# Estimation Of Technical Losses In A Distribution System

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## Abstract

*This paper presents the estimation of Technical loss in a distribution system which plays an important role in planning and hence economics of any distribution utility. In a system there are two types of losses: fixed i.e.no load losses and variable i.e. load losses which are a function of load. Out of the total system losses, technical losses can be estimated using load curve parameters. This paper focuses on how load curve parameters like load factor, loss factor, coefficient of variation and loss coefficient can be useful for the loss estimation process. A simple approach is proposed to estimate technical loss in HT feeder and Distribution Transformer with non-functional energy meters with average demand using data available with local distribution company. Also, the paper discusses the use of average demand and loss coefficient in making economic cable choices and energy losses analysis.*

*Keywords: Load factor, Loss factor, Coefficient of variation, Loss coefficient Load curve, Loss curve, Loss estimation, Technical losses and Energy losses.*



## 1. Introduction

Of all the energy sources both conventional and nonconventional, Electrical Energy is the cleanest form of energy. Electrical energy is converted from various forms of conventional and non conventional energy sources at suitable locations, transmitted at a high voltage over long distance and distributed to the consumers at a medium or low voltage. Generally, the definition of an electric power system includes a generation, transmission and distribution system. Total system loss is the account of purchased energy over the sold one. In other words, total system loss indicates how effectively and efficiently a power system is delivering power to its customers. Hence became one of the controlling factor while planning and operating strategies. Most of the power utilities have high Transmission and Distribution (T&D) losses which occurs due to technical and nontechnical i.e. commercial losses. Total system losses [1] consists of transmission and distribution losses as follows

$$\text{Total Losses } T_{Loss}=T_{TL}+T_{NTL}+D_{TL}+D_{NTL} \qquad (1)$$

Where $T_{TL}$ and $T_{NTL}$ are the technical and nontechnical transmission losses, respectively, and $D_{TL}$ and $D_{NTL}$ are technical and nontechnical distribution losses, respectively.

As the nontechnical transmission losses are negligible, total system losses consists of technical transmission loss and technical and nontechnical distribution losses. A distribution system is that of power system which distributes power to the consumers for local use. It consists of a large number of distribution transformers, feeders, and service mains,. The distribution system losses have two components, namely, technical and nontechnical or commercial, together called "total distribution loss".

## 2. Causes of Technical losses in Distribution systems ($D_{TL}$)

Technical losses in distribution systems are contributed by the high voltage (HV) to medium voltage (MV) substation transformers as well as by the MV distribution circuits, the MV to low voltage (LV) transformers, the LV circuits, the customer service drops, and the end-user meters. Loss ratios in the LV circuits, customer service drops, and end-user meters are estimated as approximately 2.3%. Transformer core (no-load) losses were estimated from 1) the number of transformers for each region of the system; 2) the average transformer kilovolt ampere capacity, calculated from available information; and 3) the magnitude of core losses in typical transformers [1].

## 3. Causes of Non-technical losses in Distribution systems ($D_{NTL}$)

In distribution systems, the sources of nontechnical losses are

1. Unread or improperly read meters and/or wrong entries of readings.
2. No meter cases, due to a lack of meters (in these cases, billing is often done on average basis);
3. Inaccurate meters; meter tampering and meter bypass;
4. Unauthorised use of supply/Illegal connections (theft)

Once total distribution losses and the technical distribution losses are known, nontechnical losses are easy to compute.

## 4. Need for loss estimation

In distribution system, generally metering is limited to urban areas. In rural areas, metering is partial i.e. loads and distribution transformers also are rarely metered. Thus Energy losses in distribution systems are generally estimated rather measured because of inadequate metering and no metering. Also data collection is costly. Generally this estimation is based on some thumb rules. The consumption of unmetered categories of consumers and no metered Distribution transformers are guessed based on some rules of thumb.

