Design aspects of the shell-type shunt reactors

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***Abstract* - The paper deals with a shell-type reactor and the determination of the optimal design parameters. The optimal design selection depends on the economically evaluated value of the unit dictated by the losses, energy price and material costs. Since the geometry of the reactor is conditioned by the electrical losses and desired inductance, which, in turn, depend on the magnetic field distribution, it is necessary to use a computer-aided design (CAD) approach. The method presented in the paper relies on the numerical procedure, where the magnetic field is calculated using the Finite Element Method (FEM) based software FEMM 4.2, and the best solution is sought iteratively**

I. INTRODUCTION

When designing large power transformers, ensuring sufficient short-circuit reactances between pairs of windings is an essential task. As a rule, this is achieved by selecting an appropriate geometry and constellation of windings within the transformer window. However, in some cases, such an approach is technically or economically unacceptable. In these cases, connecting a reactor in series with the winding is necessary. For low voltage level windings (e.g. 20 kV), a special shell-type reactor placed within the transformer's tank is used for the purpose. The design aspect should focus on adequately selecting the main reactor's dimensions (Fig. 1), i.e., the inner coil diameter, coil thickness, coil height, number of turns etc. All the stated parameters are crucial for the device economy and should be optimized to reach the lowest material and energy consumption costs.

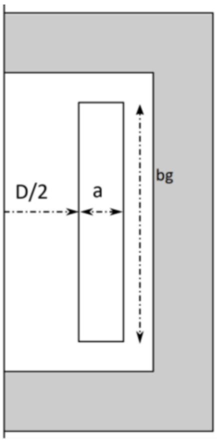

Fig.1. Axisymmetric model of the shell-type reactor; the main dimensions labelled D, a and b_g are inner coil diameter, coil thickness and coil height

II. REACTOR MODEL

Nowadays, loss determination plays a crucial role in designing energy devices. Providing an accurate loss model leads to a better design solution. While the losses in electromagnetic devices are closely related to the magnetic field distribution, it is necessary to employ a numerical procedure and techniques to complete the task. The most common approach to the field solution problem in electromagnetic devices is through the Finite Element Method (FEM). The shell-type reactor loss model presented here takes into account two loss sources. The first one is the current passing through the winding, and its impact could be evaluated directly without knowing the magnetic field distribution within the winding. The second one is the stray magnetic field responsible for the eddy currents within the winding's conductors. Once the spatial distribution of the field is known, the winding is discretized virtually in the post-processor mode, where the analytically derived expressions took place to evaluate the losses in each winding's portion. In this way the eddy currents are not computed directly with the FEM but are involved implicitly through the analytical formulas.The semi-analytical approach used here is essential to save considerable computational time compared with the full FEM treatment.

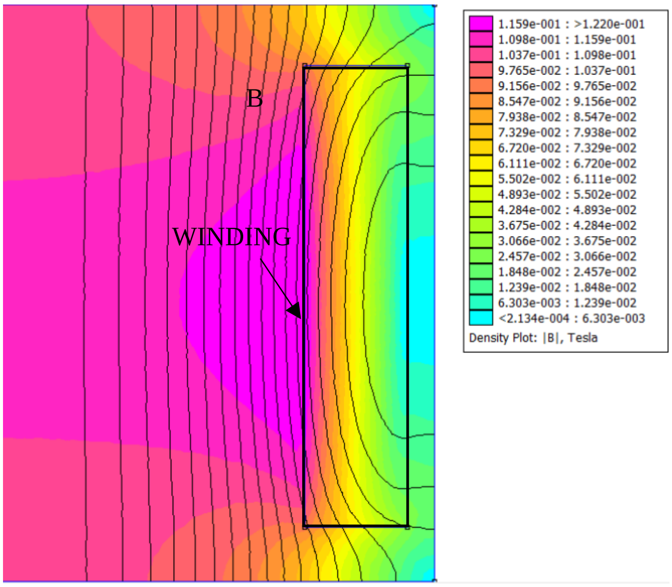

Fig.2. Magnetic field distribution within the shell-type reactor FEM model

As seen from the magnetic field distribution within the coil (Fig.2), a strong field passes through the reactor winding, causing an additional losses which can not be neglected. Moreover, the calculations show that these losses represent nearly 20% of the total load losses.

