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A Study on Development of Ultra High Voltage Off-Circuit Tap Changer

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SUMMARY

The transformer is a static device that transforms one system of voltage and current into another system of voltage and current. Most of the transformers are equipped with tap changer in order to control voltage in required by client level. The tap changers could be divided into two groups: OLTC (On Load Tap Changer) and OCTC (Off Circuit Tap Changer). This separation is based on if transformer is under operation condition or it is de-energized from the supplying grid, during changing of tap position.

In this study the inventive and mechanically robust mechanism of tap changing of 362kV and 420kV class UHV (Ultra High Voltage) OCTC is applied in conceptual design, electrical and mechanical analyses are conducted for verification with 3D Finite Element Method (FEM) based software and then the detailed design is performed.

In case of 362kV class OCTC, it is designed as 1510mm height and 441mm diameter. The prototype has passed successfully dielectric test according to IEC 60214-1 such as 1,175kV lightning impulse test, 950kV switching impulse test, 510kV/50Hz applied voltage test and its PD level has been measured below the limits. 420kV class OCTC has 1750mm height and 441mm diameter and has been satisfied successfully a 1,425kV lightning impulse test, a 1,175kV switching impulse test and a 630kV/50Hz applied voltage test and then PD measurement test has been performed in accordance with the latest IEC standard.

The di-electric tests were performed twice to ensure reliability of the OCTCs. First they were conducted in our own laboratory and after that all these tests were repeated in international independent laboratory.

After the verification of electrical withstands capability of the newly designed units, their mechanical endurance tests were conducted.

Firstly, the short circuit test was performed. The applied current in this test is 15 times rated current (15,000A) for 3 seconds. The test was carried out for the fully assembled OCTC in a test vessel filled with clean oil. The tap position of OCTC was 3 and the voltage of power supply was 640V.

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Secondary, the highest temperature rise value of prototype's contacts was measured below 12K, criteria is 15K, with applied 1.2 times rated current. For measurements of temperature rise test have been used a T type thermocouples.

On a final mechanical endurance test, the resistive torque was measured to monitor deformations and to compare them with strain gauges. The 10,000 switching operations were conducted at ambient temperature and the other 10,000 switching operations were performed at temperature higher than 75 ^{o}C. After 20,000 mechanical operations, the prototype seemed to be in a good condition. There were no failures or undue wear of the contact or mechanical part that would lead to mechanical failure if its operation continues. Measured resistive torque of prototype was 2.5 N•m at 20 ^{o}C and 3~4.5 N•m at 120 ^{o}C. In addition to this deformation and stress analysis were perform based on test temperatures separately. Finally, no signs of failure were found on final visual inspection of both prototypes after all tests were finished. From the results of all test, the development of 362kV and 420kV UHV OCTC can be completed successfully.

KEYWORDS

Off-circuit tap changer (OCTC), reliability, electric field stress, contact

1. INTRODUCTION

Tap changer influence power transformer price indeed. Not only with their prime cost but additional space should be provided by transformer designer for it. For ultra high voltage transformer OCTC also reflect to insulation distances to tank and windings. So their prices compared to the UHV transformers are negligible but their price impact some times is. Iit was decided to be designed OCTC with the respect to the transformer designer point of view, OCTC with good insulation system and reliable mechanical structure.

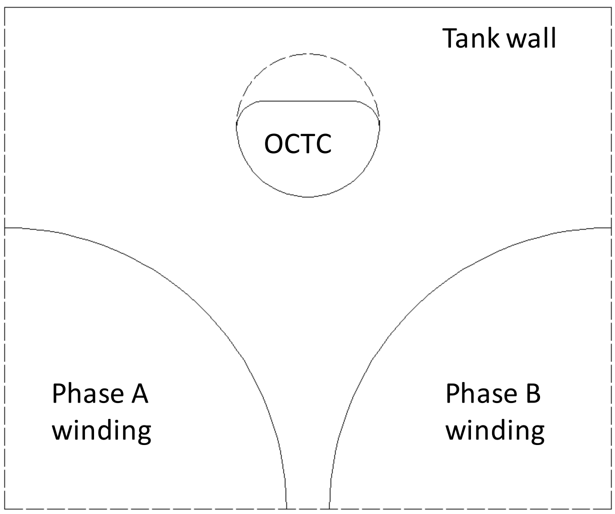

Figure 1. Schematic arrangement of OCTC and winding in transformer tank

It was chosen half cylindrical shape with one shaft and special contact and shielding system in order to reduce needed space inside transformer. Five positions with one shaft to ensure mechanical strength of tap changer. Figure one shows the benefits in space reduction due to chosen shape.

