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A Decision Tree Method for the Selection of Winding Material in Power Transformers

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Abstract. In this paper, a decision tree method is proposed for the selection of the winding material in power transformers. The proposed method is very fast and effective, since it divides by two the effort of the transformer design engineer. The accuracy of the proposed method is 94%, which makes it very efficient for industrial use.

1. Introduction

The variation in the cost of the materials used in the transformer manufacturing has direct impact in the design of the technical and economical optimum transformer, i.e. the transformer that meets the specification with the minimum cost. The material of the transformer windings can be copper (CU) or aluminum (AL). Since CU and AL are stock exchange commodities, their prices can significantly change from time to time. In addition, CU and AL conductors have different technical characteristics. Consequently, sometimes it is more economical to use CU windings instead of AL windings and vice versa. However, this has to be checked in every transformer design, which means that for each design, there is a need to optimize twice the transformer (once with CU and once with AL windings) and afterwards to select the most economical design. In this paper, a decision tree (DT) method is proposed for the selection of the winding material. The proposed method is very fast and effective, since it divides by two the effort of the transformer design engineer. The accuracy of the proposed method is 94%, which makes it very efficient for industrial use.

2. Technical and economical optimum transformer

The power transformers considered in this paper are three-phase, wound core and their magnetic circuit is of shell type. In the industrial environment considered, the technical and economical optimum transformer is calculated with the help of a suitable computer program, which uses 134 input parameters in order to make the transformer program as parametric as possible. Some of these 134 input parameters have very strong impact on the determination of the optimum transformer, e.g. the unit cost (in €/kg) of the magnetic material, the unit cost of the winding material and the type of the winding material (CU or AL).

3. Decision trees

The DT methodology [1] is a non-parametric learning technique able to produce classifiers about a given problem in order to reduce information for new, unobserved cases. Except of the *root node* (or *top node*), every node of a DT is the successor of its parent node. Each of the *non-terminal nodes* (or *test nodes*) has two successor nodes. Nodes that have no successor nodes are called *terminal nodes*. In order to detect if a node is terminal, i.e., "sufficiently" class pure, the classification entropy of the node with a minimum preset value H_{min} is compared. If it is lower than H_{min}, then the node is sufficiently class-pure and it is not further split. Such nodes are labeled LEAVES. Otherwise, a suitable test is sought to divide the node, by applying the optimal splitting rule [1]. In the case that no test can be found with a statistically significant information gain, the node is declared a DEADEND and it is not split.

4. Creation of the learning and test sets

For the creation of the learning and test sets, 6 power ratings (250, 400, 630, 800, 1000 and 1600 kVA) are considered. For each transformer, 9 categories of losses are taken into account, namely AA', AB', AC', BA', BB', BC', CA', CB', CC', according to [2]. Seven different unit costs (in €/kg) are considered for the CU and the AL winding. Based on the above, $6 \cdot 9 \cdot 7 = 378$ transformer design optimizations with CU winding (CU designs) and 378 transformer design optimizations with AL winding (AL designs) are realized. For each design, either the CU design or the AL design is the final optimum design (with the least cost). In total, $6 \cdot 9 \cdot 7^2 = 2646$ final optimum designs are collected and stored into databases. The databases are composed of sets of final optimum designs (FOD) and each FOD is composed of a collection of input/output pairs. The input pairs or *attributes* are the parameters affecting the selection of winding material. Attributes have been selected based on extensive research and transformer designers' experience. The list of 13 attributes, initially selected, is shown in Table I. The output pairs comprise the type of winding (CU or AL) that corresponds to each FOD. The learning set is composed of 1350 sets of FODs and the test set has 1296 sets of FODs.

