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An Alternative Approach for the Evaluation Of Techno-Economical Total Owning Cost (Toc) Of Distribution Transformers

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Abstract- A large number of distribution transformers are being currently used in the electricity distribution network in India. During purchasing them, it is not sufficient to evaluate and analyze only the purchase price of the transformer. There are no-load losses as well as load-losses in the transformer during its lifetime, which is about 30 years. As in present scenario system investment and energy costs continue to increase, electric utilities are increasingly interested in installing energy-efficient transformers at their distribution networks The cost evaluation of transformers is depends on total owning cost (TOC) method that consist of transformer bid price and cost of transformer losses. Therefore this study recommended an alternative approach transformer cost evaluation by TOC method. Improvements in energy efficiency of electrical equipment reduce the greenhouse gas (GHG) emissions and contribute to the protection of the environment. This work proposes a simplified model that quantifies the total owing cost of transformer.

Keywords- Distribution Transformer, Total owing cost, No-load losses, Load Losses, Energy Efficient Transformer.

I. INTRODUCTION

In present scenario energy saving is an important aspect .In our power system either power transformer or distribution transformer both play important role, they are heart of the power system. Transformer is one of the major elements to transmit and distribute the electrical power from one voltage level to another and from one end to another end.

Since present requirement of energy demand is increasing day by day so in addition to increase generation capacity it is necessary to reduce the losses belong to transformer or other losses in power system. Transformer loss plays a significant role in the losses of both utilities, transmission system and distribution system. The transformer in our system continuous loaded from generation system to transmission system and extended to distribution system. In transferring power from one end to another power losses occurred along with heat loss in which loss percentage belonging to transformers also, these losses not only impose heavy financial cost but also affect global environment. Energy efficient transformers have reduced total losses i.e. reduced no load losses and load losses. Energy efficient transformer reduces energy consumption and consequently reduces the generation of electrical energy and green house gas emission.

Energy efficient transformer cost more but use less energy than low efficiency transformer .The decision as to whether to purchase a low cost inefficient transformer or a more expensive, energy efficient transformer, is primarily an economic one. The common practice used here for determining the cost effectiveness of distribution transformers is based on total owing cost method, where TOC is equal to the sum of transformer purchasing price plus the cost of transformer losses throughout the transformer life time. By reducing the power losses in the transformer, economy of the power sector and impact on global environment can be improved in certain extent.

II. LITERATURE REVIEW

NICKEL D.L, This paper proposes a method for distribution transformer loss evaluation. Alternative methods of distribution transformer loss evaluation are examined and to investigate opportunities for improving the operating efficiencies of a distribution transformer. In this, we focused on determining the optimum performance characteristics that can be reached with conventional transformer optimizing technology under the constraints of system cost, load characteristics, and transformer design. This study also analyzed the concept of multiple efficiency transformers designed to reduce losses at the distribution level. The no load and load loss costs for a 25 KVA transformer are calculated using this evaluation technique.

BRAUNSTEIN H.R, In this paper mainly focused on load characteristics and system cost parameters since these have a significant effect on the transformer evaluation results. a companion paper shows a method for distribution transformer loss evaluation using levelized annual costs. Although there is a variation in the parameters used by various electrical utilities to perform these evaluations, therefore, this paper discusses the necessary considerations for the development and proper selection of these parameters.

GRENARD S., STRBAC G.: This paper has presented the way in which distribution companies are regulated in the UK. Because of their natural monopoly situation, their allowed revenue is defined by OFGEM and is based on the cost incurred and the value of the asset. Electricity industry in England and Wales draws distinction between energy retail ('supply') and the transportation of electricity to end customers ('distribution'). Due to their monopoly situation, the Distribution Network Operators @NOS) are required to operate their wires network within a cost based price cap regulation.

This paper discusses the basis upon which the allowable revenue is presently determined The paper points out that the network designers are under pressure to accept a minimum investment rather than minimum life cycle costs. Examples based on the comparison of the costs incurred and the revenues obtained under the current regulatory framework when purchasing an efficient rather than a standard transformer, and also when purchasing 11kV cables with optimal cross section, demonstrate the present lack of incentives to achieve efficient level of losses.

W.D.A.S. WIJAYAPALA, This paper study the current scenario of Srilanka electricity board presently a large number of distribution transformers are being currently used in the electricity distribution network in Sri Lanka. When purchasing them, it is not sufficient to evaluate only the initial price of the transformer. There are no load losses as well as load losses in the transformer during its life span, which is about 35 years. Therefore, transformer purchaser has to evaluate the total lifetime cost of the transformer, which includes its purchase price, and the cost of losses that can occur during the life of the transformer. Traditionally, this evaluation has been done based on the Total Owning Cost (TOC). This paper discusses setting up of a methodology to calculate capitalization values for losses in distribution transformers used in Srilanka, using IEEE loss evaluation guide.

