# A Simplified Approach in Estimating Technical Losses in TNB Distribution Network Based on Load Profile and Feeder Characteristics

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*Abstract:* - This paper presents an approach to estimate technical losses in utility's distribution network based on feeder's load profile and characteristics, such as such as length, peak demand to installed capacity ratio, and load distribution profile. The developed methodology is implemented in spread sheets format, which is simple and user friendly. It requires minimum set of input data, while giving reasonably accurate results. The approach is tested on a real TNB distribution network and the results are reasonably accurate. Additionally, the spread sheet developed based on the methodology could also be used to perform various energy auditing exercises.

*Key-Words:* - Distribution network; Technical Losses; Feeder Characteristics; Load Factor; Energy Audit

## 1 Introduction

The amount of energy loss in electrical distribution system is one of the key measures of distribution system performance as it has a direct impact on the utility's bottom line. Distribution system's losses can be attributed to technical and non-technical. Non-technical losses are those associated with inadequate or missing revenue metering, with problems with billing or collection systems, etc. Technical losses in the system are inherently influenced by component and system designs.

Since losses represent a considerable amount of operating cost, accurate estimation of electrical losses enables TNB to determine with greater accuracy the operating costs for maintaining supply to consumers. This in turn enables a more accurate estimate of system lifetime costs, over the expected life of the installation. It is also critical to know if the expected target of technical losses is indeed technical, whether it is possible for reduction without changing the components and system design. Lower technical losses will provide for cheaper electricity and lower production costs, with a positive influence on economic growth.

Various studies have been conducted over the years to calculate energy losses in distribution network [1-4]. Typically, in technical loss estimation studies, the technical loss level is estimated using simulations of the network. However these studies would require complete set of data to estimate the technical loss level. A study by Carlos A. Dortolina and Ramon Nadira, [5] propose a methodology called 'top-down/bottom up', where energy losses are computed in relative accuracy for specific distribution systems or feeders and then uses the results to benchmark (i.e. estimate technical losses using top down approach) other parts of the network with matching features. The main advantage of this approach is that it can handle varying degrees of data availability.

In this paper, the proposed approach is peak power loss functions of medium voltage feeders of different characteristics (variation in feeder length, peak demand, and load distribution profile) are first established through network simulation using PSS-Adept software. Subsequently, technical losses for each medium voltage feeder are estimated based on user input peak demand, load factor, and feeder length. An analytical expression incorporating weight-age factors, calculated by taking the ratio of energy flow through each feeder against the total energy supplied to the system is used to estimate technical losses contributed by the respective medium voltage network. Technical losses in distribution transformers are estimated based on empirical formulas of no load and full load loss scaled by capacity factors. For low voltage network, its technical losses level is primarily influenced by its percentage loading, besides load factor and network type (overhead or underground).

The developed methodology is implemented using spread sheets where users input relevant data such as energy sales units, peak demand, load factors, cable length, select load distribution profile, average transformer capacity, and average percent loading of low voltage network to calculate the respective technical losses of each component and the whole distribution network. Results of technical losses of each network component, that is 33 kV feeders and network, 11 kV feeders and network, 33/11 kV transformers, 11/0.4 kV transformers and low voltage network are displayed separately on the spread sheet. The methodology is tested on a real TNB distribution network which will be described later in this paper. Additionally, the spread sheet could be used to perform various energy auditing exercises, which will be shown in another case study.

## 2 Estimation of Technical Losses in Network Components

### 2.1 Peak Power Loss Functions of Medium Voltage Feeders

Medium voltage feeders (MV), particularly, 11 kV feeders are characterized by its peak demand, load factor (associated with the types of loads connected to the feeder), feeder length, and its loads distributions along the feeder. Power losses in medium voltage distribution feeders are essentially a function of three main variables, and that is, peak demand, feeder length and load distribution profile along the feeder. Typically, peak power losses of feeders are obtained by modeling each of the different types of feeders and then perform load flow simulations.

