# TDA: Tap-changer Dual Assessment

By

Eric Back,
Marcos Ferreira,
David Hanson,
and
Edis Osmanbasic

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# TDA: TAP-CHANGER DUAL ASSESSMENT

Eric Back, Director of Transmission Operations Support, PG&E
Marcos Ferreira, Regional Sales Manager, Reinhausen Manufacturing
David Hanson, CEO and President, TJ-H2b Analytical Services, Inc.
Edis Osmanbasic, Test Engineer, DV Power

## Abstract

The acronym TDA (Tap Changer Dual Assessment) is introduced to familiarize On Line Tap Changer (OLTC) testers with two test methods: laboratory oil evaluation (Tap Changer Activity Signature Analysis (TASA™)) and electrical field-test Dynamic Resistance Measurement (DRM). TASA™ is based on two fluid assessment tests that provide important information about the deterioration of OLTC materials: DGA and particle profiling. The DRM test is a fast sampling record of the winding resistance dc test current during tap changer operation. Between two tap positions, where the resistance is measured, a current graph generated during the transition provides tools for diagnostics of the tap changer performance. Speed, transition time, ripple, and other important features indicate whether possible defects exist within the tap changer. The test is an off line, non destructive, quick and powerful diagnostic tool utilized to detect incipient problems, as well as to pinpoint the exact location of defects announced by high gasses, or Bucholtz operation, tripping the transformer out of service. Modern computerized instrumentation makes this procedure an easy and intuitive test to perform, while the working group helps standardize methodology and share diagnostic experience.

## Introduction

There is always a question if one test method is sufficient to condemn a piece of electrical equipment. As we know, there is no perfect test, and having more than one test in your "tool box" is preferable when making a decision to take a transformer out of service for repair.

To provide better reliability of diagnostics applied to OLTCs, the TDA, or Tap Changer Dual Assessment, program combines two tests. The first is a laboratory evaluation of an oil sample from a tap changer (TASA™, or Tap changer Activity Signature Analysis provided by TJH2b laboratories). The second test in a TDA is Dynamic Resistance Measurement, an off line electrical diagnostic test obtained using DV Power's tap changer analyzers.

The title of the second test method Dynamic Resistance Measurement is somewhat misleading – DRM is a method of recording electrical current during winding resistance testing. Test current is recorded at a high sampling rate during this exercise, while the tap changer positions are varied from position 1 to the end and back. This method has been used as a diagnostic tool since 1994[1] on resistive-type OLTCs in Europe. DRM has proven to have very good diagnostic power.

Knowledge about performance features of a OLTC provided by a DRM test include[2, 3]:

- Ripple,
- Transition time,
- Motor current,
- Resistance,
- Contact wear,
- Contact bouncing.

Having two assessments from two different angles (materials laboratory and electrical performance test) adds greater reliability to an evaluation in the following ways:

- TASA™ - identifies the wear out of the failure mode and identifies issues;

- DRM - looks at the functionality timing sequence of the operational steps and identifies abnormalities.

## Test Methods

We are not going to elaborate on problems OLTC can cause to transformer operation, there are many papers presented on this topic, like the one showing German experience [4] with 40% participation. Maintenance interval is in tens of thousands of operations for OLTC, but HQ study referenced by Allard [5] showed 12% require maintenance before manufacturer's suggested period. Furthermore, P. Kang et al. [6] show that about 33% of OLTC failures are caused by incorrect maintenance and bad reassembly. All these presentations prove the need for a viable diagnostics of OLTC either before or after any maintenance is performed.

## Tap Changer Activity Signature Analysis (TASA™)

Historically, the first applications of DGA to evaluate load tap changer condition were based on experiences with transformers. Threshold limits were developed for the gasses produced by overheating both individually and in combination. Many factors such as design, operations, ventilation, and on line filtration affect gas levels. Consequently, this gas threshold approach offered limited success but proved the potential usefulness of fluid testing for OLTC condition assessment. Since gas data alone cannot provide sufficient information to fully assess OLTC condition, new approaches were required for OLTC evaluations. The search for this new approach led to the development of Tap Changer Activity Signature Analysis, or TASA™, which provides a condition assessment of the load path components.

In addition to providing useful information for the maintenance of insulating fluid, fluid assessment tests are used in conjunction with OLTC gas data to provide diagnostic information about the condition of on load tap changers. Keeping the oil free of water, arc decomposition products, and other contaminants is essential for proper operation of the on load tap changer. Particle profiling provides important information about the deterioration of materials that result in particle production. This includes information about in-service processes such as fluid

degradation, contact deterioration and mechanical wear of moving parts and rust formation. Two of the most important fluid degradation processes to be evaluated are charring of oil and coke formation.

## Dynamic Resistance Measurement (DRM)

The principle of tap changer operation is to make contact with the new position before breaking from the previous. This is a famous tenet of Dr. Jansen's 1926 patent; an OLTC should "make before break". Resistive and reactive tap changers are constructed differently and result in two distinctly different DRM graphs.

## Resistive Tap Changers

When a resistive-type tap changer switches from one position to the next, resistors are introduced into the circuit to minimize arcing and lower circulating current during the brief period when the tapped portion of the winding is shorted. See figure 1.

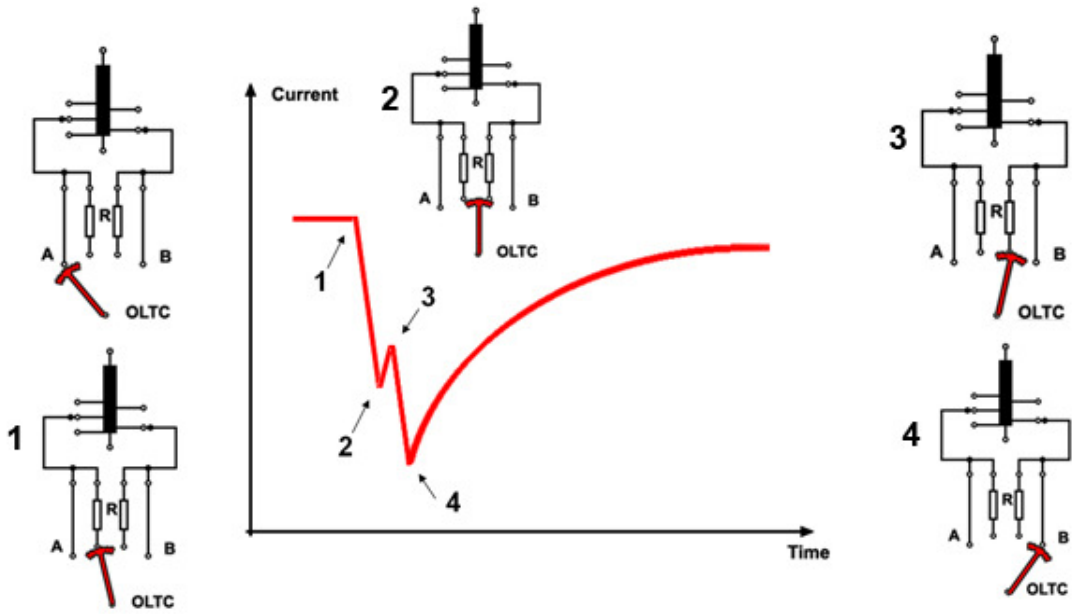



Figure 1. Dynamic Graph of Diverter Switch Operation

## Reactive (Reactance-Type) Tap Changers

The reactance-type tap changer has two arms that alternatively go from one position to the other and that way operate in bridging and non-bridging positions. A preventive autotransformer restricts circulating current, so this model can continuously operate in a bridging tap position. The current pattern during switching of a reactive tap changer is illustrated in Figures 2 and 3.