III. PROBLEM STATEMENT

In Madhya Pradesh, the power distribution company is divided into three zonal independent companies. According to the annual report 2018-19 the total number of power transformer are 5631 and total number of distribution transformer units are 4,65,370. Most of distribution transformers in today were of conventional core type (CRGO material). Although some of these transformers may be of amorphous core type, they are approaching or past the designed lifetime. Low efficiency and high losses is a serious contributing factor which broadening the gap between energy supply and energy demand which results in high operating costs in many. Therefore it is important for utilities to know the importance of highly efficient transformer which lead to low losses both no load and load and impact on environment.

IV. OBJECTIVES OF WORK

To carry out literature review on total owing cost of distribution transformers. To compute and compile data for operation and specifications of transformers (no load and load losses and design data). To calculate total owing cost of transformer. This will be done with the help of differential equation and their formulation in a MATLAB programming.

- To predict the lifetime cost of transformer base on their actual loading profile, losses and others factors impact on lifetime cost.

V. PARAMETERS AND FACTORS USED FOR THE COMPUTATION OF A & B

1. Efficiency of Transmission

The Efficiency of Transmission (ET) is defined as the energy received at the input terminals of the distribution transformer divided by the energy transmitted from the source. Normally, this efficiency varies with loading, location, voltage level or season, etc. The efficiency of transmission becomes significantly large in some instances.

2. Increasing Factor

The Increasing factor (IF) represents the total cost that the user must pay to acquire the transformer. This term includes components like purchase price of the transformer, overhead fees and tax. The CEB considers overhead cost together with labour charges. Sales taxes are also not applicable to the CEB. Therefore, components like overhead cost, sales taxes and consultancy fees are not taken for the calculation of the Increasing Factor (IF). The purchase price is the only component considered. Hence, the increasing factor is taken as 1.00 for the calculation.

3. Total power losses

- The sum of the no-load losses and the load losses, not including auxiliary losses.
- Transformer loading factor (LF)
- The root-mean-square value of the predicted loads of the power transformer over a
- Representative yearly period is an equivalent load.
- Uniform Annual Peak Load
- The term uniform annual Peak Load (PL) is given to the levelized peak load per year over the life of the transformer. It is dependent on the initial peak load, the estimated load growth rate and the maximum allowable load of the transformer.

4. Formulation For Loss Evaluation Factors A & B

- In this, the A and B factors that are used in TOC formula is computed as follows:

$$A = \frac{\mathrm{LIC} + \mathrm{LECN}}{\mathrm{ET} \times \mathrm{FCR} \times \mathrm{IF}}$$

$$B = \frac{\mathrm{LIC} \times \mathrm{PRF}^2 \times \mathrm{PUL}^2 + \mathrm{LECL} \times \mathrm{TLF}^2}{\mathrm{ET} \times \mathrm{FCR} \times \mathrm{IF}}$$

Where

- LIC is the levelised annual generation and transmission system investment cost (in $/kW-yr).
- LECN is the levelised annual energy and operating cost of transformer no-load loss (in $/kW-yr).
- ET is the efficiency of transmission.
- FCR is the fixed charge rate that represents the 'cost of ownership'.
- IF is the increase factor (it represents the total money that the user must pay to acquire the transformer, including the purchase price, overhead fee and taxes).

Where

- PRF is the peak responsibility factor that derives from the transformer load at the time of the power system peak load divided by the transformer peak load.
- PUL is the peak per unit transformer load that derives from the average of the annual peaks throughout the transformer lifetime divided by the transformer rated load loss.
- LECL is the levelised annual energy and operating cost of load loss (in $/kW-yr).
- TLF is the transformer loading factor.

