ON-LINE TAP CHANGER DIAGNOSIS BASED ON ACOUSTIC TECHNIQUE

MatPost07

R. VILAITHONG, University of Stuttgart, Germany, rummiya.vilaithong@ieh.uni-stuttgart.de
S. TENBOHLEN, University of Stuttgart, Germany, stefan.tenbohlen@ieh.uni-stuttgart.de
T. STIRL, Areva Energietechnik GmbH, Germany, tobias.stirl@areva-td.com

ABSTRACT

In this paper, a reliable acoustic measuring system for on-line condition monitoring of on-load tap changer is described. Vibration signals during the tap-change process are detected by a sound emission sensor coupled to an amplifier. The measured signature is analysed in order to determine the tap-change characteristic time. The sequence of tap-change process in the diverter switch is studied to understand the operation of the investigated tap changer. The studies were done in different tapping positions during off-load condition. The investigations took place during normal operation and under failure conditions of the tap changer, in order to verify the performance of the acoustic method.

KEYWORDS

On-load tap changer diagnosis, Acoustic measuring, Vibration signals.

INTRODUCTION

On-Load Tap Changers (OLTCs) are parts of the voltage regulating system in an electrical transmission network. They are connected to the transformer and are responsible for maintaining the voltage level under variable loading conditions. By changing a tapping on the winding, the OLTC enables the turns ratio of the transformer to vary and thus the level of output voltage. An OLTC has two main components; a selector switch and a diverter switch. A selection of tapping on the transformer winding is done via the selector switch. Load current is afterwards switched over a set of electric contacts by means of the diverter switch. The OLTCs have high failure rates compared to other electrical transmission equipments because their mechanical parts operate very frequently. Their failures can cause damage to the complete transformer unit. It is, therefore, important for the utilities to be able to assure the reliability of the OLTCs. Consequently, an extensive maintenance is required. However, a routine maintenance of the OLTCs is a major expenditure, both in time and material. Thus, a condition-based maintenance by an on-line monitoring should be a better option to observe tap changer operation characteristics.

During the operation of tap changer, series of mechanical and electrical events produce distinctive vibration and noise patterns. In principle, an analysis of these typical vibration signatures should reveal different aspects and phases of tap changer operation. Since all electric contacts are enclosed in oil filled steel tank, an on-line monitoring of the OLTCs with a non-invasive acoustic technique is proposed as a mean to investigate the vibration signals from a tap-change process. In modern high-speed resistor tap changers, the current transfer over the electric contacts via the transition resistors in the diverter switch takes place in about 40-70 ms, depending on the type of mechanism used. This transition time interval is expected to be constant as long as no fault appears. Therefore, it is possible to check the reliability of the OLTCs by monitoring the tap-change transition time [1]. In this paper, an attempt to measure the characteristic time of the transition process from the vibration signal is presented.

ACOUSTIC MONITORING METHOD

Acoustic diagnosis has been successfully applied in many industrial applications, mainly in aeronautics and manufacturing. In the field of electrical equipment, it has been applied in monitoring of circuit breakers by numerous investigators [2], [3]. For application of the acoustic diagnosis in tap changers, a record of vibration signals emitted during the tap-change should include information about transition time and bouncing characteristics of arcing contacts in the diverter switch [4].

EXPERIENCE FROM LABORATORY TEST

The studies of the acoustic method were conducted during no-load situation on a tap changer mounted in the laboratory for experimental purposes as shown in Fig. 1a. It is a diverter-switch type, series voltage up to 220 KV, current intensity from 400 to 1000 A. During the investigations, it was manually operated from tap 1 to tap 19. The acoustic sensor was fixed onto the top cover of the tap changer.

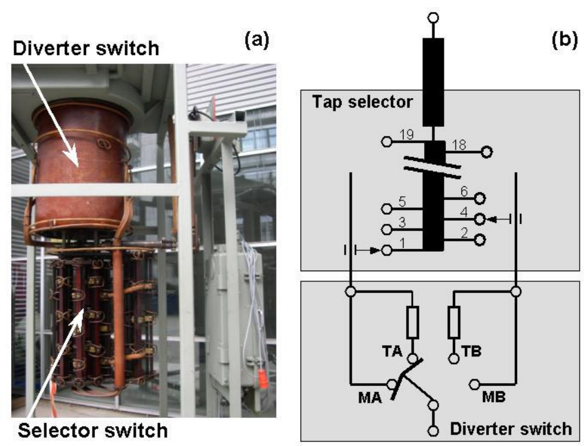


Fig. 1: Investigated laboratory tap changer (a) photo; (b) schematic

During the tap-change process, first the tap selection is done with the selector switch and then the diverter switch operates in order to transfer the current from one side of the selector to the other side. The left or right sets of contacts in the diverter switch represent the odd-tap or even-tap position of the tap changer as seen from Fig. 1b. Thus, The set of contacts at odd-tap position and the set of contacts at even-tap position are always separately considered in the investigations of tap changer.

