SHUNT REACTOR CORES up to 800 kV– 300 MVAr

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Abstract – **Shunt reactors are an essential part of high voltage grids. They are necessary to compensate capacitive currents of cables or long overhead lines.The article concentrates on the so called gapped core designs. There are radially stacked core sheets glued together with a suitable resin. Discs of a special ceramic glued together with the core discs provide the exact distance required.The production details are in the centre of interest.**

Key words – S**hunt reactors, gapped core, production aspects**

I. INTRODUCTION

Shunt reactors are mainly used for the compensation of capacity current of long transmission lines and cable. They reduce the voltage drop along the line (suppression of so called “Ferranti effect”).

Reactors are also used in filter circuits in order to eliminate certain harmonics. In this application their impedance has to be constant in a wide range of voltage to keep the resonance frequency constant.

Another application of reactors is the use as short circuit limiting reactor. They are used to protect low voltage windings of grid transformers or for the separation of rapid growing networks in parts to prevent overloading of existing switchgear.

One of the two major principles is followed for designing a Shunt Reactor:
- Winding having an iron core divided by air gaps
-Winding without an iron core inside (so called “air core”).
In this design the flux is collected outside the winding to prevent any kind of overheating in construction parts.

In this presentation we shall concentrate on iron core design with air gaps (gaped core) and radial laminated limbs as it is the - state of the art - today.

II. TECHNICAL SPECIFICATION

Among many constrains of the technical spec, the main data for the computation of shunt reactor are:

- rated power
- frequency
- rated and maximum operating voltage
- number of phases and number of legs
- sound level
- core saturation/knee point
- test voltages
- loss and temperature requirements
- kind of cooling
- environmental conditions
- transport limitations /data

Depending upon the experience and the production capabilities the designer can choose between several different reactor core designs as shown in figure 1.