## 5. Approach for loss estimation

As the Load profile data of HT feeder is readily available with the distribution company, load curve parameters are easily calculated as

**"Load factor** -The ratio of the average load in kilowatts supplied during designated period to the peak or maximum load in kilowatts occurring in that period", [2], [3].

$LD_F$=Average load/Maximum load.

**Loss factor-**The loss factor can be used to calculate energy losses for those parts of the electric system where the current flowing is proportional to system load each hour, which is case with the distribution systems. The actual losses of the system during a designated period are obtained by multiplying the total losses at maximum current by a factor which is called as loss factor [4].

Loss factor is defined as [5]

1 $LS_F1$=Actual loss (kWh) during period/Loss at maximum current (kWh) also

2 $LS_F2$=the mean of the load squared over the maximum load squared.

**"Equivalent Hours Loss Factor** - The ratio of the average loss in kilowatts occurring during a designated period to the peak or maximum loss occurring in that period. Similar interpretation of Loss Factor is Equivalent Hours [2] which can be obtained by multiplying the Loss Factor by the duration of the period".

## 6. Relation between load factor and loss factor

In 1928, Buller and Woodrow proposed a relationship between load factor and loss factor, by using a completely empirical approach [6].Three situations were studied: 1) very short lasting Peak demand, which is the value of loss factor approaches the value of load factor squared. This situation is represented by curve B as shown in Fig 1. 2) off peak load is zero, that is the load factor is equal to loss factor, represented by curve A and 3) Intermediate arrangement i.e. load is steady means the value of the loss factor approaches the value of load factor and the value of loss factor [7] lies between .

$$LD_F^2 < LS_F < LD_F \quad (2)$$

From the above cases," "For any given Load Factor, the corresponding value of Equivalent Hours will be somewhere between the limits of load factor×24 and load factor$^2$×24",[8].

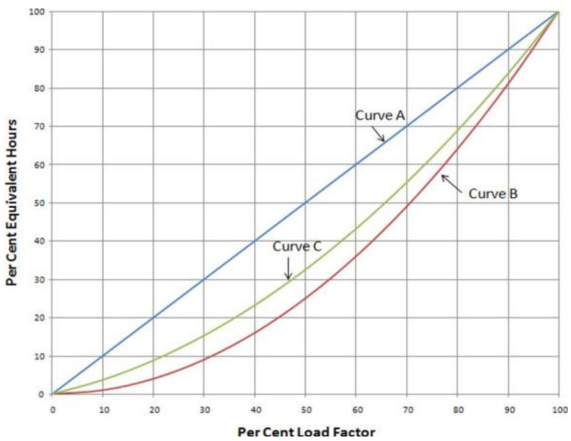


Figure 1.Relationship between load factor and loss factor [8].

In 1928, Buller and Woodrow proposed a relationship between load factor and loss factor, by using a completely empirical approach [6] represented by eq. (3). This approach was used by Hoebel in 1959. Hoebel asserted that "A number of typical load curves experienced on a large system have been studied to determine this relationship". The existing relationship between the two factors is modified later by Martin. W. Gustafson, a Transmission/ Substation design engineer. He modified the constant coefficient and also added a new coefficient for losses [2], [3].

Empirical equivalent hours loss factor

$EQ_F = (LD_F) * (1 - k) + (LD_F) * k$ (3)

Where:

$EQ_F$ = Equivalent hours loss factor

$LD_F$ = Load factor

k = constant coefficient (k as 0.3, 0.2, 0.1)

$LS_F a = (LD_F) * (1 - k) + (LD_F) * k$

*with k as 0.3,0.2,0.1*

Buller and Woodrow developed the relationship between load factor and loss factor with value of constant coefficient as 0.3. H. F. Hoebel revised the relation of loss factor and load factor with an exponential coefficient. The value for the exponent commonly used was 1.6 as per eq. (4).