Changing tap position from bridging (odd positions) to non-bridging (even positions) and vice versa provides characteristic fingerprints. A graph like the one in Figure 2 is obtained when testing a regulator that has a very low inductance. Transitions between odd and even tap position are easily observable.

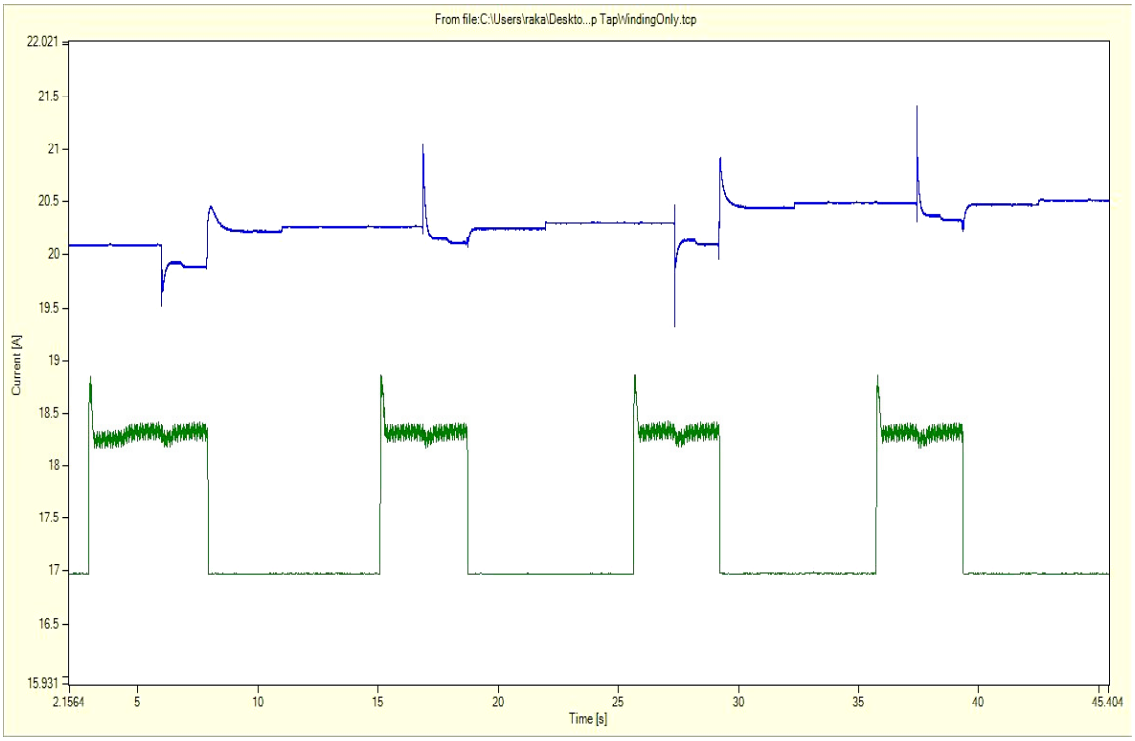



Figure 2. Graph of DRM of Low Inductance Regulator; Upper Trace is the DRM; Bottom Trace is the Current Profile of the Associated OLTC Motor

Of course, inductance of a transformer changes this graph to look similar to the example shown in Figure 3, where all 33 position transitions of an OLTC that is in good condition were recorded.

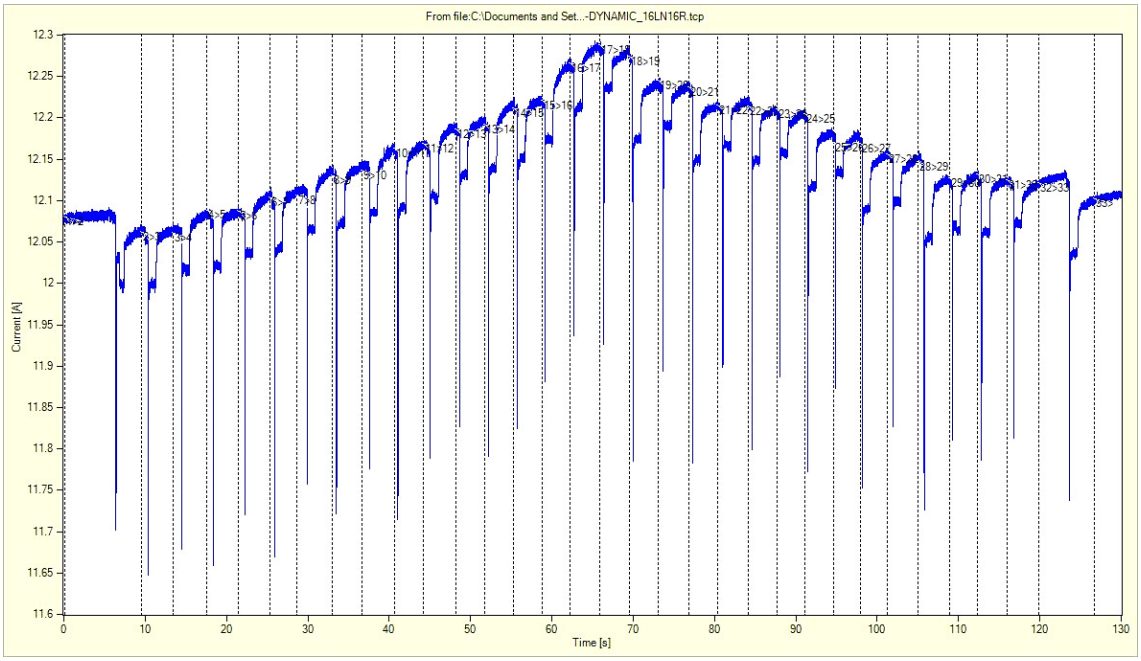



Figure 3. All 33 OLTC Switching Operations on a Power Transformer in Good Condition

## Case Studies

Several interesting cases were collected over the last year, showing correlation between the TDA and problems found with the OLTCs.

## Case Study 1: Transformer in 67 kV Substation

This case study is of transformer tested in a 67 kV substation in California. TASA™ indicated an overheating condition and contact problems. DRM was utilized to obtain further confirmation and localization of this problem. Defects were found on the reversing switch and other contact assemblies.

The first test was perfromed to obtain ohmic resistance value of the winding at all tap positions. Figure 4 is a static resistance graph that shows values for all three phases at different test currents.

