UNITED STATES DEPARTMENT OF AGRICULTURE
Rural Utilities Services

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SUBJECT: **Guide for Economic Evaluation of Distribution Transformers**

TO: RUS Electric Borrowers and RUS Electric Staff

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OFFICE OF PRIMARY INTEREST: Distribution Branch, Electric Staff Division

FILING INSTRUCTIONS: This bulletin is a new bulletin. This bulletin can be accessed via the internet on the RUS website http://www.usda.gov/rus/electric/bulletins.htm.

PURPOSE: This bulletin explains the total owning cost (TOC) method for conducting present worth dollar analysis of the cost of owning a transformer over its useful life. An Excel™ spreadsheet for calculating TOC is also included.

Christopher A. McLean
Assistant Administrator
Electric Program

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Date

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Total Ownership Cost
Purchase of Distribution Transformers

ABBREVIATIONS

BP	Bid Price
CF	Capacity Factor
CRN	Cooperative Research Network
DC	Demand Charge
DOE	Department of Energy
EC	Energy Cost
FCR	Fixed Charge Rate
HPY	Hours per Year
LL	$Watts_{LL}$ (transformer winding loss)
LSF	Loss Factor
NL	$Watts_{NL}$ (no load loss)
NRECA	National Rural Electric Cooperative Association
PL	Peak Load
RF	Peak Loss Responsibility Factor
TOC	Total Owning Cost

DEFINITIONS

Average Rate of Inflation – the estimated average rate of inflation per year for the life of the transformer

Capacity Factor (CF) - a measure of the average use of the transformer compared to its maximum possible usage, calculated by:

capacity factor = kwh sold per year through the transformer/(8760 x nameplate kva)

Demand Charge (DC) - the levelized demand charge in $/kw/year.

Energy Cost (EC) - the levelized energy cost in $/kwh to produce energy during the life of the transformer.

Energy Cost Increase per Year – the estimated average rate of increase in energy cost per year during the life of the transformer.

Expected Transformer Life in Years – the estimated number of years the transformer will be in service.

First Year Peak (percent of nameplate kva) – the estimated peak load the transformer will experience in the first year of installation.

Hours per Year (HPY) - 8760 hours unless the analysis is for a special application or seasonal use transformer, such as irrigation or pumping.

Interest Rate for Borrowing Money – the estimated average rate of interest which the borrower determines is being paid on loans.

Levelized Cost – the present value of the total cost of owning and operating a piece of equipment over its useful life converted to equal annual payments

Peak Load Growth per Year – the estimated yearly rate of increase of the transformer’s peak load during its life.

Peak Load Responsibility Factor – the proportion of system peak attributable to the load on a transformer at the time of the system peak. The peak load responsibility factor takes into account the fact that the peak load on a transformer does not usually occur at the same time as the system peak. It is expressed as the ratio of the transformers peak load at the time of system peak to the peak load on the transformer.

1 INTRODUCTION

The purpose of this bulletin is to explain the total owning cost method (TOC) for conducting consistent and meaningful present worth dollar analysis of the cost of owning a transformer during its useful life using the TOC method. This method was devised in the 1990s and continues to be widely used because of its simplicity. Transformers are a major component of a distribution system, and the cost of buying them comprises a large part of an annual equipment budget. TOC analysis can be used to compare the various manufacturers and their transformer designs on an equal basis and thus determine which transformers are the most economical to own and operate on a long-term basis.

The total owning cost includes all the expenses associated with purchasing, operating and maintaining a transformer over the life of the unit. While some expenses are relatively stable over the course of the transformer life like installation and removal costs, the borrower has little ability to control the level or timing of some expenses, such as maintenance, or external factors, such as tax and interest rates. However, the borrower can make decisions that balance the first cost of buying the transformer with the cost of core and copper losses, a significant portion of operating costs, to minimize ongoing costs over the life of the unit.

In general, a transformer with lower losses has a higher purchase price. While lower losses serve to reduce operating costs, a higher initial investment cost also results in higher tax and interest costs. The transformer with the lowest total ownership cost is usually not the one with the lowest price or the lowest losses.

As the cost of energy increases, the cost of losses becomes more significant, further justifying the time and effort necessary to perform the TOC analysis.

2 HISTORY

Distribution transformer efficiency, once a utility industry issue, is now regulated by the federal government. The Energy Policy Act of 1975 prescribed conservation standards for various consumer products. The Energy Policy Act of 1992 directed the Department of Energy (DOE) to set minimum efficiency standards for distribution transformers.