$LS_F b = \text{Loss Factor} = (\text{Load Factor})^{1.6}$ (4)

Martin. W. Gustafson revised the coefficient k as 0.08 for the constant coefficient and 1.912 for the exponent [2], [3] as he observed that the values of 0.3 for the constant coefficient and 1.6 for the exponential coefficient were not appropriate and a constant term is added which represents no load losses.

$LS_F c = \text{Loss Factor} = (\text{Load Factor})^{1.912}$ (5)

The yearly data of 11 kV feeder of urban distribution system were collected and monthly Load Factor and Loss Factor are calculated using various approaches (with k=0.3, 0.2, 0.1,0.08 and with e=1.6 and 1.912), The summary of the analysis is shown in Table 1. From the calculation, it is clear that value of k as 0.08 and value of exponent as 1.912 are appropriate. Hence the values of the coefficients are not generalised as they are very important in estimating losses. Since each system has a different load profile, which leads to different values of coefficients. Loss Factor calculated with exponent value e=1.912 is nearly same as the actual Loss Factor.

## 7. Calculation of losses from load factor

Average loss was estimated from the loss factor calculated as per previous section. The results were compared with the actual one as shown in Table. 2. Estimated (calculated) loss is nearly same as the actual one. This result will be different for another distribution utility hence it is advised that a distribution company, use previous data, for calculation of the values of the coefficients, for their respective load profiles.

## 8. Drawbacks with loss estimation using maximum demand and loss factor

No direct relationship exists between the maximum demand and energy losses. Also, the maximum demand for a given system is a certain variable and is usually measured at a lower precision as compared to the energy consumption; therefore, estimation of energy loss using maximum demand should be avoided whenever possible. There are some drawbacks [8] using maximum demand and loss factor as below

1. Demand measurement and its consequences in the evaluation of the Maximum Demand. The 24 point load curve when integrated to a 12-point load curve over two different time frames: 12a and 12b (Each point of these two curves is the mean of four points from the 24-point load curve, the maximum demands of these load curves are different.
2. The random nature of the maximum demand-maximum demand is uncertain variable and it cannot be predicted.
3. The relation between the *loss factor* and the load factor.

## 9. Approach for energy loss estimation using loss coefficient

Energy losses in a distribution system are estimated with proposed load curve parameters. Load curves of a HT feeder are readily available with the distribution utility hence feeder losses can easily be estimated using load curve parameters. But this is not the case with distribution transformers. Here some load curve parameters are discussed. Energy loss of a feeder [8] is calculated using its load curves as follows

The total load $I$ through a feeder is having two components –constant $I_{bar}$ and variable $I_{var}$. A constant load is nothing but the averaged load over a specified time period and a variable load is the difference between the value of load at a given period and average load.

$I = I_{bar} + I_{var}$ (6)

Energy Losses $= R*t*(I_{bar} + I_{var})^2$ (7)

R-resistance of line/feeder-time period, as the average value of $I_{var}$ is zero

Therefore, Energy Losses$= R*T*(I_{bar}^2 + \sigma^2)$, (8)

Energy Losses$= \Delta_{EL} = R*T* I_{bar}^2 (CV^2 + 1)$, (9)

where T-total time period, $\sigma^2$-variance , σ is the standard of deviation,CV is the coefficient of variation of load curve. It is a normalized measure of the dispersion of any distribution of points, and it is defined as the ratio of the standard variation to the mean. The coefficient of variance is a dimensionless number.

## 10. Statistical analysis

Here, the load curve parameters discussed in previous section are evaluated for a load curve. Each load curve has 24 intervals with durations of 1 Hr. In urban distribution system, it is not the practice to record hourly load data for Distribution Transformer, hence the load curves were collected from loads (HV and MV).Table 3 presents some statistics of the load curve parameters. The statistics of each parameter are the mean, minimum, maximum, standard deviation and CV. From the calculated values, it seemed that there is large variation. Hence it is advised not to take fixed value for any parameter.