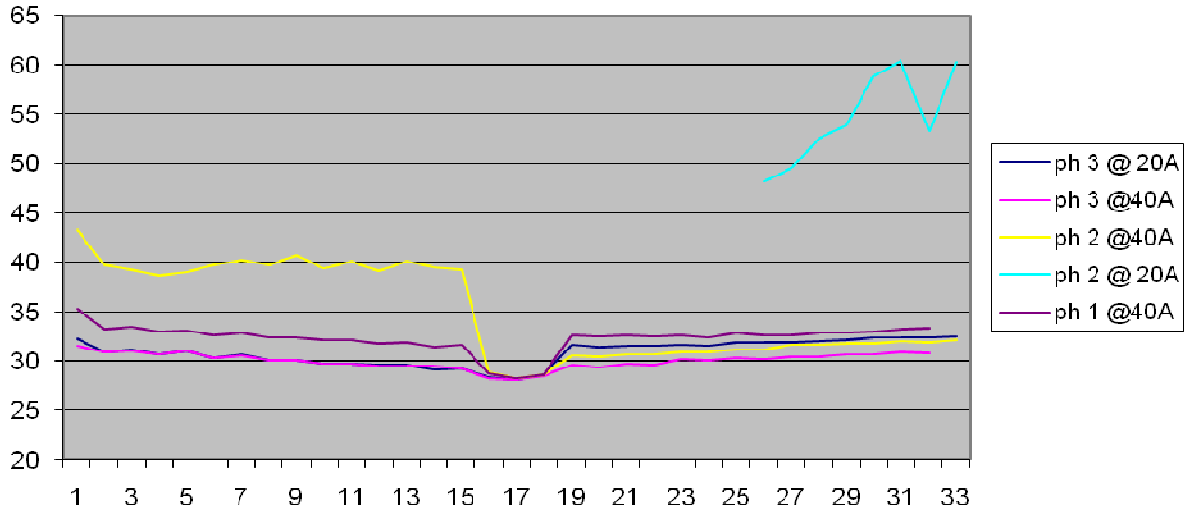



Figure 4. Static Resistances at All OLTC Positions at 20A and 40A – Case Study 1

Figure 5 includes four dynamic resistance graphs recorded with tap operation from position 16L to 16R or 1 to 33 positions.

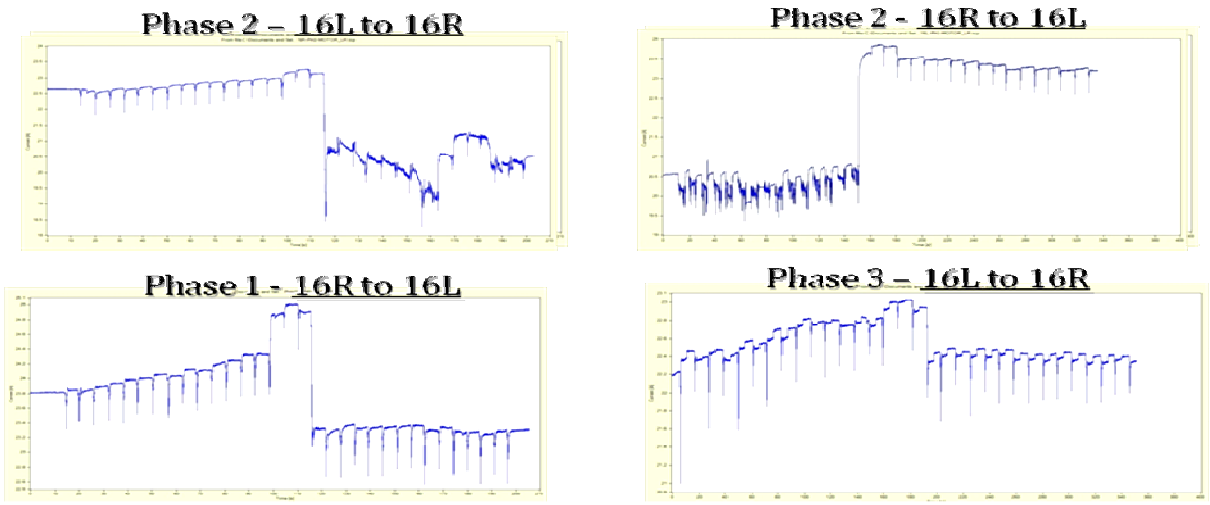



Figure 5. DRM Graphs – Case Study 1

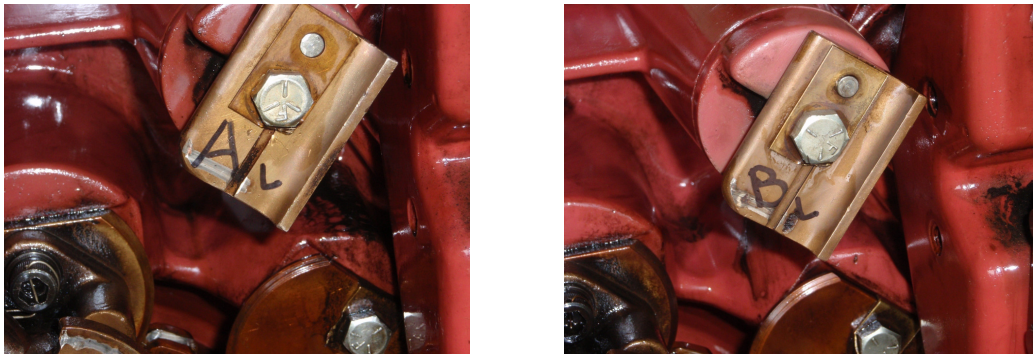



Figure 6. A and B Phase FPE LTC Contacts – Case Study 1

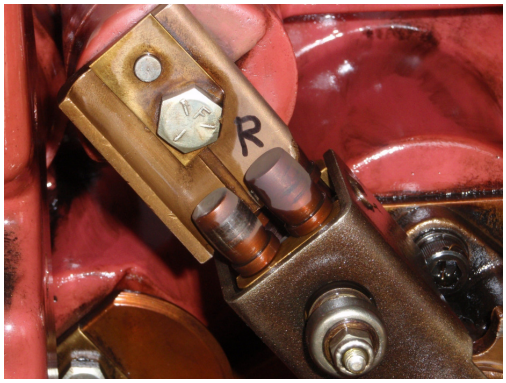



Figure 7. Reversal LTC Contact – Case Study 1

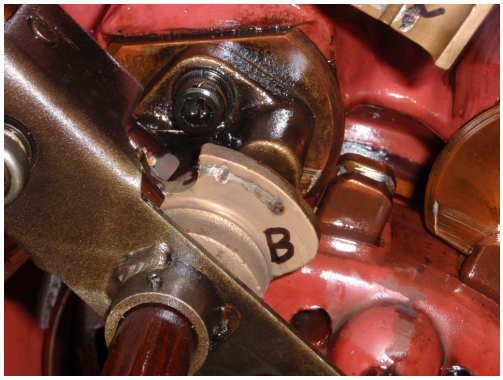



Figure 8.B Phase FPE LTC Contact – Case Study 1

## Case Study 2: Series Transformer

Another overheating problem was discovered and attributed to extended transition times of a particular tap changer with series transformer. Extended transition times made resistors overheat and generated combustible gases in excess of acceptable norms.

