

Economic Evaluation Of Substation Transformers

As electric rates increase, avoidable energy losses will become more important in specifying transformers.

Many corporations install and maintain their own substations because utilities offer discounts to customers who take service at primary distribution voltage. In the past, electrical consultants and corporate facility electrical engineers who specified substation transformers often paid little attention to the cost of operating this equipment. Today, electrical engineers who specify transformers recognize the importance of controlling avoidable energy losses. This recognition takes on more meaning as electric utility rates accelerate.

In 1970, electricity cost an average industrial user about \$.01/kWh. In 1980, power cost almost \$.04/kWh, a 300% increase in the last decade. In 1990, several economists predict the average industrial user will pay \$.09 to \$.15/kWh. By the year 2000, the cost is expected to reach \$.30 to \$.45/kWh. The fact that energy cost escalates every year has made us more cognizant of the need for better efficiency in substation transformers.

Initial cost was the major factor a few years ago in the purchase of substation transformers of a given kVA capacity, design, windings, cooling medium and enclosure, from suppliers known to provide readily available and reliable units. This situation has changed tremendously. Escalating energy costs have brought the need for economic evaluation of transformer losses. In addition, the availability of additional power is no longer assured as demand begins to exceed utility capacity, and it is essential to the national economy that energy waste be reduced. Failure to incorporate transformer economic evaluation techniques into system planning strategies can result in improper selection of a transformer. The inefficient transformer can impose a needless drain on operating budgets.

Method Of Economic Evaluation

In the past, when the cost of money was low, the lowest cost of a transformer was determined by adding the initial cost of the transformer and the cost of transformer losses. This method does not reflect the true lowest cost of the transformer since it does not take into consideration the cost of money, i.e., interest.

The lowest cost of the transformer can be determined by the expression: equivalent uniform annual cost (EUAC) of transformer ownership = EUAC of fixed costs + EUAC of operating costs.

Fixed costs consist of: initial transformer cost, associated initial costs of the transformer and the financial cost for the prior two items. The associated initial costs of the transformer include:

- Delivery charges
- Installation cost
- Insurance cost
- Possible price escalation
- Cost of field testing
- Supervision costs
- Furnishing test results
- Cost of warranty

If the initial cost of the transformer (the quote from the supplier) does not include any of the above associated costs, the following penalties may be assessed against the bid price:

- A surcharge of 10% of the bid price for not including the delivery charges.
- An additional cost of 5% to 10% of the bid price to represent cost of installation, field testing, supervision, furnishing test results, warranty and insurance.

For clarification, the insurance cost represents an expense that the transformer manufacturer or distributor has to undertake. The insurance covers the risks involved while transporting the transformer to the job site and is in effect until the transformer becomes operational. Supervisional costs relate to the services of a factory engineer and/or the electrical consultant who specified the transformer, for supervision covering the installation of the unit at the job site.

The financing cost is based upon the total initial cost of the transformer (transformer and associated costs) using the current interest rate and assuming a 30-year life on the transformer. To evaluate the operating costs without also evaluating the cost of the extra money expended to be able to take advantage of the more efficient unit will result in an erroneous decision.

The equation for determining EUAC of the fixed costs is:

$$\text{EUAC of fixed costs} = [(P)(i)] \left[\frac{(1+i)^n}{(1+i)^n - 1} \right]$$

Where P = Total initial cost
n = No. of years
i = Interest rate

Operating costs consist of: demand charge, no-load losses (core losses), winding-load losses and maintenance costs.

The demand charge represents a charge based upon the equipment the utility must own to meet the client's power requirements relating to the energy utilized by the transformer itself.

No-load loss (WC) is the kW used for hysteresis loss and eddy current loss. Because the core flux in a transformer remains practically constant for all loads, the core loss is practically constant at all loads. Core losses average about 20% to 30% of total full-load losses.

Winding-load loss (I^2R) is the kW used resulting from the ohmic resistance of the transformer windings and is

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dependent on load. Load loss is proportional to square of load current. In other words, load loss at half the full load is one-fourth of that at full load. The general level of transformer loss ratio (load loss at rated load divided by no-load loss at rated voltage) is between 3 and 4.

Maintenance costs reflect the expenses for transformer cleaning, conducting periodic inspections (at least six-month intervals) and checking signs of overheating, loose connections, rusting, corrosion, paint deterioration, temperature sensors and other auxiliary devices. Generally, maintenance work is carried out during weekends and costs could be assumed to be the same for a given size transformer.

Operating costs can be computed on an annual basis, considering no-load as continuous and constant, and average winding losses to be considered constant with the transformer operating at half load (but not necessarily continuously).