5. Formulation For Loss Evaluation Factors A & B

- The levelised costs LECN and LECL are computed as follows.

$$\mathrm{LECN} = \mathrm{CRF} \times \mathrm{HPY} \times \mathrm{AF} \times \sum_{j=1}^{\mathrm{BL}} \mathrm{CYEC} \times \frac{(1+\mathrm{EIR})^j}{(1+d)^j}$$

$$\mathrm{LECL} = \mathrm{CRF} \times \mathrm{HPY} \times \sum_{j=1}^{\mathrm{BL}} \mathrm{CYEC} \times \frac{(1+\mathrm{EIR})^j}{(1+d)^j}$$

Where

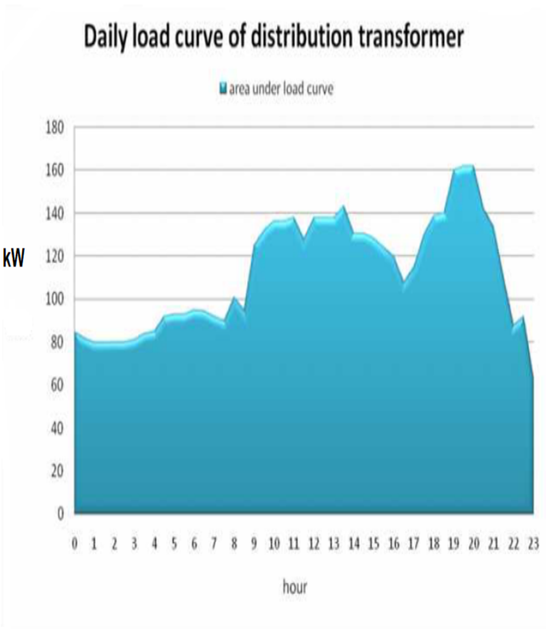
- CRF is the capital recovery factor.
- HPY indicates the hours of transformer operation per year (typically 8760 h).
- AF represents the transformer availability factor (i.e. the proportion of time that the transformer is predicted to be energized, which may be less than unity due to failures).

- BL is the number of years of transformer lifetime.
- EIR (in %) is the annual escalation rate of the energy cost (cost of electricity).
- d (in %) refers to the discount rate (interest rate).
- CYEC refers to the current year energy cost (in $/kWh).

It should be noted that throughout this work, the current year (or year 0) is defined as the year before the first year of transformer operation.

6. Calculation Of Load Factor, Prf And Pul

- The load factor (Lf) is calculated by Loss Factor (LF). Normally, the load factor is considered as a measure of the utilization of the electricity network. Therefore the load factor and the loss factor are calculated according to the daily load profile of distribution transformer.
- Peak Responsible Factor (PRF) are made using measurements made on several distribution transformers in urban areas. Transformers in urban areas (Jabalpur) were selected according to norms mentioned above.
- A sample calculation was done using data recorded from distribution transformer (200kVA).the demand curve of distribution transformer are shown in figure.



Graph .1

- Area under load curve = 2717.96 kW
- Average load = Area under the curve / 24

= 2717.96/24

= 113.24kW

According to the load curve peak load accurse at night due to domestic lightning load and it is approximated value is 160 kW.

Load factor (Lf) = Average load/ Peak load = 113.24/160

= 70.17 %

- Loss factor (LF) = (a × Lf) + (b × Lf^2) ,
- a, b – constant values dependent on loading profile
- while a = 1-b.

In the MP Discom, planning engineers uses 0.3 and 0.7 for 'a' and 'b' respectively

= (0.3 × Lf) + (0.7 × Lf ^2)

= (0.3 × 0.7017) + (0.7 ×(0.7017) ^2)

- Loss factor (LF) = 0.55

7. Peak Responsibility Factor (PRF).

Generally, the peak responsible factor indicates the relationship between the transformer peak load and the transformer load at the time of the electrical utility system peak load. The power transformer's load at the time of the system peak divided by the power transformer's peak load. Since from daily load curve of Madhya Pradesh Poorv Zone the peak load of utility occurs at 6:00 pm and peak load on transformer occur at 8:0 pm, therefore from load curve.

PRF = Power transformer's load at the time of the system peak/ Power transformer's peak load

=140/160

=0.875

7.1 Calculation of Capital Recovery (Crf)

Capital Recovery Factor (CRF).

To determine "total levelized annual costs. " Capital Recovery Factor" is used. The sum of the present worth of the costs is levelized by multiplying by the capital recovery factor.

$$\mathrm{CRF} = \frac{d \times (1+d)^{\mathrm{BL}}}{(1+d)^{\mathrm{BL}} - 1}$$

Where,

d = rate of return or discount rate or rate of interest

BL = the number of cost is levelised or life span of transformer

According to annual report, the discount rate is 10% and BL is 30 years.