A Waukesha tap changer type UZDRT made in 1996 installed in an 84 MVA 138/26 kV transformer in a Wisconsin substation was investigated in 2011. TASA™ results indicated gassing associated with overheating in oil. The unit was overhauled in September 2009 and since then TASA™ tests were performed at regular intervals: August 2009, September 2010 and January 2011.

In April of 2011 this unit was DRM tested and a newly patented technique was implemented to obtain the dynamic resistance graph on transformers equipped with a series transformer. The series transformer is a separate three phase transformer built in the tank of the large transformer itself; the objective being to minimize the current the tap changer has to carry by magnetically coupling to the main winding. This magnetically coupled winding where the tap changer is located is not electrically connected to the transformer terminals and it is impossible to perform dynamic resistance measurement following a standard procedure. This investigation was the first ever test of this type.

To perform OLTC condition assessment, a special procedure was devised to obtain the signature of the tap transitions.

Waukesha tap changer models UZD... are resistive types; resistors are inserted in the circuit of circulating current during the transition from one to the other tap position. These resistors are rated to withstand high current up to 600 Amps, but only for a very short period of time, in the order of 20 milliseconds. Similar constructions of resistive tap changers allow these resistors to heat up to 350C/660F for a short period of time. Although they are immersed in oil that removes the heat quickly, if resistors are subjected to this high current longer than normal, overheating

occurs and gasses are generated. Typical high temperature overheating gasses in oil are Methane, Ethane and Ethylene.

Gas analysis results indicated that these key gasses were elevated.

Table 1. Gas Evolution – Case Study 2

| Gases | 2009 | 2010 | 2011 |
|---|---|---|---|
| Methane | 39 | 187 | 1025 |
| Ethane | 227 | 156 | 223 |
| Ethylene | 94 | 1613 | 2465 |
| Acetylene | 648 | 1853 | 1936 |
| CO | 42 | 77 | 6698 |
| CO2 | 1738 | 6219 | 10532 |

## TASA™ Results

Tap Changer Activity Signature Analysis (TASA™) report number 3723199 performed for this transformer provided the following condition assessment of the on load tap changer components.

The TASA™ report shows a characteristic profile for both the heating of oil and the heating of solid insulation containing carbon to oxygen bonds, such as is shown in Figure 9.

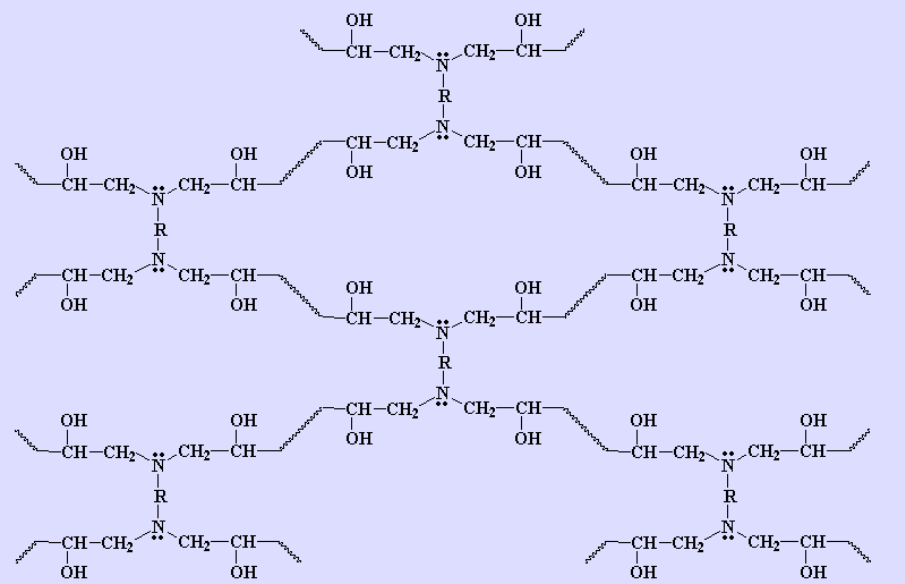


Figure 9. Epoxy resins

The relationship of carbon oxide production is a characteristic of the heating temperature and the particular insulating material. Notice the insulating material that was burned by overheating adjacent to resistors in Figure 10.

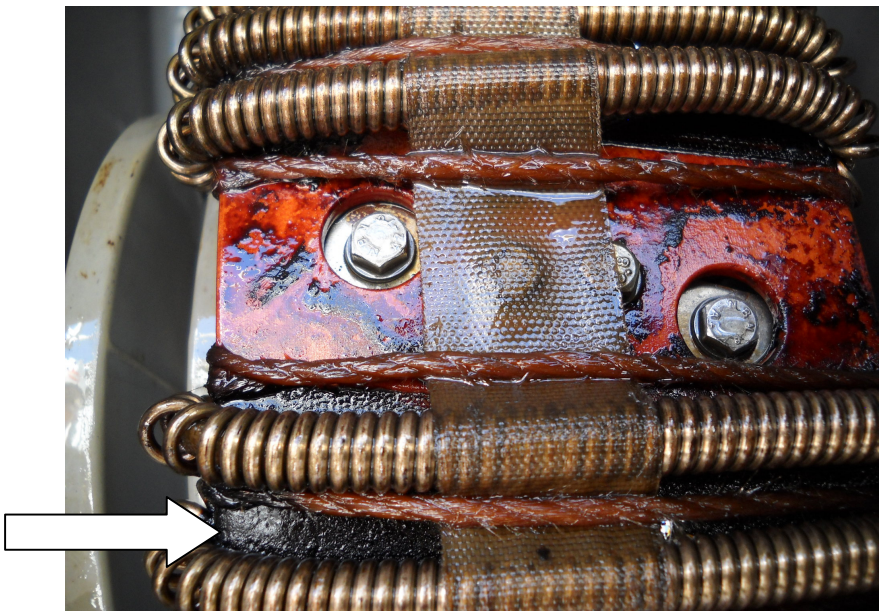


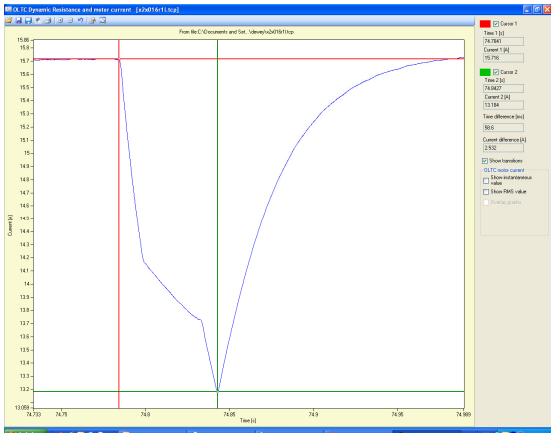
Figure 10. Burnt Insulation Caused by Overheated Resistors – Case Study 2

## Time is of the Essence

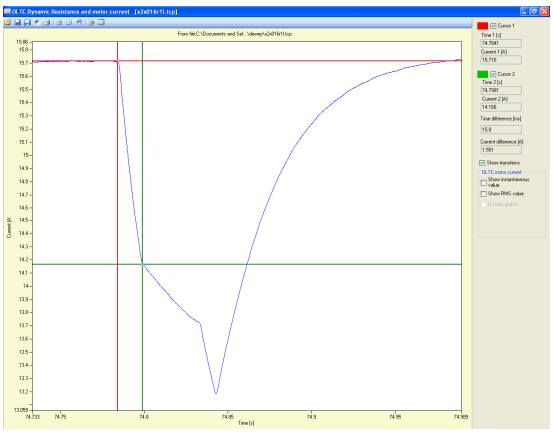
It is not a surprise that resistive tap changers are called "fast tap changers", because the speed and time is of essence during transitions.

