HOW TO BUY TRANSFORMER THROUGH COST-BENEFIT RELATION

Antônio Melo de Oliveira
melo@eee.ufg.br

Adalberto José Batista
batista@eee.ufg.br

Gilney da Costa Vaz
gcvaz@bol.com.br

Núcleo de Estudos e Pesquisa em Processamento de Energia e Qualidade - PEQ
Escola de Engenharia Elétrica e de Computação da Universidade Federal de Goiás
74605-220 – Goiânia – GO – Brasil

***Abstract* – The software for distribuition transformer economical analysis - ANET was implemented in DELPHI, which aims to present an alternative methodology for Distribuition Transformers aquisition, where the transformer cost and the load and no-load losses are compared for each supplier to be evaluated. At the end of each evaluation, the ANET makes a decreasing classification, indicating the best acquisition option.**

KEYWORDS

Energetic efficiency, economic analysis, distribution transformer, avoided cost.

I. INTRODUCTION

The distribuition transformer is an static equipment, that transforms alternate voltage and current between two windings by electromagnetic induction, without frequency changes, in consumers utilization load voltage adequate levels.

The methodologies used for distribution transformers thecnical and economical aspects evaluation by the electric utility companies, represent an important step in strategy planning that enhance these equipment efficiency. These methodologies may have a significant impact on the electric utility losses during transformers operational life, usually about 20 years when operating on rated power and 30o C constant temperature, according to ANSI C57.91 [1], and therefore, on the consumers electrical energy costs. On the other hand, if well defined, an specific methodology can assure that the aquired to be transformers present the best cost-benefit relation and can estimulate the equipment efficiency enhancement by its producers.

Due to a great number of installed units in the electrical system and long operating periods, a small distribuition transformer efficiency enhancement may represent a great amount of energy saved.

ORNL studies (Oak Ridge National Laboratory) estimate the distribuition transformers annual losses of the american electric utility companies of 61 billion kWh, and if 20 out of 40 million distribuition transformes installed in the US were replaced by ones with higher efficiency, using the amorphous metal thecnology, an annual energy save of about 6 to 14 billion kWh could be achieved. This would represent an annual amout from $300 to $700 billion dollars [2].

The use of higher efficiency transformers asures the utility benefits, through investment delayments and operational cost reduction, it also benefits consumers with medium voltage metering through comsumption and energy bill reduction. It also benefits the enviroment, through the reduction of poluent emission to the atmosphere associated to the thermoelectric utility, and the better use of hydrolic and mineral resources. These aspects are of extreme importance in the present competitiveness cenarium, besides, it complies with the rules of the present national maintainance and racional use of electrical energy politics. In this cenarium, the electric utilities must find means to cut expenses and at the same time, enhance quality, confiability and reduce electric energy costs.

II. TRANSFORMERS EFFICIENCY

The transformer efficiency, as for any electric energy converter, is defined as the raio of power output to power input, both in KW, for an specif load condition. For an established condition, the transformer efficiency can be increased through the reduction of its rated load loss, We, and/or, its no-load loss, Wo. This implies changes in the transformer project, including the choice of the materials used, and/or in its own building process. The most significative loss reduction enhancement known up to now is the use of magnetic amorphous type materials for core construction. The magnetic loss for this kind of material can get to only 20% of the ones for oriented grain silicium stain [3].

Since the power demand to be supplied by the distribution transformers widely vary, for example, in 24 hours, these transformers are projected to have a maximum efficiency for a 50% rated load. This requires the load rated loss to be about 4 times the no-load loss. Naturally, the study of the electric utility distribuition transformers average effective load for one year, estratificado by consumer type, would provide the company with more realistic data for the transformer project .

A. No-load Losses

The no-load losses are related to the magnetic losses in the transformer core material. The no-load losses are almost independent of the load condition. Therefore, they occur 24 hours a day and are considered constant [4]. Basically, the no-load losses are divided in two components: hysteresis and eddy current losses.