DOE has employed the Public Rule Making procedure to establish Final Rules for the minimum efficiency of distribution transformers. The Final Rule must be designed to achieve the maximum improvement in energy efficiency that is technologically feasible and economically justified and also result in significant conservation of energy.

The DOE standards apply to medium voltage liquid-immersed distribution transformers that are commonly used by electric utilities, including rural electric cooperatives. The standards apply to newly manufactured transformers. They do not apply to transformers that are already purchased or in service or those that are refurbished.

The first DOE Final Rule, issued in 2007, set minimum efficiency standards to become effective January 1, 2010. A review of a Final Rule must be performed every six years to determine if standards should be changed. The DOE issued a Final Rule in 2013 to become effective January 1, 2016.

NRECA has been an active participant in the DOE Ruling Makings for distribution transformers. The DOE has recognized that cooperatives buy a significant number of transformers and that those transformers may serve consumers with lower load factors and thus have longer payback periods than experienced by other segments of the utility industry.

It is important for rural electric cooperatives to carefully evaluate transformer purchases and transformer operating practices. The economics of purchases and operation can be improved by purchasing transformers evaluated under the principles of this Bulletin, as opposed to just purchasing transformers with minimum efficiency allowable as prescribed by the DOE standards.

3 TERMS

The following terms are found in the proceeding equations and are generally those for an electric system. The data obtained would be applicable to all transformers on a system. However, when the purchases are for specific applications, such as transformers for irrigation systems, the hours of usage or load or the load factor will vary based on that particular application. The results obtained will apply to that application only. The data used in the following calculations are general, and the results apply to all distribution transformers as a group used in an electric system. This Bulletin was written to be used in conjunction with the CRN Loss Manual. For a greater understanding of the individual terms, use the Loss Manual as a guide.

a Fixed charge rate (FCR). The yearly income necessary to pay for a capital investment. FCR is expressed as a percentage of capital investment. The FCR includes interest, depreciation, taxes, insurance, operations and maintenance.

Some typical values for the components of the FCR include:

Interest	5.0%
Depreciation	2.75%
Insurance	0.6%
Taxes	1.00%
Operations & Maintenance	2.76%
FCR	12.11%

b Bid Price (BP). The unit price at which a particular transformer manufacturer offers to sell transformers. This price should include transportation costs as well as sales tax if applicable.

c $Watts_{NL}$ (NL). The no load power loss in watts of a transformer at rated voltage and temperature. This is also called the transformer core loss. The no load losses are furnished by the manufacturer for the transformer being considered for purchase. In the calculations in this bulletin, the cost per watt for no load losses is represented by the symbol A.

d Watts$_{LL}$ (LL). The electrical loss in watts due to windings of the transformer only taken at full rated load. This is also called the transformer winding loss. The load losses are furnished by the manufacturer for the transformer being considered for purchase. In the calculations in this bulletin, the cost per watt for losses is represented by the symbol B. Note that the "Total Load Losses" is the sum of the NL and LL Losses.

e Hours Per Year (HPY). The number of hours per year the transformer will be energized. In general, this value will be 8760 unless it is for a special application transformer, such as an irrigation or pumping service.

f Demand Charge (DC). A charge designed to reflect the maximum size of facilities required to deliver power, expressed in dollars per kilowatt-year. For power systems that generate, transmit and distribute power, it is power (kW) at peak load from the generator, through the transmission and distribution systems to the transformer. For systems that purchase power and distribute it, the annual value for DC is the monthly demand charge including escalation, multiplied by 12 to give $/kw-year. DC′ will be used in both the A and B value calculations and indicates a levelized value that includes escalation and inflation. A detailed discussion of calculating DC′ will follow in the next section.

g Energy Cost (EC). The cost, in dollars per kWh, to produce energy during the life of the transformer, including escalation, estimated inflation and other factors which affect energy cost. EC′ will be used in both the A and B value and indicates a levelized value that includes escalation and inflation. A detailed discussion of calculating EC′ will follow in the next section.

h Peak Load (PL). The uniform equivalent maximum load on a transformer during the period of the evaluation. It is an approximation of actual transformer annual peak load since it assumes that the annual peak load increases at a constant percentage rate. This value is levelized so it can be used in the calculations for the entire life of the transformer.

