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A heuristic solution to the transformer manufacturing cost optimization problem

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Abstract

The aim of the transformer design is to completely obtain the dimensions of all the parts of the transformer based on the given specification, using available materials economically in order to achieve lower cost, lower weight, reduced size and better operating performance. In this paper, a transformer design optimization method is proposed aiming at designing the transformer so as to meet the specification with the minimum cost. Results from the application of the proposed methodology demonstrate the effectiveness and practicality of this approach.
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Keywords: Oil-immersed power transformer; Wound core type transformer; Transformer design; Transformer manufacturing; Specifications; No-load losses; Load losses; Impedance; Tolerances; Optimum transformer; Transformer manufacturing cost

1. Introduction

In today's competitive market environment there is an urgent need for the transformer manufacturing industry to improve transformer efficiency and to reduce costs, since high quality, low cost products and processes have become the key to survival in a global economy. Transformer efficiency is accomplished by reducing load and no load (iron) losses [1]. On the other hand, for maximum economy, the costs for the production of transformer, its installation, maintenance and losses must represent the minimum long-term cost to the transformer user [2]. Minimum no-load losses in particular are particularly important considering the fact that since a transformer is continuously energized, i.e., 24 h per day, every day, considerable energy is consumed in the core (no-load losses), while load losses occur only when a transformer is on load [3].

The aim of the transformer design is to completely obtain the dimensions of all the parts of the transformer in order to furnish these data to the manufacturer [4]. The transformer design should be carried out based on the given specification, using available materials economically in order to achieve lower cost, lower weight, reduced size and better operating performance [1].

The transformer design is worked out by using various methods based on accumulated experience realized in different formulae, equations, tables and charts. The transformer design methods vary between the several transformer manufacturers.

While designing a transformer, much emphasis should be placed on lowering its cost by saving the materials and reducing to a minimum labor consuming operations in its manufacture. The design should be satisfactory with respect to dielectric strength, mechanical endurance, dynamic and thermal withstand of windings in the event of short-circuit [1].

In order to meet the above requirements, the transformer designer should be well familiar with the prices of the basic materials used in the transformer. He should also be well familiar with the amount of labor consumed in the production of transformer parts and assemblies.

In this paper, a transformer design optimization method is proposed aiming at designing the transformer so as to meet the specification with the minimum manufacturing cost.

The paper is organized as follows: Section 2 presents the transformer specifications. The proposed transformer design optimization method is presented in Section 3 and an application of the proposed methodology to an actual transformer design is described in Section 4. Section 5 concludes the paper.

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Table 1
Transformer specifications

Specification	Description
IEC 60076-1	Power transformers—general
IEC 60076-2	Power transformers—temperature rise
IEC 60076-3	Power transformers—insulation levels and dielectric tests
IEC 60076-5	Power transformers—ability to withstand short-circuit
IEC 60137	Bushings for alternating voltages above 1000 V
IEC 60354	Loading guide for oil-immersed power transformers

2. Transformer specifications

The transformer manufacturing is based on the international technical specifications and customer needs. The specifications related to transformer manufacturing are shown in Table 1. Table 2 presents the tolerances according to IEC 60076-1 to be applied to transformer losses and impedance (short-circuit voltage) when they are the subjects of manufacturer's guarantees [5]. In this paper, the symbols NLL, LL, and U_k are used for no-load losses, load losses and impedance, respectively.

3. Transformer design optimization method

This section describes the method for the determination of the optimum transformer, namely the transformer that satisfies the technical specifications and the customer needs with the minimum manufacturing cost.

The methodology concerns the optimization of transformers with the following technical characteristics:

- three-phase, oil-immersed power transformers,
- magnetic circuit of shell type and wound cores,
- foil, round wire, or rectangular wire technology for both low voltage (LV) and high voltage (HV) conductors.

Fig. 1 presents the small and large core of a wound core type transformer.

The process of finding the optimum transformer is implemented with the help of a suitable computer program, which uses 134 input parameters in order to make the transformer program as parametric as possible. These 134 input parameters are split into the following eight types:

1. *Description variables* (e.g., rated power, rated low voltage and high voltage, frequency, material of LV and HV coil, LV and HV connection, etc.).

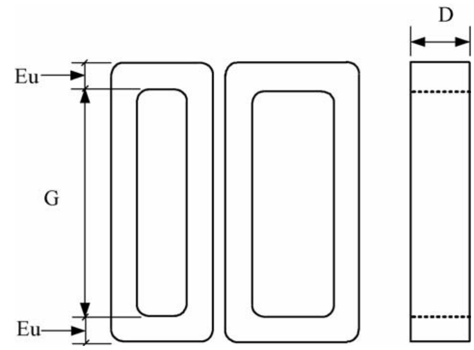

Fig. 1. Core constructional parameters.

2. *Variables that rarely change* (e.g., core space factor, turns direction space factor, specific weight of materials used, etc.).
3. *Variables with default values* (e.g., LV and HV taps, tolerance for NLL, LL, and U_k, etc.).
4. *Cost variables* (e.g., cost per weight unit for LV and HV conductor, magnetic steel, oil, insulating paper, duct strips, corrugated panels, etc.).
5. *Optional variables* (e.g., variables that can either be calculated by the program or defined by the user).
6. *Various parameters* (e.g., type of LV and HV conductor, number of LV and HV ducts, LV and HV maximum gradient, maximum ambient temperature, maximum winding temperature, etc.).
7. *Variables for conductor cross-section calculations* (LV and HV conductor cross-sections can be defined by the user or can be calculated using current density, or thermal short-circuit test).
8. *Solution loop variables* (e.g., LV turns, width of core leg, height of core window, magnetic induction, LV and HV cross-section area). It should be noted that the magnetic material properties (e.g. type, grade, thickness, specific losses, etc.) are given as input data when defining the values of magnetic induction within the solution loop variables [6].

The computer program allows many variations in design variables. These variations permit the investigation of enough candidate solutions. For each one of the candidate solutions, it is checked if all the specifications (limits) are satisfied, and if they are satisfied, the manufacturing cost is estimated and the solution is characterized as acceptable. On the other hand, the candidate solutions that violate the specification are characterized as non-acceptable solutions. Finally, among the acceptable

Table 2
Tolerances for losses and impedance

Quantity	Tolerance
(a) Losses	
(a_1) Total losses (NLL + LL)	+10% of the guaranteed total losses (NLL + LL)
(a_2) NLL (LL)	+15% of the guaranteed NLL (LL), provided that the tolerance for total losses is not exceeded
(b) U_k on principal tapping	(a) ±7.5% of the guaranteed U_k, when $U_k \geq 10\%$
	(b) ±10% of the guaranteed U_k, when $U_k < 10\%$

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