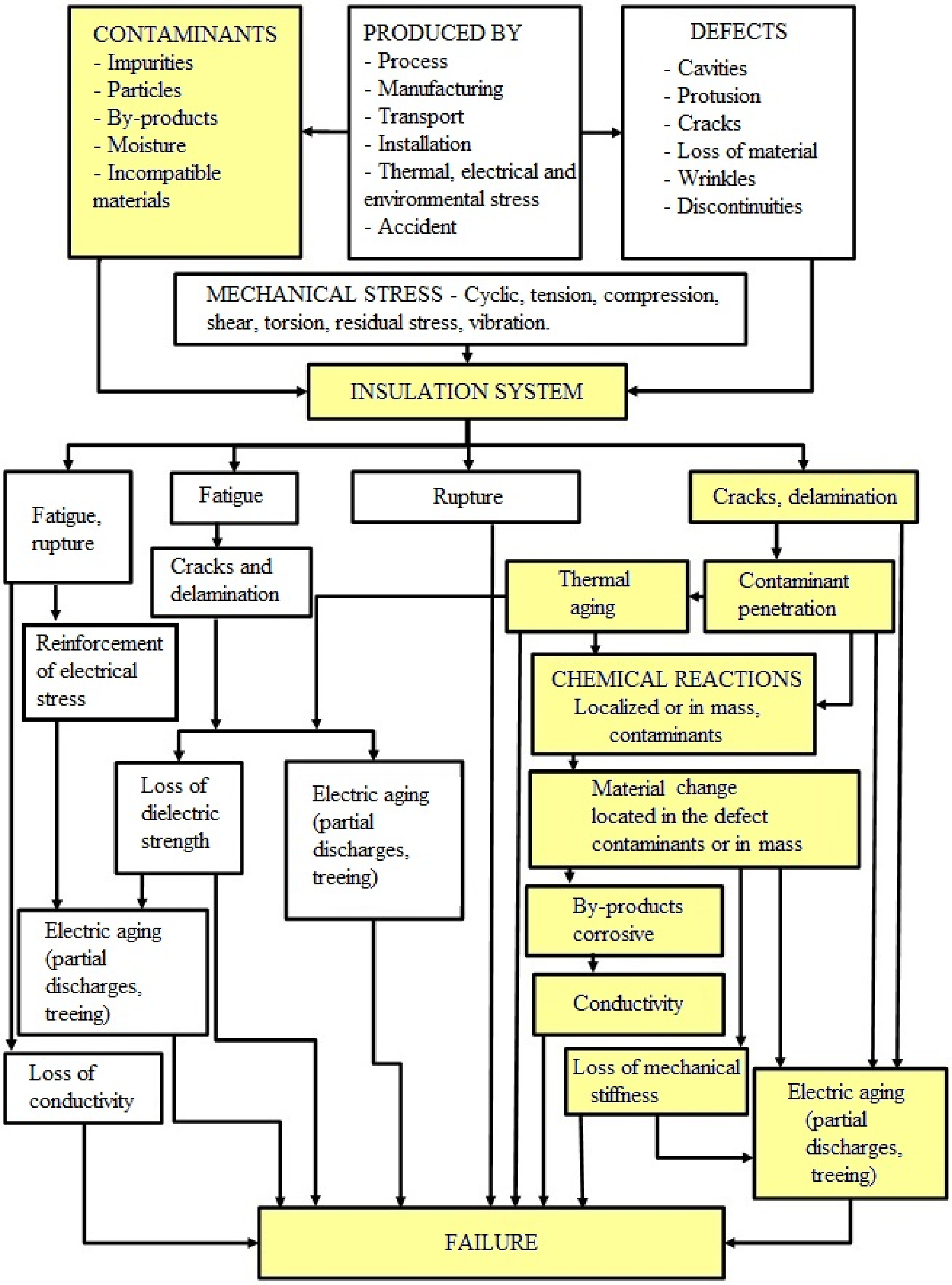

Figure 1: Flowchart of the evolution and correlation of factors that cause the aging of the high voltage stator insulation system in the rotating electrical machine (Source: IEC 60505, 2011)

The Figure 2 presents the model of a contaminated insulation. As a result of contamination, regions that are called “dry” are usually created and shown as Rdry and other Rcontamination. The drier regions are characterized by having a much greater resistance than the other contaminated regions and in this situation, any potential difference (phase-to-phase voltage) is established on this higher resistance small region.
The high potential difference, in this small contaminated region, dry and isolated, causes the rupture of the dielectric strength of the atmospheric air around it. These electrical discharges degrade and carbonize the organic resin and the insulation system tapes in the dry region, making it more conductive. The increase in conductivity in this small area makes it possible to establish the phase-to-phase potential difference in another small region and, therefore, carbonization becomes a successive process.

