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THE LOSS REDUCTION WITH ADDITIONAL RING YOKES IN UHV SHUNT REACTORS

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Abstract

Shunt Reactors are inductive loads and absorbs the reactive Power in long HV transmission lines and cables. They reduce the over voltages generated by line capacitance and increase energy efficiency of the system. The differences compared to transformers are the design of the core, clamping system and winding. The reactors contain single winding, unlike transformers. Most large HV shunt reactors are manufactured oil-immersed type and their limbs based on radial stacked gapped core concept. [1], [2]
The additional ring yokes are 2 radially stacked core package which have bigger diameter and lower height compared to other packages in limbs and they are used to collect main and stray fluxes that goes out from windings. They both are adjoined the windings from top and bottom. [6]
This paper describes recent improvements of radially stacked gapped core types with additional ring yokes and particularly the advantages of shunt reactor limbs with additional ring yokes.

The results of 3D – Finite Element simulation presents reducing of the core losses, winding losses and partial temperature rises due to additional ring yokes on core limb. A case study gives numerical results of advantages of additional ring yoke core packets.
The advanced design can ensure that the reactors with additional ring yokes have lower losses and lower temperature rises.

Key words: Shunt reactor, distributed- gapped- core, fringing effect, additional ring yoke, additional losses, eddy current losses, heat generating in the core.

1. INTRODUCTION

Shunt reactors with distributed-gapped iron core have higher inductance, smaller losses and less current in the windings compere with air core reactors. They have fixed rating or can be variable with tap-changers.
In order to avoid saturation of the core, air gaps are distributed along the core. The radially laminated core prevent fringing flux entering from flat surfaces of core steel, thereby avoiding overheating on the core packet and the winding. The fringing generates more eddy current losses. [1], [3], [4], [9]
Because of high magnetic forces arising between the core packages, their surface must be very smooth and precise. This is one of most difficult work, which needs special experience. Reactive power and magnetic flux density are in relation with the gap volume. The biggest portion of energy of the reactor is stored in the gaps. Generally small height of gaps has low fringing losses. By beveling core limb packets the eddy current losses can be reduced. [6]

2. THE BEVEL EDGE

Air gaps cause fringing effect. Small gaps have low fringing losses. The fringing can generate more eddy current losses in winding and core packets and as a result overheating occurs.

In order to reduce eddy current losses we must bevel the edge of the core packets. Eddy losses are the biggest part of the core losses. FEM simulation in fig.1 shows the difference between core Packets without and with bevel edge. [5], [6], [7]

Beveled edge on core packages reduces average flux density on limbs and provides homogeneous flux distribution according to FEM analyze results, especially flux density on package corners is reduced. This reduction provides low losses and low noise on core.
Additionally, saturation point is increased due to average flux density and inductance of limbs and core is reduced. This affect is shown in below Graph.1.

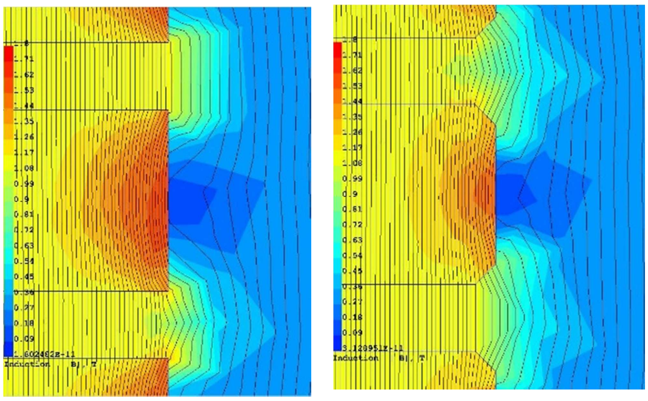
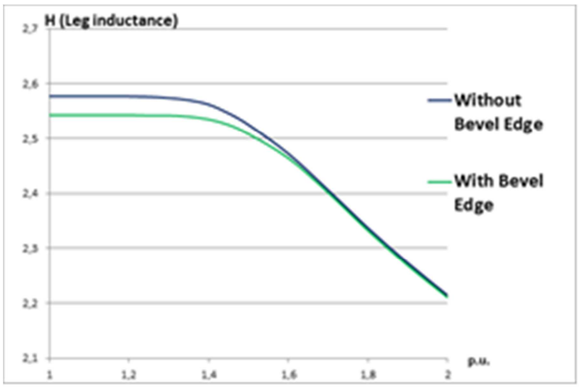


Fig.1. Two simulation pictures shows the differences between core packets without and with Bevel Edge



