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FAILURE PREVENTION IN A 525 KV THREE-PHASE TRANSFORMER THROUGH DELTA TANGENT ONLINE MONITORING OF BUSHINGS.

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ABSTRACT

Condensive bushings are an essential part of the insulation mechanism of high voltage equipment. Monitoring this component helps in the early detection of failures, making it possible to have a more effective maintenance. We will now present Cemig's experience with capacitance and delta tangent online monitoring in 550 kV and 245 kV bushings in a three-phase transformer at Mesquita Substation, and also in a pedestal current transformer.
It will be possible to verify the efficacy of bushing online monitoring in the prevention of an incipient failure as well as how tangent delta monitoring is a crucial factor in anticipating a possible failure.

KEYWORDS: Bushings, capacitance, tangent delta, Transformers, Monitoring.

- INTRODUCTION

Although the individual cost of condensive bushings is relatively low when compared to the total cost of the equipment where they are applied, failure in bushing insulation may cause severe damage to the equipment, as, for example, in the case of a power transformer, and this may start a fire which may lead to its total loss, in addition to the risk of damaging adjacent equipment due to the porcelain shards which may become projectiles while falling, or the fallen structures of the associated bus bars. Even worse than this, this kind of failure may be extremely dangerous, if there are people close to the equipment.
A study by Cigré, dated 1983 [1] shows that a many failures in power transformers start at the condensive bushings. Although there are no current statistics on this subject, the recent history of bushing events [2] virtually confirms this research. Figure 01 illustrates the data obtained in the Cigré's studies [1]. The changes in asset maintenance practices, which are mostly a result of the new rules set for the electric power sector, have taken into consideration the maintenance paradigm based on the state of the actual component. This paradigm stipulates that the best intervention point must be determined through accurate techniques and means, where an unnecessary stop should not be made. Otherwise, the state of the component must be continually verified to prevent abrupt failure, caused by unforeseen factors.
In this context, online bushing monitoring has a very important role, which is preventing possible failure that may occur between regular maintenance periods, and also postpone eventual maintenances to a more economically convenient period.

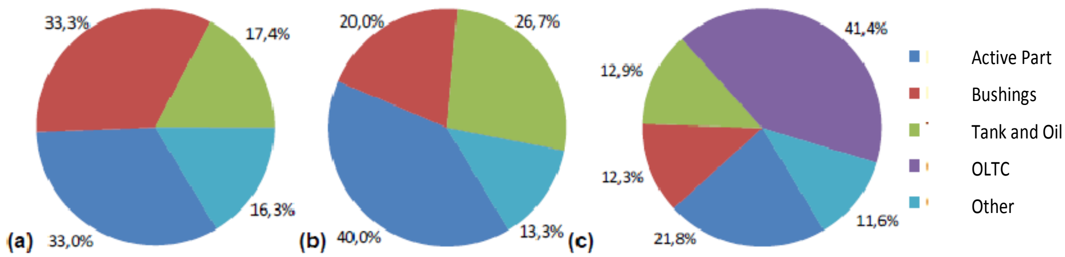

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Figure 01: Statistics of the causes of transformer downtime. (a) power plant transformers, without OLTC (b) No-OLTC substation transformers; (c) substation transformers with OLTC [1].

Another advantage of the online monitoring is the possibility of collecting data which were unknown before about the behavior of bushings under conditions of actual use, including the moments just before a failure.

The advance obtained with the analysis of those data is converted into new techniques to prevent those failures, as shown in [03].

2.0 - CONTEXTUALIZATION OF THE INSTALLATION OF THE MONITORING SYSTEM AT MESQUITA SUBSTATION

Mesquita Substation, the object of this study, is located in the municipality of Santana do Paraíso - State of Minas Gerais, next to the city of Ipatinga, in the eastern area of Minas Gerais. This substation supplies the load of great consumers ofthe electric power transmission system such as USIMINAS, ARCELOR, MITTAL and CENIBRA. It entered commercial service in June 1981. The current installed transformation power is 1,200MVA, and consists of three 500/230kV autotransformers, with 400 MVA each, two 500kV transmission lines, and five 230kV transmission lines. Figure 02 shows an aerial view of the Mesquita Substation.

