Low Loss Distribution Transformers in a South African Context

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Abstract

This paper provides an overview of the importance of losses in a distribution transformer. Current distribution transformer loss specifications are reviewed and an evaluation of the capitalisation formula is given with regards to four utilities. The way forward is reviewed in terms of loss improvement taking into account what is being done internationally. Finally a recommendation is made in terms of the best cost effective solution that allows for a reduction in losses with a small increase to the capital investment required when purchasing distribution transformers.

1. Introduction

South Africa's power stations are under extreme pressure. In the last two decades there has been a continuous increase in load demand without a significant increase in generation capacity. Relief of this pressure can be done through building new power stations, which is a lengthy and very costly exercise. This in effect will see energy tariffs increase drastically in the short to medium term in an attempt to recover these costs. Avoiding the cost of this upgrade is not possible but the costs can be controlled by using electricity effectively and efficiently. Although the cost of new power stations may be inevitable, using energy more efficiently in the interim will allow for the lead time to build the generation capacity required. In an attempt to curb the maximum demand on the network, energy users have been requested to use electricity with due caution and the network efficiency is being reviewed.

There are unavoidable losses on the country's electricity network. Up until recently losses were of insignificant value due to low energy costs and sufficient generation capacity. Statistics reveal that losses occurring on transformers found in generation, transmission and distribution networks, account for one third of the total electricity network losses. Therefore, more efficient transformers could produce: real cost savings for consumers, an effective increase in the capacity available and relief of some of the pressure on generation capacity.

The reduction of load on current coal fired generators will also effectively reduce the greenhouse gasses produced by these types of generation until renewable types of generation can be installed.

Considering the tariffs and viability of renewable generation the development of low loss transformers will be necessary to ensure that the power generated by renewable generators is delivered to the network efficiently.

2. Review of Distribution Transformer Specifications

In order to establish where the SA industry is with respect to losses in transformers it is necessary to look at the current transformer loss specifications. Most users specify or base their specification on the SABS 780 (South African Bureau of Standard, 2009 Edition 4)maximum component losses.

Losses are broken down into:

No-Load Loss (NLL), *“the active power absorbed when a rated voltage (tapping voltage) at a rated frequency is applied to the terminals of one of the windings, the other winding or windings being open circuited”* and

Load Losses (LL) “*the absorbed active power at a rated frequency and reference temperature (see 11.1), associated with a pair of windings when rated current (tapping current) is flowing through the line terminals of one of the windings, and the terminals of the other winding are short circuited.*” as defined in IEC 60076-1.

The biggest users of distribution transformers in the South African market are Eskom, large municipalities; mines and large industry. These users usually have their own distribution transformer specifications which use the SANS780 specified losses as an allowable maximum loss.

In addition to these maximum component losses, a capitalisation formula is sometimes specified as an incentive to the transformer supplier to offer transformers that are optimised in line with the cost of electricity applicable. A cost is given for each component loss as a Rand per Kilowatt (R/kW) factor.

These factors give the cost of the energy lost in the transfer of energy from one voltage level to the next in the transformer. The difference between the two component costs, Load and No Load Loss, is the loading factor. This is because No Load Losses are there as long as the transformer is energised where the Load Loss is proportional to the loading on the transformer.

The loss costs, from the factors multiplied by the component losses, are added to the sales price of the offered transformer to calculate the associated lifecycle cost of the loss.

The typical formula is as follows:
Total cost = $A + F_{NL} \times P_{NL} + F_L \times P_L$

Where:
A = Cost of purchasing the transformer, R
P_{NL} = No-load losses, kW
P_L = Load loss, kW
F_{NL} = No-load Loss Factor, R/kW
F_L = Load Loss Factor, R/kW

Each utility has different circumstances that affect their cost of electricity. For example how close the utility is to generation determines the amount of the cost that can be attributed to transmission, distribution and markup costs.
A utility may decide to include the cost of generation replacement based on the load forecast plan. This will show the utility if the cost of reducing losses is less than that of building more generation. This being the case the investment should be in reducing losses of transformers rather than investing in generation. For this reason four different utility cost factures are to be considered with varying cost factors. Where not specified Utilities have based cost factors on a life span of 25 years.

