A NEW GENERATION VOLTAGE REGULATION DISTRIBUTION TRANSFORMER WITH AN ON LOAD TAP CHANGER FOR POWER QUALITY IMPROVEMENT IN THE ELECTRICAL DISTRIBUTION SYSTEMS

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ABSTRACT

Voltage regulation distribution transformer (VRDT) is a solution to maintain supply voltage to its nominal value in the electrical distribution systems. The design presented in this paper is the new generation of VRDT equipped with an on load tap changer (OLTC), which enables voltage adjustment under loaded condition without interruption. The OLTC employed is a combination of high speed resistor type technology with vacuum tubes. The system is entirely safe and has a wide range of switchable currents from 30 A to 100 A with no significant additional losses. This advanced VRDT is designed, manufactured, tested and running successfully in the distribution grids.

INTRODUCTION

According to the norm EN 50160 (Voltage characteristics of electricity supplied by public distribution networks), it is necessary for the distribution systems to maintain supply voltage around +/- 10 % to the nominal voltage in all operating points of the grid. In fact, with recent enormous growth in the photovoltaic and other renewable feed-in's the maximum voltage rise is defined as 3 % in the low voltage grids and only 2 % in the medium voltage grids. The rest of the bandwidth is reserved for the voltage drops and adjustment accuracies. Hence, the distribution system operators are compelled to employ voltage regulation measures like capacitor banks and voltage regulation distribution transformers (VRDTs).

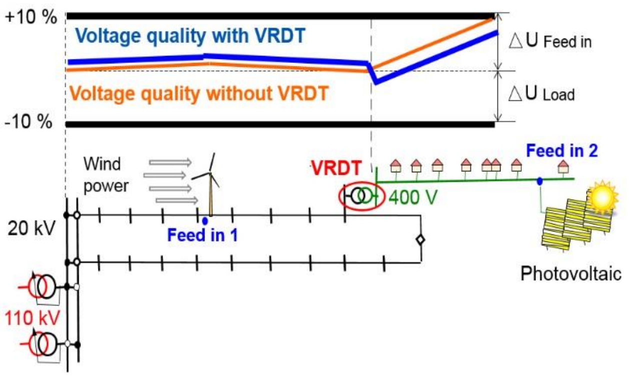

Figure 1. Influence of VRDT on the voltage quality

Voltage regulation transformers are normal transformers equipped with tap changers which dynamically adapt the voltage and permit a larger electrical supply in each operating point of the grid (as shown in the Figure 1). For medium voltage and low voltage grids VRDTs are provided with de-energized tap changer which supports voltage adjustment under off load conditions. On the contrary, high voltage grids and super grids are loaded with on load tap changers (OLTCs) [1]. As is already the case in higher voltage levels, implementation of OLTCs in the distribution transformers for the low voltage grids serves as a motivation to the new generation VRDTs.

STATE OF THE ART

OLTCs are designed to adjust the desired tap of a tap winding transformer under load conditions by altering the turns of the winding. In the initial VRDT's they are served with a preventive auto transformer (PA) or a reactor to enable operating positions of tap changer. But in the new generation, a resistor based switching principle is used. Which indeed has many advantages. The reactance type OLTC requires additional compartment for the PA, whereas the resistance type is securely installed inside the tank. However, a normal distribution transformer requires little modifications to accommodate this setup within the dimension constraints described by the customer. The resistor type switching also prevents significant contributions to transformer losses and satisfies the regulations of EU Ecodesign Directive.

ECOTAP VPD

ECOTAP VPD is a commercially manufactured OLTC by Maschinenfabrik Reinhausen GmbH (MR), Germany. It is a combination of high-speed-resistor-type switching principle with an arc quenching by vacuum technology [2]. The OLTC comes with a motor drive unit and a control unit. The control unit constantly monitors the network's voltage. If the voltage level alters more than its range for a predefined period of time, a switching pulse is released. The motor drive unit ensures the safe movement of contacts [2].