B. *Load Losses*

The load losses are related to the transformer winding losses. These losses vary accordingly to the load required current, hence, with the transformer load. In order to determine the load losses, the load factor is used. This factor is defined by [5]:

$$F_p = \frac{1}{T}\int_0^T D_{pu}^2(t)dt \qquad (1)$$

This factor can be related to the load factor, defined by,

$$F_c = \frac{1}{T}\int_0^T D_{pu}(t)dt \qquad (2)$$

through the following equation:

$$Fp = (1 - k).Fc^2 + k.Fc \qquad (3)$$

or also,

$$Fp = Fc^y \qquad (4)$$

Where:

Dpu(t) Demand in p.u. based on the peak demand (kW) in the considered time period, T (hours or minutes).

The ANEEL [6] suggests values for k between 0,15 and 0,30. As a rule this parameter must be obtained for the load, the feeder, the substation, or for the electric utility itself. Curve adjusting thecnics can be applied for this purpose. Recent studies taken place at the Núcleo de Estudo e Pesquisa em Processamento da Energia e Qualidade – PEQ, for an specific electric utility, not yet published, show that K can be as low as 0,04. In these studies, values for y were obtained from 1,86 to 1,96. Therefore, in order to determine the distribuition transformer total annual losses it is required the transformer no-load and rated load losses obtained through tests, according to the NBR 5380 [7].

Besides, it is also necessary to know the demand curve of the place where the transformer will be installed, in order to obtained the factors mentioned above. Figure I illustrates the active (demand), reactive and apparent power curves, in the period from 00h00min a 24h00min, gathered throuhg the metering of an commercial establishement. Using expression (1), the demand curve loss factor of figure 1 is determined as 0,468.

FIGURE I
Load curve of a commercial establishement

Example 1: A 75 kVA 3-phase distribuition transformer with no-load losses of 320 W, rated load losses of 1130 W and loss factor of 0,468. What are the transformer total annual energy losses?

$$P = (Wo + Fp.We).8760/1000 \text{ (kWh/year)} \qquad (5)$$

P = (320 + 0,468.1130).8760/1000 (kWh/year)
P = 7.435,84 (kWh/year)

III. ECONOMICAL ANALYSIS

The equation used in the ANET methodology is based in the method defined as “hard-evaluation of the Lowest Total Owning Cost (TOC)” implemented and improved since 1980 by the Edison Electric Institute in cooperation with the Institute of Eletrical and Eletronic Engineers (IEEE) [2], [8]. The ANET methodology adapted the TOC method to the data provided by the NBR 5440/1999 [8], data obtained through metering in distribuition system and historical avaluation data provided by the electric utility.

The expression used for the Distribuition Transformer Economical Analysis in the ANET software is:

$$ANET = (A.Wo + B.We).Mp + Pr \qquad (6)$$

Where:

ANET: Proposal actual Value (R$)

A: No-load losses unitary actual present (R$ /W)

B: Load losses unitary actual value (R$ /W)

Pr: Transformer market price (R$)

Mp: Losses multiplying factor

The losses multiplying factor consider the losses from the generation or delivering spot to the evaluated transformer. Usually the amount lies from 50% to 70% of the electrical system total losses which is about 15% [9].

Variable A equation:

A = (Cd x 12 + Ce x 8.760)/1000 * FVP (n, i) (7)

Where:

Cd: Avoided demand cost at the transformer voltage class, [R$/kW.month]

Ce: Avoided energy cost at the transformer voltage class, [R$/kWh]

FVP: Actual value factor

A in [R$ / W]

Thus:

$$FVP = [((1 + i)^n – 1) / (i (1 + i)^n)] \quad (8)$$

Where:

n: Transformer life (years)

i: Effective annual tax rate

Variable B equation:

$$B = (Cd \times 12 + Ce \times 8760 \times Fp)/1000 * FVP (n, i) \quad (9)$$

Where:

Fp: Loss factor = $K*Fc + (1 – K)*Fc^2$

K: Constant (from 0.15 to 0.30)

Fc: Load factor

B in [R$ / W]

Example 02: What are the no-load and load losses actual value in a period of 20 years, considering a tax rate of 12% per year and a loss factor of 0.468, if the energy and demand average cost are R$ 9,07/kW.month and R$ 0,13281/kW.h, respectively?