**PL^2 is used in the calculations, instead of PL since PL^2 is used in the basic formula for A and B*

The following is the approximation for calculating the PL^2 value for the life of the transformer:

$$(\mathrm{PL})^2 = \frac{(\mathrm{PL_I})^2[(1+i)^n - (1+g)^{2n}]}{(1+i)^n[(1+i) - (1+g)^2]} * \mathrm{CRF}_n$$

PL_I = the anticipated peak load during the first year of installation expressed as a decimal equivalent

g = the decimal equivalent of the estimated annual percentage increase in peak load during the life of the transformer

i = the average rate of interest which the borrower determines is being paid on the loans

n = the number of years which the transformer will be in service

p = the estimated average increase in energy cost per annum during the useful life of the transformer

CRF_n = the capital recovery factor used to levelize the total present worth evaluation. It converts the sum into a uniform annual series whose total present worth is identical to the actual present worth**.** It is defined as follows:

$$\mathrm{CRF}_n = \frac{i(1+i)^n}{(1+i)^n - 1}$$

i Peak Loss Responsibility Factor (RF). A factor that adjusts for differences between the peak load on a transformer and peak load on the distribution system, which typically do not occur at the same time. The transformer′s contribution to the system peak load is usually only a fraction of the load on the transformer at its peak load, so it is therefore most often less than one (1). Since losses vary with the square of the load, the peak loss responsibility factor is the square of the peak load responsibility factor.

The following is the equation for estimating the peak load responsibility factor:

$$\left(\frac{Transformer\ load\ at\ time\ of\ system\ peak}{Transformer\ peak\ load}\right)$$

Then to get the peak loss responsibility factor, square the previous equation:

$$\mathrm{RF} = \left(\frac{Transformer\ load\ at\ time\ of\ system\ peak}{Transformer\ peak\ load}\right)^2$$

j Loss Factor (LSF). The ratio of the average transformer losses to the peak transformer losses during a specific period of time. If the system (or individual transformer) load factor is known, the loss factor can be calculated for the system of transformers or the individual transformer as follows:

$$\text{Load Factor} = \left(\frac{kWh\ per\ year}{8760 * peak\ kW}\right)$$

$$\text{Loss Factor} = 0.2 * (Load\ Factor) + 0.8 * (Load\ Factor)^2$$

4 TOTAL OWNING COST METHOD

The total owning cost of a transformer is the sum of the first cost, or cost of purchasing the transformer, plus the cost of losses. Transformers experience two types of losses, core losses and winding losses. The core losses are due to the fields that magnetize the transformer core and are always present regardless of the transformer loading, which is why these losses are referred to as no-load losses. The winding losses are due to the normal I^2R losses in the windings on the transformer. These vary with the square of the load on the transformer, which is why these are referred to as load losses.

A transformer bid typically specifies the bid price, no-load losses in watts, and load losses in watts. These loss values should be provided by the manufacturer and should not be exceeded by test values of the transformers delivered. A basic method of transformer evaluation is to assign a cost per watt in $/watt for each the no-load and load losses. The cost per watt for no-load losses is the transformer design A value, and the cost per watt for load losses is the transformer design B value. The A and B values help to determine the total ownership cost of the losses on any given transformer with a load loss and no-load loss value.

The Total Ownership Cost method is based on the levelized costs associated with owning the transformer, including the cost of the transformer, losses, inflation, increases in energy costs and increases in demand charges, if applicable. The levelized cost is the present value of these costs converted to equal annual payments.

The levelized cost is not an average. Using energy as the example, with energy costs rising, the levelized energy charge is higher than the energy cost in the early years of the project and lower than the energy cost in the later years.

The total ownership cost of a transformer is calculated:

$$\mathrm{TOC} = \mathrm{Bid\ Price} + (\mathrm{A} * \mathrm{NL} + \mathrm{B} * \mathrm{LL})$$

Where:

$$\mathrm{A} = \frac{\mathrm{DC}' + (\mathrm{HPY} * \mathrm{EC}')}{(\mathrm{FCR} * 1000)} \text{ in \$/watt}$$

$$\mathrm{B} = \frac{(\mathrm{PL}^2 * \mathrm{RF} * \mathrm{DC}') + (\mathrm{PL}^2 * \mathrm{HPY} * \mathrm{LSF} * \mathrm{EC}')}{(\mathrm{FCR} * 1000)} \text{ in \$/watt}$$

As shown in the following sections, the transformer with the lowest total ownership cost is not necessarily the one with the lowest purchase price. The utility typically provides the manufacturer with the A and B values to be used in the TOC evaluation for use in transformer design.