2. DESIGN STAGE

The design of so important device, for the reliability of most commonly met device in electric network is a though job. It was started from the smallest part. They were analyzed few types screening elements for these parts that are not allowing good shape of the electric fields. For example screen caps for connection points between insulation bars and electrical contacts, figure. 2, that is connecting the different tap leads, and shields for main insulation system for getting smooth field shape in order to minimize the distances between different parts.

- **Screen caps**

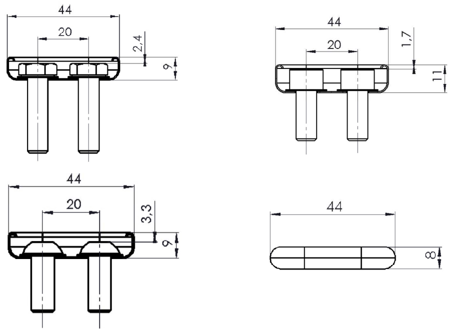

Figure 2. Different screen caps

Figure 2 shows four different suggestions for screen caps were developed. Special models were analyzed in order to choose the best variant. The results from analyzes show that the caps have very similar results The chosen ones were produced and tested in order to prove di-electric strength and to verify analyzes' results.

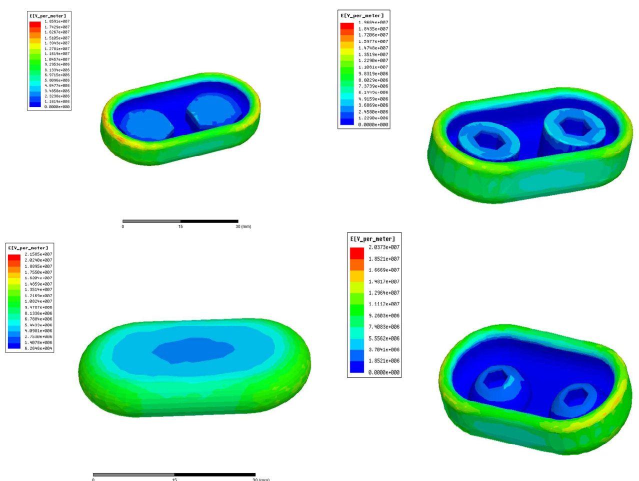

Figure 3 Different screen caps analysis results

- **Electrical shields**

In the field of high voltage equipment not all parts could be with shape that ensure the uniform. Of the filed in order to prevent appearance of partial dischargers or even provoking a full brake down through insulation system of the device. This is the reason why some special care is taken to strengthen the insulation system but not with insulation material, with some metal parts, that has potential, with special shape and position in order to hide (screen) the contacts or parts with not so smooth shape.