A = (12. Cd + 8760.Ce).FVP(n,i)/1000 = R$ 9,50/W

B = (12.Cd + 8760.Ce.Fp).FVP(n,i)/1000 = R$ 4,36/W

At each proposal to be evaluated by the ANET software, the performance parameters are the following:

a) Market Price (Pr): price that the supplier will make a transformer available, that includes the shipping, handling, taxes and insurance costs. The market price must be less or equal the one established at the electrical utility acquisition;
b) No-load Loss (Wo): the supplier will provide in its proposal the valid no-load loss amount, which must be less or equal the amount established by the NBR 5440/1999;
c) Load Loss (We): the supplier will also provide in its proposal the valid load losses, which must be less or equal the total loss amount subtracted by the no-load losses from the NBR 5440/1999.

IV. SIMULATION

The ANET methodology converts the transformer losses for its estimated life period into actual value currency, adding this amount to the transformer market price.

The advantage on using the actual value over the annual value is that the differences in the final evaluation of the suppliers proposals are bigger, as the actual value is algebrically bigger than the annual value.

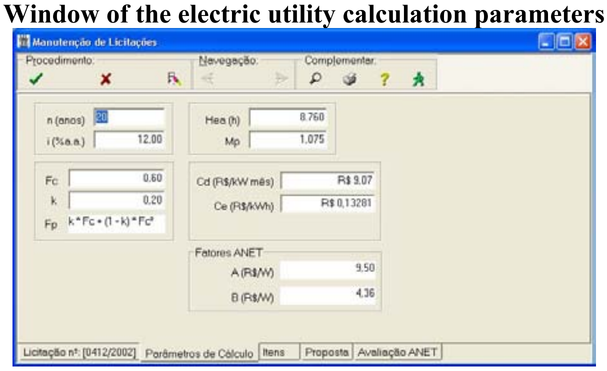
The ANET software has got a menu bar, according to figure II, which contains the data base and calculation parameters managing options. In the Licitantion option, the user provides all necessary elements to be applied in the proposal formulation.

Example 03: Supose the electric utility aims to aquire a 75 kVA 3-phase transformer lot – voltage class 13,8 kV. Previously, the suppliers are familiar with the methodology and the calculation parameters to be adopted: n = 20; I = 12; Cd = 9,07; Ce = 0,13281; Fc = 0,6; K = 0,2.

In the licitation option at the ANET menu bar, after informing the licitation basic data, the utility calculation parameters are confirmed, according to the window in figure III.

FIGURE II
ANET software main manu

FIGURE III
Window of the electric utility calculation parameters



Supposing there are four suppliers and that its performance parameters are the ones in table I.

TABLE I
Performance parameters of the analised suppliers

	Performance Parameters		
Suppliers	**Market Price (R$)**	**No-load Losses**	**Load Losses**
A	1.710,00	330,00	1.120,00
B	1.740,00	325,00	1.110,00
C	1.789,00	318,00	1100,00
D	1.840,00	315,00	1.100,00

Considering that all supplier porposals meet the thecnical requirements established at the ABNT and utility rules, it can be observed in table 1 that supplier A presents a better acquisition option as it offers the lowest market price. Although, in figure IV we realize that transformer A is the one with the lowest efficiency. Here lies a paradigm, is the A suppier indeed the best acquisition option? The ANET methodology aims to point out the supplier that presnts the best cost-benefit and brakes this paradigm. In figure V we do have the best acquisition option that is proposed by the C supplier, although its not the one that presents the lowest cost nor the transformer with the highest efficiency, when analysed as a whole, it's the best aquisistion option.