In this study, four different load distribution profiles (evenly distributed load profile, load concentration at the middle of feeder, load concentration at the source of feeder, and load concentration at the end of feeder) were modeled for load flow simulations to determine the respective peak power loss functions.  Examples of peak power loss functions for two different load distribution profiles (evenly distributed, and load concentration at the end of feeder) are shown in Fig. 1 and Fig. 2. The power loss functions that are shown in the graphs below are then transformed into analytical formula to estimate energy losses of medium voltage feeder associated with different load distribution profile.

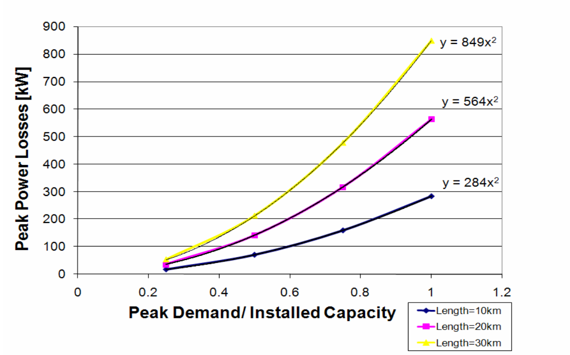


Fig. 1. Peak Power Loss Functions of 11 kV Feeders with Evenly Distributed Loads along Feeder

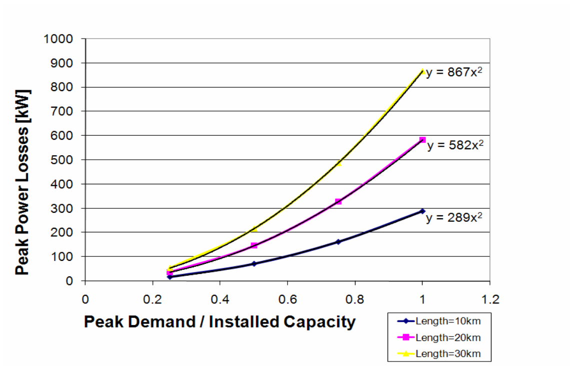


Fig. 2. Peak Power Loss Functions of 11 kV Feeders with Loads Concentration at End of Feeder

The following equations are used to estimate energy loss of each individual MV feeder.

$$E_N^{Loss} = \left(P_{Peak}^{Loss}\right)(LoadF)(LossF)(T) \quad [1]$$

Where,

$E_N^{Loss}$ is the estimated energy loss of feeder N,

$P_{Peak}^{Loss}$ is the peak power loss of feeder N,

$LoadF$ is the load factor of feeder N,

$LossF$ is the loss factor of feeder N, calculated based on the empirical formula,

$LossF = \alpha(LoadF) + \beta(LoadF^2)$ , in which $0.15 \le \alpha \le 0.30$ and $\beta = (1-\alpha)$ , and,

T is the period of evaluation.

Based on [1], user is able to estimate percentage energy loss of individual feeders by keying in feeder peak demand, feeder length, selection of feeder type, load factor, and values of $\alpha$ and $\beta$ . The equation to determine percentage energy losses in feeder N is as follows,

Percentage energy losses in feeder N,

$$E_N^{Loss}[\%] = (E_N^{Loss}) * 100 \Big/ E_N^{Supplied} \quad [2]$$

Where,

$$E_N^{Supplied} = (P_{Peak}) * LoadF * T \quad [3]$$

## 2.2 Estimation of Percent Technical Losses in MV Network

The amount of energy supplied through each MV feeder is generally not the same as some feeders are heavily loaded with higher peak demand and load factor, whereas some are lightly loaded with lower load peak demand and load factor. Therefore, in order to determine the percentage energy losses of the MV network, it is necessary to take the normalized average percentage energy losses of all MV feeders that made up the MV network. The equations used are as follows:

$$E_{MV\ Network}^{Loss} = \sum_{N=1,2,3...} W_N E_N^{Loss}[\%] \quad [4]$$

Where,

$$W_N = \frac{E_N^{Supplied}}{E_{Total}^{Supplied}}$$ , of which

$E_{Total}^{Supplied}$ is total energy supplied to the MV network.