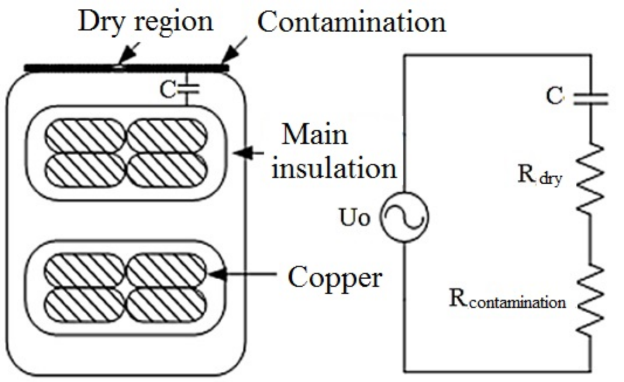

Figure 2: Coil head cross section of a high voltage stator and its respective equivalent circuit that shows the leakage current flow (Source: LIN, L; 2016)

The effects of contaminants on the windings have always been a cause for concern. Soltani (2009) evaluated the effect of moisture on the insulation dielectric by using the technique of measuring leakage current in direct current. He used bars and coils with different insulation technologies (asphalt, epoxy and polyester) and submitted to different humidity degrees. In this study, it was demonstrated that a modern epoxy-insulation has a significant decrease in the values of polarization index and insulation resistance, when subjected to contamination. The gradual reduction in the polarization index value is directly related to the exposure time to the simulated humid environment. Soltani also noted that partial discharges tend to drop in windings with high moisture content.
An analogous behavior is observed when measuring insulation resistance in 1 minute. Soltani (2011) observed that the impact is even greater on the insulation resistance values and concluded that humidity affects the insulation resistance through the formation of a conductive layer on the coil and consequently increases the leakage current.
Neti (2011) has simulated ways to detect the effects and trends of humidity and leakage paths in the windings. It was used the high sensitivity differential protection technique, monitoring the tendency of dielectric losses during the spraying of contaminants in the windings and also monitoring the activity of partial discharges. Both measurements were effective in detecting the tendency of failures by contaminants on windings surfaces. It was demonstrated in the study that a contaminated insulation presents an increase in the partial discharges level and can lead to an imminent failure.
Similarly, Neti (2011) found an increase of dielectric losses due to surface contamination of the coil heads. The successive cycles of contaminating spray were interrupted by the insulation rupture. The contamination caused an increase in the surface conductivity of the windings coil heads, increasing partial discharges and the superficial leakage path.
In this work, it was used the same simulation technique, but analyzing the effects with all the evaluation tests currently practiced.

Lin (2016) studied the influence of water steam in together with coils contaminated with lubricating oil. In large machines it is very common to have oil contamination or oil mist due to small leaks in the bearings. This contamination leads to increase partial discharges, however with the mixture of water steam mist, causes the partial discharges to increase much more. The author used contaminated oil coils and varied the relative humidity, concluding that in 80% of the cases, the leakage paths increase considerably and degrade the insulation quickly. Lin (2016) also showed that contamination by oil and graphite can occur in the wound stator coil heads and that it has conductive properties.
The objective of this article is to present the effects of contaminants on windings surfaces, even with insulation developed with the most modern technology available on the market. The parameters used for the analyzes were based on the most modern equipment available for evaluation, such as: insulation resistance, tan delta and partial discharges.

2. MATERIALS AND METHODS

2.1. Diagnostic techniques

The techniques used in the detection of insulation failures have shown a considerable evolution and have reduced the unexpected failures frequency. It is common to find several diagnostic methods, from consolidated techniques to test conditions that are not widespread in international communities. It is extremely important to note that non-standardized diagnostic methods generate a series of divergences between manufacturers, users and companies specialized in selling diagnostic services. The efficiency of non-standardized methods is not being discussed here, however it is observed that techniques that have not been widely discussed generate misinterpretation and, finally, a delay in decision making.
The diagnosis of the insulation system depends on the equipment availability, qualified personnel and resources of the user, to contract the specialized services. As mentioned, the minimum insulation tests are not defined in a Standard, so a safe approach to diagnosing the insulation system is presented below.

2.1.1. Insulation resistance

The diagnosis of the insulation system performed according to IEEE43 is definitely the most widespread and provides a quick and accessible response. The imposition of DC voltage and leakage current measurement makes it possible to determine important characteristics such as the insulation resistance value for 1 minute and the polarization index (PI). Although the test run is relatively simple, the figure 3 shows the equivalent insulation circuit for an insulation resistance and polarization index test.

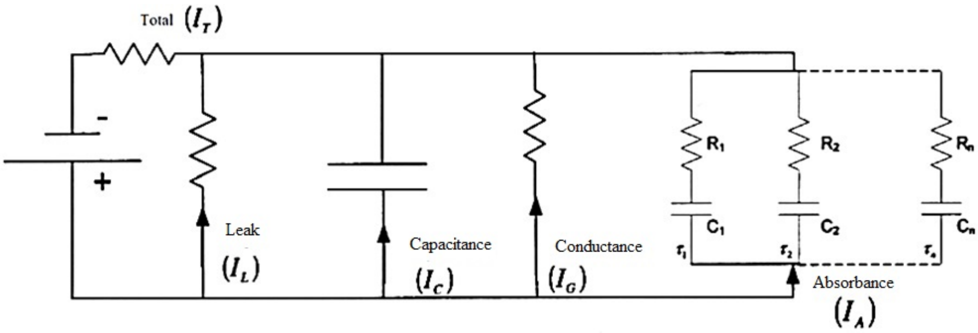

Figure 3: Insulation monitoring equivalent circuit during the insulation resistance test (Source: IEEE43; 2013)

The Figure 4 shows the equivalent circuit currents behavior of the insulation system. The leakage current I_L is constant over time and normally flows over the insulation surface. The capacitive current I_C has a high magnitude for a short period, as it decays exponentially with time and applied voltage and depends on the insulation geometry. The I_G current is constant in the time and flows from the surface in contact with the core to the energized conductor and is directly related to the insulation system type. The I_A current is the result of the molecular polarization process and electrons displacement.