"Table 1.Comparision of Loss Factors"

| Month | Actual values | | | Measured values | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $LD_F$ | $LS_F1$ | $LS_F2$ | $LS_Fa$ | | | $LS_Fb$ | $LS_Fc$ | |
| May-12 | 0.8102 | 0.6564 | 0.6633 | 0.7025 | 0.6871 | 0.6718 | 0.7140 | 0.7187 | 0.6687 |
| Jun-12 | 0.8756 | 0.7667 | 0.7513 | 0.7994 | 0.7885 | 0.7776 | 0.8086 | 0.8255 | 0.7758 |
| Jul-12 | 0.7339 | 0.5386 | 0.5464 | 0.5972 | 0.5776 | 0.5581 | 0.6095 | 0.6042 | 0.5534 |
| Aug-12 | 0.6713 | 0.4507 | 0.4666 | 0.5169 | 0.4948 | 0.4727 | 0.5285 | 0.5183 | 0.4668 |
| Sep-12 | 0.8067 | 0.6507 | 0.6394 | 0.6975 | 0.6819 | 0.6663 | 0.7091 | 0.7132 | 0.6631 |
| Oct-12 | 0.7773 | 0.6042 | 0.6115 | 0.6561 | 0.6388 | 0.6215 | 0.6683 | 0.6681 | 0.6178 |
| Nov-12 | 0.6422 | 0.4124 | 0.4182 | 0.4813 | 0.4583 | 0.4353 | 0.4923 | 0.4807 | 0.4288 |
| Dec-12 | 0.8373 | 0.7011 | 0.7133 | 0.7420 | 0.7283 | 0.7147 | 0.7527 | 0.7620 | 0.7121 |
| Jan-13 | 0.8402 | 0.7059 | 0.7179 | 0.7462 | 0.7328 | 0.7193 | 0.7568 | 0.7666 | 0.7168 |
| Feb-13 | 0.8307 | 0.6901 | 0.6457 | 0.7323 | 0.7183 | 0.7042 | 0.7433 | 0.7514 | 0.7015 |
| Mar-13 | 0.8934 | 0.7982 | 0.8095 | 0.8267 | 0.8172 | 0.8077 | 0.8350 | 0.8558 | 0.8061 |
| Apr-13 | 0.8027 | 0.6443 | 0.6481 | 0.6918 | 0.6760 | 0.6601 | 0.7035 | 0.7069 | 0.6569 |
| AVG | 0.7935 | 0.6349 | 0.6359 | 0.6825 | 0.6666 | 0.6508 | 0.6935 | 0.6976 | 0.6473 |



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“Table 2.Comparision of actual and calculated loss”

| Month | Actual loss | Peak loss | Proposed load factor | Calculated loss |
|---|---|---|---|---|
| May-12 | 16.6139 | 25.0458 | 0.6687 | 16.7470 |
| Jun-12 | 18.8178 | 25.0458 | 0.7758 | 19.4295 |
| Jul-12 | 20.7289 | 37.9392 | 0.5534 | 20.9968 |
| Aug-12 | 23.6642 | 50.7215 | 0.4668 | 23.6743 |
| Sep-12 | 21.3193 | 33.3450 | 0.6631 | 22.1121 |
| Oct-12 | 21.7723 | 35.6051 | 0.6178 | 21.9955 |
| Nov-12 | 17.9095 | 42.8298 | 0.4288 | 18.3635 |
| Dec-12 | 13.9798 | 19.5995 | 0.7121 | 13.9572 |
| Jan-13 | 12.8731 | 17.9322 | 0.7168 | 12.8537 |
| Feb- 13 | 12.6556 | 19.5995 | 0.7015 | 13.7489 |
| Mar-13 | 15.8658 | 19.5995 | 0.8061 | 15.7998 |
| Apr-13 | 15.0064 | 23.1563 | 0.6569 | 15.2104 |
| AVG | 17.6005 | 29.2016 | 0.6473 | 17.9074 |