The diverter switch is normally equipped with transition resistors to avoid short-circuit under operation, the set of contacts is therefore composed of main contacts (M) and transition contacts (T). The sequence of the transition process from one tap position (A) to another tap position (B) can be described in the following five phases.

Phase 1: MA and TA are being closed
Phase 2: TA is being closed, MA is opened
Phase 3: TA is being closed, TB is closed
Phase 4: TA is opened, TB is being closed
Phase 5: TB is being closed, MB is closed

MA and TA represent the main and transition contacts at position A, whereas MB and TB represent the main and transition contacts at position B as depicted in Fig. 1b.

The technical details of contacts in the diverter switch vary among tap changers from different manufactures. Fig. 2 shows a photograph of the contacts in the studied type of diverter switch. The contacts are held in place by extension springs. The switching energy is loaded by drive motor. It is then stored in the springs.

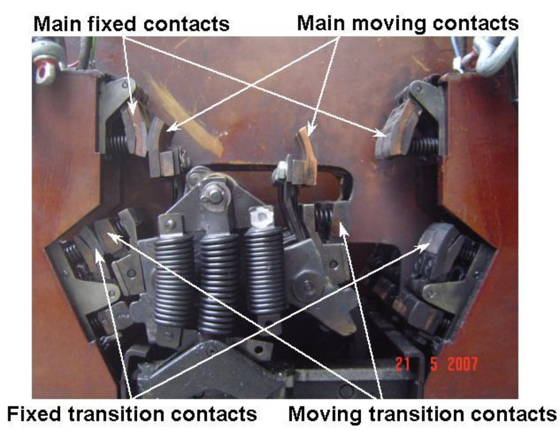


Fig. 2: One-phase contacts of a diverter switch

Measuring system description

Fig. 3 illustrates the schematic diagram of the acoustic monitoring system. The acoustic signal was detected by a piezoelectric sound emission sensor (res.-freq. about 80 kHz) fixed with wax on the top cover of tap changer. Then the vibration signal was amplified by a signal pre-amplification module and was sent to a measuring circuit for the tap-change characteristic time measurement. The output of characteristic time measurement was afterward transferred to an Ethernet TCP/IP field bus coupler with analog input module connected to a PC, using as an output data acquisition unit. The monitoring system is automatically triggered. The complete vibration signatures and some analog signals were captured by an oscilloscope.

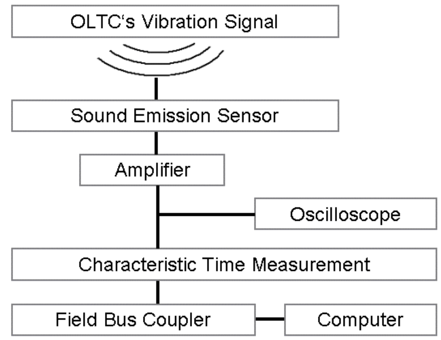


Fig. 3: Acoustic monitoring system

Tap-change characteristic time measurement

The tap-change characteristic time was determined from the vibration signatures. The measuring circuit for the tap-change characteristic time is shown in Fig. 4. At first the acoustic signal is transformed into a RMS-Signal (Route Mean Square). The higher the acoustic signal amplitude the higher is the RMS-Signal. Subsequently the RMS-Signal is compared to a reference value in comparators so that a high/low-signal is obtained. The high/low-signal is fed into an 8-bit binary counter, which is timed by a 1-MHZ quartz oscillator permitting to measure the duration of the stable state of the high/low-signal. The binary signal with the time information (characteristic time of max. 255ms) is transformed into a 4-20 mA output current for the monitoring system by a D/A converter.