FIGURE IV
Suppliers transformer efficiency (%)

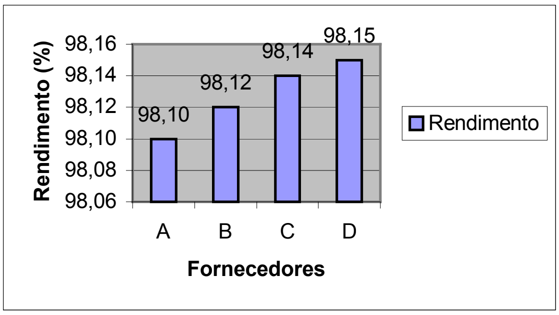
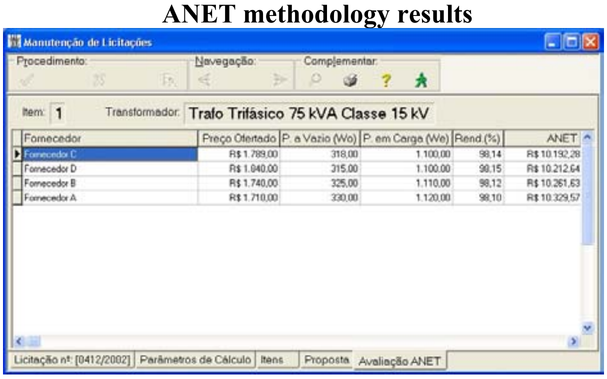


FIGURE V
ANET methodology results



V. CONCLUSION

The distribuition transformer is of fundamental importance to electrical systems operating in alternate current, making the appropriate voltage distribuition and transference to the equipments possible.

The quality and stability enhancement together with the electrical system loss and operational cost reduction are extremely relevant to the present competitiveness cenarium and also complies with the rules of the present national maintainance and racional use of electrical energy policy.

The alternative aquisition proposal adopted at the ANET methodology shows to be objective and mathematically valid. The results presented by the ANET simulation software suggest that the lowest price, regarding distribuition transformers with diversified performance parameter, is not the best acquisition option. Although all evaluated transformers meet the thecnical and financial requirements established by the utility, the losses costs has a significant impact in the final evaluation, which must be taken into account.

The ANET methodology reveals the advantage of working with the actual value instead of the annual value, since the differences at the final suppliers proposal evaluation get bigger, as the actual value is algebrically bigger than the annual value.

REFERENCES

[1] COMPANHIA ENERGÉTICA DE MINAS GERAIS – ST/DN-275. *Especificação técnica transformadores para redes aéreas de distribuição – 15 kV e 24,2 kV*, 1997.

[2] KENNEDY, Barry W. *Energy efficient transformers*. New York: McGraw-Hill, 1998.

[3] CHEIM, Luiz. *Experiência com transformadores monofásicos de núcleo amorfo*. Revista Eletricidade Moderna, Maio, 1998.

[4] OLIVEIRA, José Carlos et al. *Transformadores*: teorias e ensaios. São Paulo: Edgard Blücher; Itajubá, MG: Escola Federal de Engenharia, 1984.

[5] GÖNEN, Turan. *Eletric Power Distributio System Engineering*. New York: MacGraw-Hill, 1986.

[6] AGÊNCIA NACIONAL DE ENERGIA ELÉTRICA. *Resolução n.º 271 de 19 de Julho de 2000*: Aprova o Manual para elaboração do programa anual de combate ao desperdício de energia elétrica.

[7] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS – NBR-5380. *Transformador de potência*: método de ensaio, 1993.

[8] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS – NBR-5440. *Transformadores para redes aéreas de distribuição*: padronização, 1999.

[9] CIPOLI, José Adolfo. *Avaliação das perdas de energia no sistema elétrico*. Revista Eletricidade Moderna, Outubro, 1990.