“Table 3:Statistics of Load-Curve parameters”

## 11. Application

In urban Distribution utility, major current issues are associated with economic cable selection and estimation of Distribution Transformer losses. Economic cable sizing plays an important role. Generally, in these organisation, a thumb rule is being applied that same current cable size is selected according to load requirement, for example for 130A load, cable of 185 sqmm size is selected inspite of its current carrying capacity which may leads to high percentage of No load losses as a result of under loading. The concepts for energy losses estimation can be applied [8] for

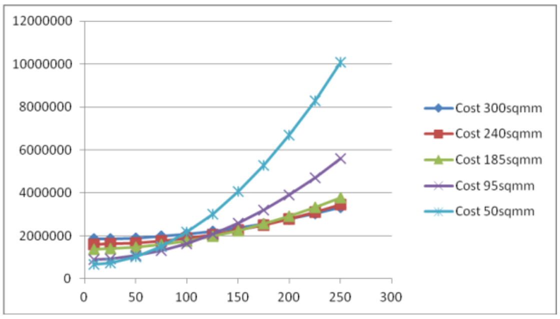
1. Economic cable choice.
2. Estimation of losses in distribution transformers
3. Improvement in loss estimation analysis.

### 11.1 Economic cable choice

For correct cable selection, the constant and variable costs of each available cable option must be analyzed. Cable Curve is the graph between fixed parameter along X-axis (either CV or Average current) and variable parameter along Y-axis (total cost including fixed and variable cost).Cable curves for various cable sizes (300sqmm, 240sqmm, 185sqmm, 95sqmm and 50sqmm) were drawn for fixed Current (different CV) and fixed CV (different Average current). It is observed that there is no significant change in the value of variable cost at any CV for any cable size. And the significant difference in variable cost is compensated by the fixed cost. Hence drawn cable curves at fixed CV (0.1) at different values of average currents as shown in fig 2 for all available cable sizes can be used for economic selection of cables. Various curves at different current are analized.For example, for current between 200 to 210Amp, two cable options are possible. Below 209Amp, 240sqmm XLPE cable can be selected but above 209Amp, it is suggested to use 300 sqmm cable because though fixed cost of 240sqmm is less, variable cost make its total cost greater than that of 300sqmm.

“Table 3:Statistics of Load-Curve parameters”

| Parameter | Statistics | 22 KV | 11 KV |
|---|---|---|---|
| $LD_F$ | Mean | 0.76 | 0.68 |
| | Min | 0.01 | 0.01 |
| | Max | 1.00 | 1.00 |
| | Sigma σ | 0.04 | 0.07 |
| | CV | 0.06 | 0.10 |
| $LS_F$ | Mean | 0.60 | 0.50 |
| | Min | 0.01 | 0.01 |
| | Max | 1.00 | 1.00 |
| | Sigma σ | 0.06 | 0.09 |
| | CV | 0.10 | 0.18 |
| k | Mean | 0.10 | 0.15 |
| | Min | 0.00 | 0.00 |
| | Max | 1.00 | 1.00 |
| | Sigma σ | 0.02 | 0.05 |
| | CV | 0.20 | 0.30 |
| CV | Mean | 0.53 | 0.27 |
| | Min | 0.00 | 0.00 |
| | Max | 9.80 | 9.80 |
| | Sigma σ | 0.06 | 0.08 |
| | CV | 0.11 | 0.28 |
| LSC | Mean | 1.28 | 1.08 |
| | Min | 1.00 | 1.00 |
| | Max | 97.00 | 97.00 |
| | Sigma σ | 0.06 | 0.04 |
| | CV | 0.04 | 0.04 |




"Figure 2. Economic cable curve for fixed CV"

### 11.2 Estimation of distribution transformer losses

Losses estimation in distribution transformers using loss factor and maximum demand [8] is as below .