Figure 02: Aerial view of Cemig's Mesquita Substation, located in the eastern Minas Gerais region.

In mid-2005, Cemig was a pioneer when it installed Treetech's BM condensive bushing monitor in the 550 kV and 245 kV bushings of the T-2 Autotransformer at Mesquita Substation. At that time, that system was also installed in a 550-kV pedestal CT on the same busbar as the T-2 autotransformer.

The choice was motivated by the suspicions concerning a certain family of bushings with a history of failure in the electric power sector. In figure 03, some details of the physical installation of the bushing monitor in the autotransformer and in the pedestal CT can be seen.

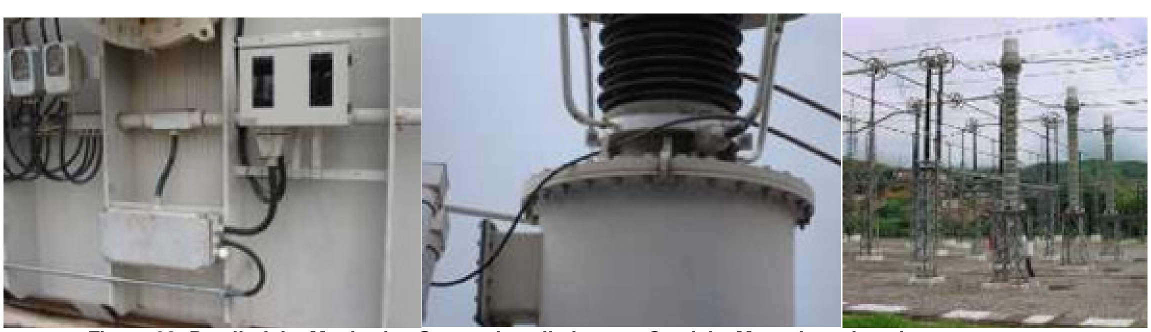


Figure 03: Detail of the Monitoring System installations at Cemig's Mesquita substation.

In addition to the bushing monitoring system, insulating oil moisture monitoringwas also installed at the T-2 of Mesquita substation, together with an integration of the oil and winding temperature monitoring systems.

A wireless network was used to connect the sensors at the substation yard to the Sigma monitoring system which had been installed. Using a wireless network was a practical, low-cost and safe solution to transmit data from the sensors to the monitoring system.

This was a way to ensure Cemig would have easy access to all data and diagnoses issued by those sensors. Those data are used by Cemig's maintenance crew to improve the asset's utilization and foresee possible failures between maintenances and routine verifications.

3.0 - METHODOLOGY FOR THE ONLINE MONITORING OF CAPACITANCE AND TANGENT DELTA

Capacitance and tangent delta are acknowledged to be some of the main parameters for the diagnosis of bushing insulation condition, because those parameters are directly affected by the insulation deterioration. For instance, a short circuit in the insulation layers causes an increase in capacitance, while infiltrating moisture due to tightness failure causes an increase in the tangent delta.

ANSI / IEEE C57.19.100-1995 standard [4], published prior to the popularization of online monitoring, suggests hat capacitance and tangent delta tests should be performed at typical intervals from 3 to 6 years.

A comparative study [5] correlating the offline measurements of capacitance and tangent delta with the analyses of gases dissolved in bushing oil with suspected defects in evolution testifies to the effectiveness of the capacitance and tangent delta measurements for the diagnosis of bushing failures.

Online monitoring is the answer to the need for continuing verification of these parameters, ensuring the operating status of the bushing and anticipating incipient insulation defects. But for the online monitoring of the bushings to take place safely, with accuracy and reliability, some critical points need to be observed, as described below:

3.1 Bushing Leakage Current Measurement

In order for the measurement of the leakage currents of the tap test or voltage test to be done in a safe and efficient way, adapters will be needed to serve as electric and mechanical interface between the tap and the electric circuits which will carry the current to the measurement site. The tap adapters used in Cemig's application have all requirements to fulfill this application with good performance and safety. In figure 04 there are some details of this installation.