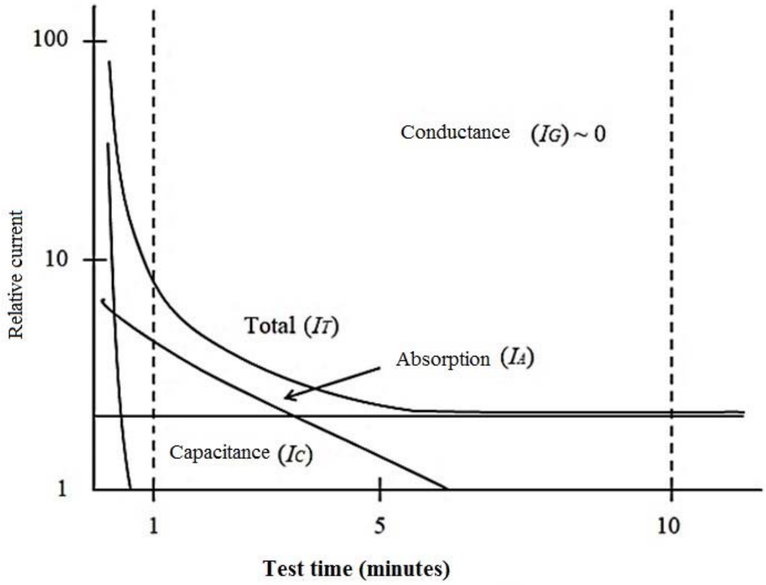

Figure 4: Current behavior of the insulation system equivalent circuit

2.1.2. Dielectric Discharges (DD)

The dielectric discharge test measures the discharge current 60 seconds after the charge is completed for a period of 30 minutes.

$$DD = \frac{I_{discharge}\,(1\text{min})}{U.C_{insulation}}$$

The insulation system is subjected to a charging process similar to the dielectric in a capacitor, as shown in figure 5. The timer is standardized on 30 minutes of charging, which is usually enough time for total absorption to happen.

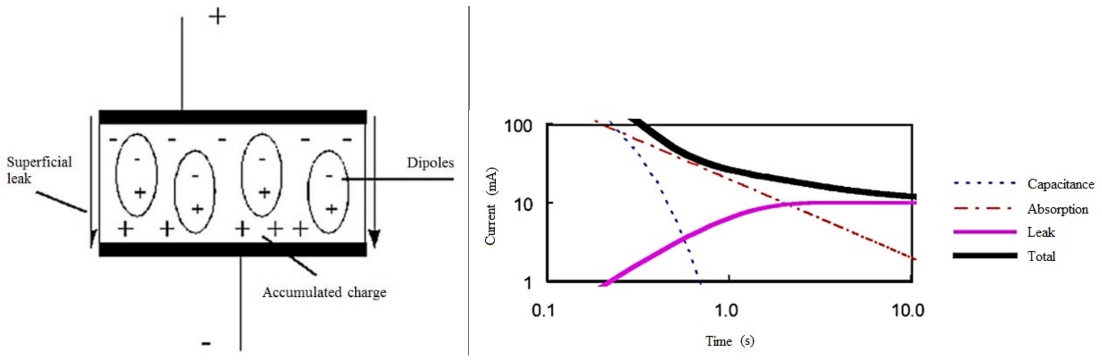

Figure 5: Charge of the insulation system - Involved electric currents (Source: Megger)

The charge that is stored during the insulation test is automatically discharged at the end of the test. The discharge rate depends only on the discharge resistors and the amount of charge stored in the insulation, as shown in Figure 6.

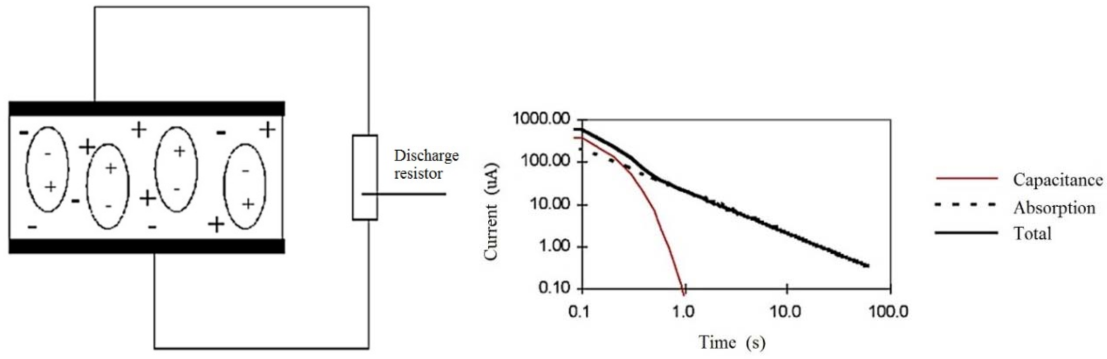

Figure 6: Insulation system discharge - Involved electric currents (Source: Megger)

The dielectric discharge test measures the discharge currents 1 minute after finishing the insulation test. At this point, the capacitive current generally becomes insignificant compared to the resorption current. The level of resorption after this period shows the state of the insulating material, as long as the insulation has been fully charged for total absorption to occur (usually 10 to 30 minutes). A high resorption current shows that the insulation has been contaminated, usually by moisture. A low current usually shows that the insulation is clean and has not absorbed much water.