Graph.1. Saturation Curves

3. THE ADDITIONAL RING YOKE

The Stray fluxes create the stray losses. The additional ring yokes collect main and stray fluxes which go out from windings. It is a challenge that to optimize the additional ring yoke, as a magnetic shunt. With this solution the additional (structural) losses and the copper losses can be reduced. A simple view of shunt reactor with additional ring yoke is given in figure 2. [6], [8], [13]

The assembling must be done very carefully. Otherwise expected result couldn’t be reached. Especially the assembly of core limbs and yokes is so complicated. And also additional ring yoke must be centered very precisely on the core limb. [14]

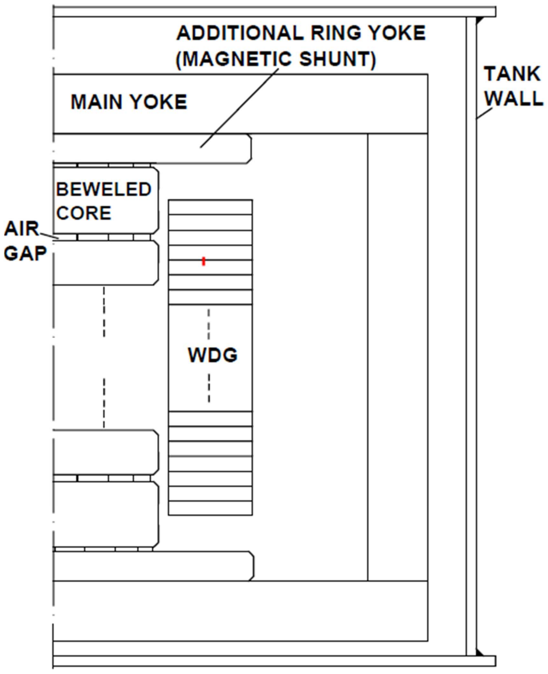


Fig.2. Cross section of single phase shunt reactor core with additional ring yoke

4. THE ELECTROMAGNETIC SIMULATION

The electromagnetic simulation of the core along the limbs applied by means of three-dimensional finite element method (3D-FEM) is shown in fig. 3 and 4. [6]

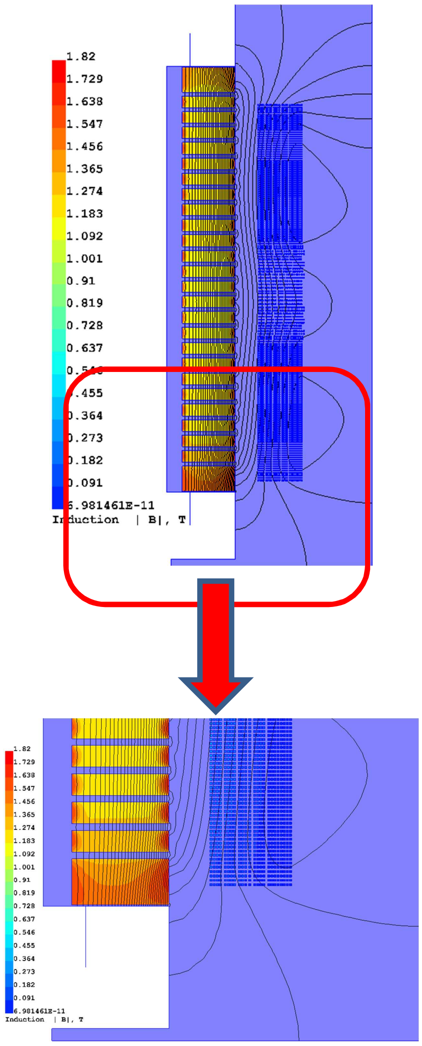


Fig.3. Distribution of the magnetic fields in reactor cross-section (Without Additional Ring Yoke)