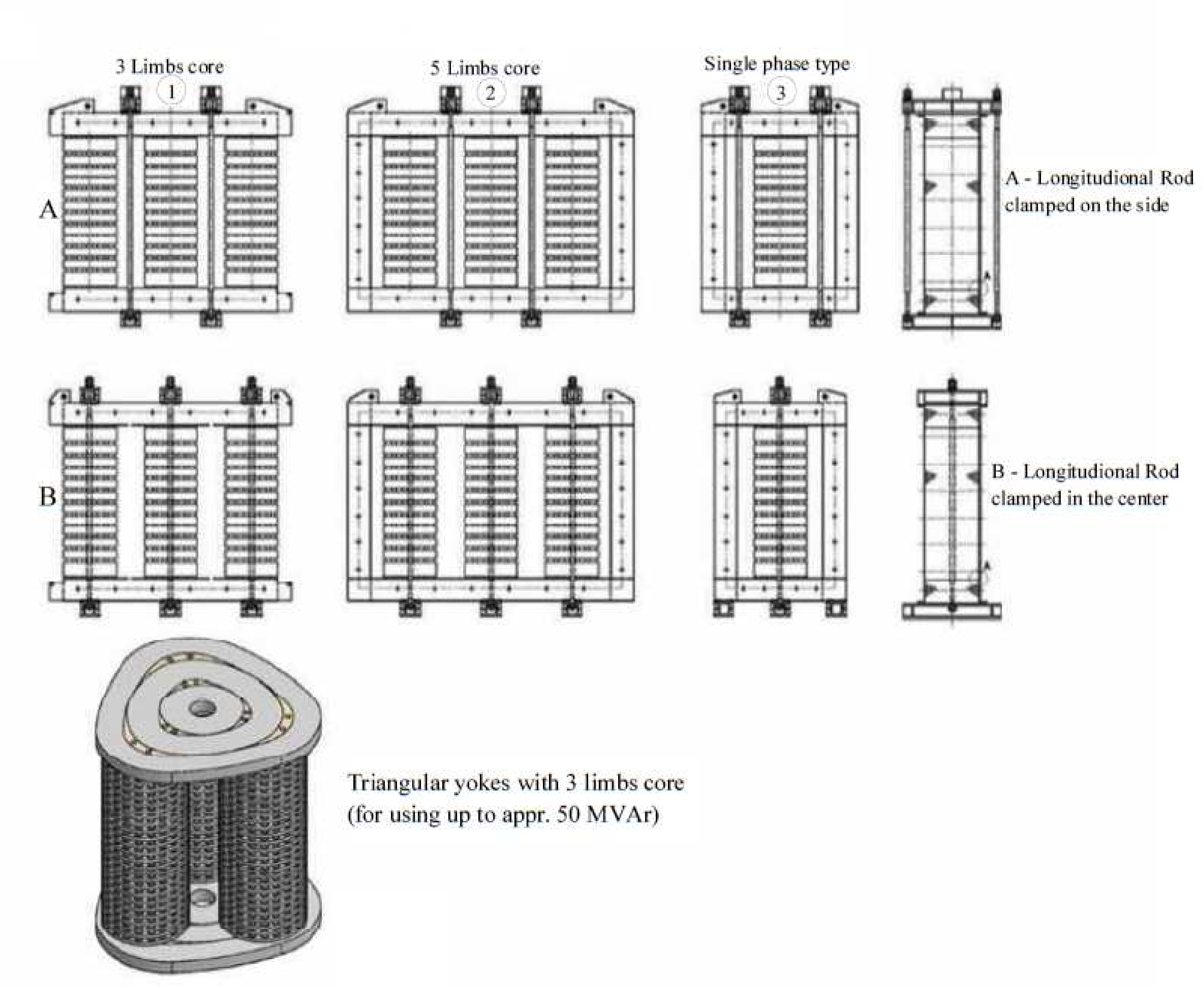

Fig. 1 Schematic drawings about reactor cores

III. THE FUNDAMENTAL CHARACTERISTICS OF THE REACTORS ARE EXPRESSED BY THE FOLLOWING EQUATIONS:

Phase winding – current

$$I_N = \frac{S_N}{\sqrt{3}U_N} \qquad (1)$$

$[S_N] = VA$
$[U_N] = V$
$[I_N] = A$

Impedance

$$Z_N = \frac{U_N}{\sqrt{3}I_N} \qquad (2)$$

$[Z_N] = \Omega$

$Z_N >> R$
$Z_N \cong X_N$

Self Inductance

$$L_N = \frac{X_N}{2\pi f} \qquad (3)$$

$[L_N] = H$
$X_N = \Omega$
$[f] = Hz$

Stored Magnetic Energy in the Self Inductance

$$W_{MN} = \tfrac{1}{2} L_N I_N^2 \qquad (4)$$

$W_{MN} = VAs$

IV. CORE CROSS SECTION

The core cross section depends upon rated power, frequency, winding (number of turns), length of air gap, noise requirements, loss requirements and so on.
The experience gives some additional figures like iron filling factor in the radial laminated discs (93 -97 %), typical rated induction (0.9 – 1.5 T), middle hole in the disc (15 – 20mm in case of external tie rods and 80 – 200mm in case of internal tie rods), core material and others.

Energy develops in 4 places;

- Air gaps on the legs
- Air gaps between legs and yokes
- Volume between the core and winding
- Volume of winding

The biggest portion of the energy occurs in the air gaps of legs and the rest in the other sections.

Fig. 2 Core Package for Longitudinal Rod clamped on the side

Figure 2 shows a radially stacked core disc for reactor with external clamping in detail. The air gaps are formed from C 221-type ceramic defined in IEC 60672. Those ceramics are magnetically neutral and have an extreme high module of elasticity.
The core packages and ceramic discs are glued and impregnated under vacuum, resulting in a robust construction. For additional safety there is a bandage of epoxy bonded glass fibers.
Typically all ceramic discs have the same diameter (60 …120mm).The thickness of ceramic discs is measured and classified to equalize the height of iron legs.

Fig. 3 Core Package for Longitudinal Rod clamped on the centrally

Due to different magnetic permeability’s of core packages and air gaps, a tensile strength occurs between the sheet packages such as the magnetic poles of electro magnets. These strengths which have an effect on the air gap, try to reduce the air gap by changing between 0 and a maximum value and with frequency value of 2 times of network frequency. The pressure onto the ceramic supports is inversely proportional by the elasticity modules of ceramics.

