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21, rue d'Artois, F-75008 PARIS
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TREND IN THE RECENT IMPROVEMENT OF GAPPED-CORE UHV SHUNT REACTOR DESIGN

Equipment Development
- **UHVAC Transformers**
- **UHVAC Instrument Transformer**

Selim Yürekten , s.yurekten@enpay.com
Karadenizliler Mah Fakulte Cad no: 147/A 41140, İZMİT, TURKEY
ENPAY Transformer Components
TURKEY

Abstract:
There are tendency worldwide to increase the transmission voltage in long distance for economical aspects, and one of the main elements of this lines is Shunt reactor .The demand of large capacity shunt reactors rises to compensate the reactive power. Actually the shunt reactors have mainly two functions, one is to reduce the overvoltage along the line and stabilize the system Voltage within acceptable limits. (Suppression of so called 'Ferranti Effect'). Second function is to limit the Transfer of reactive power in transmission the line. Shunt reactors must be studied especially for their impacts on transmission line protection in different distance (like short-medium-long line) implementations in order to find the best solution. There are different types of shunt reactors. By construction can be dry or oil immersed type, for both with gapped-iron core or core-less (so called 'air core').
This paper introduces the outline of recent improvements of radially laminated core type shunt reactor and the representative case studies, which clearly highlight the differences of the core packets. The simulation results shows of reducing of the core losses due to beveling of core packets and reducing of the additional losses and copper losses due to using of additional ring yokes (shunts). The weight of core and winding are also reduced. There is also some information about comparison of Centre pressing and outside pressing of the limbs.

Key words - Shunt reactor, gapped- core, Eddy current, fringing effect, optimization, bevel edge core packed, additional yokes, additional losses, vibration and sound level.

I.INTRODUCTION

Shunt reactors contain the same components as power transformers. The fundamental difference is that the reactor core limbs have non magnetic gaps inserted between packets of core steel (so called 'gapped-core') to avoid saturation of the core. Because of this reason reactors are complicated. The volume of the gap is in relation with reactive power of the reactor and max. magnetic flux density as well. The core limbs are produced by using of radially stacked silicon steel lamination packages, [1], [2].

Some of important problems in shunt reactors:

-High stray losses, create local overheating
-Vibrations of the Active part, create local overheating and damage the insulation
-Vibration of the Tank, create leakages
-High sound level, required to apply expensive sound screen materials

All this problems can be studied with the finite element method (FEM) simulation programs. The paper discusses particularly the advantages of bevel edge core packed and additional ring yoke (shunt) which need advanced production technology, because the manufacturing practices have a significant impact on core performance, [3], [5].

II. THE FUNDAMENTAL CHARACTERISTICS AND FEATURES

The magnetic induction is provided by the magnetic energy in the magnetic circuit of the shunt reactor. The most of energy storage is in the air gaps of limbs and the smaller parts in the other section,[9].
The fundamental characteristics of the reactors can be determined by the following equations, [4].

Current $I = S / U$

Impedance $Z = U / I$
$Z >> R,\ Z = X$

Self inductance $L = X / 2 \pi f$
Or, reactance $L = \mu_o . <A.N^2 / \Delta$

Stored magnetic energy
In the self inductance, $W_{MN} = 1/2.\ L.\ I^2$
(or the rated stored energy)

Stored magnetic energy,
(Density per m3 in the
Space) $w_m = B^2 / 2 \mu$

Stored magnetic energy
In normal air gaps $W_m = B^2 .\ V_{\delta 1} / 4 \mu_o$

Stored energy in reactor $\sum W_M = W_{M\delta 1} + W_{M\delta 2} + W_{Mv\text{-}c} + W_{MW}$

Number of turns $N = \Delta .B / \sqrt{2} (4 \pi 10^{-7}).\ I$

Magnetic flux density $B = \sqrt{2}.\ \mu_o .N.I / \Delta$

$I = A$
$S = VA$
$U = V$
$Z = \Omega$
$L = H$
A=effective surface of air gap (m²)
Δ = total gap length (m)
$X = \Omega$
$f = Hz$
$W_{MN} = VAs$
$\mu = \mu_o M_r$ A/m
$\mu_o = 4 \pi 10^{-7}$ h/m permeability of air-vacuum
μ_r = relative permeability of material, fora air $\mu_r=1$
B = magnetic flux density (peak value), Tesla
δ_1 = total length of normal air gap
$V_{\delta 1} = m^3$
$W_{M\delta 1}$=stored energy in normal air gaps
$W_{M\delta 2}$=stored energy in air gaps between upper yoke and upper package +between lower yoke and lower package
$W_{Mv\text{-}c}$=stored energy in the volume between internal surface of the winding and external surface of the packages
W_{MW} =stored energy in the winding volume
N = number of turns

