Estimation of Distribution Transformer Losses in Feeder Circuit

V. A. Kulkarni and P. K Katti

Abstract—Losses of distribution transformers (DT) in a distribution system (DS) depend on mainly load. Actual measurement of these losses in substation (SS) feeder circuit is not easy due to many inconveniences like difficulty in installation of meters, unfavourable locations and conditions. But as the DT losses are sizeable they need to be considered for overall loss calculations. In this paper, an approach is developed to estimate the DT losses in a feeder circuit. Losses of individual DTs are calculated and summed up to give the losses due to DT circuit. A sample case of a large power system is considered. The losses are calculated by the said approach. The overall DT circuit losses are 8.57% of the total import.

Index Terms—Feeder circuit, Loss calculation, Loss factor, Transformer losses.

I. INTRODUCTION

Energy losses of a power system are calculated by two methods:

- i. Actual readings and
- ii. Analytical calculations.

A large DS comprises of feeder lines, DTs and end users. Generally the loss measurement is through a simple empirical formula given by Losses equal to difference between input and output in units (kWh). However, if it is required to estimate the losses of individual sections like only feeder or transformer circuits, it is practically difficult. For this purpose, it is necessary to install the meters in the individual circuits. Because of topography, vast area and inconveniences in installing and noting down, the actual readings method is practically difficult.

The analytical method may be approximate. Sometimes the results may differ too much with that of the practical values giving rise to big gap in the two estimations. Therefore, the best method is to combine these two methods and estimate the best possible losses near to accuracy[8].

In this paper, a method that includes the load variability and corresponding actual readings are considered. The period is one month.

The two methods are used to estimate the losses in the transformer circuit in a feeder and a new approach is presented.

The organization of this paper is as follows:

Firstly, the power system SS, its components like feeder and DT are discussed. Various losses in DTs are discussed.

Next, approach for estimating the losses of DT circuit is presented using actual readings available and analytical methods.

A large power system is considered as sample case study. The load profile, based on the consumer's data, is described. The approach is implemented for the loss calculations. Results and conclusions are drawn on the basis of calculations.

II. SUBSTATION (SS) FEEDER CIRCUIT

Energy is supplied from the substation to the end users (consumers) by feeder circuit. It can be divided into two parts as :

- i. HT feeder line which a conductor overhead or underground (ACSR or HT cable) and
- ii. Ttransformer (DTs).

Fig.1 shows a typical feeder circuit indicating the deployment of DTs in branches and sub branches.

Fig.1. Typical Feeder Circuit

A. Distribution Transformers(DT) Losses

Since transformers are inductive in nature they consume the power with lagging power factor. But the key input for estimating distribution transformer energy loss is the transformer load that determines the power factor and energy consumed. The distribution transformer rated capacity does not reflect their actual consumption. Therefore, there is no measured load records for distribution transformers when the feeder is supplying the energy. The loss due to DT is of significance as it contributes to some percentage of total input units. Attempts may be made to minimize these losses.

Losses are broadly classified as [1]:

- i. *No load losses*(W_i) : Taking place in iron /core part comprising of hysteresis Losses and eddy current losses in the Core considered to be constant irrespective of load.
- ii. *Winding losses or load loss* (W_{wdg}): Taking place in the winding part. As a function of load current, can be divided into (I^2R) loss and stray losses. The stray losses are caused by eddy-currents that produce stray electromagnetic flux in the windings, core, core clamps, magnetic shield and other parts of the transformer

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- iii. *Other losses* (W_{other}): dielectric loss (due to electrostatic reversal in insulation and circulating currents), load unbalance, oil leakage, loss of life, lack of maintenance, improper up keep of distribution boxes, and joints loose connections. Generally the value is less than 1% of total energy input to the system.

The most important losses are W_i and W_{wdg} . The other losses are described mainly to give a complete picture on losses.