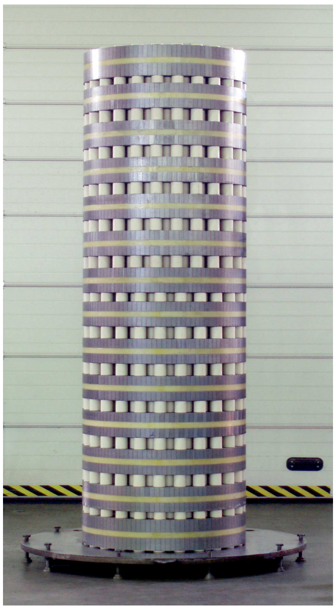

Fig. 4 Assembled Leg

As a result of elastic shape changes of ceramic supports, mechanical vibrations occur on iron core packages and yokes and this causes noise. Tie rods are assembled and upper-lower yokes are assembled in order to prevent free shifts between core sheet packages and yokes. Springs should be placed in the press construction in order to protect the pre-pressure and balance length differences of iron core and press construction during the temperature changes.

V. THE FRINGING EFFECT

The radially stacked laminations prevent fringing flux from entering flat surfaces of core steel, there by avoiding overheating.

Fig.5a shows the field lines without fringing effect and fig 5b shows a field plot of real field lines. This effect increases the diameter of package by a certain percentage.

The field plot shows also that the air gap should not be too high since the higher the gap, the higher the fringing effect and the higher must be the diameter of the winding to prevent big losses in the copper.

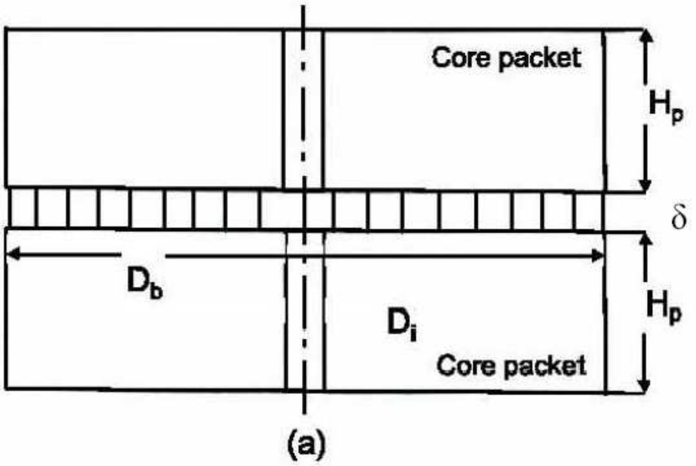

Fig. 5a

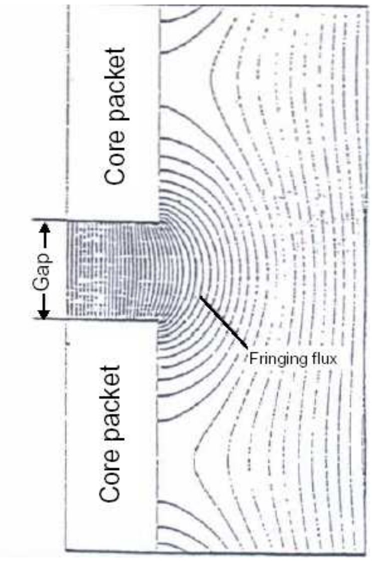

Fig. 5b

VI. INRUSH CURRENT

Alike transformers, the shunt reactors when switched on to AC power- source take large currents. Although, the amplitude of reactor's inrush current is not as large as transformers they need to be calculated for determination of the electro-magnetic forces which give rise to compression in the winding, generating vibration and noise.
It will be assumed that in the switching phenomena at the instant of time t = 0, a step voltage is applied to the reactor winding. Since the step voltage involves all high frequency voltage components and since at high frequencies, the effect of iron core diminishes, the phase windings of the shunt reactor can be taken as air-core coil.