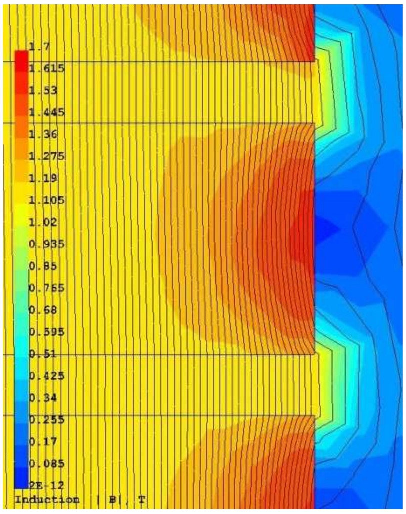
III.THE FRINGING EFFECT AND LOSSES

The radially stacked laminations prevent fringing flux from entering flat surfaces of core steel, thereby avoiding overheating on the core packet and the winding. For this reason gap size must be decided very carefully. Generally small gaps have low fringing losses. This effect increases the diameter of package by a certain percentage. The biggest portion of the energy occurs in the air gaps of the limbs and the rest in the other sections.

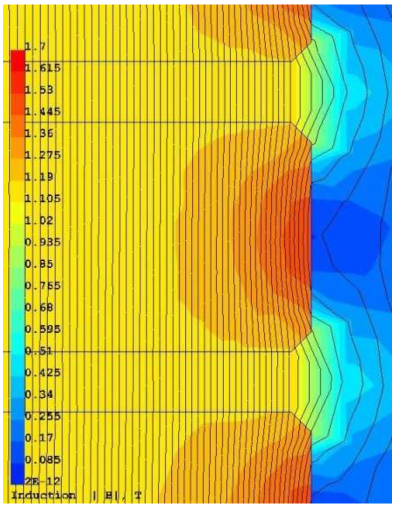
The losses of gapped core reactor are:

1. Winding losses
2. Core losses in yokes
3. Core losses in limbs.
4. Additional (structural) losses by leakage flux

Core losses composed of 67% eddy current losses and 33% hysteresis losses. By beveling core limb packets the eddy current losses are reduced. The following simulations show the different.

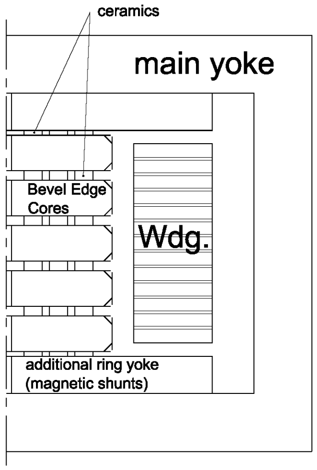


Core Package without Bevel Edge



Core Package with Bevel Edge

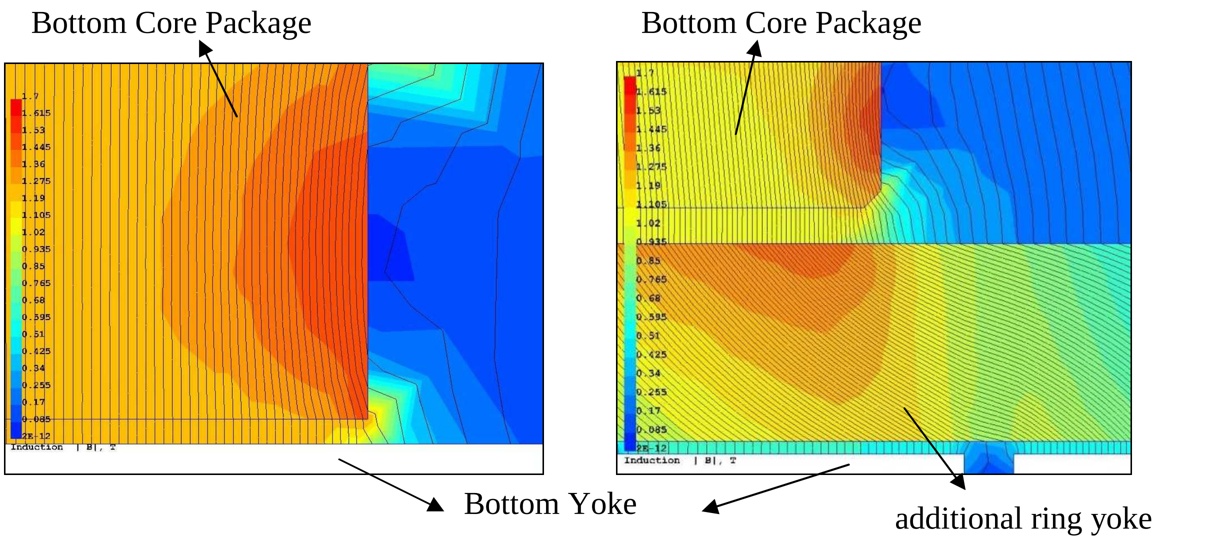
By using magnetic shunts as additional ring yoke, the additional losses can be reduced. Below pictures illustrated schematically and the production reality of new combination.



