A NOVEL INTEGRATED VACUUM TAPPING INTERRUPTER

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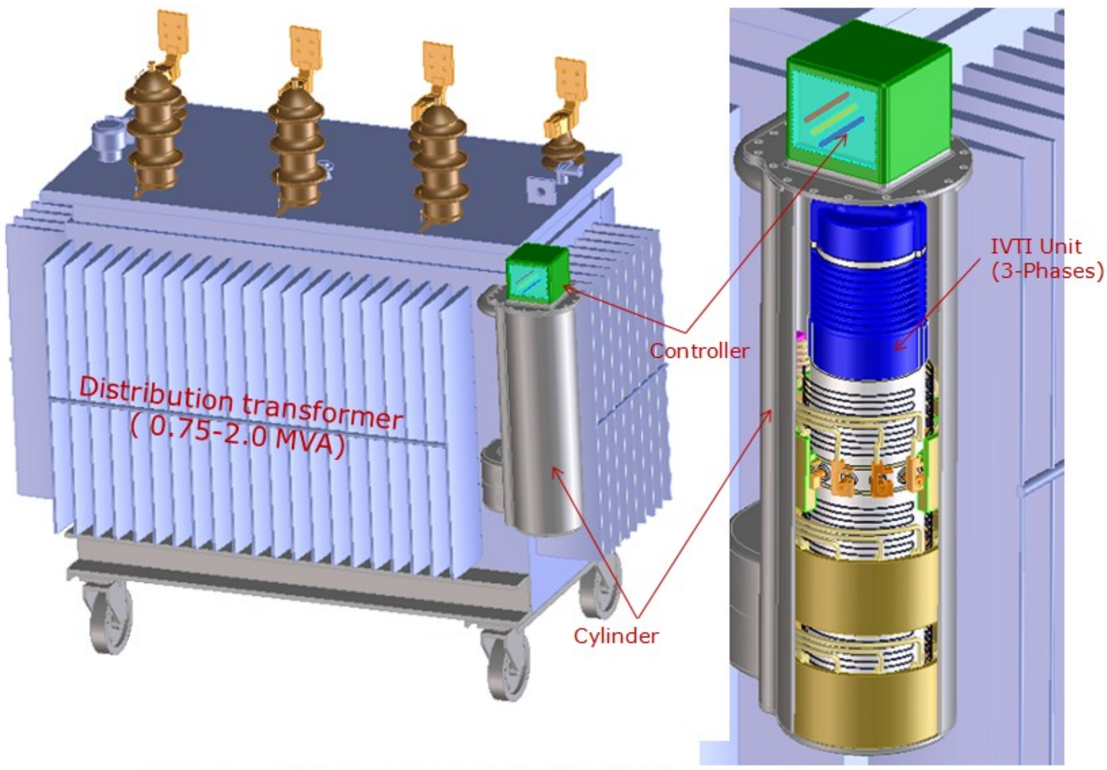
INTRODUCTION AND BACKGROUND

The On-load-Tap-Changer (OLTC) is now very popular used on power transformers for keeping the supply voltage stable under variable loads. However the concept of smart grid is more and more reality in the 21th centenary, therefore the OLTC has been starting into distribution transformer market [1]. As the Integrated-Vacuum-Tapping-Interrupter (IVTI) designed has the same function as the existing OLTC, but it brings a significant smaller volume and reduction of the cost with total oil free of contacts, thus it would potentially be a key role in the distribution transformer market. In fact the IVTI is a combined conventional OLTC and vacuum interrupter integrated into a single vacuum bottle which it is achieved by compacting the contacts, transition integrated circuits, tap driving and changing mechanism into a single vacuum insulation chamber. The figure below is an example of IVTI Unit (3-Phase) mounting on the distribution transformer.