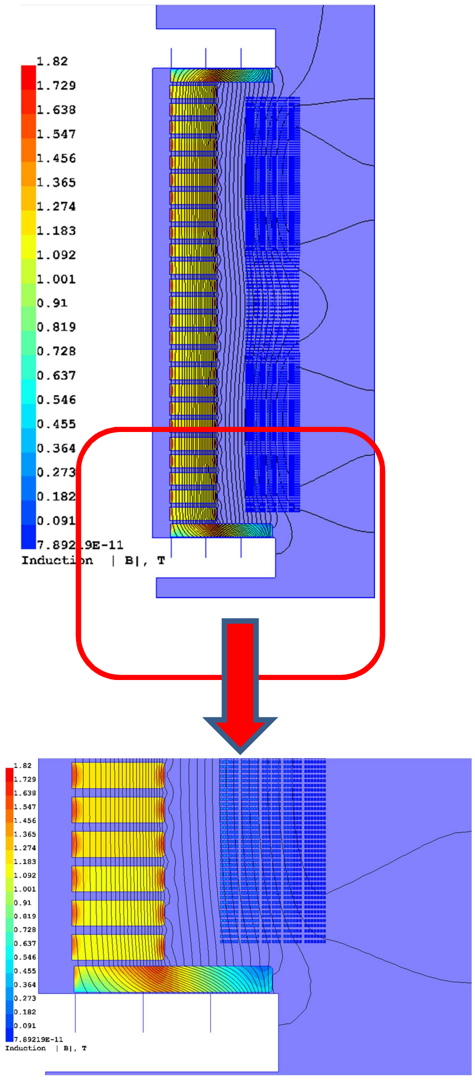


Fig.4. Distribution of the magnetic fields in reactor cross-section (With Additional Ring Yoke)

5. DISTRIBUTION OF THE FLUX DENSITY IN DIFFERENT TYPE OF REACTORS

Additional ring yokes provide homogenously transfer of magnetic fields occurred in windings around limb to yoke, thus stray fluxes are minimized. By means of previous affects, additional ring yoke reduces average induction (flux density). The electromagnetic simulation of the single phase shunt reactor core with/without additional ring yoke by means of three-dimensional finite element method (3D-FEM) is shown in fig. 4 and 5.

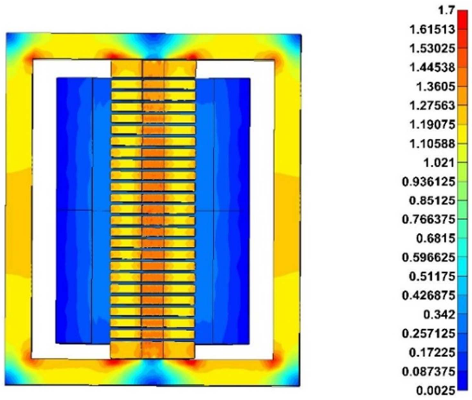


Fig.5. Distribution of the flux density in reactor core type 1/2
(Without Additional Ring Yoke)

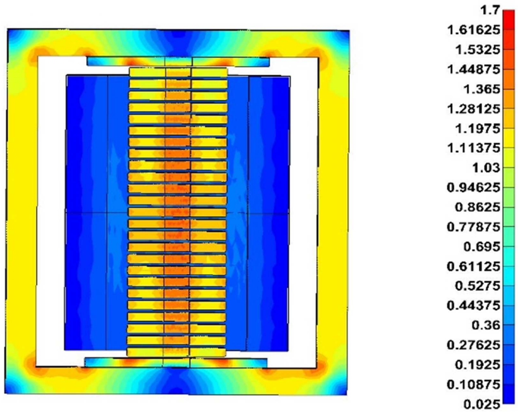


Fig.6. Distribution of the flux density in reactor core type 1/2
(With Additional Ring Yoke)

6. CASE STUDY

6.1-Calculation of Losses for Reactor Core with different Power and Voltage

Additional ring yoke reduces the winding losses by collecting stray fluxes causing eddy currents on windings. Additionally, it reduces core losses by reducing average flux density in core. In addition to additional ring yoke ıt is possible to improve losses some more with the bevel edge applied to all packets in the limb. The improvements are numerically given in table-1 for 1 phase and in table-2 for 3 phases below obtained by FEM analyze. Based on above electromagnetic simulation results, the loss saving on 3 phases cores is less than 1 phase cores.

Table 1. 1 phase, Approx. Total Loses (Core + Winding) in kW

	Without Additional Ring Yoke and Bevel Edge	**With Additional Ring Yoke and Bevel Edge**	**Loss Saving**
80 MVAr 800 kV	121	112	9
100 MVAr 800 kV	133	123	10
240 MVAr 1100 kV	288	275	13
280 MVAr 1100 kV	312	295	17

Table 2. 3 phases, Approx. Total Loses (Core + Winding) in kW

	Without Additional Ring Yoke and Bevel Edge	**With Additional Ring Yoke and Bevel Edge**	**Loss Saving**
150 MVAr 420 kV	256	250	6

6.2-Distribution of the temperature fields in reactor cross-section

The stray fluxes inducing additional eddy currents, generate high temperature rise on yoke. This may result in reduction of the shunt reactor lifetime. Additional ring yoke and bevel edge prevent high temperature rising on core by reducing average magnetic flux density. Temperature rise obtained by FEM analyse are shown in figure-7 and -8 and also numerically given in table-3 below.