Figure 04: Detail of the tap adapters used in the BM bushing monitoring system installed at Mesquita Substation.

After a simplified analysis, we notice the tap adapter is merely a jack allowing the electric contact between the bushing and the measurement input of the bushing monitor. This simplified approach is both wrong and dangerous, because we need to take into consideration that the bushing tap should never be kept open. Among the electric characteristics the adapter must have to meet safety requirements and monitoring performance, the most important are the differentiated mechanical design and the protection against failure in the electric connection of the measurement circuit or in case an accidental disconnection occurs.

The tap adapter used has a protective circuit inside it which has a twofold role. The first application is the redundant protection against tap opening if the connection cables between the adapter and the measurement module of the bushing monitor are accidentally disconnected. This is an instant protection, limiting the voltage in any part of the secondary circuit of the tap adapter in ≈15 Vac. The protections which were used may conduct for an indeterminate amount of time and are sized according to the atmospheric impulse test (BIL) 12,050 kV - 765kV bushing. In addition to that, each adapter has a double protection layer, which, working in parallel, provides redundant protection.

These characteristics are ensured by a mechanical design that makes these protections inaccessible during the handling and installation of the adapter. The second function is the primary protection against associated overcurrents (several kA) and overvoltages which occur at the bushing tap when there are overvoltages caused by switching maneuvers or atmospheric impulses. This function is supplemented by the secondary protection inside the BM itself, so that the primary and secondary protections work together in a coordinated way to avoid damage to the BM and to the adapter.

3.2 Mathematical and statistical treatment of the measurements to extract the information about insulation capacitance and tangent delta;

The measurement of mA and µA electrical values in electromagnetically aggressive environments, such of the one of a high voltage substation, has been a constant challenge when designing accurate and reliable systems to monitor electric equipment. In the specific case of bushing monitoring, some techniques are used to approach this challenge.
Treetech has adopted, in its condensive bushing monitor, the technique of the vectorial sum of the leakage currents of a three-phase assembly. This technique presents some advantages, such as the online monitoring of both capacitance and tangent delta changes, in addition to not demanding the measurement of phase-ground voltages applied to the bushings. Some techniques cannot monitor the tangent delta. Others have as a requirement the measurement of the phase-ground voltages applied to the bushings, and often there are no power transformers available at the facility to provide this information.
In each of the bushings the leakage current flows through capacitance C1 to the ground, going through the capacitive tap, and this current is a function of the phase-ground voltage and insulation impedance. Any changes in this current would reflect a change in bushing impedance. In principle, this current may be used to measure this change. However, the mostly capacitive nature of the leakage current and the magnitude of the changes that one desires to measure lead to the challenge to measure changes of a 0.6% magnitude in the dissipation factor - which may be the difference between a new bushing and a bushing that is at risk - and this change virtually does not change the total leakage current flowing from a bushing.
The leakage current vectorial sum technique, used to go around this problem, uses the fact that there is a phase shift among the three leakage currents of approximately 120º, and they normally have the same magnitude. Therefore, the vectorial sum tends to be much smaller than each one of the individual leakage currents, as illustrated in Figure 05 (a) for a given initial capacitance and delta tangent condition.

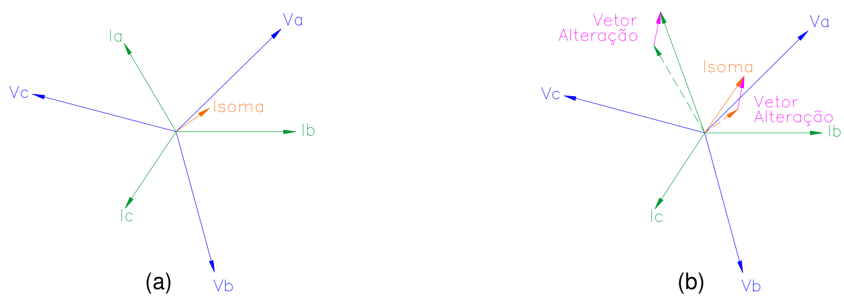


Figure 05: Leakage currents of three bushing in a three-phase system and their sum; (a) For one certain initial condition; (b) With a change in capacitance and dissipation factor of the phase A bushing.