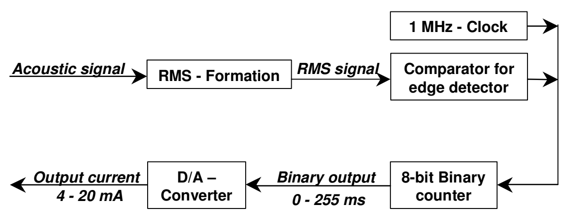


Fig. 4: Measurement of the characteristic time

The acoustic emission signal waveforms are shown in Fig. 5. The measurements were done at odd-tap position and even-tap position as illustrated in Fig. 5a and Fig. 5b respectively. RMS signals and signals from comparator are also presented. The measurements had been recorded for a complete tap-change cycle. The form of the vibration signatures is a transient signal, which is typical for non-repetitive machines. The vibration signatures between odd-tap and even-tap are not significantly different. The whole transition process of tap-change takes around 150 ms.

Transition sequence investigation

Next, the switching period of transition process was studied. Different values of resistors were additionally connected at the end of each contact set in the diverter switch. The constant voltage was supplied across the contacts and additional resistors. Consequently, different current levels were detected during different phases of contacts movement. These levels of current were measured by mean of the voltage levels by the oscilloscope. The voltage signal appears during the five phases transition process is also shown in Fig. 5. Number 1 – Number 5 in the figures present the five phases of transition process as described before. Thus, the switching period of each transition phase can be determined from the interval between dot lines.

The vibration signatures with higher amplitude are found in phase 3 and phase 5. In these phases the transition contact and the main contact are closed. The characteristic times; t_X and t_Y are here determined from the comparator signals. These characteristic times appear also in phase 3 (transition contact closure) and phase 5 (main contact closure) of the transition process. This shows that tX and tY can detect the transition contact closure und the main contact closure respectively.

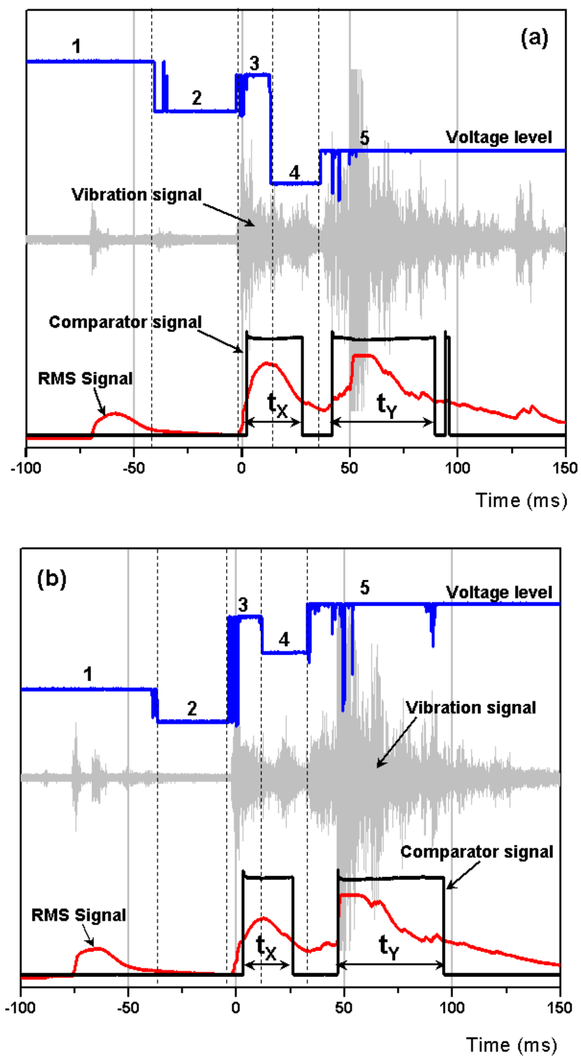


Fig. 5: Signals during tap-change in normal condition (a) at odd-tap position; (b) at even-tap position

Monitoring criterion

Further, the repeatability of the characteristic times measured during the operation of tap changer is investigated for 19 different taps. Fig. 6a presents the characteristic time t_X and t_Y measured during the transition process at the odd-tap position. The dot-lines show the range of the measured data: t_X ranges from 24 to 33 ms, t_Y ranges from 45 to 53 ms. Fig. 6b depicts the results for the even-tap position: t_X ranges from 16 to 30 ms, t_Y ranges from 41 to 57 ms.