B. Loss Calculation Approach

T = Period of consideration (day/month/year)

$$\text{kVA}_{\text{av}} = \text{Average of recorded kVA from load curve} = \frac{\sum_{i=1}^T \text{kVA}(i)}{T}$$

Load factor (L_d): It is the ratio of the average kVA consumed during a designated period, to the maximum demand (MDkVA) occurring in that same period. A system load factor measures the degree of utilisation of the power supply system. By increasing the system load factor, the need to provide larger building transformer capacity may be avoided and the construction of new generating and transmission plant may be delayed or the magnitude of the increase reduced. It is given by [7]

$$\text{Load factor} = L_d F = (\text{kVA}_{\text{av}}) / (\text{MDkVA})$$

Loss factor ($L_s F_{\text{actr}}$): It describes the average electrical energy losses for electricity transmitted during T . Ideally, to calculate the load losses it would be necessary to integrate the squares of all momentary ratios of actual load to the rated load. This is practically difficult. Therefore, summation of energy consumed in transformers is developed given by [2]-[5]:

$$\text{Loss factor} = L_s F_{\text{actr}} = L_d F^2 + (0.273) (L_d F - K)^2$$

where $K = (\text{kVA}_{\text{min}}) / (\text{kVA}_{\text{max}})$ (as per load curve)

$$\text{Now, } W_{\text{wdg}} = W_c [(MD \text{ kVA}) / (Tr \text{ kVA}_{\text{total}})]^2 (L_s F_{\text{actr}})$$

where W_c = Full load Copper loss

W_i and W_c can be obtained from the standard losses table available.

$Tr \text{ kVA}_{\text{total}}$ = Total ratings of all transformer kVA

Transformer energy losses are given by $TR_{\text{Enloss}} = (W_i + W_{\text{wdg}} + W_{\text{other}}) T$

Total Losses for all distribution transformers can then be calculated by summing the losses for individual transformer as below:

$$\text{Total Transformer energy losses} = \sum_{i=1}^n TR_{\text{Enloss}}(i)$$

III. SAMPLE CASE STUDY

A large scale power system is considered in Pune, India. The Substation (SS) is located in dense industrial area comprising Small Scale Industries (SSIs), medium and large industries. Working voltage of SS is 220kV /22kV having 44 feeders. 90% of the power is supplied to industries. Feeder No12 is selected for sample study. The period of study was one month (for 30 days) in May 2010. The feeder is drawn through distance of 15 km. Figure 2 shows the load curve profile the feeder circuit.

Maximum consumption is 68541 units on sixth day,

minimum is 58000 units on fifth day and average is 62533.3 units. And maximum is 38000kVA on twentieth day, minimum is 13876 kVA third day and average is 20562.8 kVA.

Standard transformer losses are shown in Table I.

Fig.2(a). Load Curve Units (kWh)

Fig.2(b). Load Curve kVA

TABLE I: STANDARD TRANSFORMER LOSSES

Sl. No.	Transformer rating kVA	W_i (W)	W_c (W)
1.	100	350	2500
2.	200	570	3300
3.	315	800	4600
4.	500	1100	6500
5.	1000	1800	11000
6.	2000	3000	20000

All are oil immersed transformers. Overall transformer capacity is 44205kVA. It is clear from the table I that 2000 kVA transformers have the major share of about half of the total capacity. These transformers are mainly used for SSIs which are LT consumers. Table II shows the details of the transformers in the feeder circuit and their share in the overall transformer capacity.

TABLE II: DETAILS OF TRANSFORMERS USED

Sl. No	Transformer rating kVA	Qty	Total kVA	Percentage (%) of Overall Total capacity
1.	100	15	1500	3.39
2.	200	10	2000	4.52
3.	315	07	2205	4.99
4.	500	15	7500	16.97
5.	1000	11	11000	24.88
6.	2000	10	20000	45.24
Total Overall		68	44205kVA	
Tr kVA_{total}				

Out of 68 DTs, 50 (73.5%) are installed before 20 years. The total transformer capacity is loaded to 87% (38000 MD kVA of feeder). The power system is very large and the available manpower is proportionately less. Hence routine maintenance of transformers is carried out once in three years. Therefore, transformer losses are expected to be more.