2.1.3. Step voltage

The step voltage test is applicable to electrical machines with a rated voltage greater or equal to 2300V. This test can be performed for evaluations at the factory, as well as for machines in the field. The voltage application to perform this test can be done in steps with recommended times of 1 to 3 minutes for each step. The typical increment is 1 kV per minute. The test is plotted on the XY axes (current versus applied voltage), resulting in a progressive and continuous current response. The Figure 7 shows the example of voltage steps and possible results for evaluations.

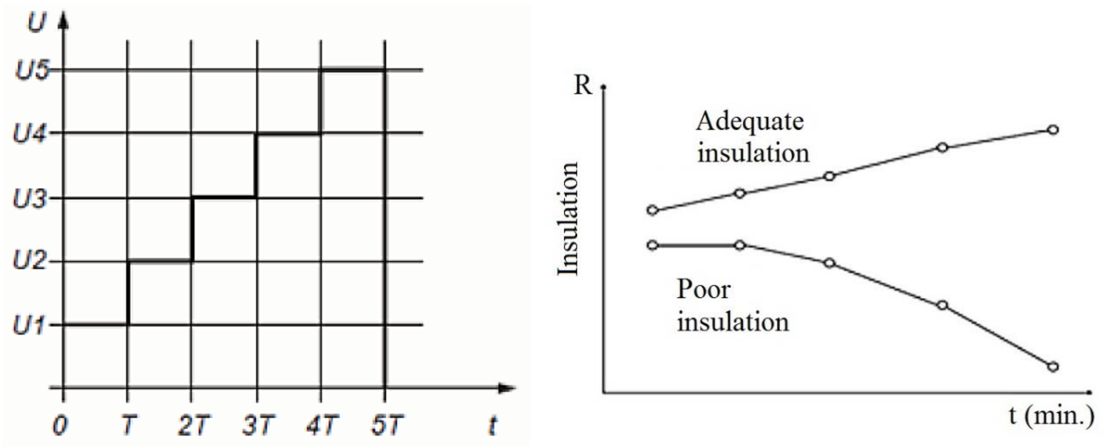

Figure 7: Typical voltage step and insulation behavior under voltage step test. (Source: BALAN H; 2010)

2.1.4. Dielectric losses (Tan Delta)

The dielectric losses determination in the diagnosis of the high voltage insulation system has proven to be one of the most important evaluation methods. The method is standardized, but without a defined limit for complete windings, which requires the trend curves determination to monitor the evolution of losses. According to the IEEE286 Standard, the causes for the dielectric losses increase can be, since manufacturing failure, characterized by a deviation in the curing process, up to the evolution of partial discharge levels. Similar to the method presented earlier, the loss angle varies according to the dielectric currents I_o, the charge current of the geometric capacitance I_P, the polarization current I_{pd}, the ionization current of the partial discharges, and the leakage current I_L. The Figure 8 shows how each mechanism can affect dielectric losses.

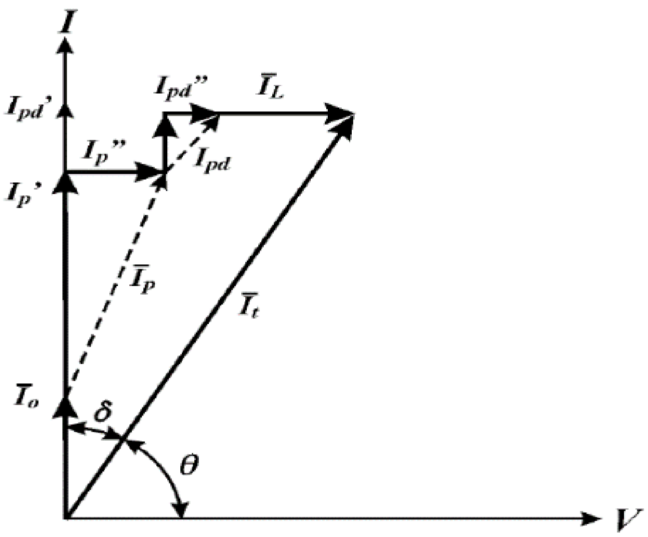

Figure 8: Representation of dielectric loss mechanisms (Source: MORETTI; 2016)

2.1.5. Partial discharges

Monitoring the trend of partial discharges has proven to be an efficient tool in preventing premature failure of the insulation system. It is undeniable that the method, already standardized, has a prominent role, allowing the diagnosis to be made online. The Figure 9 presents the typical example of a capacitive coupling assembly for online monitoring of partial discharges (PD). A capacitive coupler is installed in each of the phases, usually by an individual connection. The coupling generates a low voltage signal that is later filtered and treated using specific software.