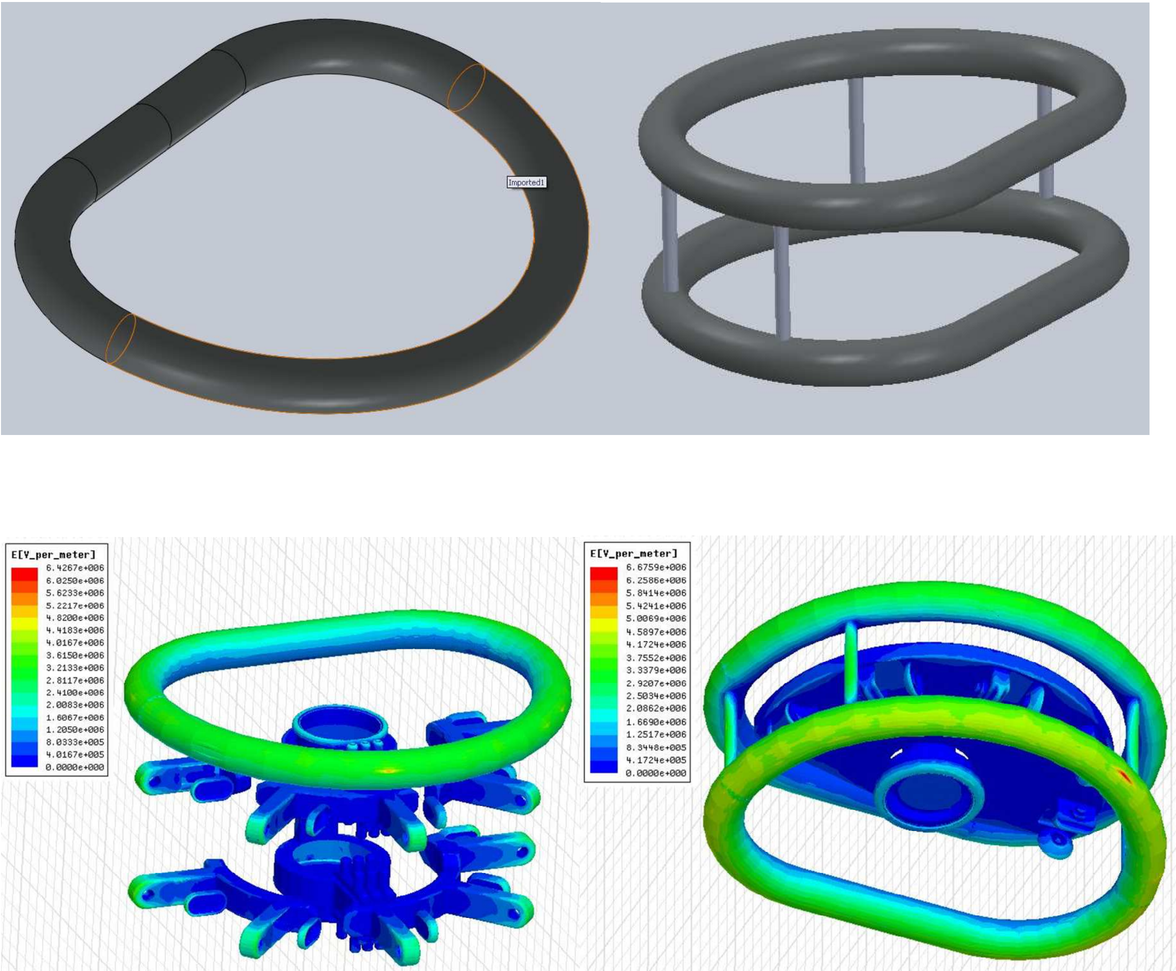

Figure 4 Electrical Shields for main insulation

On figure 4 are shown the chosen electric shields that cover the earthed top plate with switching mechanism and electrical contacts of the OCTC. The special design allow to minimize the height of the two OCTC (362 kV and 420kV class) to 1510mm and 1750mm respectively.

- **Insulation bars**

Of course it is not all matter of designing uniform electric field. Even with the most smooth filed there should be done special investigation about the required insulation distances. OCTC insulation systems is consist not only oil gaps but also some creepages distances should be checked.