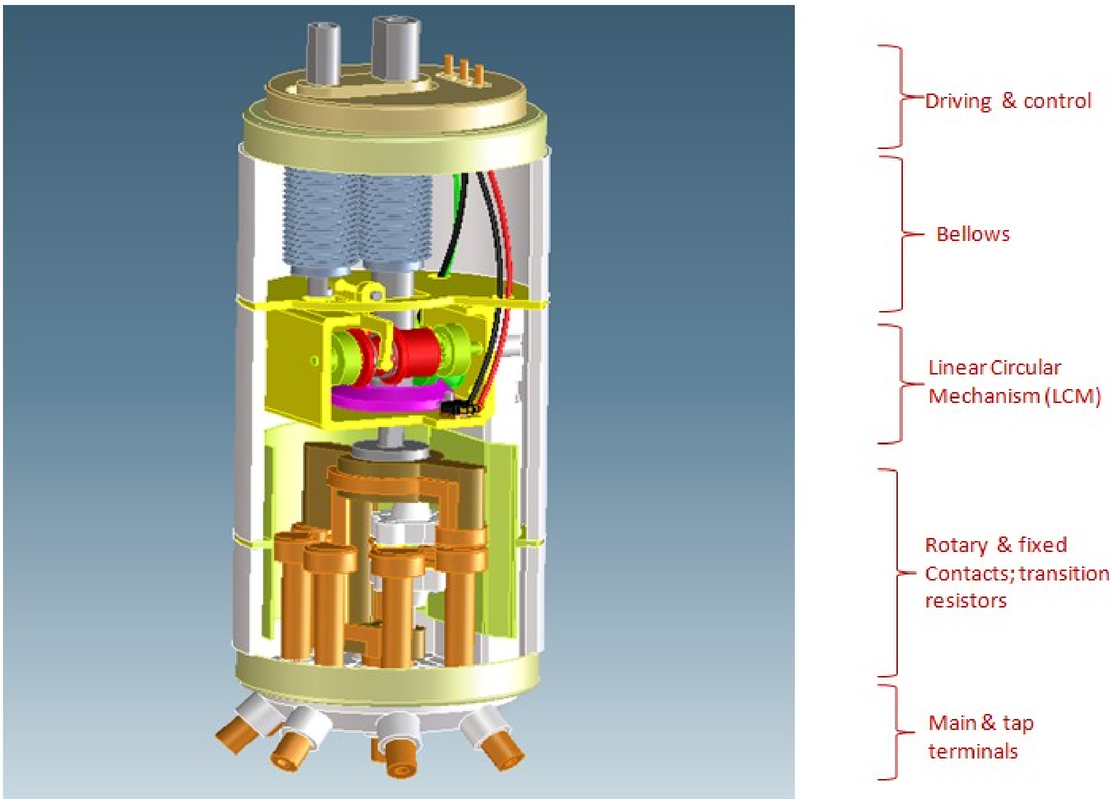
An example IVTI mounts on distribution transformer

IVTI DESIGN

As the IVTI is a totally new concept with integrating the transition integrated circuits, tap changing and interrupter mechanisms inside a single vacuum chamber resulting in a significant reduction of volume by using much smaller electric clearance in vacuum condition. As well as the simplified overall system and mature double resistors by-pass transition circuits have the higher reliability by a transition rotor with epicycioidal movement. In general, the distribution transformer is working at 10kV and less rate of 2MVA. In order to compromising the market demand and research, the 5-step IVTI with maximum 12KV and rated 200A is introduced as the starting point which the expected technical engineering specification in design of IVTI is as follows:

- The Rated voltage: 10(kV)
- Rated through-current: 200(A)
- Rated frequency: 50 & 60 (Hz)
- Maximal step voltage: 600 (V)
- Operation positions: 5
- Operation Frequency: up to 1.6/per-minute
- Impulse withstand voltage to earth: 42 (kV)
- Impulse withstand voltage between adjacent taps: 10 (kV)
- Rated breaking current: 4(kA)
- Rated duration of short-circuit: 4(s)
- Rated working condition: 253 to 338K (-20 to 65 C^{o})
- Operation life: 300000 (cycles)

The movement loci of the rotary contact are investigated in comparison with a mechanical driving machine for optimizing and engineering design of IVTI. The figure below is the one phase IVTI unit with maximum 12kV, 200A 5-step.