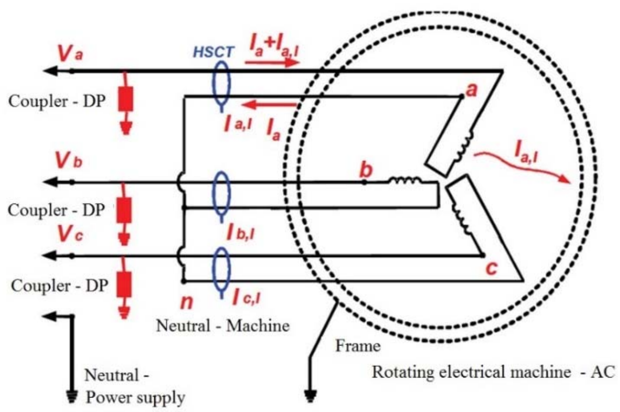

Figure 9: Typical example of capacitive coupling installation for partial discharge monitoring. (Source: NETI, P; 2011)

The Figure 10 shows the position of the partial discharges' sources within the angular spectrum of the sinusoidal voltage signal applied during the diagnosis. For each voltage level during the test, the predominance magnitude of the partial discharges is verified.

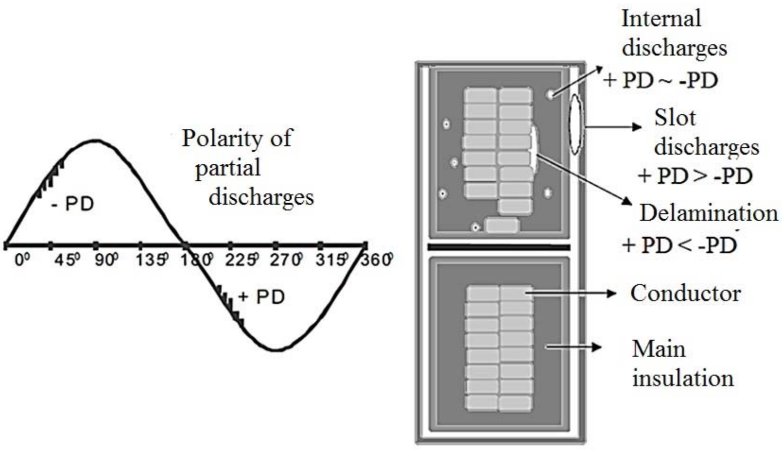

Figure 10: Partial discharges' sources in a high voltage insulation for rotating electrical machines (Source: MORETTI; 2016)

2.2. Experimental sample preparation

In order to demonstrate the relation between surface contamination and the damaging effects to the dielectrics used in the stator windings of high-voltage rotating electrical machines, a prototype was manufactured containing all the necessary characteristics to support a nominal voltage of 4.16kV. So that the sample's behavior could be faithful to the high voltage stator, all the necessary materials were used, such as: conductors individual insulation, main insulation with mica, surface finish layer. To finish the process, the stator was subjected to the VPI impregnation process.
For process viability reasons, the tape against corona effect was not used. This fact has no impact on the study, since the conclusions are relative, in other words, the results are presented by comparing the ideal sample with the sample submitted to the contaminant. The Figure 11 shows the sample in its original form.

Figure 11: Sample of high voltage stator (Source: WEG)

This sample was subjected to the aging test by the Voltage Endurance Test (VET) for a period of 400 hours. The main purpose of executing the VET is to create a degradation condition similar to that found on the machine during operation. Details of the VET are not presented here, since the main objective is the assessment of surface contamination on an insulation already degraded by operational conditions such as temperature and electrical stress.
With the aged sample, firstly, measurements of the initial conditions without contaminants were performed for comparisons. Then, the most common contaminating materials were selected, looking for similarity to those found on the applications, such as saline water and moist soot.
In order to simulate the dielectric behavior of the electrical machines' windings used in saline environments (oil platforms), around 35g of salt were used for each liter of water, a relation found approximately in seawater. The Figure 12 presents the sample being sprayed with the contaminant, on both sides of the coil heads.

Figure 12: Sample of high voltage stator - Contaminated (Source: WEG)

Immediately after the end of the measurements, to analyze the effect of the saline water contaminant on an aged winding, the sample once again went through a washing, cleaning and drying process to return to the initial conditions. In these conditions, new measurements were performed as comparisons with a new contamination process.
Electric machines operate in the most diverse applications and therefore, they are also subject to the most diverse contaminants suspended in the air. This soot that contaminate the windings during the operation was represented by the application of a fine and moist sawdust on the sample, as shown in Figure 13.

Figure 13: Sample contaminated with fine moist sawdust (Source: WEG)

3. MEASUREMENTS AND ANALYSIS OF THE RESULTS

3.1. Prototype with aged insulation and contaminated with saline water

As an initial condition, there is a sample of stator winding to 4.16kV, which was subjected to the accelerated aging process. The insulation aging was simulated by two factors: voltage and temperature.
After aging ends, the sample underwent a rejuvenation process and was subsequently subjected to dielectric tests. At Table 1 it is found that the results presented in the column “Initial conditions” demonstrate that the sample has ideal parameters to be used as a reference.
After the saline water application, it was found that the W phase insulation resistance showed a very low level and, therefore, the other tests were not performed to avoid greater damage. Evaluating the root cause of the sample failure, it is concluded that the high level of surface contamination added to a possible crack caused by the simulated operational effects during the VET test were the causes of the low level of insulation.