So,

CRF = 0.106

7.2 TEST DATA

- The proposed method is used for economic evaluation of three different transformers shown in Table A. (Model 1 to Model 3 denoted as DT1 to DT3).
- These models correspond to three –phase oil filled naturally cooled distribution transformer 50Hz, 200 KVA. The typical distribution transformer load profile of MPPKVVCL Jabalpur shown in figure 4 is used i.e domestic profile

Transformer type (Core type)	Capacity, KVA	No load loss, Watt	Load loss, Watt	Purchase price in dollar, $
D1(CRGO steel)	200	500	2800	3076.92
D2(Hi-B grade)	200	300	2300	3538.72
D3(laser grade)	200	180	2300	4000.00

Table 7.2.1 (Table A)

Input Parameters For The Calculation Of A And B-(Loss Evaluation Factors)

INPUT PARAMETERS			CALCULATED PARAMETERS			
Symbol	Values	Unit	Symbol	Value	Unit	Equation
AF	0.95	_	CRF	0.106	_	
HYP	8760	h/yr	LF	0.55	_	
BL	30	Yr	PUL	0.8125	_	
CYEC	0.089	$/kW	TLF	0.6025		
EIR	0.035	Per year	LECN	1241.27	$/kW-yr	
FCR	0.193		LECL	1306.604	$/kW-yr	
d	0.10	Per year	A	9467.03	$/kW	
PRF	0.875	_	B	3403.90	$/kW	
If	0.7017	_				
IF	1					
ET	0.7998	_				
LIC	148.32	$/kw-yr				
ITL	0.40					
TPLIF	0.025					

Table 7.2.2(Table B)

7.3 Evaluation Of Toc

In order to compute the A and B loss evaluation factors, the input parameters which are shown in Table B are required. Based on input data of Table B it is found that

A = $9467.03/kW and B=$3403.9/Kw

The TOC results for the three different transformer models as shown in Table A are presented in Table C these outcomes depend on factor A and B of Table B, the purchase price as well as losses of each transformer model of Table A, employing TOC formula . Table C shows that despite the fact that transformer design D1 is the cheapest one regarding the purchase price, the transformer model D1 is the unfavorable and worst investment in long term scenario, because it has the highest TOC. In contrast, it is clear that transformer model D3 is the favorable and profitable investment in long term, because it has the lowest TOC. Although the purchase price of D1 is 23.08% cheaper than the purchase price of D3, the TOC of D1 is 29.25% more expensive than the TOC of D3 throughout the 30 years of transformer life time. The above mentioned difference in the TOC of D1 and D3 is attributed to the difference in the cost of losses of D1 and D3, as Table C shows.

Cal7.4 Calculations For Toc Values For D1, D2 And D3

Table 7.2.3 (Table C)

Transformer type (core type)	Capacity KVA	No load loss, Watt	Load loss, Watt	Purchase price In dollar $	TOC when installed in Madhya Pradesh (in dollar,$) A=9467.03 B=3403.90
D1 (CRGO steel)	200	500	2800	3076.92	17346.37
D2 (Hi-B grade)	200	300	2300	3538.72	14207.40
D3 (Lazer grade)	200	180	2300	4000.00	13533.04

VIII. RESULT ANALYSIS

- Based on the results summarized in Table B and Table C, TOC can be calculated for any transformer if the no-load loss and full load loss and the initial purchase price are known.
- Table C shows the Total Owning Cost (TOC) for typical 33kv/400V 3- phase distribution transformers used in Madhya Pradesh Electricity Board based on whether they are installed in rural, semi-urban or urban areas of Madhya Pradesh together with their initial purchase prices for comparison.
- The no-load loss and load loss values of transformers presently used by the MPSEB as

summarized in Table A were used for this calculation.

- The results clearly show that customers should not get misled by the attractive low initial prices of transformers but that they need to be guided by the Total Owning Cost (TOC) taking life time costs due to transformer losses into consideration.
- They should also be concerned of the type of the load profile applicable to the transformer they purchase, as indicated in this study from the load profiles of transformers Installed in urban areas of Madhya Pradesh.
- Table C., it is shows that transformer D3 with laser grade core material has highest purchase price i.e. 4000US$ but instead of that it has lowest cost over 30 years i.e. 13574.9$ compare to remaining two models D1 and D2 transformers.
- It is recommended that replace the old D1 model transformers with new.
- It is recommended that in future environmental cost due to losses may be included to evaluate the TOC of distribution transformer.

Future Scope

- Installation of new technology based superior transformer by replacing old conventional design transformers installed in MPPKVVCL Jabalpur.
- New Installations could be energy efficient transformers instead of CRGO which is beneficial for the incremental of load factor in MPPKVVCL Jabalpur.
- Decreased energy loss reduces maximum demand which result in decreased energy generation, lesser capital cost and better environmental effects (CO2 emissions).

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