The effect of the escalating cost of energy can be assessed by determining the equivalent uniform annual cost (EUAC) of energy. The EUAC of energy is defined as the present value of a non-uniform series of annual costs resulting from a constant exponential growth. When calculating the EUAC of energy, three aspects of energy must be considered: demand charge, no-load loss and winding-load loss (at 50% load). Data on no-load and load losses must be obtained from the transformer manufacturer. The load loss is based on 50% load because most transformers are designed to have a maximum efficiency at approximately this load level. An equation is used to take into account the cost of inflation and the exponential growth of the cost of electric power. This equation is used three times, once for each of the three different energy aspects.

EUAC of energy charge =

$$\left[\frac{(a^{n+1}-1)}{(a-1)} - 1 \right] \left[\frac{b^n}{b^{n-1}} \right] (i) [(\$/\text{kWh}^* \text{ or } \$/\text{kW}^*)]$$

Where $a = \frac{(1+g)}{(1+i)}$

$b = (1+i)$

$n = \text{no. of periods}$

$i = \text{interest rate (cost of money in \%)}$

$g = \text{energy cost escalation rate (\%)}$

$* = \text{energy charge or demand charge.}$

To help simplify economic evaluation, computer programs have been developed to provide quick, accurate and easy to use information to evaluate the costs aspects of various elements.

EUAC Of Operating Transformer

$$\begin{aligned} \Sigma \text{EUAC} &= \text{EUAC of demand charges} + \text{EUAC of no-load losses} + \text{EUAC of winding-load losses} + \text{EUAC of maintenance.} \\ &= \text{EUAC of [demand + WC + } f^2\text{WL + main-} \\ &\quad \text{tenance]} \end{aligned}$$

Where f is a percentage of full load, 50% being used for this application.

Calculation Procedure

A substation transformer specification calls for the bidders to assume the power tariff as:

Demand charge = \$8/kW month

Energy charges = \$.06/kWh

Cost of money (i) = 12%

Power cost escalation rate (g) = 6%

Transformer operating life (n) = 30 years

Assume no-load losses as constant and winding-load losses computed as continuous with transformer operating at half-rated kVA (50% of full load).

Manufacturer B furnished the following information along with the bid as per specifications:

7500 kVA transformer, 7% impedance, efficiency at 25%, 50%, 75%, 100% and 112% of full load equal to 99.33%, 99.47%, 99.43%, 99.34% and 99.3% respectively.

No-load (WC) = 11.95 kW

Winding-load loss ($f^2\text{WL}$) = (f^2) (30.70 kW)

A. Neglecting effect of rate increases ($g = 0$)

Annual cost of demand charges

= (demand charge per month) (12 months) \times (no-load loss + winding-load loss)

= (\$8) (12) [11.95 + ($1/2$)² \times (30.70)]

= \$1884

Annual no-load loss energy cost

= (energy cost/kWh) (no-load loss) (8760 hours/year)

= (\$.06) (11.95) (8760) = \$6281

Annual winding-load loss energy cost

= (energy cost/kWh) (winding-load loss) (8760 hours/year)

= (\$.06) [$(1/2)^2 \times$ (30.70) (8760)]

= \$4034

Annual maintenance cost is assumed as \$1000.

Thus, the total annual operating cost is:

$$\$1884 + \$6281 + \$4034 + \$1000 = \$13,199$$

B. Consider power cost escalation rate ($g = 6\%$)

EUAC of demand charge

$$= \left[\frac{\left(\frac{1.06}{1.12} \right)^{31} - 1}{\frac{1.06}{1.12} - 1} - 1 \right] \left[\frac{(1.12)^{30}}{(1.12)^{29}} \right] (.12) (\$8.00/\text{kW month})$$

= (14.035) (0.1344) (8)

= (1.886) (8) = \$15.10/kW month

EUAC of no-load and winding-load energy charges

= (14.035) (0.1344) (\$.06/kWh)

= \$.11/kWh

Total EUAC of Operating Transformer

= EUAC of (demand charge, energy losses and maintenance)

= \$15.10/kW month \times 12 months/yr [11.95 + ($1/2$)²

\times (30.70)] + \$.11/kWh \times 8760 hours/yr \times

[11.95 + ($1/2$)² \times (30.70)] + \$1000

= \$23,467

It can be seen that by using the escalating cost of power compared to assuming power at a constant cost, there is a change in the transformer's operating cost from \$13,199 to \$23,467, or \$10,268 more.

Non-Effect of Impedance

Transformer impedance is usually more reactive in nature compared to the resistive component and, hence, transformer losses or efficiency will be independent of impedance value. Therefore, as impedance has little effect in evaluating transformers from an economic viewpoint, this factor is not considered.

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Depreciation Tax Benefit

Many engineers make an economic analysis of investment alternatives on a before-tax basis. Engineers must look at the attractiveness of investment on an after-tax basis by analyzing the effects of investment tax credit and depreciation.