Active part of reactor in cross-sectional view

Bevel edge core limb and additional ring yokes of a single ph. reactor

In order to collect total main flux that goes out from windings are covered by additional ring yokes, adjoined with main yokes, [6], [7].



Core Package without Bevel Edge

Core Package with Bevel Edge and with Additional ring yoke

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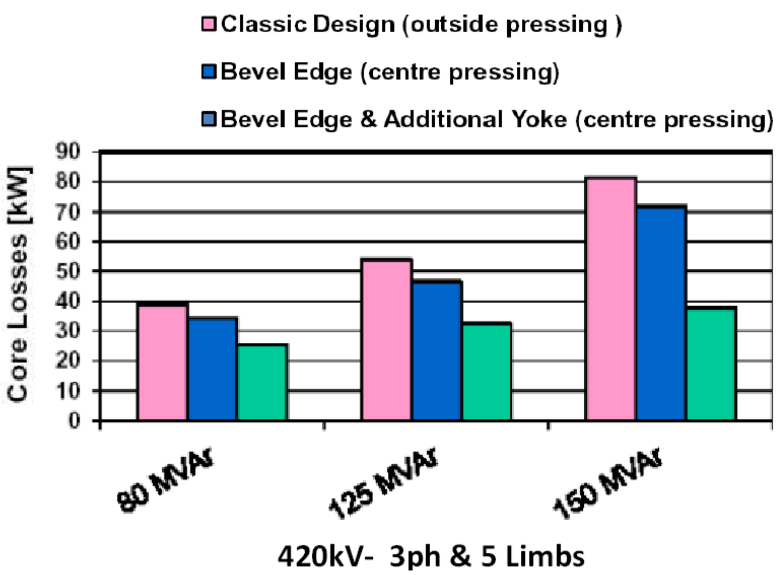
The graphic illustrate the core loss differences compared with classic and state-of-the-art designs in three different powers, in 420 kV. 3ph&5 limbs



The case study below shows the advantages of bevel edge core packets and additional ring yokes in numerical samples.