5 ENERGY ESCALATION AND INFLATION

Accounting for inflation in economic studies is a difficult and complex issue. The purpose of this section is not to provide a comprehensive analysis of the subject but rather to provide some general guidelines.

One method of handling inflation is to increase future variable costs, such as the costs of losses, by the percentage represented by the general inflation rate. Since the calculations for A and B do not have any provisions for costs that increase over the years, an equivalent level cost that takes into account future cost increases should be used. This is sometimes referred to as the levelized value. The following equation derives such a value and can be used to adjust for inflation (See Appendix 1 for derivation):

$$A' = A * X * \frac{(1 - X^n)}{(1 - X)} * CRF_n$$

Where:

$X = \text{inflation adjustment} = \frac{(1+r)}{(1+i)}$ for $r \neq i$

A' = the cost adjusted for inflation

A = the base cost before inflation

n = the number of years in the inflation period, usually the life of the transformer

i = the average rate of interest being paid on loans

r = the average year over year rate of inflation over the life of the transformer

While this method reflects increases in future costs, it fails to take into account that the value of money decreases with inflation. Another method of handling inflation is to assume that the increase of costs in the future will be balanced out by the decrease in the value of money, thus allowing us to ignore inflation all together. The problem with this approach is that the assumption does not always hold true, because costs of certain items may increase faster than the inflation rate.

A third, more realistic method of treating inflation is to compensate both for the increase in costs associated with the generation and transmission of electric power and for the decrease in the value of the dollar associated with the generally prevailing inflation rate. This compensation can be accomplished calculating an equivalent inflation rate (r′) that can be used in the original equation for X.

$r' = \frac{(1+P)}{(1+ig)} - 1$ for $P \geq ig$

Where:

r' = The equivalent inflation rate

P = the rate of increase in costs per kwh associated with power generation and transmission expressed as a decimal

ig = the inflation rate for the economy as a whole expressed as a decimal

Now the equivalent inflation rate can be used in the original equation for X as follows:

$$X = \frac{(1+r')}{(1+i)} \text{ for } r' \neq i$$

If the equivalent inflation rate r' and the interest rate i are the same, the cost adjusted for inflation and the base cost will be the same as was described in Method 2.

6 EXAMPLE

The following example illustrates the process of determining the total ownership cost for a 50 kVA pad mounted distribution transformer including calculating the levelized values for peak loading and energy costs.

Bid Price = $3,000

NL = 94 Watts (from manufacturers 50 kva transformer)

LL = 464 Watts (from manufacturers 50 kva transformer)

DC = $120/kw-Year (the initial demand cost calculated by the borrower)

DC′ = levelized demand cost, to be calculated

EC = $0.05/kwh (the initial energy cost)

EC′ = levelized energy cost, to be calculated

PL_I = 80% (the initial peak load)

PL = levelized annual peak load, to be calculated

RF = .81 Peak Loss Responsibility Factor (assuming a peak load responsibility factor of .9)

LSF = .3 Loss Factor

FCR = 14.2%

Assumptions:

50 kva transformer

30 year lifespan

Initial peak load: 80% of rating or .8

Load Growth (*g*) = 1%/year or .01

Interest Rate (*i*) = 5%/year or .05

Energy Escalation Rate (*p*) = 3%/year or .03

General Inflation Rate (*ig*) = 2.5%/year or .025

$$\text{CRF}_{30} = \frac{.05(1+.05)^{30}}{(1+.05)^{30}-1} = \frac{.05(4.32)}{(4.32)-1} = .065$$

$$(\text{PL})^2 = \frac{(.8)^2[(1+.05)^{30}-(1+.01)^{60}]}{(1+.05)^{30}[(1+.05)-(1+.01)^2]} * .065$$

$$(\text{PL})^2 = \frac{.64}{4.32} * \frac{[4.32-1.82]}{[1.05-1.02]} .065$$

$$(\text{PL})^2 = 12.34 * .065 = .8021$$

To calculate the levelized demand and energy costs:

$$r' = \frac{(1+P)}{(1+ig)} - 1 \text{ for } P \geq ig$$

$$r' = \frac{(1+.03)}{(1+.025)} - 1 = .0049$$

$$X = \frac{(1+r')}{(1+i)} \text{ for } r' \neq i$$

$$X = \frac{(1+.0049)}{(1+.05)} = .957$$

$$\text{DC}' = \text{DC} * \text{X} * \frac{(1-\text{X}^n)}{(1-\text{X})} * \text{CRF}_n$$

$$\text{DC}' = 120 * .957 * \frac{(1-.957^{30})}{(1-.957)} * .065$$

$DC' = 120 * 16.3 * .065 = \$127.30$ per kw-year

$$EC' = EC * X * \frac{(1 - X^n)}{(1 - X)} * CRF_n$$

$$EC' = 0.05 * .957 * \frac{(1 -.957^{30})}{(1 - .957)} * .065$$

$EC' = 0.05 * 16.3 * .065 = \$0.053$ per kwh

To calculate the A and B values:

$A = \frac{DC' + (HPY * EC')}{(FCR * 1000)}$ in \$/watt

$A = \frac{127.30 + (8760 * 0.053)}{(.142 * 1000)}$ in \$/watt

$A = 4.169$ in \$/watt

$B = \frac{(PL^2 * RF * DC') + (PL^2 * HPY * LSF * EC')}{(FCR * 1000)}$ in \$/watt

$B = \frac{(.8021 * .81 * 127.30) + (.8021 * 8760 * .3 * .053)}{(.142 * 1000)}$ in \$/watt

$B = 1.37$ in \$/watt

To calculate the transformer’s total ownership cost:

$TOC = \text{Bid Price} + (A * NL + B * LL)$

$TOC = \$3000 + (\$4.169/W * 94\ W + \$1.37/W * 464\ W)$

$TOC = \$4027.56$

The total ownership cost should be calculated for each transformer under consideration. The transformer with the lowest total ownership cost would be the most economical lifetime investment. A spreadsheet has been included in Appendix 2 to assist with the calculations.

APPENDIX 1

EQUIVALENT LEVEL COST FORMULA

The following illustration provides a derivation of Equation 9, which is used to adjust cost evaluations for inflation. Equation 9 will produce a level cost (or energy charge rate) that will yield the same total present worth value as a cost (or energy charge rate) that is increasing at r percent per year.

The present worth of a cost increasing at r percent per year is:

$$\mathbf{PW} = \mathbf{A} * \left[\frac{(1+r)}{(1+i)} + \frac{(1+r)^2}{(1+i)^2} \cdot \cdot \frac{(1+r)^n}{(1+i)^n} \right]$$

where:

i = the time value of money

r = the rate of inflation

A = the cost before inflation

PW = the present worth
n = the time period in years

If we let $\mathbf{X} = \left(\frac{1+r}{1+i} \right)$

then:

$$PW = A * X * (1 + X + X^2 \ldots X^{n-1})$$

Algebraic manipulation yields the following:

$$\mathbf{PW} = \mathbf{A} * \mathbf{X} \left[\frac{1-X^n}{1-X} \right]$$

Multiplying the above by the capital recovery factor to get an equivalent level yearly cost yields:

$$\mathbf{A'} = \mathbf{A} * \mathbf{X} \left[\frac{1-X^n}{1-X} \right] \left[\frac{i(1+i)^n}{(1+i)^n - 1} \right]$$

APPENDIX 2

ECONOMIC EVALUATION OF DISTRIBUTION TRANSFORMERS

This spreadsheet shows a method for calculating the levelized energy cost of producing energy over the life of the transformer in $/kwh. The program uses typical values as a starting point. In the electronic form of this bulletin, the evaluation formula will be updated as new data is entered.

	Data:		
Demand Charge	$120.00		
Energy Charge	$0.05		
Fixed Charge Rate	14.2%		
Hours per year	8760		
Capacity Factor	0.5		
Peak Load Responsibility Factor	0.9		
Energy Cost Increase per Year	3.0%		
Average Inflation	2.5%		
Interest Rate for Borrowing Money	5.0%		
First Year Peak (%of nameplate Kva)	80%		
Peak Load Growth per Year	1.00%		
Expected Transformer Life in Years	30		
Formula = Price + A* core loss + B* coil loss			
		A =	**$4.169**
		B =	**$1.378**
Loss Factor (LSF)	0.300		
PL^2	0.80712		
equivalent inflation rate r'	0.00488		
Inflation adjustment (X)	0.95703		
Inflation adjustment factor	17.0398		
levelized inflation adjusted factor	1.06083		
CRFn	0.06505		
DC'	$127.30		
EC'	$0.0530		

An electronic Excel™ copy of this spreadsheet is available from the NRECA T&D System Planning Subcommittee Chair and the Staff Director of the RUS Electrical Engineering Branch.