$\Delta_{EL}=(\Delta P_{no\_load}+ (D_{max}/S_{rated})^2.\Delta P_{load}).T.LS_F$ (12)

where $\Delta P_{no\_load}$ and $\Delta P_{load}$ are the standard no-load losses and load losses of the transformer, both in watts, $D_{max}$ is the maximum load, and $S_{rated}$ is the rated apparent power of the transformer, in KVA

Estimating losses using maximum demand and loss factor [8] leads to imprecision that can be avoided with the concepts of average Demand and Loss Coefficient as follows

$\Delta_{EL}=(\Delta P_{no\_load}+(D_{avg}/S_{rated})^2.\Delta P_{load}).T.LSC$ (13)

Distribution Transformer's average demand was obtained from the yearly consumption data (KWH).Also from the available data with metered Distribution transformers; Loss coefficient can be estimated that is necessary to estimate the *loss factor*. It was assumed that all DTCs on the same HT feeder are equally loaded depending upon the feeder loading. In this way, total average total loss and technical loss can be estimated using loss coefficient and average demand. Subtracting estimated technical loss from estimated average total loss, nontechnical loss can be obtained easily with no meter or non-functional energy meters. And accordingly further actions can be initiated to reduce commercial losses.

### 11.3 Energy losses analysis

Losses can be computed directly when load curve of an electrical element is available but where load curve is not available, estimation can be done using average demand and loss coefficient. The power loss at the average load value remain unchanged, as the energy that flows in the line is the same .Hence estimation of energy losses using average demand remained unchanged The three load curves one 24 pt load curve and two integrated load curves differ only in their variability. The percent variation of energy losses from each load curve scenario varies same as that of LSC.

## 12. Conclusion

Various papers has been presented to calculate the energy loss in a distribution systems based on various parameters, however in a developing economy like India where the distribution system is still evolving with the rapid urbanisation and rural electrification, minimum information is available in the system performance and behaviour patterns , in such situation a very basic and simple method of estimating loss using Load factor and loss factor along with loss coefficient can become a corner stone for successful and timely calculation of energy loss in the distribution system without changing much of its components. The Estimation thus received can be used to understand the energy loss in the rapidly growing distribution systems based on the simple characteristics. Based on the results there is a good opportunity to maximise the system efficiency by designing correctly in terms of optimum cable sizes suiting to comparable networks.

## 13. References

[1] Carlos A. Dortolina and Ramón Nadira," The loss that is unknown is no loss at all: a top-down/bottom-up approach for estimating distribution losses", ," *IEEE Trans.Power Syst.*, vol.. 20, no. 2, pp.1119-1125, MAY 2005.

[2] M.W. Gustafson, J. S. Baylor, and S. S. Mulnix, "The Equivalent hours Loss Factor revisited," *IEEE Trans. Power Syst.*, vol. 3, no. 4, pp. 1502–1507, Nov. 1988.

[3] M. W. Gustafson and J. S. Baylor, "Approximating the system losses equation," *IEEE Trans. Power Syst.*, vol. 4, no. 3, pp. 850–855, Aug. 1989 .

[4] T. Murali Krishna Loss Estimation: A Load Factor Method", ACEEE Int. J. on Electrical and Power Engineering, Vol. 4, No. 1, Feb 2013.

[5] Sarang Pande and Prof. Dr. J.G. Ghodekar," Computation of Technical Power Loss of Feeders and Transformers in Distribution System using Load Factor and Load Loss Factor,IJMSE,VOL.3,No.6,June2012.

[6] F. H. Buller and C. A. Woodrow, "Load factor equivalent hours values compared," *Electr. World*, Jul. 1928.

[7] Turan Gönen, "*Electric Power Distribution System Engineering*", McGraw-Hill, 1986.

[8] Leonardo M. O. Queiroz, A. Roselli," Energy Losses Estimation in Power Distribution Systems", *IEEE Trans. Power Syst.*, vol27, no. 4, pp. 1879–1887, Nov. 2012.

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