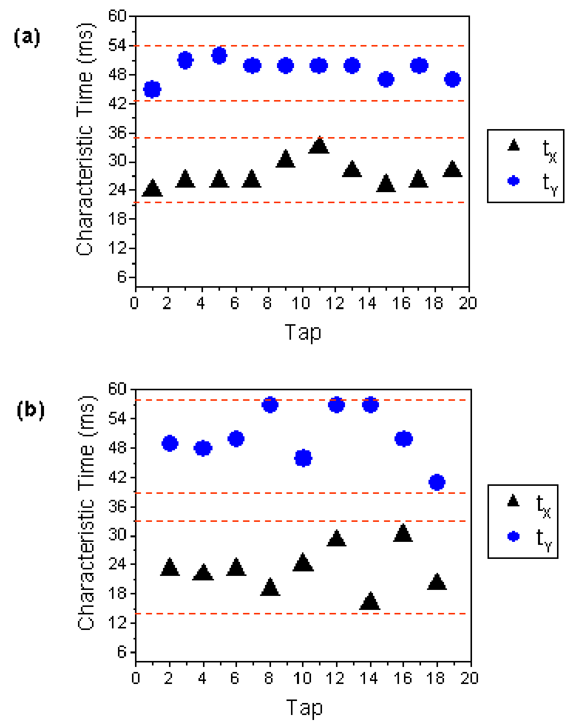


Fig. 6: Measured characteristic times (a) at odd-tap position; (b) at even-tap position

It can be noticed that the measured characteristic times are varying within a tolerance band. The size of this tolerance band probably varies according to the precision of the tap-change process. Therefore, with a number of measured signatures K and the average characteristic time $\bar{t}_x$, the standard deviation σ_t can be calculated:

$$\bar{t}_X = \frac{(t_{X1} + t_{X2} + t_{X3} ....t_{XK})}{K} \quad (1)$$

$$\sigma_t = \sqrt{\frac{\sum (t_X - \bar{t}_X)^2}{K}} \quad (2)$$

For the investigations at odd-tap position, the average characteristic time for t_X is 27 ms and for t_Y is 49 ms and the standard deviation for the characteristic time t_X is 2.5 and for t_Y is 2.1. For the even-tap position, the average characteristic time for t_X is 23 ms and for t_Y is 51 ms and the standard deviation amounts to t_X is 4.2 and to t_Y is 5.2. The values of the average characteristic time and standard deviation are set to be the criteria for monitoring the tap changer situation. Therefore, they must be investigated and defined before the real monitoring process. The standard deviation presents the distribution of the measured data set. The higher value of the standard deviation shows the farther of the measured values from the average value.

SIMULATION OF DEFECTS IN TAP CHANGER

The most serious faults in tap changers are mechanical faults. They can lead to loss of synchronization within the selector switch or between selector and diverter switch of the same phase. The mechanical faults also lead to electrical faults such as burning of contacts or transition resistors and insulation breakdowns. The most frequent mechanical failure causes are contacts erosion and driving mechanism problems [5]. They can cause slow or incomplete diverter operation faults.

To prove the ability of this acoustic monitoring system to detect the condition of the contacts in a diverter switch, two types of possible defects had been simulated in the laboratory tap changer. The first defect is a barrier between contacts and the second defect is a missing main contact.

Barrier between contacts

Two different barriers were placed between the contacts at the odd-tap position of the diverter switch. The first barrier (Fig. 7a) is a plastic plate of 2 mm thickness put into the three poles of the diverter switch and covers the main and the transition contacts. A copper rod of 5 mm diameter is used as a second barrier (Fig. 7b) and is placed between the contacts of the first pole.

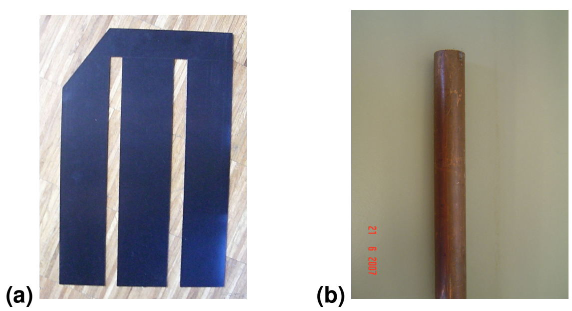
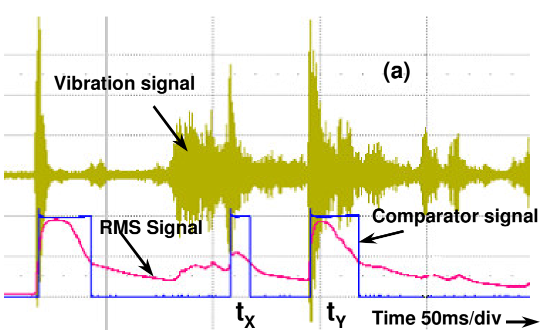


Fig. 7: Samples for tap changer defect investigation (a) plastic plate; (b) rod

Fig. 8a shows the acoustic signature recorded during the switching process with the plastic plate obstructed between the contacts. The signature is obviously different from the signatures under normal condition (see also Fig. 5a). Fig. 8b shows that the measured characteristic times are significantly influenced and the time interval is varying and is much lower than under normal condition. The measured t_X ranges from 5 to 30 ms and t_Y ranges from 20 to 24 ms.