III. OPTIMIZATION ON LOSSES

Providing a customer with the best solution requires a precise estimation of losses. While the coil geometry and losses are tightly related, the optimum design is achieved by considering material cost along with the cost of losses. This approach is often called “Total Ownership Cost”, or shortly TOC. It turns out that the optimal geometry can be achieved by varying three design parameters of the winding: turn voltage, coil height and current density. The comparison between a ”Lowest Purchase Cost” and a TOC approach for a three-phase 1000 kVA shell-type reactor is depicted in Fig.3. Both costs are given concerning turn voltage.

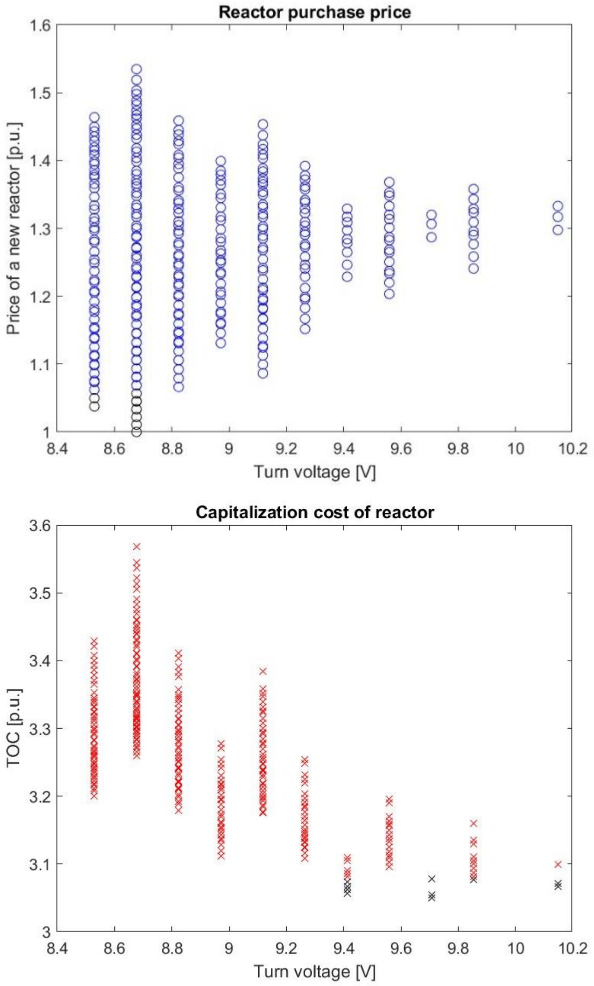

Fig.3. The cost of a new reactor (blue circles) and the capitalised cost of a reactor (red dots)

However, for the case study, the results indicate that paying 30% more for the low-loss reactor is more economical, giving a 10% overall lower cost. In brief, due to the high energy cost, the losses play a crucial role in the reactor design and should be adequately considered. As seen from Fig. 3, the higher values of the turn voltage lead to a more economical design, i.e., a design with lower losses. This latter conclusion can be taken as a general rule and poses a practical hint from the design aspect. In addition to Fig. 3, table 1 gives basic parameters for the lowest purchase price design and the lowest TOC design. In the presented calculations, the evaluation of load and no load losses considered in calculations were 4000 €/kW and 15000 €/kW, respectively.

Table 1: Basic parameters for both, the lowest purchase proce and the lowest TOC design.

	Lowest purchase price	Lowest TOC
Coil parameter	Value	Value
u_{ov} - turn voltage	8,68 V	9,71 V
N - no. Of turns	43	38
b_g – height	300 mm	300 mm
D - inner diameter	481 mm	541 mm
g – current density	2,72 A/mm^2	2,00 A/mm^2
a - thickness	90 mm	108 mm
M_{fe} – mass of iron core	1684 kg	2041 kg
M_{cu} – mass of cooper	640 kg	876 kg
P_{fe} – core losses	158 W	185 W
P_k – total winding losses	14122 W	10828 W
Additional losses in % of I^2R	19,8 %	25,1%
L_0 – inductance	1,361 mH	1,375 mH
$Purchase\ price$	1 p.u.	1,306 p.u.
TOC	3,3 p.u.	3,05 p.u.

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