All the DTs are essentially located near the load centers. The cables drawn to the loads are not more than 25 mts., reducing the losses in the cables.

Table III indicates the calculated values of various factors

TABLE III: FACTORS USED FOR LOSS CALCULATIONS

$L_d F$	0.539
K	0.365
$L_s F_{actr}$	0.298

Transformers in electricity distribution companies have low loadings for many reasons. DTs are protected against short circuit, but not against overload or excessive temperature. The anticipated high variability of load and the need to reserve capacity to provide resilience against failure of other equipment are some of the reasons[9].

IV. RESULTS

As per the load curve data, total consumption (SS import) is 1876000units, 616884 kVA per month.

Although transformer capacity is loaded to recorded value up to 38000 MD kVA collectively but considering the low values of the factors, it can be noted that in terms of loading, the utility of transformers is less.

Table IV presents the losses of DTs grouped as per the ratings.

TABLE IV(a): DAILY ENERGY LOSS OF TOTAL TRANSFORMER CIRCUIT

Sl. No.	Transformer Type (kVA)	Qty	Energy Losses in Units(kWh)			Total Units (kWh)
			W_i	W_{wdg}	Other losses W_{other}	
1.	100	15	108	147	27	282
2.	200	10	112.8	158.4	41	312.2
3.	315	07	103.6	155.2	34	292.8
4.	500	15	324	459.3	78	861.3
5.	1000	11	475.2	871.2	146	1492.4
6.	2000	10	720	1056	237	2013
Total Σ			1843.6	2847.1	563	5253.7

TABLE IV(b): MONTHLY ENERGY LOSS OF TOTAL TRANSFORMER CIRCUIT

Sl. No.	Transformer Type (kVA)	Qty	Energy Losses in Units(kWh)			Total Units (kWh)
			W_i	W_{wdg}	Other (Oil, Joints, Life)	
1.	100	15	3240	4410	810	8460
2.	200	10	3384	4752	1230	9266
3.	315	07	3108	4656	1020	7864
4.	500	15	9720	13779	2340	25839
5.	1000	11	14256	26136	4380	44772
6.	2000	10	21600	31680	7110	60390
Total Σ			55308	76251	15870	156591

The table V shows losses of each group as percentage of total import units in the feeder.

TABLE V: RATING WISE TRANSFORMER LOSSES FOR ONE MONTH

Sl. No.	Transformer Type (kVA)	Percentage(%) Of Total input (import) Units(kWh)
1.	100	0.45
2.	200	0.5
3.	315	0.63
4.	500	1.38
5.	1000	2.39
6.	2000	3.22
Total Σ		8.57%

Fig. 3 shows the losses of the transformers grouped according to the ratings.

Fig.3. Transformer losses as percentage of total import

V. CONCLUSIONS

The method used in this paper makes use of the past data of the feeder circuit. By calculating the factors, the losses can be easily calculated.

Total losses due transformers in the feeder circuit is 8.57% of the total input to the substation.

This quantity of loss is seemingly little high as compared to normal losses of 5 to 6% in a feeder circuit. More losses in present case can be attributed to life, poor maintenance and environmental aspects. If maintenance work is done with planning, at least 5000units (0.3%) can be saved. It can be noted that the losses are more for high rated transformer groups. This is because they are connected to bulk LT consumers. The network is large and covers many versatile types of machinery. Hence the losses are expected to be more. Transformers of low ratings are connected to HT consumers. Compared to LT consumers, HT consumers are less in number and are cautious about energy saving activities. Energy Conservation in HT sector is comparatively wide and easy.

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