



## 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 heuristic optimization method is proposed aiming at designing the transformer so as to meet the specification with the minimum manufacturing cost. Results from the application of the proposed methodology demonstrate the effectiveness and practicality of this approach.

### 1. Introduction

The aim of the transformer design is to completely obtain the dimensions of all the parts of the transformer to furnish these data to the manufacturer. 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 manufacturing cost by saving the materials and reducing to a minimum labor consuming operations in its manufacture. The design should be satisfactory with respect to electric strength, mechanical endurance, dynamic and thermal resistances of windings in the event of short-circuit. In this paper, a heuristic optimization method is proposed aiming at designing the transformer so as to meet the specification with the minimum manufacturing cost.

### 2. Transformer specifications

The transformer manufacturing is based on the international standards and also on customer needs (technical specifications). Tolerances should be applied to certain rated transformer quantities when they are the subjects of manufacturer's guarantees [2].

### 3. Transformer manufacturing cost optimization method

The power transformers considered in this paper are three-phase, wound core and their magnetic circuit is of shell type. The transformer manufacturing cost is equal to the sum of the total materials cost plus the labor cost. The heuristic optimization method aims at finding the so-called technical and economical optimum transformer, i.e. the transformer with the minimum manufacturing cost. The proposed optimization method 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. The computer program allows many variations in certain design variables, which are called solution loop 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, from the acceptable solutions, the transformer with the minimum manufacturing cost is selected, which is the technical and economical optimum transformer.

#### 4. Results and discussion

The proposed transformer manufacturing cost optimization method is already applied in a transformer manufacturing industry. The efficiency of the proposed algorithm is presented through an actual design example of a transformer with rated power 160 kVA, rated voltages 20/4 kV, vector group Dyn11, frequency 50 Hz. The constraints related to transformer losses and short-circuit impedance ( $U_k$ ) are the following: maximum copper (Cu) losses 3000 W, maximum iron (Fe) losses 380 W, minimum  $U_k$  3.6% and maximum  $U_k$  4.4%.

The transformer designer gives appropriate and enough alternative values to the solution loop variables and the computer program considers 8000 candidate solutions. From these 8000 candidate solutions, 2025 are acceptable solutions, while the rest 5975 are rejected (non-acceptable) solutions, since they violate the specification, for example they violate at least one of the constraints for Cu losses, Fe losses, or for  $U_k$ .

Table I presents the first 5 (cheapest) and the last 5 (more expensive) solutions from the total 2025 accepted solutions. It is noticed that the cheapest solution (technical and economical optimum transformer) costs € 1121.99 and the most expensive solution costs € 1418.32. Namely, the optimum technical and economical solution is 26.4% cheaper than the most expensive solution.

The technical and economical optimum transformer is the transformer number 1 of Table I, which has the following technical characteristics (not listed in Table I): copper losses 2838.8 W, iron losses 364.1 W, short-circuit impedance 4.03%, so the technical and economical optimum solution satisfies the constraints for losses and short-circuit impedance. As it can be seen from Table I, the manufacturing cost of the optimum transformer is €1121.99, the height of core window (G) is 225 mm, the width of core leg (D) is 190 mm, the low voltage (LV) coil has 32 turns, the rated magnetic induction is 17500 Gauss, the LV conductor is sheet with width 207 mm and thickness 0.3 mm and the high voltage (HV) conductor is wire with diameter 1 mm.

Sensitivity analysis can be carried out in order to check if the optimum solution can be further improved. For example, if we consider only the variation of the cross-section area (CSA) of the low voltage coil and if we execute again the transformer optimization program, we obtain the results of Table II, from which it is concluded that the optimum solution is the same with the one already found in Table I. Moreover, from Table II, it is concluded that, in general, the copper losses are decreased with the increase of the cross-section area of the low voltage coil.

Table I: Acceptable solutions

<i>Number</i>	<i>Cost (€)</i>	<i>G (mm)</i>	<i>D (mm)</i>	<i>LV turns</i>	<i>B (Gauss)</i>	<i>LV conductor</i>	<i>HV conductor</i>
1	1121.99	225	190	32	17500	207 x 0.3	1
2	1123.44	230	190	33	17500	212 x 0.3	1
3	1123.77	225	220	30	17500	207 x 0.3	1
4	1123.95	230	190	31	17500	212 x 0.3	1
5	1124.87	225	237	30	17500	207 x 0.3	1
2021	1401.83	180	152	26	13000	162 x 0.4	1
2022	1406.16	195	152	27	13000	177 x 0.4	1
2023	1408.16	190	152	26	13000	172 x 0.4	1
2024	1409.87	185	152	26	13000	167 x 0.4	1
2025	1418.32	195	152	26	13000	177 x 0.4	1

Table II: Variation of cross-section area (CSA) of low voltage (LV) coil

<i>Input variables</i>							<i>Output variables</i>			
G (mm)	D (mm)	LV turns	B (Gauss)	LV conductor	LV CSA (mm <sup>2</sup> )	HV conductor	Cu losses (W)	Fe losses (W)	$U_k$ (%)	Cost (€)
225	190	32	17500	207 x 0.30	62.10	1	2838.8	364.1	4.03	1121.99
225	190	32	17500	207 x 0.31	64.17	1	2804.4	364.1	4.04	1124.39
225	190	32	17500	207 x 0.32	66.24	1	2772.3	364.1	4.06	1128.05
225	190	32	17500	207 x 0.33	68.31	1	2742.4	364.1	4.07	1130.48
225	190	32	17500	207 x 0.34	70.38	1	2714.5	368.4	4.08	1140.64
225	190	32	17500	207 x 0.35	72.45	1	2688.4	368.4	4.10	1144.33

#### References

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