Utility 1 uses the following cost factors in their capitalisation calculations:

F_{NL} = 31 200 R/kW
F_L = 6 700 R/kW

Utility 2 uses the following cost factors in their capitalisation calculations:

F_{NL} = 56 430 R/kW
F_L = 11 789 R/kW

Utility 3 uses the following cost factors in their capitalisation calculations:

F_{NL} = 58 062 R/kW
F_L = 12 529 R/kW

Finally Utility 4 specifies loss factors with the following breakdown:

F_{NL} = 0.52 R/kwh x 24 hours x 365 days x N years R/kW
F_L = 0.52 R/kwh x 24 hours x 365 days x N years x Load factor R/kW

Where for transformers:
Up to 200 kVA the Load factor = 0.3
315 kVA - 500 kVA the Load factor = 0.4
Above 500 kVA the Load factor = 0.6

Up to 315 kVA the life N = 20 years
Above 315 kVA the life N = 25 years

Giving:

Up to 200 kVA	F_{NL} = 91104 R/kW
	F_L = 27331.20 R/kW
315 kVA	F_{NL} = 91104 R/kW
	F_L = 36441.60 R/kW
500 kVA	F_{NL} = 113880 R/kW
	F_L = 45552 R/kW
800 kVA up	F_{NL} = 113880 R/kW
	F_L = 68328 R/kW

The comparison above confirms the cost of energy is different for different consumers. The specifications also vary in complexity: from those that just specify maximum SANS 780 component losses to those that take into account life cycle time and load factor.

So does the general approach of evaluating the life cycle cost with the use of a capitalisation formula work or should one just work with maximum losses as has been the case in past?

3. Evaluation of the use of the capitalisation formula

To simplify the analysis and evaluation of the capitalisation formula method, we shall consider 100 kVA 11 kV transformers of different loss level. SANS 780 specifies no load losses of 300 W and load losses of 1700 W. The SANS losses will serve as a maximum losses or lowest efficiency design for this evaluation. Costs have been converted into per unit (PU) values using the SANS costs as a base value. The component losses are converted to efficiency so as to normalise the effects of both components.

A number of designs are compared with varying efficiency, sales price and total cost of ownership (calculated with the different capitalisation formulas) in figures 1 and 2.

Efficiency	NLL kW	LL kW	Sales PU	Utility 1 TCO PU	Utility 2 TCO PU	Utility 3 TCO PU	Utility 4 TCO PU
SANS 780 98.04%	0.3	1.7	1	1	1	1	1
98.12%	0.22	1.7	1.03	0.96	0.94	0.94	0.93
98.26%	0.07	1.7	1.74	1.27	1.11	1.1	0.99
98.37%	0.08	1.6	1.69	1.23	1.07	1.06	0.95
98.43%	0.25	1.4	1.41	1.15	1.06	1.05	0.97
98.53%	0.14	1.4	1.48	1.12	1	0.99	0.89

Figure 1: Cost comparisons of various efficiency transformers

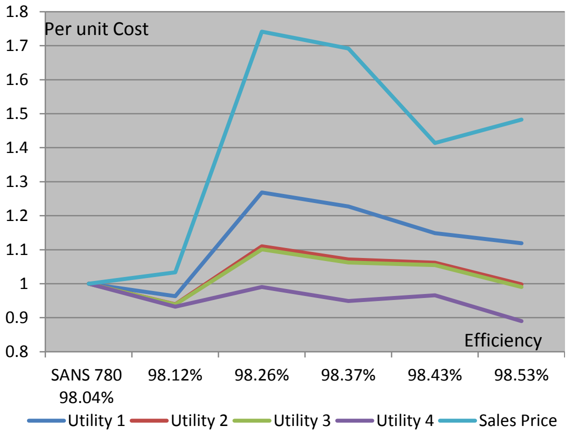

Figure 2: Per unit cost verses efficiency

It can be observed that the sales price increases as the efficiency of the transformer improves.
This is attributed to the use of more conductor area, more core area, better materials and improved manufacturing techniques needed to ensure the transformer loss is reduced.

The spike in sales price and the capitalised costs at 98.26% can be attributed to a technology change to amorphous type transformers. A possible reason why this amorphous example shows such a spike in costs is that it is imported technology as opposed to the locally manufactured grain oriented designs that dominate this analysis. Since amorphous transformers are generally designed to Chinese or Indian specifications there is an additional cost associated in introducing new designs in amorphous technology.

A second amorphous quote was obtained to try and investigate the reasons for the spike mentioned above. The quote was for a Chinese specification transformer (the 98.37% design), similar in size and specification to that in the comparison. The quote proved to be slightly more cost effective. This proves that the cost in changing designs to meet the South African specification does not affect the cost of importing amorphous technology greatly. Costs for this technology will have to be reduced by cutting out importation costs.