Now, supposing a change in the capacitance and in the dissipation factor of the bushing in phase A, as shown in Figure 5(b), the change vector which expresses the displacement of current Ia from its initial value up to its final value is also reflected in the current total sum, which changes in relation to its initial value according to the same change vector.
This change vector has a virtually insignificant weight when compared to the magnitude of the leakage current of phase A. But this is not what happens when this vector is compared to the total sum current, which allows its detection and as a result the detection of the change in the bushing impedance under study. Therefore, the technique of the vectorial sum of the leakage currents allows an increase in sensitivity which makes it feasible to monitor the changes both in the capacitance and in the tangent delta of the insulation.
However, the bushing leakage currents are a function not only of their capacitances and tangents delta, but also of the phase-ground voltages of the system. Since the latter are often not available for measurement by the monitoring system, as explained above, the possible influence of variations in the phase-ground voltages on the measurements of the variations in capacitance and tangent delta is eliminated through advanced signal processing proprietary techniques, which include also statistic data treatment.
These statistic treatments assume the use of a data mass accumulated along the system's operation time, which is continually updated with the most recent leakage current and total current sum measurements.. Due to that, the online monitoring system has some time to respond to the variations occurred in capacitance and tangent delta, varying from some hours to some days, in order to confirm that the capacitance change and/or tangent delta change is real and not caused by voltage oscillation in the electric power system.
The changes in capacitance and tangent delta are used to increase the initial values programmed in the BM. This is how the BM indicates the current value of the capacitance and tangent delta corresponding to the one obtained in an offline bushing test by using the initial value and the posterior changes.

4.0 - CASE STUDY: AN OCCURRENCE IN THE MESQUITA SUBSTATION– CEMIG

During the period from 2005 to 2010, the monitoring system was in continuous operation. No alarm was registered for the bushing status, indicating that until then the bushing was working normally. Table 01 shows the initial parameters for bushing monitoring in T-2 and in the pedestal CT.

Table 01: Initial values of the bushing monitoring in the T-2 and in the Pedestal CT

Phase	550 kV		245 kV		550 kV CT	
	Capacitance	Tangent Delta	Capacitance	Tangent Delta	Capacitance	Tangent Delta
A	583.0 pF	0.180 %	511.0 pF	0.360 %	472.0 pF	0.300 %
B	583.0 pF	0.180 %	519.0 pF	0.360 %	470.0 pF	0.300 %
C	583.0 pF	0.180 %	511.0 pF	0.360 %	475.0 pF	0.300 %

High capacitance and very high capacitancealarm values were parameterized for a variation of 3% and 5% in relation to the initial value. High tangent delta and very high tangent delta values were parameterized for a variation of 100% and 200% in relation to the initial value. Table 02 shows these values in pF and %.

Table 02: Parameterization of the bushing monitoring alarms for the T-2 and the Pedestal CT

Phase	550 kV				245 kV				550 kV CT			
	Capacitance (pF)		Tangent Delta		Capacitance (pF)		Tangent Delta (%)		Capacitance (pF)		Tangent Delta (%)	
	High	Very high	High	Very high	High	Very high	High	Very high	High	Very high	High	Very high
A	600.49	612.1	0.360	0.540	526.3	536.5	0.720	1.080	486.2	495.6	0.600	0.900
B	600.49	612.1	0.360	0.540	534.5	544.9	0.720	1.080	484.1	493.5	0.600	0.900
C	600.49	612.1	0.360	0.540	526.3	536.5	0.720	1.080	489.3	498.8	0.600	0.900

On 02/20/2011, a Sunday, the bushing monitor issued a high capacitance trend alarm for the 230 kV bushing, phase B. The Mesquita Substation operators notified the Maintenance Engineering department at Cemig about this alarm [6].

On 02/22/2011, Tuesday, Cemig's Maintenance Engineering staff contacted Treetech so this alarm could be verified. On this same date, the alarm showing a capacitance increase trend indicated 9 days remaining to reach the programmed high capacitance alarm value. The BM also indicated that the time remaining for the measurement to reach the high tangent delta alarm value was of 63 days. See table 3 for the values measured by the bushing monitor at the moment of the analysis.