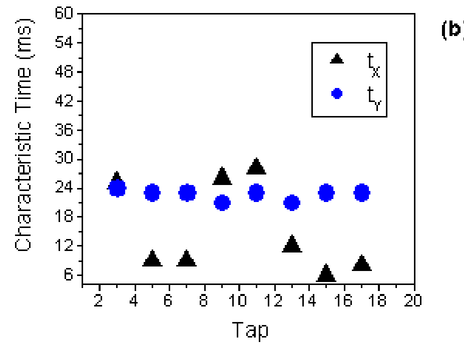


Fig. 8: Plate investigation (a) signals; (b) Characteristic times

Fig. 9a and Fig. 9b show two different signatures, which were captured during the operation of the tap changer with the copper rod between the contacts. They differ strongly to each other and to the normal condition. Therefore, the measured characteristic time is also significantly different and is non-repeatable.

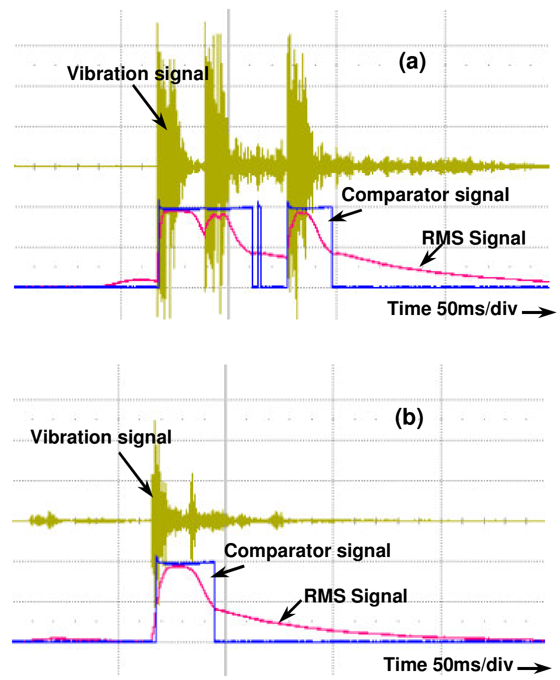


Fig. 9: Different signals from rod investigation (a) signals at tap 1; (b) signals at tap 15

Lost of main contacts

Another attempt for defect simulation is to investigate the switching time when the main moving contacts from all three poles at the odd-tap position are missing. The shape of the recorded signature shown in Fig. 10 is different from the signatures recorded from the normal condition. Again also the measured switching time interval is obviously different from normal condition and is non-repeatable.

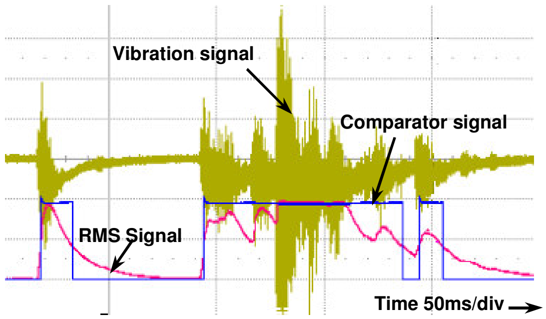


Fig. 10: Signals from contact lost investigation

CONCLUSION

An acoustic measuring system for tap changer diagnosis is presented in this paper. A characteristic time is obtained from the vibration signal. This characteristic time may be used as monitoring criteria for tap changers. This has been verified with artificial defects (foreign parts obstructed between the contacts and the loss of contacts). The acoustically measured characteristic time under fault conditions is significantly different from normal operation. Therefore, the acoustic monitoring system is suitable to detect major defects in a tap changer. It is expected that further investigations will also allow to detect small defects and different kinds of defects can be separated from each other. As a result, the acoustic monitoring system has a good potential to be part of comprehensive condition monitoring system.

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