VII. IRON LOSSES OF LEGS

Let the losses of packages be denoted by P_b and $\nu_{1.5}$ (w/ kg) the specific loss of laminated steel at 1.5 T. $\nu_{1.5}$ differs for different material, M5 – 0.3 mm, HIB 0.23 etc…The iron losses is calculated by

(G_b = the weight of magnetic material)

$$P_b = (1.2)\, \nu_{1.5}\ G_b \left(\frac{B}{1.5}\right)^x \quad \mathrm{W}$$

Where 1.2 is loss increase factor for packages

$x = 2.2 – 2.6$ for $B \le 1.5$ T
$x = 2.7 – 3$ for $B > 1.5$ T

B: induction in the packages in T

VIII. CORE SATURATION, KNEE POINT

The curve below shows us the saturation level of the reactor core. The impedance is linear above a certain percentage of rated power (e.g. 130 %).
The core steel starts to saturate. The knee point shows us the beginning of saturation (impedance is no more linear).
If core saturation happens the iron core acts like an air core. Induction above the knee point can cause hot spots as a consequence.

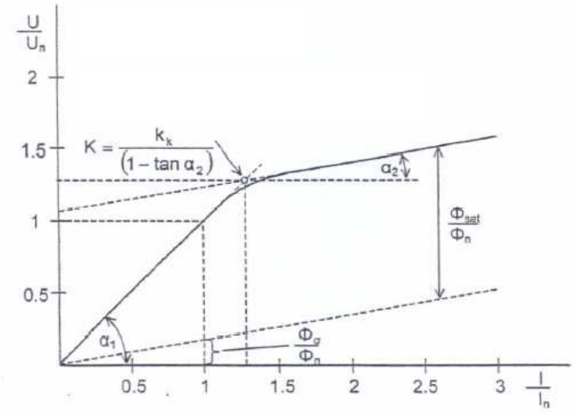

Fig. 6 Core Saturation, Knee Point

IX. CORE DESIGNS

Fig. 7 - 5 Limb Reactor Core clamped on the side

Fig. 8 - 3 Limb Reactor Core clamped on the side

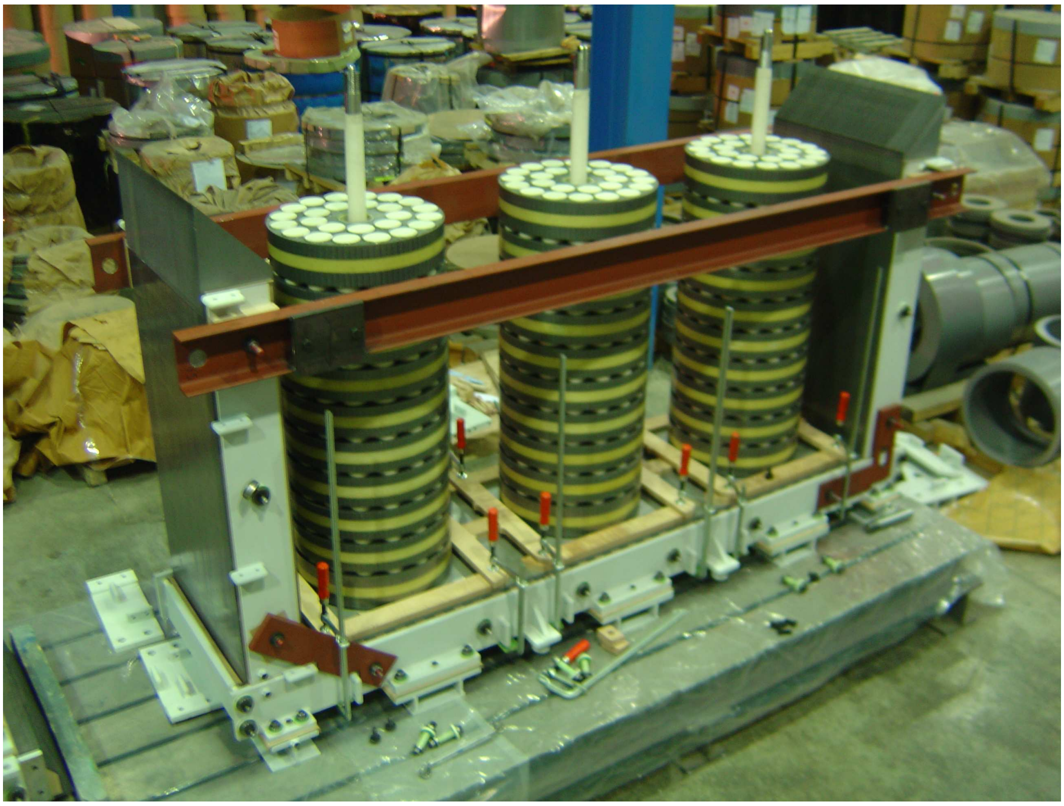

Fig. 9 - 5 Limb Reactor Core clamped in the centre

Three phase shunt reactors can be produced with three or five limbs. Production of five-limb reactors is expensive; however it has following advantages;

- Each phase can be applied separately and thereby can be tested independently.
- Zero impedance is equal to the straight constituent impedance. Hence fault currents which are flowing from star point are smaller than fault currents on core with 3 limbs.

- The height of core with 5 limbs is less than the height of core 3 limbs.

There are also wound yoke applications on reactors up to power level off app. 50 MVAr. In case of wound yoke there is no need for clamping plates and consequently no losses in that steel structure. By the triangle arrangement of legs the mechanical design of tank can be somewhat smaller than a design with legs in line.
The wound yoke reactor is electrical complete symmetrical.

Fig. 10 Wound Yokes

X. CONCLUSION

Modern reactors with gaped core design are state of the art if the production facilities are able to fulfill very strong requirements as:

- Special core cutting machines with very small tolerances
- Very reliable core stacking process for radial sheets (high filling factor)
- Long time experience in gluing of radial stacked sheets
- Good relation to ceramic disk manufacturer to minimize tolerances
- High reliability in manufacturing of cores to prevent deviations in noise, core loss and vibration at the ready made reactor

ENPAY as supplier of transformer components has more than 20 years experience in manufacturing all different gaped core designs and is ready to help any transformer manufacturer to produce reliable reactors.

XI. INTERNATIONAL STANDARDS FOR SHUNT REACTORS

- IEEE C57.117 Guide for Reporting Failure Data for Power Transformers and Shunt Reactors on Electric Utility Power Systems
- IEEE C57.21 Requirements, Terminology and Test Code for Shunt Reactors Over 500 KVA
- IEEE C37.015 Application Guide for Shunt Reactor Switching
- IEEE C57.136 Guide for Sound Level Abatement and Determination for Liquid-immersed Power Transformers and Shunt Reactors Rated Over 500 KVA
- IEEE C37.109 Protection of Shunt Reactors
- IEEE C57.113 Guide for Partial Discharge Measurement in Liquid –filled Power Transformer and Shunt Reactors
- IEEE C57.125 Guide for Failure Investigation, Documentation, and Analysis for Power Transformers and Shunt Reactors
- IEEE 1080 Guide for the protection of Shunt Reactors
- IEC 1989:1991 Seperating Tranformers , Autotransformers and reactors
- IEC 289 Reactor
- VDE 0565 Teil 2- 2 Drosseln zur Unterdruckung electromagnetischer stönungen
- IEC 60076-1 Power Transformers Part 1: General
- IEC 60076-2 Power Transformers Part 2: Temperature Rise
- IEC 60076-3 Power Transformers Part 3: Insulation Levels, Dielectric Tests and External Clearances in Air
- IEC 60076-4 Power Transformers Part 4: Guide to the Lightning Impulse and Switching Impulse Testing – Power Transformers and Reactors
- IEC 60076-5 Power Transformers Part 5: Ability to Withstand Short Circuit
- IEC 60076-10 Power Transformer Part 10: Determination of Sound Levels
- IEC60672-3 Ceramic and glass-insulating materials Specifications for individual materials

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