The OLTC consists of a selector module and a switching module. The selector module has stationary contacts, which are connected to the taps of the regulating winding of the transformer and moving contacts that switch to the desired stationary contacts. This part of the OLTC does its operation off load, i.e. for a switching from tap n to tap n+1 the selector prepares the current path to tap n+1. In order to allow a switching principle with only one vacuum tube, the selector module consists of a main tap selector and a transition tap selector.

The switching module does the switching under load from the current tap (n) to the desired tap (n+1), forcing the load current to change its path from tap n to tap n+1. Not interrupting the load current through the transformer during the switching operation, the switching module makes contact with tap n+1 before breaking contact with tap n. The main switching contact, is a vacuum tube, quenching arcs in vacuum, hence the transformer oil is protected from contamination and the contact wear in minimum. When contact is made on both taps (n and n+1) a circulating current is flowing, which is driven by the step voltage between taps n and n+1. The resulting circulating current stresses the step winding between tap n and n+1 and the OLTC additionally to the flowing load current. In order to prevent the damages, circulating current is limited to an admissible value by a transition resistor. Interrupting the current path through tap n (again an arc is quenched in the vacuum tube) the load current is now forced through tap n+1. This permits the movable main tap selector to safely make a contact with the desired tap (n+1) without any interruption.

Thus, the main tap selector established a perfect contact with the desired tap (n+1) and the winding between the taps n and n+1 is completely added without any arcing in oil. In case of further changes in the voltage, above sequence of operation is repeated for a maximum number of 500,000 tap-change operations [2].

New generation VRDT

A new generation VRDTs equipped with ECOTAP VPD are commercially developed for the electrical distribution network by SBG Transformers GmbH, Germany. Figure 2 shows the three-phase high voltage (HV) winding connection of the distribution transformer to the OLTC.

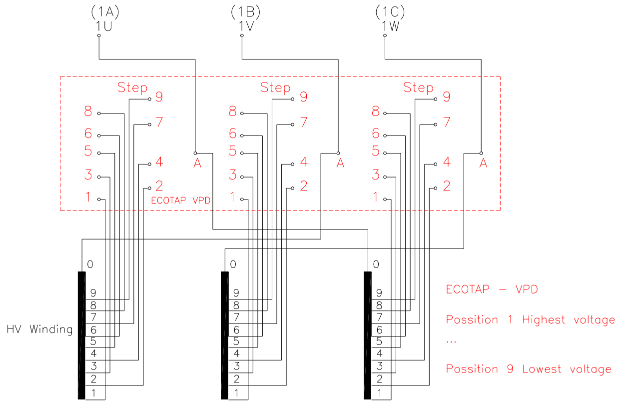

Figure 2. HV winding connection to the OLTC

Tap winding is connected to the start of the main winding, while the end is connected to the bushings. Service positions from 1-9 of main winding are linked to the corresponding positions of the OLTC. The highest voltage of the tap, which includes all the turns of the HV winding is drawn from the service position 1 and the lowest from the position 9. Whereas, position 5 provides the nominal voltage of the transformer.

CASE STUDY

In order to verify the practical applicability and performance of the new generation VRDTs, two different transformers installed in the utilities are selected for a case study. The chosen units, case I: 400 kVA, 20/0.4 kV, 11.6/577.4 A, 50 Hz Dyn5 and case II: 4000 kVA, 20.5/0.66 kV, 112.7/3499 A, 50 Hz, Dy5 include three-phase oil transformer with OLTC. A series of routine and special tests are performed on both the cases.

OLTC, accessible for 9 steps of HV (+/- 4*2.5 %) is embedded under the top tank wall cover of the transformers, as shown in the Figure 3. The transformers are designed under the dimension specifications set by the customer.