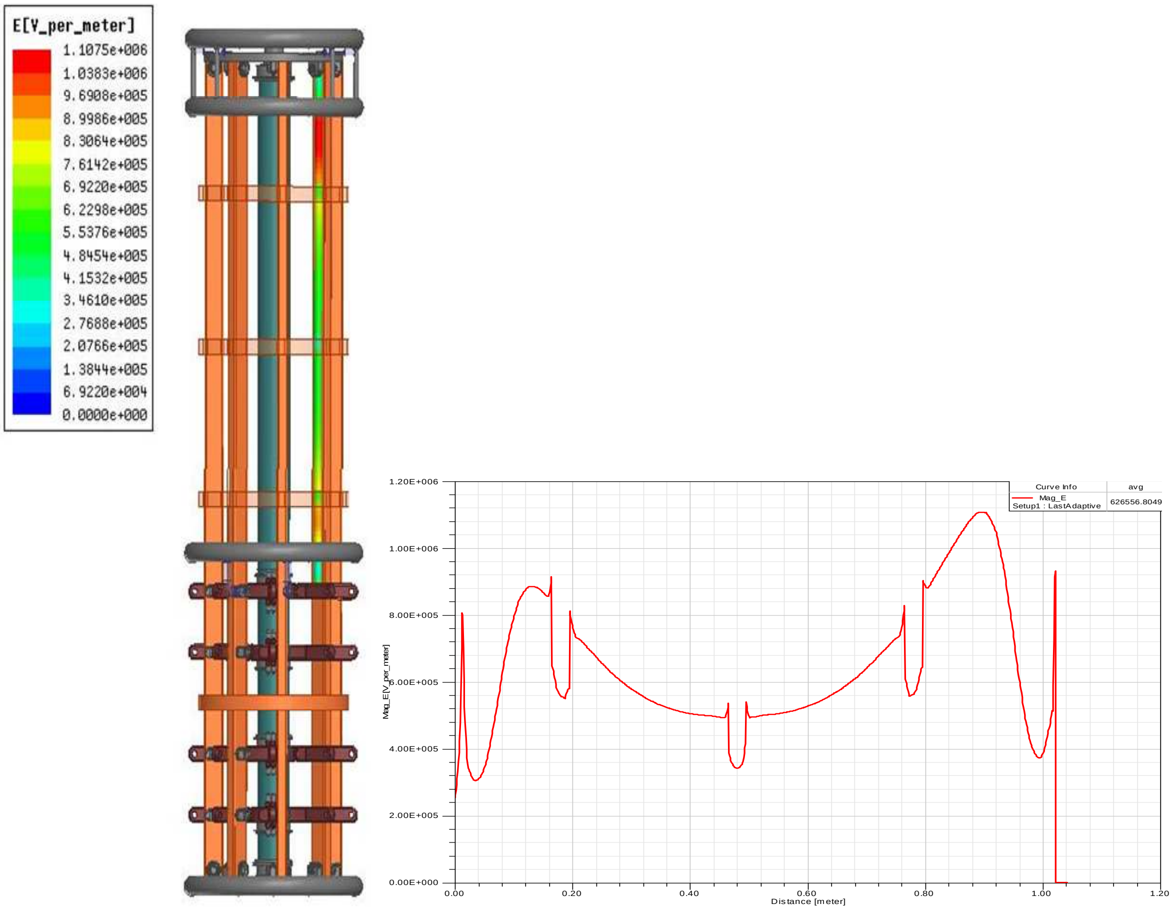

Figure 5 Field Stress among insulation bar.

There are few theories about brake down phenomenon in transformer oil but none of them are totally accepted. In our study we are based on average field stress in oil gap. It was calculated safety margins in most critical points in insulation system of the OCTCs. 3D FEM software was used in order to analyze exact field distribution around metal parts of the tap changer. Also it was checked the creepage distance along insulation bars. Figure 5 shows the filed stress along creepege line on the surface of the insulation bars.

But insulation bars main purpose is not only for insulating the metal parts with different potentials, but also to ensure mechanical strength of the tap changers during normal operation and also during short circuit event in the transformer. Special test were conducted to ensure this construction in different conditions.

A simulation for deformation due to mechanical effects of tap winding leads during short circuit event in transformer was performed.