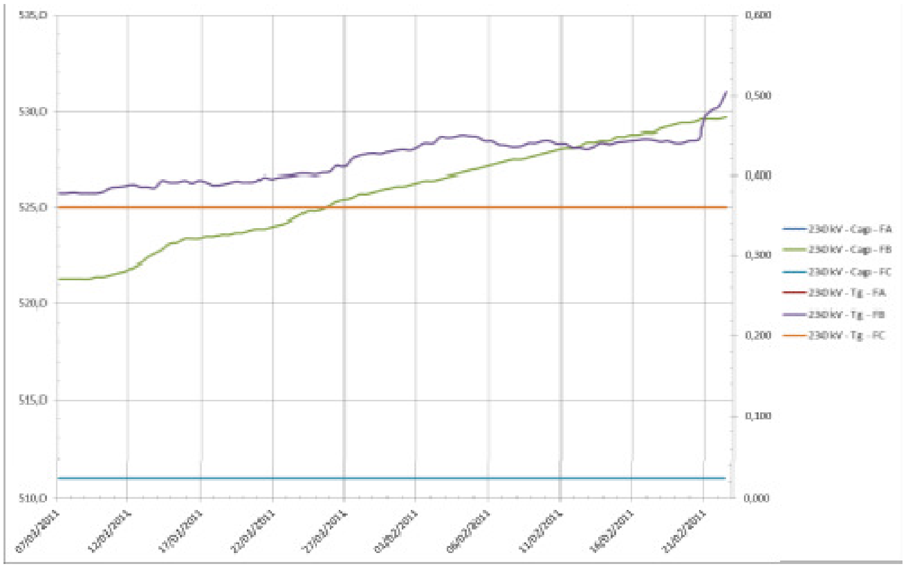
Table 03: Bushing monitoring values on 02/22/2011, at the moment of the analysis

Phase	550 kV		245 kV		550 kV CT	
	Capacitance	Tangent Delta	Capacitance	Tangent Delta	Capacitance	Tangent Delta
A	583.0 pF	0.202 %	511.0 pF	0.360 %	472.0 pF	0.300 %
B	583.0 pF	0.180 %	529.8 pF	0.454 %	470.0 pF	0.300 %
C	583.0 pF	0.180 %	511.0 pF	0.360 %	475.0 pF	0.300 %

We can notice that there was a 2.08% variation in capacitance and a 26.11% variation in the tangent delta of the 245kV bushing in phase B. All pertinent analyses were made, and the trend towards an increase both in capacitance and tangent delta were confirmed. After this confirmation the Cemig's engineering team scheduled a system shutdown for 02/27/2011, a Sunday, to perform offline tests that could confirm the bushingstatus. Cemig also prepared to replace the bushing, if the problem was confirmed.

From this point on, both Cemig and Treetech mobilized a team of technicians to follow the evolution of the measurements indicated by the system with the purpose of keeping operation safe.

See in graph 01 the measurements up to 02/22/2011.



Graph 01 – Evolution of the capacitance and tangent delta values for the 245 kV assembly