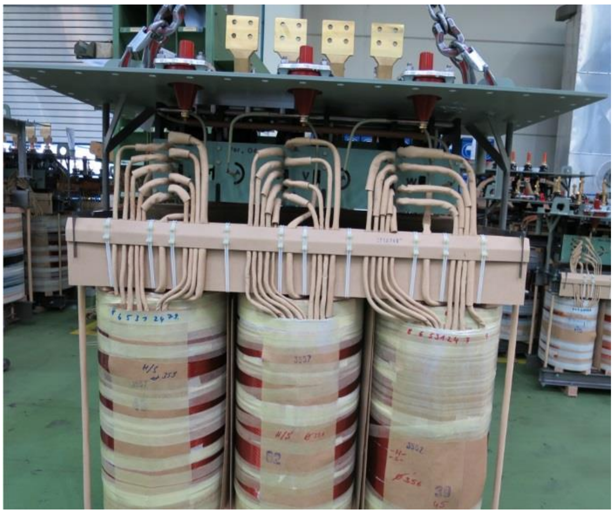

Figure 3. Active part view of the VRDT from HV side

Routine tests

IEC standard 60076-1 provides the guidelines to perform tests on the manufactured transformers to validate the design and calculations. Routine tests include measurement of short circuit (SC) impedance, losses and currents under load and no load conditions of nominal, one plus and one minus tappings of the transformer. Table 1 indicates the guaranteed and measured values for the principal tapping position 5 of the selected VRDTs. The short circuit percentage impedance measured is under the tolerance accepted to the guaranteed values, which is indeed within the values recommended by the standard.

Case		SC impedance (%)	Load loss (W)	No load loss (W)
I	Guaranteed	4.00	3850	430
	Measured	4.09	3748	389
II	Guaranteed	6.24	29700	3300
	Measured	6.27	29404	2955

Table 1. Routine tests results

According to the Directive 2009/125/EC, EU Ecodesign regulation No. 548/2014, Part-1. The maximum load and no load losses allowed for case I are 4600 W and 430 W and for the case II the minimum peak efficiency index (PEI) required is 99.465 %. Whereas, the PEI measured is 99.534 %. Hence the routine tests confirmed, there are no significant extra losses in the new generation VRDTs with OLTC.

Special tests

Special tests including short circuit withstand test, lightening impulse (LI) voltage test, partial discharge (PD) measurement and determination of temperature rise and sound levels are performed on the selected transformers. SC and LI tests are conducted and certified by the licensed independent test laboratories and the remaining special tests are performed within the manufacturing company.

Short circuit withstand test

According to the standard IEC 60076-5 the ability to withstand the dynamic effects of the short circuit of a transformer could be determined by a short circuit test. Symmetric and asymmetric values of short circuit currents are calculated as prescribed in the standard. SC test was executed for the tapping positions 1, 5 and 9 to evaluate the performance under different operating voltage levels. The duration of SC test is 500 ms and 260 ms for case I and case II respectively. The measured values are within the tolerances allowed by the standard and they are the average values of all 3 measurements conducted on each phase of the selected VRDTs. As a result, both the transformers successfully passed the SC withstand test.

Lightening impulse voltage test

The test is performed within the regulations set by the standards IEC 60076-3 and IEC 60076-4. For both the cases 100 % full wave of 125 kV is taken as a test voltage and 137.5 kV is taken for 110 % chopped wave. To reduce the risk of external flashovers in the test circuit, the test voltage is treated with a negative polarity. A LI wave of 1.2/50 µs front/tail time with approximately 50 % of full wave and 55 % chopped wave is considered a reference impulse for the test. The chopping time for the chopped LI wave is chosen between 2 to 6 µs.

With the help of an oscillogram, voltage and current transients of the reference and three subsequent impulses with full and chopped waves on each winding of the transformers for the tapping positions 1, 5 and 9 are recorded. Since there are no significant differences between voltage and current transients recorded from the reference and test values, the test is considered successfully passed. Also no external flashovers in the test circuit or in the bushing spark gap have been encountered.

Partial discharge measurement

Regardless of many available PD diagnostics methods, an electrical method is preferred following the IEC standard 60076-3. The principle is to determine the voltage change at the terminals caused by the injection of calibrated amount of charge of 50 pC. The actual charge transfer across the localized breakdown is unpractical to measure. Hence, the apparent charge corresponding the voltage change is measured by the coupling capacitor of 1000 pF, which is connected across the measuring equipment.