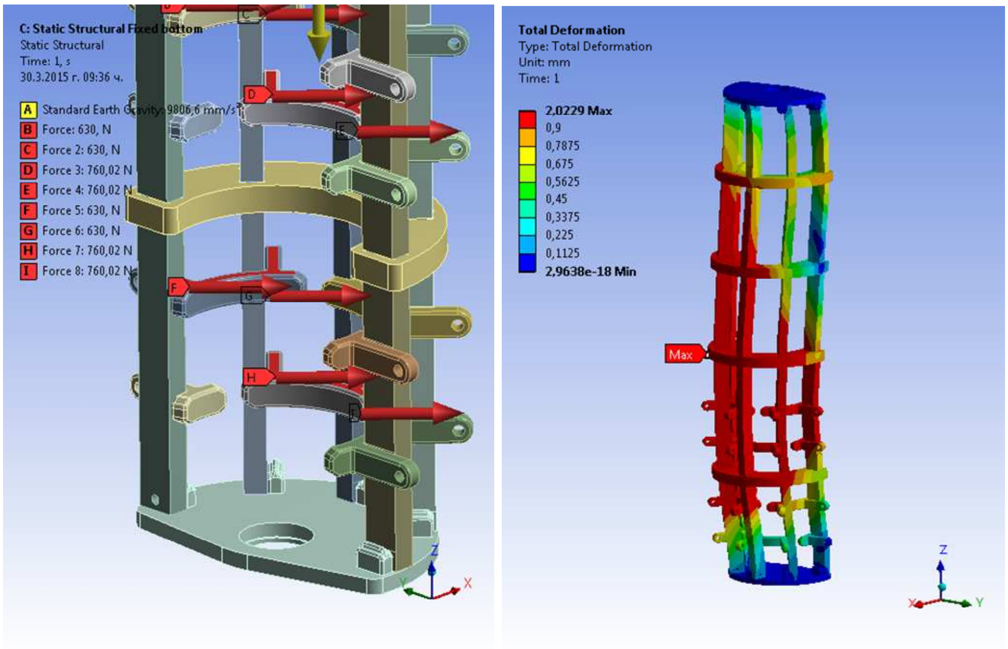

Figure 6. Total deformation during short circuit.

It was applied frictional force of 210N on each contacts and 340N Tangential for on the moving contacts. It was calculated about 2 mm maximum deformation for both variants of Off-Circuit Tap Changers, which are acceptable form mechanical and functional point of view. Due to the more height of 420kV variant it was necessary to put additional third fortifying plate in order to ensure mechanical withstand of the structure.

3. TYPE TESTS ACCORDING IEC 60214-1; 2014

- Electrical Test

The tests were conducted according the latest IEC 60214 -1:2014 Standard. On table 1 are shown the test voltages for the 362kV and 420 kV voltage levels. The tests were performed in insulation vessel filled with clean transformer oil. Prototypes were put to stay in the oil for a 12 hours before performing tests. The reason for this is to ensure that there is no air bubbles in the oil.

Highest voltage for equipment U_m kV	Full wave lightning Impulse kV	Chopped wave lightning Impulse kV	Switching impulse kV	Applied voltage kV
362	1 175	1 290	950	510
420	1 425	1 570	1 175*	630

Table. 1 Test voltages for class 362kv and 420kV Off-Circuit Tap changers according IEC 60214-1: 2014 [1]

After satisfactory results of lightening strikes with 3 negatives and + positive pulse per each test. The electrical withstand of the main insulation to 50 Hz field was performed.

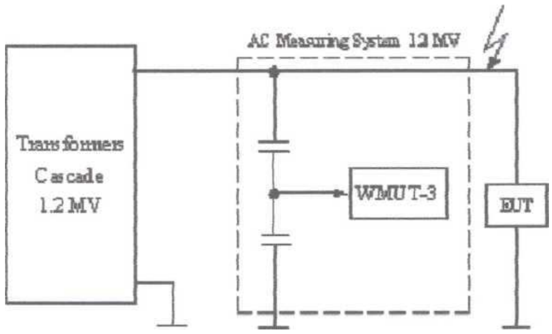

Figure 7. Electrical scheme for AC test.

On the OCTCs was applied voltage of 510kV for 362kV class and 630KV for 420 Class prototypes for 60 sec. These tests represent more than 40 % higher than normal operating voltage for both voltage classes. Finally 1 minute power frequency test was repeated with 5% higher voltage without any oscillation of the supplied test voltage.
Additionally for class II OCTC IEC require PD measurements test. The test was performed with the sequence presented in standard IEC 60214-1: 2014 . PD measuring method was according IEC 60270.