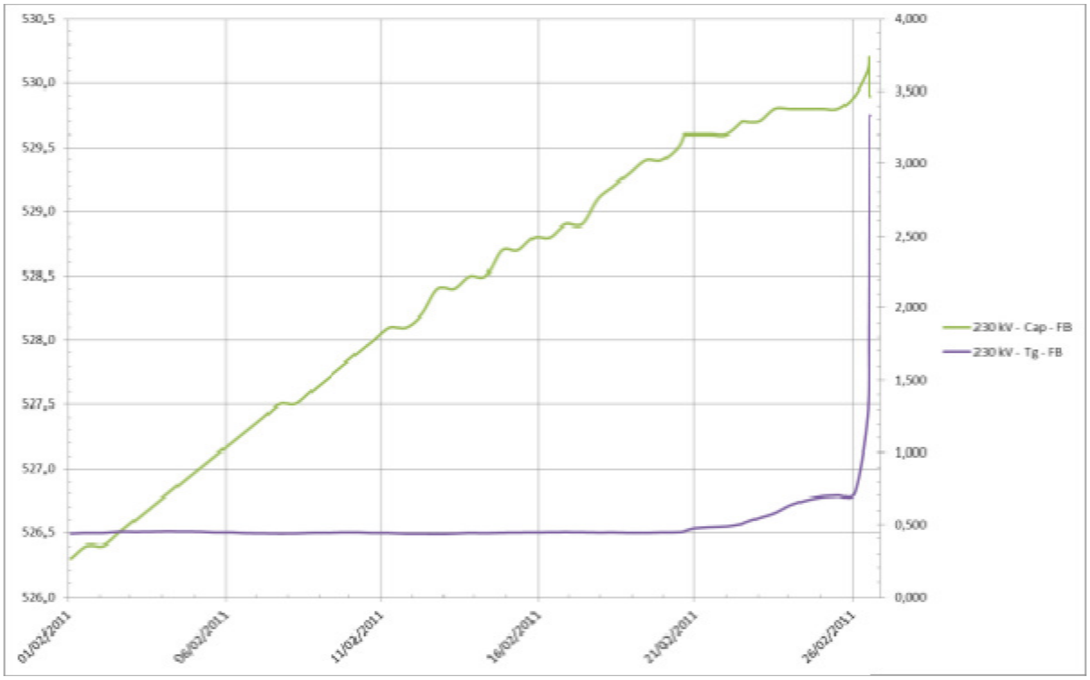
Until the Saturday before the scheduled shutdown, the capacitance and tangent delta values evolved according to what was planned by the monitoring, and there was no need to reschedule.

Still on Saturday, 02/26/2011, at 11:55 am, the BM bushing monitor showed a sudden increase in the value of the tangent delta of phase B of the 245 kV assembly. The monitor showed a variation in the tangent delta indication, within a very short time interval, from 0.490%, to 1.263%, above the very high alarm limits, while the measured capacitance varied very little, with a value of 530.1 pF. Cemig's and Treetech's teams on standby at the site did analyses based on the indications issued by the system, to verify the existence of indication consistency.

Both Cemig's Operation and Maintenance Engineering teams took immediate action and and started negotiations to shut down the transformer as an emergency measure.

Since it is a piece of equipment that is a part of the Basic Network of the National Interconnected System, the shutdown was negotiated with the ONS [National Electric Power System Operator], which authorized the operation of the T-2 autotransformer at 3:13 pm through CLM 748/201, since the maneuver took place in real time.

Cemig immediately sent a team to take the first offline measurements of the suspected defective bushing, as soon as the transformer was shut down, to verify the validity of the indications issued by the online monitoring. During this waiting period, both company teams followed the evolution of the tangent delta online, and it started to go up very quickly until the transformer was shut down, reaching 3.331% at the most critical moment. Graph 02 shows the critical evolution taking place in the moments just before shutdown.



Graph 02 – Detailed evolution of the values monitored in the moments before shutdown.

Around 3:40 pm the necessary maneuvers for shutdown were over, and the transformer, duly insulated, had its suspected defective bushing submitted to the offline test. Following the recommendation by the Treetech team, Cemig's team measured the values of the tangent delta as soon as possible, because tangent delta varies with temperature. The typical behavior is that the tangent delta goes down as the temperature goes down for the same condition of insulation deterioration. This is why it is so important that this measurement was made as soon as possible. At the moment of the shutdown, the bushing monitor indicated a capacitance value of 529.9 pF and 3.329% for the tangent delta. Table 04 shows the data obtained through the offline measurements and by the online monitoring system.

Table 04: Values of the offline measurements and online measurements for the suspected defective bushing

Source	245 kV		
	Capacitance (pF)	Tangent Delta (%)	Notes
BM online Monitor	529.90	3.329	-
Offline measurements	517.28	2.600	Ambient temperature: 34 °C Top Oil Temperature: 61.3 °C
Offline measurement counterproof	517.60	2.440	Ambient temperature: 32 °C Top Oil Temperature: 56.4 °C

After the offline measurements confirmed the indications of the online monitoring, Cemig decided to keep the transformer offline until the defective bushing could be replaced. The replacement was scheduled for Monday, 02/28/2011.