The graphs obtained in Case Study 2 (Figure 11) indicate Transition Times (TT) from one position to another in the order of 60 ms (milliseconds). See Table 2

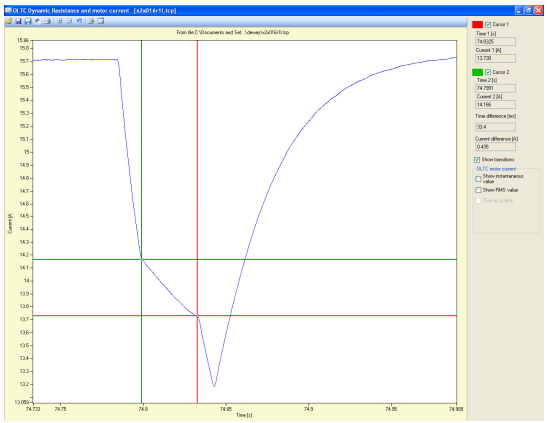
These times are very dependent on the adjustment of "switch fingers", or contact fingers; a special device was made to achieve proper finger adjustment. Figure 12 shows contact fingers with the rolling contacts in stationary position. The middle finger is touching the fixed contact. The right and left outer fingers, connected through the resistors R1 and R2, move over the fixed contacts only during the short transition time.



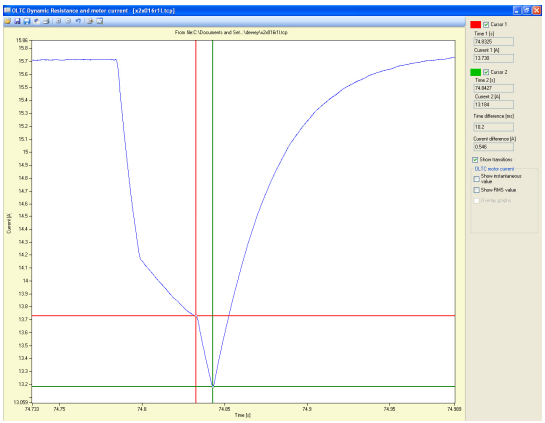
Total TT =58 ms



TT - Segment R1 = 15ms



TT, Segment R1+R2 = 33 ms



TT Segment R2 = 10 ms

Figure 11. Four Transition Time Segments – Case Study 2

Table 2. Order of Resistors in Circuit and Transition Time Measurements – Case Study 2

| Resistor(s) | TT |
|---|---|
| R1 | 15 ms |
| R1 and R2 | 33 ms |
| R2 | 10 ms |

When resistors R1 and R2 are alone in the circuit, they carry load current, but when they are both inserted, during the middle transition period, circulating current heats them with additional energy (over and above load current). Original design calculations of time and energy dissipation were 20/20/20 milliseconds. The actual measured middle period (R1+R2, with

circulating current) of 33-milliseconds (Table 2) represents a 50% time increase over designed TT; i.e., a 50% increase in heating energy applied to the OLTC resistors.

Following all the data evaluation, opening the compartment revealed burn marks on the tap resistor epoxy support structure, as shown on the Figure 10.

Checking the alignment of the contact fingers determined that some of them were more distant from center than others; this increased distance increased the time resistors were in the circuit.

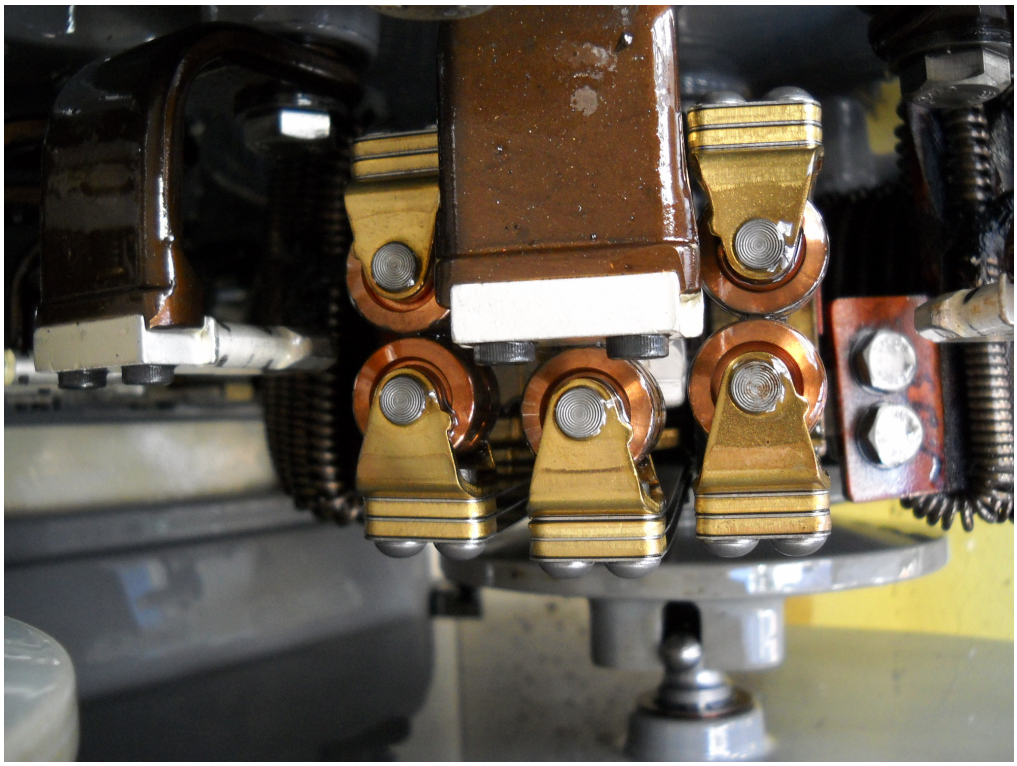


Figure 12. Tap Changer Contact Fingers, called "Switch Fingers" – Case Study 2

## CASE Study 3: TASA™ Code 4*

TASA™ report number 1224020 provided for this 2 MVA Westinghouse transformer at our station indicated a code 4* on June 2011. A TASA™ code of 4* (four-star) indicates a serious problem. TASA™ analysis repeated every 6 months tracked a problem that drastically increased in severity: up to the final 4* code of "extreme abnormal dissipation of energy is noted." See Table 3 and Figure 13.