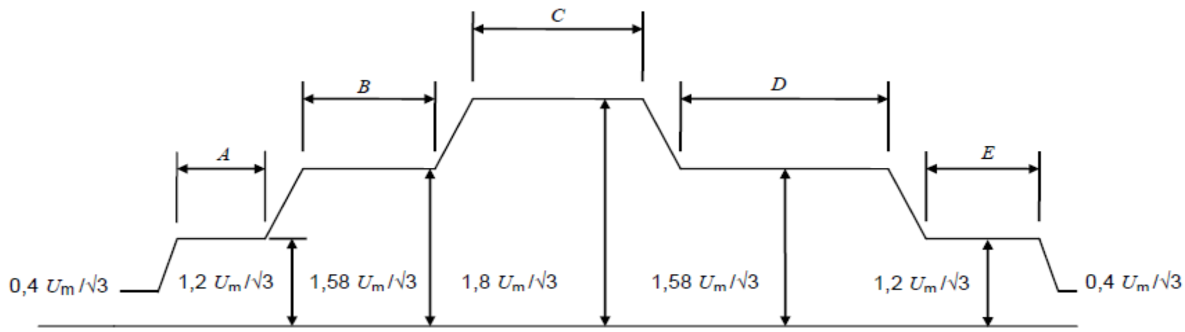

Figure 8. Time sequence for the application of test voltage (de-energized tap-changer) [1]

Table 2 shows the results of PD measuring. The test was according IEC 60214-1; 2014 and the these voltages according table 2.
All the measured values are far bellow recommended in the standard. For example the recommended levels for PD after stress level (1.8 times nominal voltage) when the voltage is 383kV, the permitted PD is 50 pC and for the next stage is 30 pC and it was measured 8 pC and 7 pC respectively

Test Voltage [kV]	Time	PD level [pC]
0.4 Um/√3=97	1 min	6
1.2 Um/√3	1 min	7
1.58 Um/√3	5 min	8
1.8 Um/√3	1 min	-
1.58 Um/√3	5 min	7
	10 min	9
	15 min	8
	20 min	8
	25 min	7
	30 min	7
	35 min	8
	40 min	8
	45 min	8
	50 min	9
	55 min	8
	60 min	8
0.1.2 Um/√3	1	7
0.4 Um/√3	1	6

Table 2. PD measurements results

Table 2 shows the results of PD measuring. The test was according IEC 60214-1; 2014 and these voltages according table 2.
All the measured values are far bellow recommended in the standard. For example the recommended levels for PD after stress level (1.8 times nominal voltage) when the voltage is 383kV, the permitted PD is 50 pC and for the next stage is 30 pC and it was measured 8 pC and 7 pC respectively
In order to double ensure di-electric strength of the two devices a second test of the insulation system were performed in international independent laboratory. All test in table.1 and additionally Pd measurements were repeated in order to prove again that the design based on results of 3 D FEM analyses were with the enough safety margin and it was decided too proceed with other type test that are mentioned in the standard. A final test protocol was done and stamped.

- Mechanical Test

Short Circuit test – the test was performed according the IEC 60214-1; 2014 but even with higher current for longer time. On the OCTC was applied 15 000 A, and applied voltage of 640 V for 3 sec. The prototype passed it without any deformation or sign of a problem.
On a final mechanical endurance test, the resistive torque was measured to monitor deformations and to compare them with strain gauges. The 10,000 switching operations were conducted at ambient temperature and the other 10,000 switching operations were performed at temperature higher than 75 ^{o}C. After 20,000 mechanical operations, the prototype seemed to be in a good condition. There were no failures or undue wear of the contact or mechanical part that would lead to mechanical failure if its operation continues. Measured resistive torque of prototype was 2.5 N•m at 20 ^{o}C and 3~4.5 N•m at 120 ^{o}C. In addition to this deformation and stress analysis were perform based on test temperatures separately. Finally, no signs of failure were found on final visual inspection of both prototypes after all tests were finished. From the results of all test, the development of 362kV and 420kV UHV OCTC can be complete successfully.

4. CONCLUSION

In the paper are shown main stages in development of UHV OCTCs. A special attention was paid to even the smallest parts of the tap changer in order to get as a results reliable device. Strict tests were performed to verify the di-electric and mechanical strength in order to prove that the OCTC will withstand the worst events that can appear during transformer operation, like lightening strike and short circuit on the transformer line exits. Special parameters were monitor during mechanical endurance to ensure the stable operation of the OCTC during normal working condition for the transformer.

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