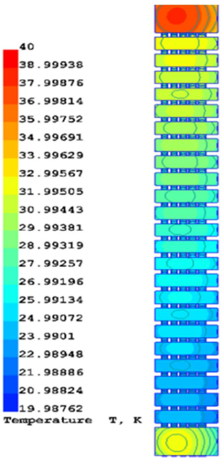


Fig.7. Distribution of the heat fields in reactor cross-section (Without Additional Ring Yoke)

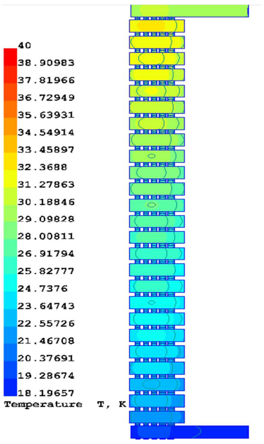


Fig.8. Distribution of the heat fields in reactor cross-section (With Additional Ring Yoke)

Table 3. Temperature Rise in 80 MVAr_765kV_1ph Reactor Core

	Temperature rise in reactor core depends on ambient temperature ΔT [K]	**Temperature Reduction [K]**
Without Additional Ring Yoke and Bevel Edge	38,20	5,60
With Additional Ring Yoke and Bevel Edge	32,60	

CONCLUSION

Recent trends in design and manufacture of magnetic circuits in shunt reactors with distributed-gapped core are discussed in this paper [12], [15]. The losses of gapped-core reactors occur in the windings, in yokes and in limbs by leakage flux. The reduction of the eddy losses due to beveling edges of the core packets is shown by FEM Simulation. It is a challenging task to model and analyze behavior of the core in a shunt reactor due to additional ring yoke. [8], [10], [11] Modeling of the characteristics using electromagnetic simulation and the corresponding numerical implementation has been reported.

It has been compared with FEM analysis the distribution of the temperature fields in core cross-section. The difference of numerical results is shown the in table 3.In addition to design and calculation practices, state-of-the-art manufacturing processes are essential to meet to objective.

REFERENCES

[1] K.Eckholz, S.Yurekten, *Shunt Reactor Cores up to 800 kV-300 MVAR*, ARWTR,Advanced Research Workshop on Transformers, Spain ,2010

[2] S.V. Kulkarni, S. A. Khaparde, *Transformer Engineering: Design, Technology, and Diagnostics, second edition*, 2012

[3] S. Yurekten, *New Trends in UHV Shunt Reactor Core Technology*, Gridtech Proceedings, New Delhi, 2011

[4] S.Yurekten, *Reliable Quality and optimized Design of components for Power Transformers and Reactors*, TRAVEK, XIIth International Scientific and Technical Conference, Moscow , 2012

[5] A.P.S.Baghel,S.V.Kulkarni, S.Yurekten, *Modern Trends in design and Manufacturing Practices of the Core in Power Transformers*, 5th International Conference on Large Power Transformers-Modern Trends in Application, Installation, Operation& Maintenance, New Delhi, 2013

[6] S. Yurekten, *Trend in the Recent Improvement of Gapped-Core UHV Shunt Reactor Design*, CIGRE International Colloquium on Ultra High Voltage in association with CIGRE, Nev Delhi, 2013

[7] N. Takahashi, T. Nakau, D.Miyagi, S.Nogawa, M. Kuwata. '3-*D Eddy Current Analysis of Bevel Edge Core Reactor Using Modelling Technique of Laminated steel'*, (IEEEJ, 2008)

[8] G.N. Alexandrov, *Energy transmission by AC Current*, 1997

[9] Martin Christoffel, *The Design and Testing of EHV Shunt Reactors*, IEEE, June 1967

[10] CIGRE, *WG A2.48 Technology and utilization of oil insulated HV Shunt Reactors*

[11] *IEC Standard 60076-6 Power Transformers-Reactors*, December 2007

[12] *Indian Standard 5513-2 Reactor specification-Shunt Reactors*, 1990 (re-affirmed 2003)

[13] Christoph Ploetner, *Sound Levels of Oil-immersed Shunt Reactors Development- Prediction-Specification*, CIGRE SC A2 Colloquium 2015

[14] Salvador Magdaleno-Adame, Juan C Olivares-Galvan, Rodrigo Ocon, *Temperature Reduction in the Clamping Bolt zone of Shunt Reactors: Design Enhancements*, December 2014

[15] Abbas Lotfi, Ebrahim Rahimpour, *Optimum Design of Core Blocks and Analyzing the Fringing Effect in Shunt Reactors with Distributed Gapped-core*, Elsevier, 2013