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Decision Support System for Evaluating Transformer Investments in the Industrial Sector

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Abstract. This paper presents a decision support system (DSS) for evaluating transformer investments in the industrial sector. The DSS evaluates transformer bids based on the total owning cost (TOC). Among all transformer offers, the most cost-effective and energy-efficient transformer is the one with the lowest TOC. The DSS compares the selected offer with the other competing offers. Moreover, the proposed DSS deals with the uncertainty of the values in the TOC formula by performing a sensitivity analysis.

1. Introduction

Transformer losses are categorized as no-load losses (NLL) and load losses (LL). No-load losses include losses due to no-load current, hysteresis losses and eddy current losses in core laminations, stray eddy current losses in core clamps and bolts and losses in the dielectric circuit. Load losses comprise losses due to load currents, losses due to current supplying the losses, and eddy current losses in conductors due to leakage fields.

Transformer efficiency is improved by reducing transformer losses. Costs for the transformer user comprise costs for the purchase of the transformer, installation, maintenance and cost of losses. An understanding of transformer economics is necessary to weigh the transformer cost against the benefits of transformer efficiency.

This paper presents a decision support system (DSS) for evaluating transformer investments in the industrial sector. The DSS evaluates transformer bids based on the total owning cost (TOC), where the TOC is defined as the first cost plus the calculated present value of future losses. Among all transformer offers, the most cost-effective and energy-efficient transformer is the one with the lowest TOC. The DSS compares the selected offer with the other competing offers. Moreover, the proposed DSS deals with the uncertainty of the values in the TOC formula by performing a sensitivity analysis.

2. Decision support system for transformer evaluation

In the proposed DSS, the purchasing decision is based on the minimization of the calculated TOC:

$$TOC = BP + A \cdot NLL + B \cdot LL \tag{1}$$

where BP is the transformer bidding (purchasing) price (€), NLL are the transformer no-load losses (W), LL are the transformer load losses (W), A is the no-load loss factor (€/W) and B is the load loss factor (€/W). The factors A and B are calculated as follows:

$$A = PV_m \cdot EP \cdot HPY \cdot 10^{-3} \tag{2}$$

$$B = A \cdot L^2 \tag{3}$$

where PV_m is the present value multiplier, EP is the electricity price (€/kWh), HPY are the hours of transformer operation per year (typically $HPY = 8{,}760$) and L is the per unit load. The PV_m is defined as $PV_m = \frac{(1+d)^n - 1}{d \cdot (1+d)^{n-1}}$, where d is the discount rate and n is the transformer project life (years). The per unit load L is defined as $L = S/S_r$, where S is the transformer actual load (kVA) and S_r is the transformer rated power.

3. Results and discussion

Table I shows nine transformer offers for three-phase, oil-immersed, power transformers, with loss categories as defined in [1].

Table II makes the evaluation based on the TOC, with the following data: EP=0.05 €/kWh, n=30 years, d=7%, L=0.5, $\cos\phi = 0.9$. It is concluded from Table II that the TOC ranking is different than the BP ranking.

Table III shows the savings due to the selection of S9 supplier (most expensive BP but lowest TOC) instead of S4 supplier (cheapest BP but highest TOC).

Table IV performs a sensitivity analysis of the electricity price when analyzing the savings due to the selection of S9 instead of S4 supplier.

Table I: Transformer offers

Supplier	Rated power (kVA)	Bidding price (€)	No-load losses (W)	Load losses (W)	Loss category
S1	1,000	8,835	1,700	10,500	AA'
S2	1,000	9,410	1,400	10,500	AB'
S3	1,000	9,985	1,100	10,500	AC'
S4	1,000	8,395	1,700	13,000	BA'
S5	1,000	8,535	1,400	13,000	BB'
S6	1,000	8,640	1,100	13,000	BC'
S7	1,000	9,400	1,700	9,500	CA'
S8	1,000	9,535	1,400	9,500	CB'
S9	1,000	10,295	1,100	9,500	CC'

Table II: Evaluation based on the total owning cost

Supplier	Efficiency (n)	Wattage losses (W)	Energy losses (kWh/yr)	NLL cost (€)	LL cost (€)	Cost of losses (€/yr)	Total cost of losses (€)	TOC (€)	BP ranking	TOC ranking
S1	99.05%	4,325	37,887	9,887	15,266	1,894	25,153	33,988	4	7
S2	99.11%	4,025	35,259	8,142	15,266	1,763	23,408	32,818	6	4
S3	99.18%	3,725	32,631	6,397	15,266	1,632	21,663	31,648	8	3
S4	98.91%	4,950	43,362	9,887	18,901	2,168	28,787	37,182	1	9
S5	98.98%	4,650	40,734	8,142	18,901	2,037	27,043	35,578	2	8
S6	99.04%	4,350	38,106	6,397	18,901	1,905	25,298	33,938	3	6
S7	99.10%	4,075	35,697	9,887	13,812	1,785	23,699	33,099	5	5
S8	99.17%	3,775	33,069	8,142	13,812	1,653	21,954	31,489	7	2
S9	99.23%	3,475	30,441	6,397	13,812	1,522	20,209	30,504	9	1

Table III: Savings due to the selection of S9 instead of S4 supplier (EP=0.05 €/kWh)

BP (€)	n	Wattage losses (W)	Energy losses (kWh/yr)	Cost of losses (€/yr)	Simple payback (yr)	Total cost of losses (€)	TOC (€)
-1,900	0.33%	1,475	12,921	646	2.94	8,578	6,678

Table IV: Savings due to the selection of S9 instead of S4 supplier (sensitivity analysis of electricity price)

EP (€/kWh)	BP (€)	n	Wattage losses (W)	Energy losses (kWh/yr)	Cost of losses (€/yr)	Simple payback (yr)	Total cost of losses (€)	TOC (€)
0.04	-1,900	0.33%	1,475	12,921	517	3.68	6,862	4,962
0.05	-1,900	0.33%	1,475	12,921	646	2.94	8,578	6,678
0.06	-1,900	0.33%	1,475	12,921	775	2.45	10,294	8,394
0.07	-1,900	0.33%	1,475	12,921	904	2.10	12,009	10,109
0.08	-1,900	0.33%	1,475	12,921	1,034	1.84	13,725	11,825
0.09	-1,900	0.33%	1,475	12,921	1,163	1.63	15,440	13,540
0.10	-1,900	0.33%	1,475	12,921	1,292	1.47	17,156	15,256

References

[1] CENELEC harmonization document 428.1 S1, 1992.