Table 1: Test results - Sample contaminated with saline water

Tests		Samples					
		Initial conditions			Contaminated		
		U	V	W	U	V	W
R. ohmic	Ω	0.11	0.11	0.11	0.11	0.11	0.11
R1min @ 40ºC	GΩ	4.82	4.87	4.72	3.40	4.20	**0.02**
IA	-	1.9	1.9	1.9	-	-	-
PI	-	5.20	5.00	5.20	-	-	-
Tan δ @ 20ºC	%	3.71	3.84	4.25	-	-	-
Average Tan δ (Tip-up)	%	0.24	0.18	0.46	-	-	-
Max Δtanδ	%	1.46	0.94	1.05	-	-	-
QM +	mV	181	191	-	-	-	-
QM -	mV	-	112	-	-	-	-
DD	-	1.50	1.60	1.50	-	-	-
DAR	-	4.20	4.20	4.80	-	-	-

3.2. Test 2 - Revitalized sample and contaminated with saline water

Due to the failure detected in test 1, the sample was submitted to the revitalization process. The revitalization process consists of rejuvenating the winding superficial area, preventing contaminants from causing a deficit in the stator insulation degree. After revitalization, the wound stator sample was subjected to new tests to guarantee the initial condition and later to be subjected to the superficial contaminant effect.
At Table 2, it can be observed that contamination by saline water has a significant impact on the insulation resistance causing a considerable drop in the polarization index in the W phase. This drop, both in the insulation resistance and in the polarization index, is directly related to an increase in the superficial leakage current.
The increase in dielectric losses Tan δ @ 20ºC for the W phase and the drop in the average of Tan δ (Tip-up) for U and W phases are noteworthy. The drop in the average of Tan δ (Tip-up) may be related to the leakage current increased and, therefore, a change in losses at all test voltage levels.
There was no significant change in the levels of partial discharges when comparing the revitalized sample to the contaminated sample. This behavior indicates that superficial contamination does not consistently allow the propagation of “tracking” when the electric field is maintained for a short period. “Tracking” is an accumulative phenomenon and requires the constant existence of an electric field to generate an impact in the measurements of partial discharges.
The response to the dielectric discharge indicates that the insulation did not absorb the contaminant. This behavior is consistent with the fact that the sample has undergone the rejuvenation process, that is, the sample is encapsulated.

The DAR data shows that contamination has no direct impact on absorption. This behavior is coherent to the fact that the absorption current is directly related to molecular polarization and, therefore, involves the measurement of currents with magnitudes greater than the leakage current.
It is noteworthy that the epoxy-mica insulation has a non-hygroscopic characteristic, so when applying the contaminant, it was verified through the dielectric discharge (DD) and absorption ratio (DAR) tests that there were no significant changes since it was not expected absorption of moisture present in the contaminant.

Table 2: Test results - Sample contaminated with saline water

Tests		**Samples**					
		Initial conditions			**Contaminated**		
		U	**V**	**W**	**U**	**V**	**W**
R. ohmic	Ω	0.11	0.11	0.11	0.11	0.11	0.11
R1min @ 40ºC	GΩ	7.04	6.44	7.27	6.21	**3.78**	**1.77**
IA	-	1.9	2.0	2.1	1.8	1.9	1.4
PI	-	5.5	5.5	4.4	3.9	4.6	1.0
Tan δ @ 20ºC	%	3.36	4.26	4.26	3.38	4.28	**4.80**
Average Tan δ (Tip-up)	%	0.16	0.15	0.12	**0.07**	0.14	**0.04**
Max Δtanδ	%	0.80	0.94	0.77	0.66	0.74	0.58
QM +	mV	251.0	242.0	146.0	200.0	289.0	129.0
QM -	mV	53.0	233.0	131.0	171.0	293.0	117.0
DD	-	0.8	0.8	0.9	1.0	1.0	1.0
DAR	-	4.2	4.6	4.2	4.2	4.5	4.2