Table 3. Evolution of Gas in Transformer OLTC – Case Study 3

| GASES | Aug. 2010 | Jan. 2011 | June 2011 |
|---|---|---|---|
| Methane | 5 | 14 | 2644 |
| Ethane | 9 | 10 | 1044 |
| Ethylene | 49 | 58 | 5581 |
| Acetylene | 0 | 9 | 127 |
| CO | 83 | 49 | 248 |
| CO2 | 462 | 432 | 551 |

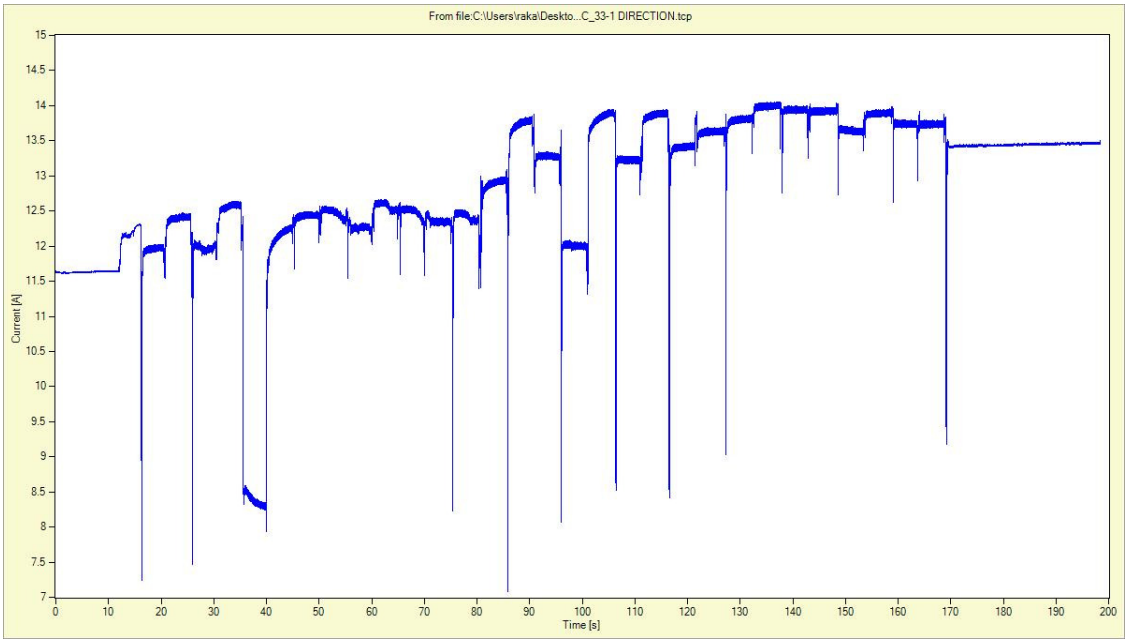



Figure 13. Dynamic Resistance Graph of the OLTC with TASA™ 4* Code – Case Study 3

Compare the DRM graph of this transformer exhibiting extreme energy dissipation with the graph of a transformer in good condition in Figure 3.

Subsequent TDA confirmed a serious problem; the unit was opened to reveal severe coking and contact burning. See Figures 14 through 17.