## 2.3 Estimation of Percent Technical Losses in Distribution Transformers

Energy losses in transformers are dependent on no load losses, full load losses, capacity ratio (% loading), and loss factor. The analytical expression to estimate energy losses of transformers is as follows:

$$E_{Tx}^{Loss} = \left(P_{no-load}^{Loss} + (CF)^2 (P_{full-load}^{Loss})(LossF)\right)(T) \quad [5]$$

Where,

$P_{no-load}^{Loss}$ is the transformer no load power loss

$P_{full-load}^{Loss}$ is the transformer full load power loss

$CF$ is the capacity ratio, of which

$$CF = \text{Tx Max Demand} / \text{Tx Capacity}$$

Ideally, energy losses of each individual transformer should be calculated using the given expression (5) followed by the estimation of percentage energy losses of all transformers in the circuit/network. However, due to the large number of transformers operating in the network, percentage energy losses is estimated based on the average maximum demand and average installed transformer capacity.

To facilitate the determination of no load and full load losses for the whole range of transformer capacity, curve fitting technique is used to establish the equation relating no load and load losses with transformer capacity.

## 2.4 Estimation of Percent Technical Losses in Low Voltage Network

Unlike medium voltage feeders of which the feeder length could vary over a big range, low voltage (LV) feeders are kept within certain length so as to avoid any under voltage problem at consumers point. These being the case, peak power loss function of LV feeders are established based on a fixed length. Subsequently, feature such as load distribution profiles is not relevant in the characterization of LV feeders. Some primary variables of LV networks that influence technical losses in LV network is the type of conductors used, (i.e., overhead lines or underground cables), percentage loading (i.e., peak demand/installed cable capacity), and load factor which is dependent on load types.

However, again due to the extensiveness of LV network, it is not realistic to estimate technical losses for each and every individual LV feeder/network coming out from the distribution substation. Hence, the first step in the estimation of technical losses in LV network is to determine peak power loss functions associated with overhead or underground network. See Fig. 3. Subsequent steps involve the estimation of average load factor, peak demand, and percentage loading of LV network.

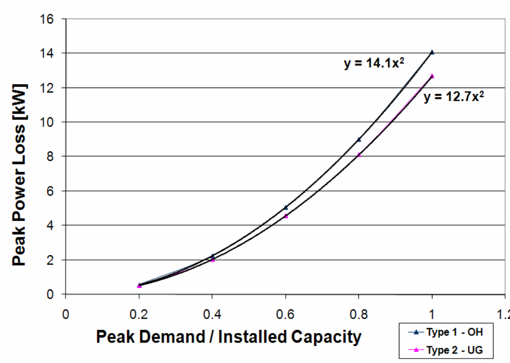


Fig. 3. Peak Power Loss Functions of Overhead and Under-ground Low Voltage Network

## 2.5 Estimation of Percent Technical Losses for the Whole Distribution Network

Estimation of the percent technical losses for the whole distribution network is done by taking the sum of the percent technical losses of each component, i.e, MV feeders, transformers, and LV network. The equation is as follows:

$$E_{Dist.Sys}^{Loss}(\%) = E_{33kV}^{Loss}(\%) + E_{Tx\,(33/11)}^{Loss}(\%) + E_{11\,kV}^{Loss}(\%) + E_{Tx\,(11/0.4)}^{Loss}(\%) + E_{LV}^{Loss}(\%) \quad [6]$$

## 3.0 Case Study 1 – Applications for energy auditing exercises

As mentioned earlier, the spread sheet could be used to perform various energy auditing exercises. For example, the impact of having higher average transformer installed capacity on technical losses, the impact of increasing the percentage loading of low voltage feeders, etc. could be done by just changing a few input parameters in the spread sheet.

A typical distribution network, fed from a Main Intake Substation which supply loads to two zones, North & South, through three voltage levels (33 kV U/G cables, 11 kV U/G cables and LV) is used to test the methodology. The base case data for the distribution network is given below.