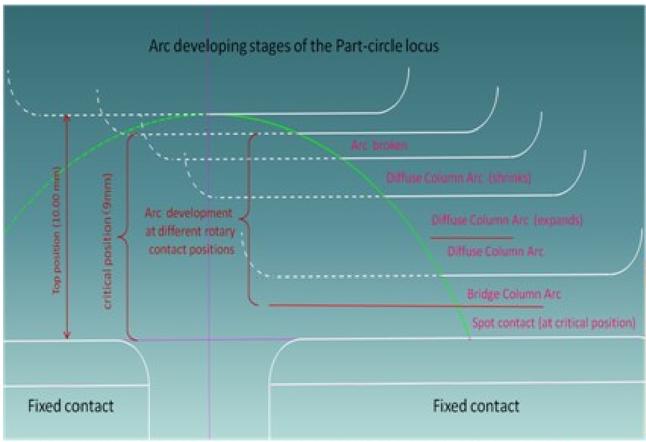
Integrated Vacuum Tapping Interrupter

BUILDING MODELS AND SIMULATION

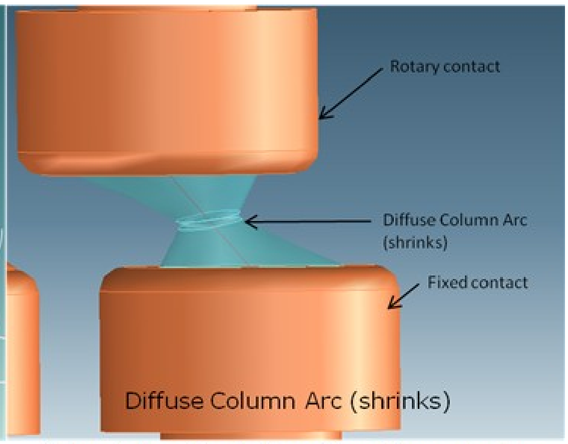
The theoretical principles underlying the operation of the IVTI are first presented as the core in the paper. The two aspects in contact movement loci and electrical arcs are in investigation. In fact the electrical arc formation depends entirely on the properties of the contact material and is always initiated within metal vapor generated from the contacts during the breaking process. At the application currents (rated breaking current is 4kA) used in the IVTI, the arc can be assumed to be in Natural Diffuse Mode [2]. However, the arc generated within the IVTI should also be assumed to be gradually twisted and separated as the rotary contact moves along a selected locus during the break operation. It may also be assumed that the arc is generally stationary on the butt contacts; therefore the diffuse column arc roots will be stationary during the lifetime of the arc. These assumptions simplify the subsequent analysis.The optimized and selected rotary part-circle locus has been determined after comparing to three rotary loci. The electrical arc formation depends entirely on the properties of the contact material and is always initiated within metal vapor generated from the contacts during the breaking process [3]. There is the arc development model has been built for study and simulation with 6 statuses during the break operation as follows:

- Spot contact(s) generated (at critical position)
- Bridge Column Arc formed
- Bridge column arc converts into Diffuse Column Arc
- Diffuse Column Arc expands
- Diffuse Column Arc shrinks with equal value double heading conical shape
- Arc breaks

The ANSYS was introduced in simulation with the arc development model stated above based on finite element analysis (FEA). The theoretical discussion concentrates on an explanation of the developing models of the electrical arcs generated during contact breaking operation. The figure below is the optimized rotary part-circle locus with arc 6 development statuses (left) and the arc model at Diffuse Column Arc shrinks status (right).



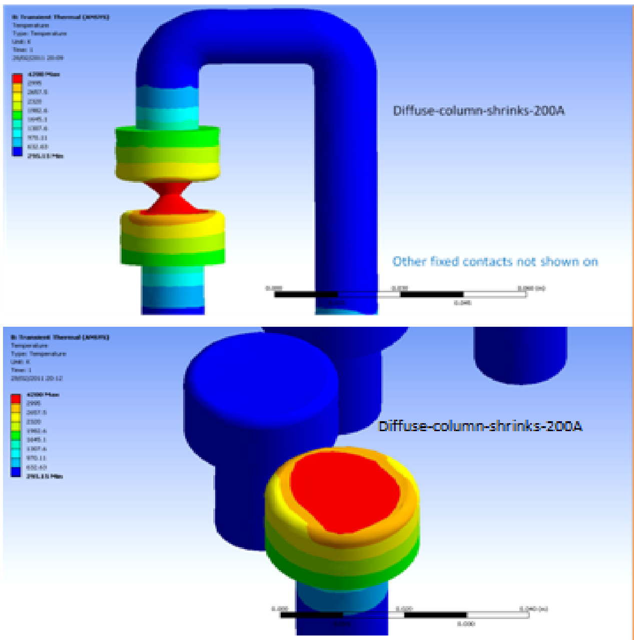
The part-circle locus and arc development statuses with related positions during contact break