IV.CASE STUDIES

1. Magnetic study of core + yoke (125 MVAr – 420 kV)

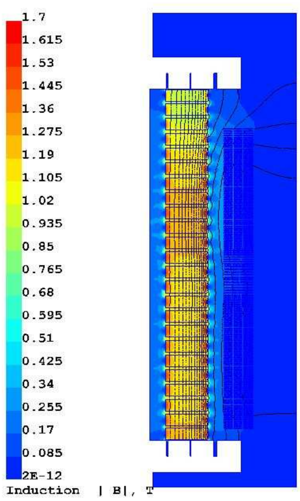
Centre pressing - 3 ph & 5 Limb

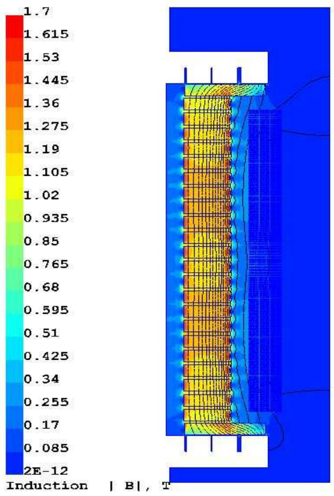
Calculation of Losses

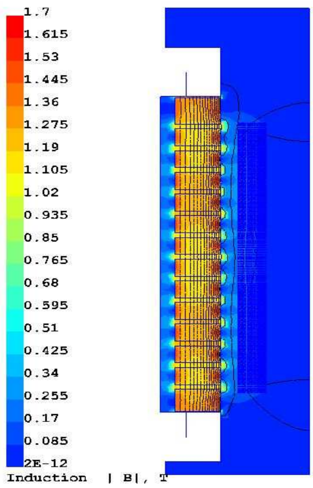
New Design				Classic Design	
New Design Core Package with Bevel Edge		Core Package with Bevel Edge and Additional Ring Yoke		(Without Bevel Edge and Without Additional Ring Yoke)	
Core Losses	Winding Losses	Core Losses	Winding Losses	Core Losses	Winding Losses
kW	kW	kW	kW	kW	kW
47,15	210,85	43,48	209,07	51,31	217,01

Calculation of Mass

New Design				Classic Design	
Core Package with Bevel Edge		Core Package with Bevel Edge and Additional Ring Yoke		(Without Bevel Edge and Without Additional Ring Yoke)	
Mass of Silicon Steel	Mass of copper	Mass of Silicon Steel	Mass of copper	Mass of Silicon Steel	Mass of copper
ton	ton	ton	ton	ton	ton
49,95	12,40	51,34	12,40	53,32	14,91







2. Mechanical shock test of shunt reactor core packet

Core Limbs must be robust enough against short circuits. In order to confirm the mechanical stability and robustness of the core packets mechanical shock test is performed. [10].

Mechanical Shock Test of shunt reactor core packet:

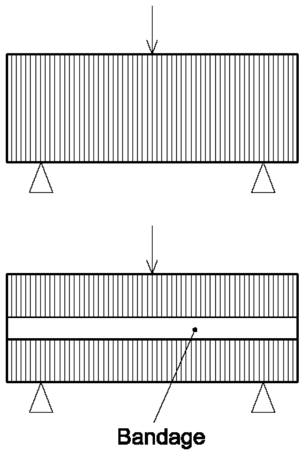
Scope of test : Pressure testing of the core package with ceramic discs which compares with reactor gapped core limb.

Test conditions: Room temperature (20+-3 C)

Test method : Determination of flexural strength Test or 3.point bending test

Sample dim. : D (ø) =660 mm. without glass bandage
D (ø) =660 mm. with glass bandage
H=210mm.

Test results : 188, 13 (kN) without glass bandage
357,33 (kN) with glass bandage



Result of the tests are specified that the core packets with glass bandage compare with non bandage have approximately double mechanical strength in bigger power and higher voltages up to 1200 kV.

V. SOUND LEVEL AND VIBRATION

Shunt reactors are high level of sound source. One part of the sound is caused by the leakage flux field. Leakage flux in structural components produces forces and these forces create vibration. Vibration occurs mainly due to magnetic attraction force of the core gap. Mechanical stress, vibration and sound level affected each other. By precision in the manufacturing and resistant materials can be given long term stability in sound level [8]. In order to reduce sound level and vibration a relevant magnetic flux density must be selected and the overall core shut be tightened. Vibrations depend on the quality of beams and clamping structure. Also the quality of the ceramic parts in gaps and antimagnetic steel parts affect the sound level. The forces and vibrations are created in the tank walls and shunts mounted on the tank. Low level of sounds are created also in cooling fans and in oil pump.
To reduce the sounds and vibrations there are some of following solutions:

-Resonant plates attached to the tank wall
-Double-walled tanks
-Thicker tank wall
-Exterior sound panels (can reduce the sound level up to 6-10 dB.) [11].

The vibration level test is carried out in accordance with IEC 60076-10-1

VI.CONCLUSIONS

Shunt reactors are an important part of Transmission lines and used to compensate the capacitive reactive power of transmission and distribution systems, they keep the operating voltages within admissible levels. We studied gapped-core type reactors and introduced some of their problems. The radially stacked laminations prevent fringing flux, thereby avoiding overheating on the core packed and winding. The loss of gapped core reactor occurs in the windings, in yokes, in limbs, by leakage flux.

Simulations show the reduction of eddy current losses by beveling core limb packets. The additional ring yokes (shunts) can reduce the additional losses. The simulations give clear idea for those reductions.

The case study presents numerical implementation. The losses and weights from cores and windings are smaller in new model design in comparing of classical design.

The last case study has a result the core packets with glass bandage have double mechanical strength compare with non bandage.

Shunt reactors are significant sound source. The sound and vibration level tests are made in accordance with IEC 60076-10-1.

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