On Sunday, 02/27/2011, with the arrival of the Cemig crew who would change the bushing on the following day, new offline measurements were taken with an instrument manufactured by a different company with the intention to confirm the data obtained by the first instrument. Table 05 shows the results of this new measurement.

Table 05: Values of suspected bushing offline and online measurements

Source	245 kV		
	Capacitance (pF)	Tangent Delta (%)	Notes
Offline measurements	515.00	0.780	Ambient temperature: 31 °C Top Oil Temperature: 34.8 °C
Offline measurement counterproof	514.10	0.910	Ambient temperature: 31 °C Top Oil Temperature: 34.8 °C

With these new measurements, we verified the bushing showed significant changes in tangent delta even under the most favorable temperature conditions. Measurement variations were expected and then we decided to go ahead and change the bushing as planned.

In this opportunity, a visual inspection of the bushing was also conducted to try and determine a possible cause for the defect. Cemig's maintenance team detected a place in which there was a small oil leakage in the bottom part of the bushing, close to the flange. This leakage might have been the cause of the symptom which was detected. The leakage spot can be seen In Figure 06.

Figure 06: Cemig's team replacing the defective bushing.

On 02/28/2011 the maintenance crew changed the defective bushing. Figure 07 shows some steps of the operation conducted by the Cemig's crew.

Figure 07: Cemig's crew replacing the defective bushing.

To better understand the kind of failure which occurred in the bushing and caused the change in its dielectric parameters, a sample of the insulating oil was collected to be analyzed by the gas chromatograph at Cemig's lab. The results of this analysis are shown in Table 06.

Table 06: Results of the gas chromatography analysis of the defective bushing oil

Dissolved Gases	H_2	O_2	N_2	CH_4	CO	CO_2	C_2H_4	C_2H_6	C_2H_2	Total Combustible Gases
Concentration in PPM	5,446.0	18,750.0	82,987.0	869.0	130.0	550.0	3.7	325.0	0.0	

The values highlighted in red were higher than the typical values indicated in the standard *IEC 60599 ed2.1– Mineral oil-impregnated electrical equipment in service - Guide to the interpretation of dissolved and free gases analysis* table A.9 [7], reproduce in Table 06.

Table 06: Reference Values according to IEC 60599 ed2.1

Table A.9 – 95 % typical concentration values in bushings

Values in microlitres per litre

H_2	CO	CO_2	CH_4	C_2H_6	C_2H_4	C_2H_2
140	1 000	3 400	40	70	30	2

It is evident that the result of this gas chromatography analysis showed high H_2 values, thus confirming the existence of a defect. The correlation of the other gases through the Duval Triangle method, shown on Figure 08, reveals that this defect was in an incipient stage, and it can be classified as low-energy partial discharges, with evidence of evolution towards medium energy partial discharges. No combustible gases indicating arc and high overheating were found, such as C_2H_4 and C_2H_2, which matches the fact that there was no significant change in capacitance.

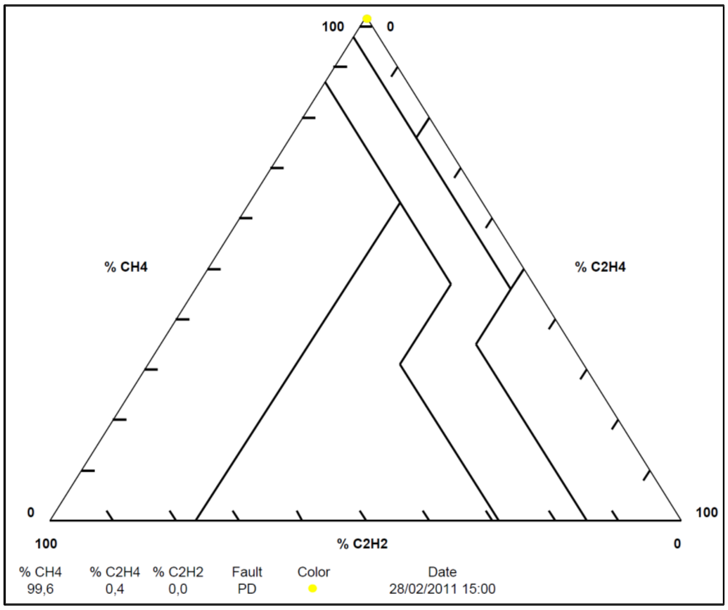


Figure 08: Duval Triangle and its diagnostic zones

This shows the decision to shut down was correct and the monitoring system worked as it should, avoiding a probable bushing explosion and serious damage to the transformer.