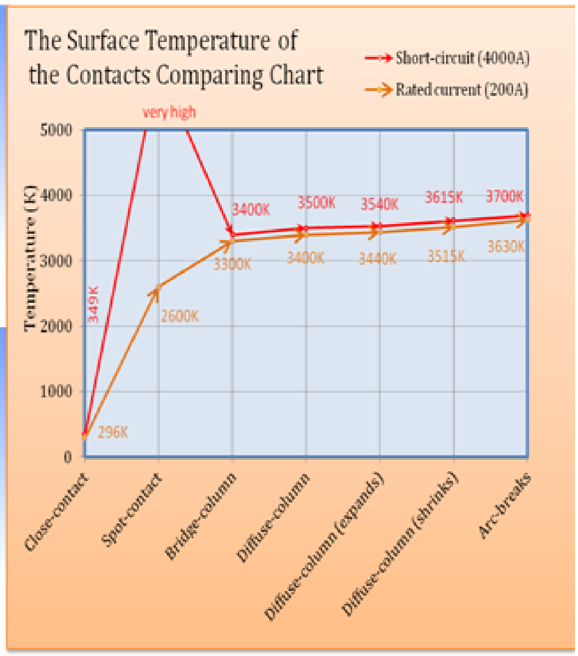
Diffuse Column Arc shrinks status with equal value double heading conics

RESULT AND EXPLANATION

As the result of the simulation, there is a series temperature map of contact surface to be created relating to each 6 statuses of arc development model. As well as the temperature tending curves of the contact surface of the contacts under normal maximum 200A and 4000A at the short circuit conditions are produced for a comparison between the two curves, the curve (4000A) always above the curve (200A), suggests that the models work well even under extreme conditions. A discussion of the possible damage that can be produced on the surfaces of the contacts as a result of these arcs is then presented. As well as a discussion of the other parameters such as contacts movement contact shape, breaking speed etc. that could be used to reduce the possibility of arcs occurring will also be given. All theoretical discussions conclude with a description of the optimized engineering design of IVTI. The figure below is the temperature map of contact surface at arc model at Diffuse Column Arc shrinks status (left) and comparison of temperature tending curves.



The contact surface temperature map at diffuse Column Arc shrinks with equal value double heading conics (as an example)



The temperature curves of the surface of the contacts under 200A and 4000A conditions

CONCLUSION

By combining an OLTC and integrated interrupter into a single vacuum chamber, the development of the novel IVTI would be the potential a key role in application of distribution transformers which is the part of smart grid new market in the 21th centenary.

The arc development model has been built for study and simulation with 6 statuses during the break operation. ANSYS 12.1 software was introduced to simulate the arc development model built using the optimised and selected locus. The result of the temperature map of contact surface and comparison of temperature tending curves has been used to explain the working phenomenon of IVTI at the extreme condition. In general, therefore, it could be said that the design parameters (particularly the cross section of the contacts) selected for IVTI are reasonable for distribution transformers.

The latest development of the IVTI combines internal driving motor (reluctance or stepper type) and external resistors. It could easier increase the number of the steps and prevent extra thermal issues due to the larger current flowing though the transition resistors as well as getting higher rate for application of bigger transformers.

REFERENCES

[1] C. Oates, A. Barlow, V. Levi, "Tap Changer for Distributed Power, Paper 0420", *19th International Conference on Electricity Distribution,* Vienna, 21-24 May 2007

[2] L. Falkingham, "The Evolution of Vacuum Interrupter Arc Control Systems", *18th International Conference on Electricity Distribution,* Turin, 6-9 June 2005

[3] P. G. Slade, 2008, *The Vacuum Interrupter Theory, Design, and Application,* CRC Press, Oxon, UK, Chapter 2.2, 130.