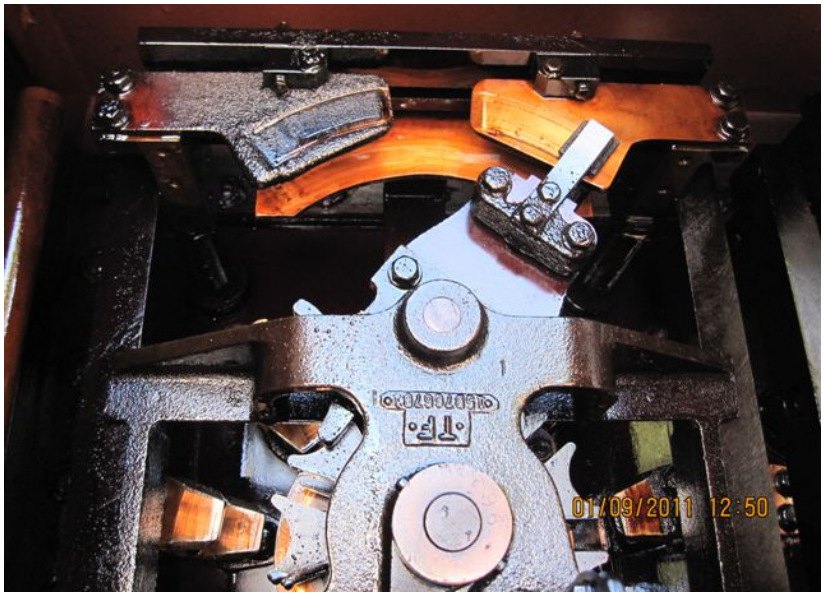



Figure 14. Coking – Case Study 3




Figure 15. Burning – Case Study 3

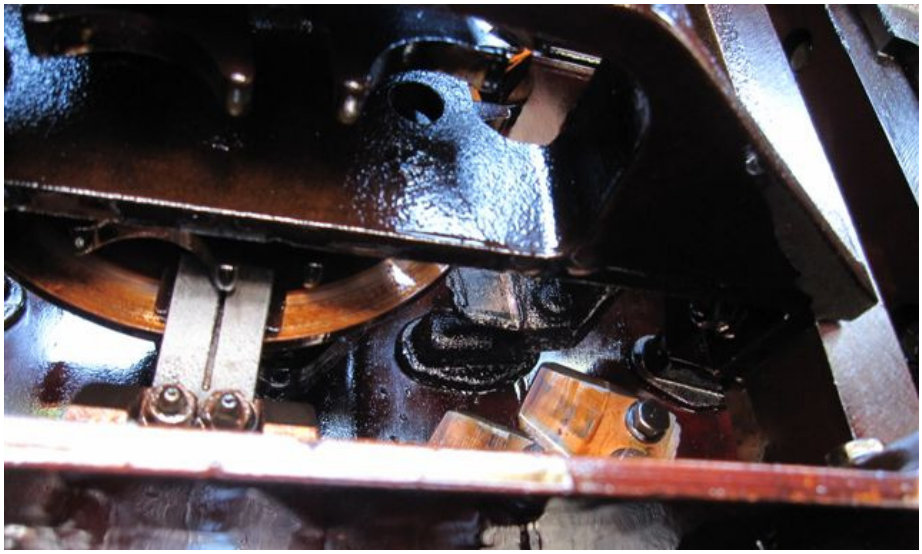


Figure 16. Contacts Carbonized – Case Study 3

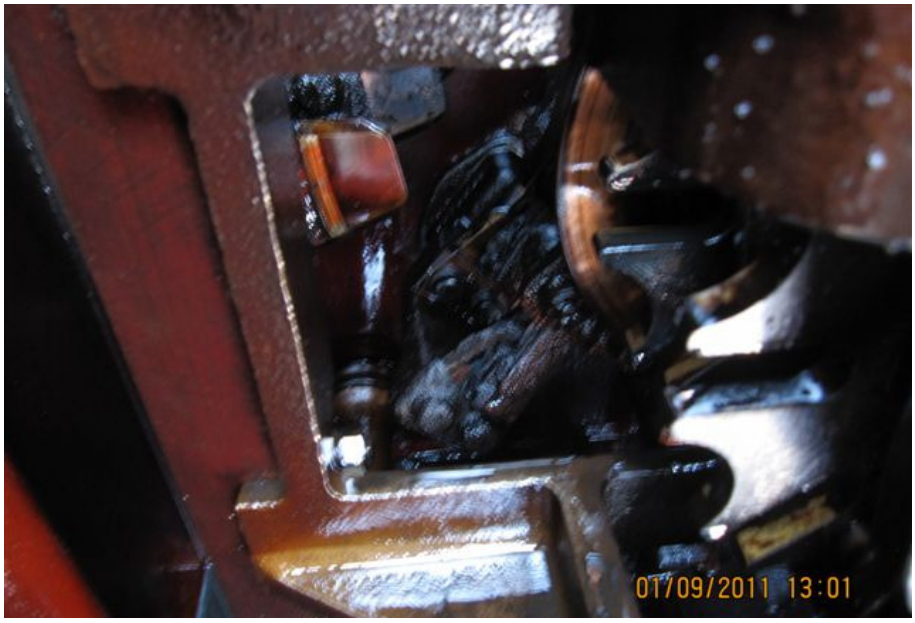



Figure 17. Contact Burned – Case Study 3

## CASE Study 4: Substation LTC

TASA™ had been conducted on this substation transformer regularly over a couple of years. Surprisingly, July 2011 TASA™ results returned code 4*; four-star indicates the presence of a serious problem. Results for this Reinhausen RMV-1 LTC showed acetylene increased to 1026 ppm (parts per million) and methane over 30,000 ppm. These results were commented as: "An extreme abnormal dissipation of energy is noted. This is terminal indication of fault or wear activity".

The dynamic resistance graph showed the characteristically problematic area associated with the X1 phase reversal switch and several other contact operations.

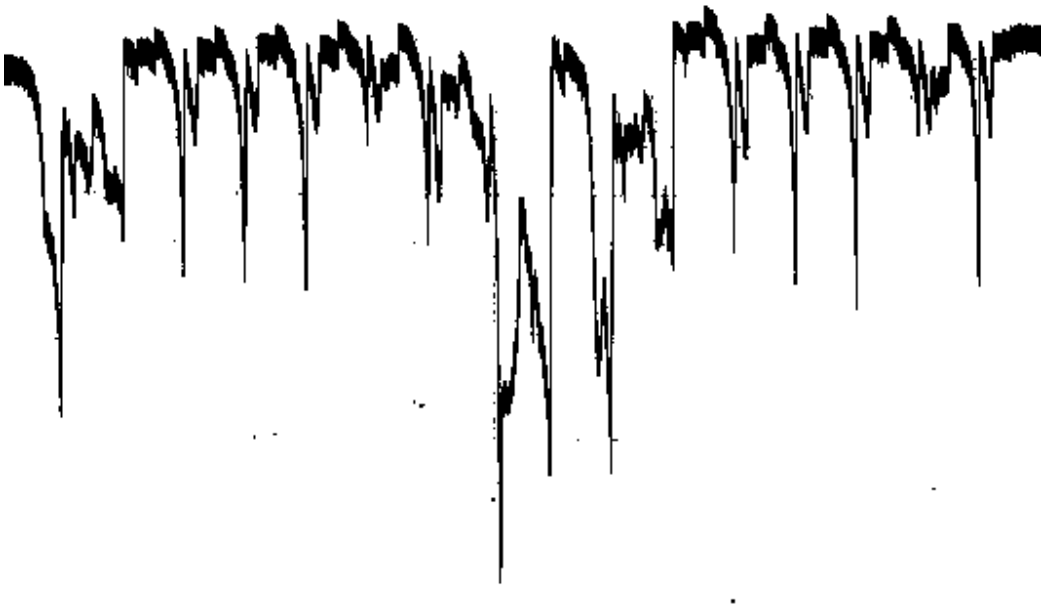


Figure 18. DRM Graph of the Phase X1 – Case Study 4

A visual inspection confirmed that there was an issue with the X1 reversing contacts. Heavy coking was observed on the slip ring, upper stationary and moving reversing contact. Pitting on the stationary and slip ring where the contact fingers normally sit on all three phases was also noted. This bank has undergone a substantial fault at some point in its life. No other issues were noted in the LTC compartment. See Figures 19 through 24.

To remediate the problems with this tap changer, all the coking was cleaned from the slip ring and the upper stationary and moving contact on the X1 phase were replaced. Micro ohm testing was performed on all three phases of reversing contact assemblies; testing verified that they were all less than 17 micro ohms. The LTC compartment was cleaned, and new oil was installed.

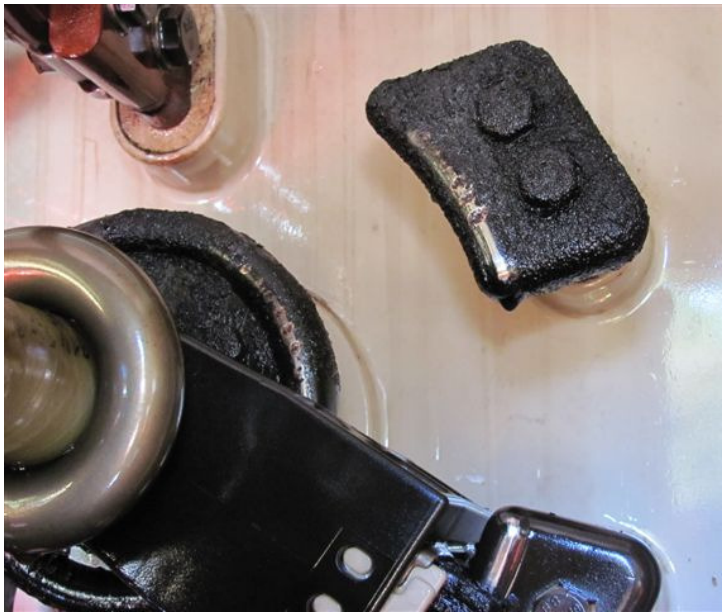


Figure 19. Coked Reversal Contact – Case Study 4

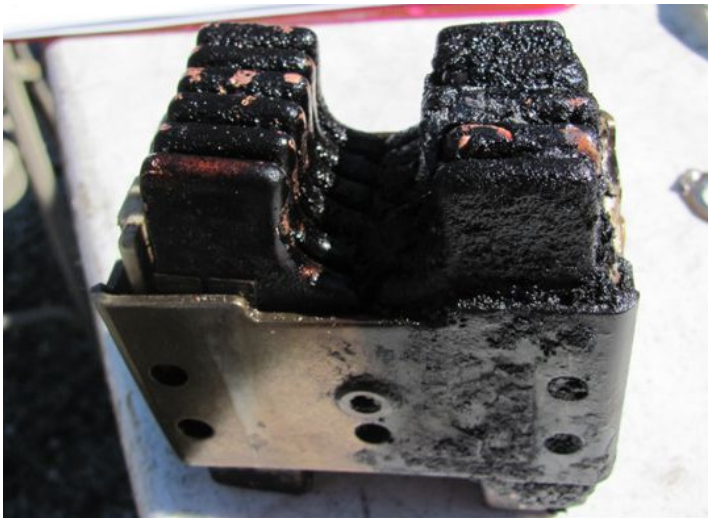


Figure 20. Coked Contact – Case Study 4



Figure 21. Coked Contact – Case Study 4



Figure 22. Coked Contact – Case Study 4



Figure 23. Coked Contacts – Case Study 4



Figure 24. Reversal Switch Contacts – Case Study 4

## Tabular Data Presentation

Table 4 provides an example of the way DRM results are represented numerically. Powerful DV Win software extracts important features from DRM graphs and presents them in tabular form for easier comparison and analysis.