3.3. Test 3 - Revitalized sample and contaminated with moist sawdust

After performing the tests with a sample contaminated with saline water, the sample was subjected to a new washing process to eliminate contamination. After cleaning, the stator was subjected to new tests to assess the impact of contamination by moist sawdust.
The Table 3 presents the results of the tests before and after contamination by moist sawdust. The results presented in the "Initial conditions" column, demonstrate that the prototype presented better results for the insulation resistance (R1min @40ºC) and polarization index (PI). There was a drop in dielectric losses (Tan δ @ 20ºC) and a small improvement in the response to (DAR). This behavior is consistent since the prototype was subjected to the cleaning process to eliminate the contaminant.
In the "Contaminated" column, it is observed a drop in the insulation resistance value (R1min @ 40ºC), possibly caused by the excess of contaminating material. When inserting a contaminating material in an amount sufficient to obstruct the ventilation channels, there was a variation in the phase capacitance value, affecting the capacitive current during the polarization process. Considering that the other characteristics, absorption and leakage, were not affected, there was an increase in the values of (AI), (PI) and (DAR). On the other hand, there is an increase in dielectric losses (Tan δ @ 20ºC), which can demonstrate that the leakage current is more expressive when the test is performed in alternate current.
The levels of dielectric discharge (DD) showed a considerable increase. This increase indicates homogeneity loss of the insulation caused by the insertion of the contaminating material between the stator ventilation channels.
The levels of partial discharges represent a downward trend in magnitudes when comparing the test before and after contamination. This behavior may be related to the high humidity applied to the sawdust during the contamination simulation. The high humidity causes an increase in the leakage current between the windings of different phases "equalizing" the potential difference over the contaminating material. The effect of the leakage path (tracking) is caused when the contaminated region presents a high potential difference and this occurs only in contaminated and dry regions, according to the model in figure 2.
Soltani (2009) verified a similar behavior. In the study on the humidity effect on the partial discharge activity, Soltani (2009) has identified that after successive days of exposure to high humidity, the partial discharge activity was suppressed.

Table 3: Test results - Sample contaminated with moist sawdust

Test		Samples					
		Initial conditions			Contaminated		
		U	V	W	U	V	W
R. ohmic	Ω	0.11	0.11	0.11	0.11	0.11	0.11
R1min @ 40ºC	GΩ	9.73	9.59	14.05	**8.40**	**7.31**	**11.05**
IA	-	1.80	1.74	1.50	**1.9**	**1.8**	**2.1**
PI	-	4.43	4.29	3.37	**5.7**	**5.0**	**4.8**
Tan δ @ 20ºC	%	2.60	2.50	3.40	**2.75**	**2.88**	**4.00**
Average Tan δ (Tip-up)	%	0.04	0.15	0.10	0.06	0.06	0.06
Max Δtanδ	%	0.70	0.70	0.60	0.70	0.88	0.75
QM +	mV	206.0	310.0	243.0	108.0	147.0	182.0
QM -	mV	53.0	175.0	287.0	85.0	128.0	175.0
DD	-	0.9	0.9	1.0	**1.71**	**1.74**	**1.77**
DAR	-	3.70	3.65	3.67	4.2	4.7	4.9

4. CONCLUSION

The main objective of this article is to present the effects of contaminants in the medium voltage insulation system applied to the rotating electrical machines' windings. Thereunto, in a wound stator prototype with a nominal voltage of 4.16kV, two contaminants commonly found in the most diverse applications were applied. The tests chosen for evaluation were selected due to normative reference, methodology and the ability to diagnose failure trends.

The prototype was subjected to a VET cycle for accelerated aging, but maintaining the parameters of the insulation system within the acceptance criteria. Right at the first contamination with saline water, the isolation was affected, bringing the high isolation rates to zero in one phase (W) of the winding, making it necessary to interrupt the experiments. This absorption of the contaminant was due to micro-cracks in the insulation.

For the repetition of this contaminant, it was necessary to rejuvenate the prototype and then perform a new measurement, returning the insulation values. As it is a superficial contamination, there was a significant impact on the leakage current, a behavior that could be validated through the drop in the polarization index after contamination. The increase in leakage current also showed a change in the dielectric losses' behavior, which could be seen in the increase in Tan δ @20ºC for the W phase and drop in the Average Tan δ (Tip-up) of the U and W phases. The Average Tan δ (Tip-up) is related to the increase of losses in the lowest steps of test voltage.

After revitalizing the prototype, the second contaminant, wet sawdust, was applied in sufficient quantity to completely obstruct the stator ventilation channels. This situation affected the phase capacitance value and, therefore, increased the capacitive current during the dielectric polarization. The increase of capacitive current reduced the insulation resistance, however causing an opposite effect to that expected for (AI), (PI), (DAR). It is intuitive to conclude that contaminated windings have low values of (AI), (PI) and (DAR), but possible changes in geometric capacitance can significantly affect these indices. The index (DD) showed a significant response, demonstrating that the insertion of the contaminant caused homogeneity loss of the stator insulation. Partial discharges show a downward trend when subjected to the contaminant with high moisture content.

The downward trend in partial discharges may be aligned with the publication "*Electrical insulation for rotating machines, STONE C.G., 2014*".This publication shows that contaminated and so-called "humid" regions do not cause the appearance of a high potential difference, therefore it does not allow electrical discharges to cause the appearance of damage by Leakage paths. As the machine temperature is increased due to the operation, the surface humidity decreases and allows the appearance of discharges, triggering other phenomena such as corona effect and leakage paths.

Experiments have shown that aged insulation systems are easily affected by contaminants, even with good insulation parameters when clean and dry. With rejuvenation, the insulation system proved to be more resistant to contaminants, but with variations in some measured parameters. The stress factors inherent in electrical machine operation, combined with contaminants, accelerate the degradation of the insulation system and can cause the equipment to lose its reliability level. The loss of reliability is directly linked to the risk of reduced availability and consequently unexpected production downtime, where the electrical machine is involved. It is recommended to monitor the parameters of the rotating electrical machine and predictively perform the necessary maintenance.