Depreciation tax benefit

$$= \text{Initial premium price of energy efficient transformer} \times \text{depreciation rate} \times \text{tax rate}$$

Energy savings on an after-tax basis

$$= (\text{Cost of energy saved}) (1 - \text{tax rate})$$

Overall transformer ownership cost will be reduced if depreciation tax benefits and after-tax energy savings are included in the economic evaluation.

Sample Calculation

Figure 1 compares the bid price, various other costs associated with the purchase of a transformer (assume unit has 30 year life), transformer losses, operating costs and annual cost of transformer ownership from four different transformer manufacturers. EUAC of fixed costs may be less for the less efficient transformer (Mfg. A); but the overall equal uniform annual cost of ownership is higher than that of the more efficient transformer (Mfg. D). The best economic choice is obviously the transformer built by Mfg. D.

Transformer ownership cost will be lower for higher energy rates. Energy savings on an after-tax basis and depreciation tax benefits will also reduce the overall ownership costs.

The past decade has seen the escalation rate for energy costs substantially exceed the inflation rate for the general economy, and this condition may become worse in the foreseeable future. The economic impact of this situation is reflected in many ways, one of which involves transformer selection based on annual cost considerations.

When considering the initial cost of a transformer, the cost of the money used that is expended on the transformer must also be factored into the overall price. Therefore, the least costly transformer initially will be the one which incurs the least cost over time, including interest expense. The best transformer is that which gives the greatest value per dollar of investment and provides adequate service. This is rarely the case with the lowest capital cost investment. The method of economic evaluation used in this discussion provides an opportunity to realize savings through proper selection of substation transformers. **EC**

Item No.	Transformer Parameters	Transformer Manufacturer			
L1	Bid price	65,990	69,690	74,700	84,600
L2	Delivery time (in weeks)	22	28	20	26
L3	Price escalation to delivery date	None	None	None	None
L4	Delivery charges	6,599*	None	None	None
L5	Installation cost	5,000	5,000	5,000	5,000
L6	Cost of testing	2,640**	None	None	None
L7	Cost of warranty (Min. one year)	Included	Included	Included	(4,230)***
L8	Impedance in %	7	7	7	7
L9	No-load losses in kW	12.4	11.95	10.45	8.3
L10	Winding load losses in kW	25.5	30.70	40.55	29.05
L11	Total transformer losses (no-load & winding) in kW	37.9	42.65	51.00	37.35
L12	Initial costs (L1-L7)	80,229	74,690	79,700	85,370
L13a	Financing costs (at 12% for 30 years)	218,571	203,470	217,120	232,570
L13b	Fixed costs (initial costs-L12 + financing cost-L13a)	298,800	278,160	296,820	317,940
L13c	EUAC of fixed costs	9,960	9,272	9,894	10,598
L14a	EUAC of demand charges at \$15.10/kW	3,402	3,556	3,730	2,820
L14b	EUAC of no-load loss energy at \$0.11/kWh	11,949	11,515	10,070	7,998
L14c	EUAC of winding-load loss energy at \$0.11/kWh	6,143	7,396	9,769	6,998
L14d	EUAC of transformer maintenance	1,000	1,000	1,000	1,000
L14e	Total EUAC of operating costs (items 14a, b, c, d)	22,494	23,467	24,569	18,816
L15	EUAC of transformer ownership (items L13c and L14e)	32,454	32,739	34,463	29,414
L16	Total cost of transformer ownership [(item L15) × (30 years)]	973,620	982,170	1,033,890	882,420
L17a	Annual depreciation tax**** benefit (from premium price over Mfg. A)				372
L17b	Annual after-tax energy savings at tax rate at 40% (energy savings between Mfg. D and Mfg. A)				2,207
L17c	Total tax benefits for 30 years				77,370
L17d	Overall transformer ownership cost (L16-L17c)				805,050

Remarks

- *10% surcharge for not including delivery charges
- **4% surcharge for not including cost of testing
- ***5% credit for offering 5 year warranty
- ****3.33% straight line method at 40% tax rate

Fig. 1. Economic evaluation of a substation transformer.

The Author

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Transformer Cost Evaluation Form

Use this form to compare operating costs of transformers in your particular circumstances. Instructions are given below. If you have any questions, your Dow Corning representative will be happy to help you.

Transformer Rating _____ KVA

_____ / _____ KV

Job Title _____

CALCULATIONS	TRANSFORMER				
	1	2	3	4	5
1. Core Losses					
2. Total Losses at Full Load					
3. Total Losses at Expected Load					
4. Energy Cost					
5. Total Annual Operating Cost					
6. Present Value of Annual Cost					
7. Installed Transformer Cost					
8. Total Transformer Cost					

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