Table 4. Example of a Tabular Presentation of Measured Parameters at 15 Tap Positions

| Date Time | Connection | Current [A] | R1(25°C) [mOhm] | R1(75°C) [mOhm] | V1 [mV] | Ripple % | Tap Position | Transition time [ms] |
|---|---|---|---|---|---|---|---|---|
| 5/8/2010 13:58 | 1U – 1N | 10.74 | 291.2437 | 347.36 | 3126.641 | 0 | 1 | 0 |
| 5/8/2010 13:59 | 1U – 1N | 10.93 | 285.0616 | 339.9868 | 3116.955 | 8.5 | 2 | 46.8 |
| 5/8/2010 14:00 | 1U – 1N | 11.15 | 279.0591 | 332.8277 | 3112.185 | 8.5 | 3 | 48.1 |
| 5/8/2010 14:00 | 1U – 1N | 11.37 | 272.5099 | 325.0166 | 3097.266 | 8.4 | 4 | 46.8 |
| 5/8/2010 14:01 | 1U – 1N | 11.57 | 266.7406 | 318.1357 | 3085.091 | 8.4 | 5 | 45.5 |
| 5/8/2010 14:02 | 1U – 1N | 11.78 | 260.5021 | 310.6952 | 3067.431 | 8.8 | 6 | 45.7 |
| 5/8/2010 14:02 | 1U – 1N | 11.99 | 254.1737 | 303.1474 | 3046.654 | 9.5 | 7 | 44.4 |
| 5/8/2010 14:03 | 1U – 1N | 12.25 | 246.5858 | 294.0975 | 3019.804 | 10.4 | 8b | 50.6 |
| 5/8/2010 14:04 | 1U – 1N | 12.25 | 245.8175 | 293.1812 | 3010.838 | 11.2 | 9 | 48.5 |
| 5/8/2010 14:04 | 1U – 1N | 12.52 | 239.5066 | 285.6543 | 2997.603 | 11 | 10 | 50.8 |
| 5/8/2010 14:05 | 1U – 1N | 12.74 | 233.2372 | 278.1769 | 2972.571 | 10.9 | 11 | 48.8 |
| 5/8/2010 14:05 | 1U – 1N | 13 | 227.2802 | 271.0721 | 2954.72 | 10.9 | 12 | 47 |
| 5/8/2010 14:06 | 1U – 1N | 13.24 | 221.025 | 263.6117 | 2926.333 | 10.6 | 13 | 45 |
| 5/8/2010 14:07 | 1U – 1N | 13.52 | 214.9339 | 256.347 | 2906.878 | 11.2 | 14 | 45.6 |
| 5/8/2010 14:07 | 1U – 1N | 13.77 | 208.6241 | 248.8214 | 2873.16 | 12.2 | 15 | 45.7 |

## Conclusion

Each new test methodology must address not only the selection of proper parameters but even simple things like defining common terminology, outlining features that are of interest, avoiding inappropriate connections, methods of addressing substation interference, etc. Also, various test instruments in use around the world operate at different current values, with different sampling rates, with single-phase or three-phase recording. This makes a simple comparison more difficult requiring greater effort in the standardization of procedures.

In October of 2010, the AMforum association formed a working group of experts and practitioners with extensive experience in this field to exchange knowledge on OLTC testing methods and interpretation of results. A workshop was organized in Madrid to review present practices[9]. As a result of working together and sharing different methods of applying the test, the working group will be in a position to make procedure recommendations, including the optimum technique for testing.

Most of the DRM research was conducted in the Netherlands[11, 12]. Valuable areas of study for the working group are the special tests performed in Malaysia[10] compared with the procedures used by Spanish experts, and different techniques being in use in Poland and Ireland.

## References


1. H.F.A.Verhaart, KEMA. *"Tussenrapport over faaloorzaken van distributie- en koppeltransformatoren op basis van de onvoorziene nietbeschikbaarheid."*, rapport 43613-T&D 94-102278, 1994.

2. H. F. A. Verhaart, *"A diagnostic to determine the condition of the contacts of the tap changer in a power transformer."*, CIRED, Brussels, Belgium, 1995, paper 1.13.

3. "*Dynamic resistance measurements in LTC"*, Luis Miguel Perea, Angel Ramos Gómez Unión Fenosa Distribución, Spain, José Luis Lozano Gómez Norcontrol Soluziona, Spain - Proceedings of the EuroDoble Colloquium 2000.

4. "*Transformer failure causes in Germany"*, IEH Liebnitz University Hanover -Shering Institute, Institute of electric power systems, Division of high voltage engineering.

5. Presentation on OLTC diagnostics, Laurent Allard, ABB Secheron, Euro TechCon Chester UK 2010.

6. P.Kang, D. Birthwistle, et al. *"Non invasive on line condition monitoring of OLTC"*, IEEE proceedings January 2000, Generation, transmission and distribution, Volume 3, pp.2223-2228

7. IBEKO Power AB "*Manual of Winding Resistance Ohmmeter RMO60TD",* February 2011.

8. MR OLTC instruction manual.

9. Report of the First Workshop on DRM, organized by AMforum, Madrid May 16, 2011.

10. "*Experience on Dynamic Contact Resistance Test on Eroded and Worn-Out Tap-Changer Contacts*", R. Samsudin, Yogendra , A.Berhanuddin, Y. Zaidey, M.Haneef , TNB Research Sdn Bhd, Malaysia.

11. "*Reproducibility of Dynamic Resistance Measurement Results of On-Load Tap Changers – Effect of Test Parameters*"; J.J. Erbrink, R. Leich, et al. Delft University of Technology, Delft, and Liandon, Alkmaar, the Netherlands– presented in Japan 2010.

12. Doctoral thesis: "*OLTC Diagnosis on High Voltage Power Transformers using Dynamic Resistance Measurements*", Jur Erbrink, Technische Universiteit Delft, 28. March 2011.

**Raka Levi**, Dr.Eng., has over 25 years of asset performance and condition assessment experience, specializing in apparatus test, monitoring and diagnostics. His education includes Ph.D. in the field of HV diagnostics for circuit breakers, and ME from the RPI, New York. Raka started an European technical committee on HV diagnostic and maintenance, and coordinated its activities as the convener. He has been running committees that assemble asset managers and operation specialists of major European utilities since 1995. In 2010 he organized a working group on Dynamic Resistance Measurement bringing together experts and practitioners of this methodology in Europe.