The testing sequence is implemented on both the cases as defined by the standard. During this process, the measurement of PD is carried out on all 3 phases using an oscilloscope. Subsequently, all the measured PD values are lower than the base value of 50 pC establishing a successful passed test for both the cases.

Determination of temperature rise

With this test, the winding and oil temperature rise of the VRDTs is measured and compared to the specifications allowed by the IEC standard 60076-2. The test is conducted on a short circuited transformer in two back-to-back phases. The initial phase is to determine the top oil temperature and the later phase is to determine the average winding temperature rise. The measured total loss, which is the sum of the highest load loss value caused by the maximum current tapping position 9 and the no load loss is supplied to the corresponding transformers. The power supply is maintained until the rate of change of top oil temperature has fallen below 1 K/h and has endured for a period of 3 h. During the end of the phase with total losses the top oil and the ambient temperatures are measured to get the temperature difference of oil from the ambient.

Again for the next phase without a break, the test current is reduced to the nominal value for the windings and is continued to supply for 1 h. Then the supply of power is detached. Temperature and the DC resistance of both LV and HV aluminium windings are measured immediately to calculate the average temperature rise from the ambient conditions.

Case	Temperature rise (K)	LV winding	HV winding	Oil
I	Guaranteed	65	65	60
	Measured	63	62	58
II	Guaranteed	80	80	75
	Measured	78	78	73

Table 2. Temperature rise test results

Table 2 shows the comparison of maximum allowed to the measured temperature rise. The results obtained at maximum ambient temperature of 40°C for case I and 25°C for case II. From the results, it can be concluded that the test was conveniently passed.

Determination of sound levels

Determination of 'A' weighted sound pressure levels and the corresponding calculation of sound power levels are accomplished on the selected VRDTs according to the IEC standard 60076-10. To record the sound pressure level (Lp), a microphone is utilized at a calculated measuring distance and the measuring height, as specified in the table 3. 6 measuring positions, which are not more than 1 m apart are considered on the contour around the active transformer.

The microphone is moved with a constant speed of maximum 1 m/s on the prescribed contour and the sound is recorded at all 6 chosen positions. The average value of Lp is measured and corresponding sound power level (Lw) is also calculated. Table 3 displays the measured values for both the cases. The values obtained are under the guaranteed values agreed with the customer, indicating no extra noise is created by the new generation VRDT.

Case	Measuring distance (m)	Measuring height (m)	Lp (dB)	Lw (dB)
I	0.3	0.91	34	43
II	0.3	1.30	44	57

Table 3. Sound levels test results

Comparison

Two three-phase oil distribution transformers identical to each other with 250 kVA, 20/0.4 kV, 7.2/361 A, 50 Hz, Dyn5 are selected for the correlation. The routine test results of one transformer with OLTC and the other without OLTC are compared in table 3.

Results	Guaranteed	With OLTC	Without OLTC
SC impedance (%)	4.00	3.91	4.13
No load loss (W)	300	277	283
Load loss (W)	2750	2622	2674
Lw (dB)	45	37	36
Length (mm)	1180	1100	1060
Width (mm)	760	740	740
Height (mm)	1550	1500	1250
Total weight (kg)	1450	1280	1110

Table 3. Measured quantities comparison

The guaranteed values are the maximum allowable values with no tolerances. However, SC impedance is permissible with +/- 10 %. Hence, table 3 validates the addition of OLTC to the distribution transformer brings no critical difference in the dimensions, noise and also the losses.

CONCLUSIONS

The new generation voltage regulation distribution transformer with an on load tap changer provides the unique feature of stabilizing the voltage for distribution systems without an interruption of power supply. The high speed resistor and vacuum tube technology used in the tap changer ensures fast and safe regulation of voltages under loaded conditions. The case study proved that the VRDTs with different power rating are designed and manufactured within the dimensions constrains, have passed all the routine and special tests specified by the IEC standards and EU Ecodesign regulations. The comparison between transformers with and without OLTC provides an insight to the adaptability of new generation VRDT in the electrical distribution system, which indeed contributes the improvement of power quality.

Acknowledgments

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