It can also be noticed that for utilities 1-3, the total cost of ownership calculations indicate the 98.12% efficiency design is the cheapest total cost of ownership.

If the main focus of design evaluation is to reduce losses without concern for the sale price but not increasing the total cost of ownership from the SABS 780 value, then the 98.53% efficiency design could be motivated for in Utilities 2, 3 and 4. This course of action would assume that the finances are available for the sale price of 48% more than the SABS 780 transformer cost. As reducing losses may be the ultimate goal of the utility, what can be done to drive down losses of distribution transformers?

4. Further loss improvement

To further reduce losses, more materials can be put into the design thus increasing costs and the size of the transformer. Ideally the utility would not like the transformer to grow in size, weight or cost. The growth in size and weight could mean the poles or plinths need to be upgraded to hold the new transformer. This would incur even more costs. The driver for this action would then be: an electricity cost that is higher than the cost of the changes required to reduce losses in the transformer.

Ideally, in this situation, a new technology, improving the material characteristics or improving the method materials, should be used so that cost, size and weight are contained.

A technology improvement in the form of amorphous core type transformers is not manufactured locally or to local specifications currently. Localising the amorphous technology has challenges. The amorphous technology uses thin ribbons of core, which are only supplied in two standard widths, to give extremely low no load losses. The thickness of the core makes it difficult to handle during manufacturing and the ageing properties of amorphous material is still questionable. An added difficulty in manufacturing is that in order to get the superior characteristics found on this type of core it needs to be processed by annealing the core in a magnetic field. The windings for the transformer are rectangular instead of round. Rectangular windings are not as strong, as circular windings, from a short circuit point of view.

Currently the sources of amorphous core materials are limited to two companies with a capacity that is great deal smaller than traditional sources of core steel.

Given these challenges surrounding amorphous core and the fact that current technologies give similar results on the extreme capitalisation calculation, this technology does not currently make financial sense. This may change should the cost of energy continue to increase.

A working group has been reviewing the SANS 780 specification to reflect the needs of the industry as a whole.

The graph of the efficiencies of different international specifications (Figure 3 (Geldenhuys, 2009)) shows that the SANS 780 efficiency is lower than the specifications published in Canada, US, Japan and European specifications.

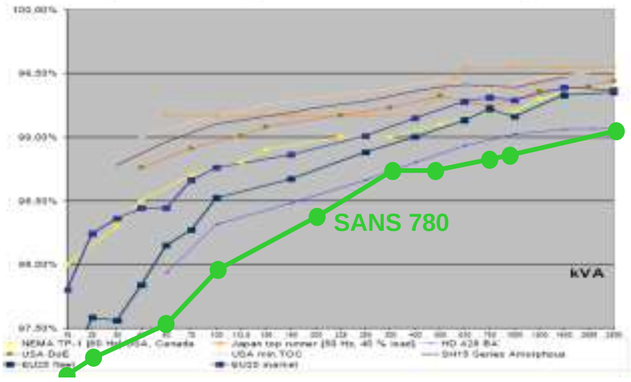

Figure 3: SA benchmark (Geldenhuys, 2009)

Considering the short fall of our generation capacity, the ever increasing cost of electricity and the need to reduce the carbon produced by power plants, this situation needs to be improved. Given the information presented thus far it is evident that capitalisation formulas look after the specific need of the utility involved.

However there still needs to be a drive to reduce the maximum allowable losses in the South African industry without increasing the costs too much. From the values given in Figure 1 it would seem that the simplest way to do this is to reduce the losses incrementally. This approach has the benefit that it will push the local suppliers and utilities towards reducing losses and raise awareness that there are total cost of ownership improvements that can be made without great changes in upfront costs. This will not bring South Africa in line with efficiency level as set by other international specification bodies, but will also not see the purchase price of transformers increase by 50% or more of the current prices in one step, depending on the level of specification chosen.

Given the fact that the capitalisation formula allows for customers with greater need to reduce losses, this incremental approach to reducing maximum losses seems to be the best compromise at this time for the South African industry.

5. Conclusion

The South African electricity industry is under pressure to reduce costs, reduce emissions and increase output. Years of cheap electricity, an abundance of coal and an excess of generating capacity have led to an industry that is complacent and in dire need of measures to curtail these ills. The risk however is a knee jerk reaction to lack of action for a prolonged time, with respect to control of losses in distribution transformers. The case has been presented for an incremental decrease in maximum losses in the SANS 780 specification and the use of the capitalisation formula to ensure that utilities get optimised transformers that do not cost the industry dearly.

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