Table I: Attributes

Symbol	**Attribute Name**	**Symbol**	**Attribute Name**
I_1	CU unit cost (€/kg)	I_7	Guaranteed FE losses (W)
I_2	AL unit cost (€/kg)	I_8	Guaranteed winding losses (W)
I_3	I_1 / I_2	I_9	I_7 / I_8
I_4	FE unit cost (€/kg)	I_{10}	Rated power (kVA)
I_5	I_4 / I_1	I_{11}	Guaranteed short-circuit voltage (%)
I_6	I_4 / I_2	I_{12}	I_7 / I_{10}
		I_{13}	I_8 / I_{10}

5. Results and discussion

Fig. 1 shows the DT for the selection of the winding material. The success rate of the DT, tested with the independent test set, is 94%. Each terminal node produces one decision rule, on the basis of its CU index, i.e. the ratio of CU designs over the FODs of that node. For example, from terminal node 30 the following rule is derived: *if* $I_3 > 0.9320$ and $I_7 > 860$ and $I_5 \le 0.3722$, then choose AL, since the CU index of node 30 is 0.0.

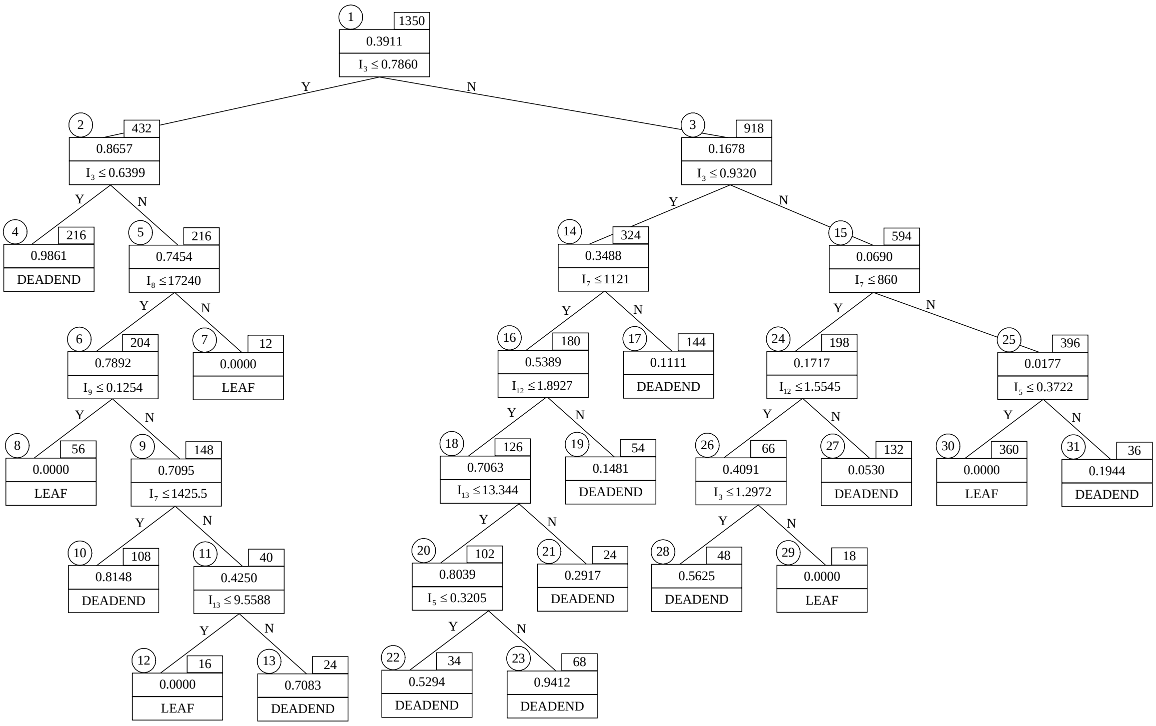

Fig 1: Decision tree for the selection of winding material.

References

[1] L. Wehenkel, Automatic Learning Techniques in Power Systems. Kluwer Academic, Boston, 1998.

[2] CENELEC harmonization document 428.1 S1, 1992.