5.1 - CONCLUSION

Responding to a growing demand for better quality indexes, availability and reliability, Cemig, motivated by the its suspicion in relation to a certain family of bushings with history of failure in the electric power sector, installed, in the Mesquita substation, the BM condensive bushing monitor by Treetech in the 550 kV and 245 kV bushings of the T-2 autotransformer and of a 550kV pedestal CT as well.

In addition to this motivating factor, online bushing monitoring is known to contribute to the reduction of maintenance costs through improvement in the maintenance planning process and intensive use of the maintenance paradigm under condition, reducing the number of shutdowns for routine tests.

Additionally, online monitoring has provided valuable data on the kind of defects which can appear in this component and their evolution time. The installation of the BM condensive bushing monitoring system has offered several advantages, and the primary purposes listed below were completely fulfilled:

- The reduction in failure risk with real time bushing diagnosis;
- The increase in availability through predictive maintenance instead of preventive maintenance (less maintenance shutdowns).
- The lower maintenance costs due to avoiding unnecessary maintenance;
- The preservation and improvement of the corporate image with the reduction in shutdowns and catastrophic failures.

This article has demonstrated the importance and effectiveness of bushing capacitance and tangent delta online monitoring, highlighting the importance of the tangent delta monitoring for the detection of incipient defects, since in the described experience there was no significant capacitance change, although the tangent delta increased ten times in relation to the initial values of the offline tests.

Therefore, it has been proven that bushing failures may be detected in real time, avoiding severe damage to the equipment from explosion and possible fire, and reducing the losses caused by measurement failure in condensive bushings.

6.0 - BIBLIOGRAPHIC REFERENCES

[1] ELECTRA, "An International Survey on Failures in Large Power Transformers in Service", Paris, CIGRE, Ref. number No. 88 1983

[2] Melo, Marcos A. C., Alves, Marcos, “Experiência com Monitoração On-Line de capacitância e tangente delta de Buchas Condensivas”, XIX SNPTEE – Seminário Nacional de Produção e Transmissão de Energia Elétrica [National Electric Power Production and Transmission Seminar] Rio de Janeiro, Brazil, 2007.

[3] Alves, Marcos, Pena, Miguel C Medina, Severino, Cláudio “DEFEITOS DE EVOLUÇÃO RÁPIDA E MUITO RÁPIDA EM BUCHAS DETECTADOS POR MONITORAMENTO ON-LINE”, XXI SNPTEE – Seminário Nacional de Produção e Transmissão de Energia Elétrica [National Electric Power Production and Transmission Seminar] Florianópolis, Brasil, 2011.

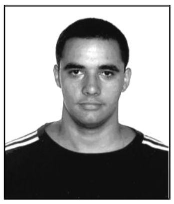
[4] The Institute of Electrical andElectronic Engineers, ANSI/IEEE Std C57.19.100-1995, “IEEE Guide for Application of Power Apparatus Bushings”, March/1995

[5] Melo, Marcos A. C., “Investigação de Ocorrências em Buchas de Transformadores e Reatores Utilizando o Doble M-4000”, IV Conferência da Doble Brasil [Fourth Doble Brasil Conference] – Cemig. Belo Horizonte, Brazil, 2003.

[6] Relatório Técnico de Ocorrência – SE Mesquita [Occurrence Technical Report - Mesquita Substation] – 04/2011

[7] IEC 60599 ed2.1– Mineral oil-impregnated electrical equipment in service - Guide to the interpretation of dissolved and free gases analysis

7.0 AUTHOR BIOGRAPHIES



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