5. THANKS

The authors would like to thank WEG Equipamentos Elétricos S.A. for the prototype used in the experiments, for the possibility of using the structure and equipment and for all the support during the development of this work. Thanks also go to Professor Dr. Julio Carlos Teixeira from UFABC, for his review of the study proposal.

6. REFERENCES

[1] BALAN H., BUZDUGAN M., MUNTEANU RA, BOTEZAN A., COZORICI I., AVRAM V .; *Insulation resistance testing of the medium voltage switches*, 2010. Annals of the University of Craiova, Electrical Engineering, N 34, 2010.
[2] INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS. IEEE 43: Recommended practice for testing insulation resistance of rotating machinery, New York, 2000. Available at: <https://standards.ieee.org/findstds/standard/43-2000.html>. Accessed on: 15 June 2014. Exclusive access for subscribers to the electronic collection.
[3] INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS. IEEE 56: IEEE Guide for Insulation Maintenance of Electric Machines, New York, 2016. Available at: <https://ieeexplore.ieee.org/document/7830766>. Accessed on: 7Out. 2019. Exclusive access for subscribers to the electronic collection.
[4] INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS. IEEE 95: IEEE Recommended Practice for Insulation Testing of AC Electric Machinery (2300 V and Above) With High Direct Voltage, 2002. Available at: <https://ieeexplore.ieee.org/document/996345>. Accessed on: 28Jul. 2020. Exclusive access for subscribers to the electronic collection.
[5] INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS. IEEE 1434: Guide for the measurement of partial discharges in AC electric machinery, New York, 2000. Available at: <http://standards.ieee.org /findstds/standard/1434-2000.html>. Accessed on: 15 June 2014. Exclusive access for subscribers to the electronic collection.
[6] INTERNATIONAL ELECTROTECHNICAL COMMISSION 60505: Evaluation and qualification of electrical insulation system, Switzerland, 2011. Available at: <https://webstore.iec.ch/publication/2276>. Accessed on: 29 Aug. 2019. Exclusive access for subscribers to the electronic collection.
[7] LIN, L; KANG, A; SONG, J; LEI, Z; ZHAO, Y; ISENBERG, A; Effect of Water Vapor on Oil-contamination Discharge of Stator Windings. China, 2016. Available at: <https://ieeexplore.ieee.org/document/7736828>. Accessed on: 7Out. 2019. Exclusive access for subscribers to the electronic collection.
[8] MEGGER; User guide - MIT515, MIT525 and MIT1025, 2008. Available at: <https://megger.com/10-kv-diagnostic-insulation-resistance-tester-mit1025#overview>. Acesso em: 28 Jul. 2020. Acesso exclusivo para assinantes da coleção eletrônica.
[9] MEGGER; *Dielectric discharge test*. Available at: <https://megger.com/support/ technical-library / application-notes / dielectric-discharge-test>. Accessed on: 28 Jul. 2020. Exclusive access for subscribers to the electronic collection.
[10] MORETTI, D,R; Investigação experimental sobre faltas em isolação de alta tensão aplicada em estatores de máquinas elétricas, 2016. Dissertação (mestrado) - Curso de Pós-Graduação em Engenharia Elétrica da Universidade Federal de Santa Catarina, Florianópolis-SC, 2016.
[11] NETI, P .; ZHANG, P .; IQ, X .; ZHOU, Y .; YOUNSI, K .; SHAH, M .; WEEBER, K .;*Online detection of endwiding contamination in industrial motors*, 2011. Available at: <https://ieeexplore.ieee.org/document/05996159>. Accessed on: 26 Nov. 2019. Exclusive access for subscribers to the electronic collection.

[12] SPEZIA, FR; MORETTI, DR; Effects of the lubrication oil over the endurance of na insulation system of medium voltage turbogenerators. INSULEC International Conference on Electrical & Electronic Insulating Materials & Systems, 2015.
[13] SOLTANI, R .; DAVID, E .; LAMARRE, L .; LAFORTUNE, L .; Effect of humudity on charge and discharge current of large rotating machines bar insulation. Canada, Available at: <https://ieeexplore.ieee.org/document/7736828>. Accessed on: 7Out. 2019. Exclusive access for subscribers to the electronic collection.
[14] STONE CG; CULBERT I .; BOULTER EA; DHIRANI, H ..;*Electrical insulation for rotating machines*. USA, 2014.
[15] VON ROLL; Fundamentals of Insulation Technology, 2008.

	**Walter Evaldo Kuchenbecker** holds a PhD in ENERGY, in the research line of Rotating Electrical Machines by UFABC. Currently, he participates in the research program RDC (Researcher Doctor Collaborator) and is a coursing postdoctoral in ENERGY at the same university. Your researches and publications are focused on rotating electrical machines. Has 33 years of experience at WEG Equipamentos Elétricos S.A., also focused on applications, manufacture and analysis of electrical machines, he has also been, for the past 11 years, supervisor of quality and electrical tests areas.
	**Daniel Rodrigo Moretti** is a Master in ELECTRICAL MACHINES, in the line of research of Rotating Electrical Machines insulation by UFSC. Currently, he works with field service at WEG Equipamentos Elétricos S.A. – ENERGIA unit. Has 9 years of experience at WEG focused on applications, manufacturing, quality control and analysis of electrical machines.