Units from Transmission Grid (MWh): 15,000
Peak Demand (MW): 30
Load Factor: 0.69

33 kV Feeder Data
Average Feeder Length: 20 km
Total No of Feeders: 2

11 kV Feeder Data
Average Feeder Length: 15 km
Peak Demand/Feeder: 2 MW/Feeder
Total No of Feeder: 20

33/11 kV Transformer Data
Total Installed Capacity: 120 MVA
Total No of Tx: 4
Installed kVA per Tx: 30 MVA
Average Peak Demand per Tx: 7.5 MW per Tx

11/0.4 kV Transformer Data
Total Installed Capacity: 120 MVA
Total No of Tx: 250
Installed kVA per Tx: 480 kVA per Tx
Average Peak Demand per Tx: 116 KW per Tx

LV Network Data
Percentage of Underground Network: 10 %
Average percent loading per LV Feeder: 50%

Results of the estimated technical losses of the base case and five other cases (Case I, Case II, Case III, Case IV and Case V) described below are shown in Table I.

| COMPONENTS | TECHNICAL LOSSES [%] | | | | | |
|---|---|---|---|---|---|---|
| | Base | Case I | Case II | Case III | Case IV | Case V |
| 33 kV Feeders | 0.82 | 0.82 | 0.82 | 0.82 | 0.82 | 0.82 |
| 33/11 kV Trans. | 0.44 | 0.44 | 0.44 | 0.44 | 0.44 | 0.44 |
| 11 kV Feeders | 1.77 | 1.77 | 1.77 | **2.80** | 1.77 | 1.77 |
| 11/0.4 kV Trans. | 1.11 | **1.51** | **0.92** | 1.11 | 1.11 | 1.11 |
| LV Network | 1.65 | 1.65 | 1.65 | 1.65 | **3.23** | **0.59** |
| **Total** | **5.79** | **6.19** | **5.61** | **6.82** | **7.37** | **4.73** |

Table 1: Estimated Technical Losses for Base Case and Five Other Cases

Case I
11/0.4 kV capacity increased to 800 KVA per transformer.
Case II
11/0.4 kV capacity decreased to 320 KVA per transformer.
Case III
Two of the 11 kV feeders outage. Load transferred to two other feeders.
Case IV
Percentage loading of LV network increase to 70%
Case V
Percentage loading of LV network decreased to 30%.

### 3.1 Analysis of Results and Impact of Changes in Network Loading and Configuration

As indicated in Table 1, the estimated technical losses of a typical base case distribution network come to about 5.79% which is a reasonable and realistic level, comparable to figures calculated based on sales and energy meter reading at main-intake. As the developed methodology is based on an analytical approach implemented using excel spread sheet, the impact of changes in network components loading, network data, etc on technical losses could be without much difficulties.

Examples cases are illustrated in Case I -V. Case I and II show that lightly loaded transformers incur higher percent losses. Case II shows higher that technical losses increased substantially when 11 kV feeders are loaded higher with longer length (this occurs whenever there is a need to transfer load due to cable fault). Case IV and V indicate the impact of LV loading on technical losses.

## 4.0 Case Study II – Real TNB Distribution Network

The methodology is tested on a real TNB distribution network that is well-planned and relatively new to calculate the technical losses. The distribution network is made up of three voltage level, i.e. 33kV, 11 kV and low voltage. To achieve the desired security and reliability, feeders and transformers are mostly loaded to below 50% capacity.

The peak demand of distribution network is between 200 - 250 MW. Average monthly energy from transmission grid is about 160,000 MWh. Total number of 33 kV feeders is 37. Most of the 33 kV feeders are relatively short, i.e., less then 8 km, with peak demand less than 50% capacity. Total number of 11 kV feeders is 116. Most of the 11 kV feeders are relatively short as well, i.e., less than 12 km with average peak demand of 50% capacity. 33/11 kV transformers are loaded to about an average of 40% capacity, whereas 11/0.4 kV transformers are loaded to about an average of 50% capacity. Low voltage networks are all (100%) underground and loaded to about 50% peak capacity.
Summary results of technical losses estimated using the spread sheet is shown in Table 2.

From Table 2, it can be observed that the overall estimated technical losses of the selected distribution network is about 3.2%, which is considered very low. This is due to the fact that its MV feeders are relatively very short in length and loaded below the 50% peak capacity. Hence, in this case low voltage network contribute about 30% of the total technical losses. The estimation was verified by TNBD

| ***Components*** | ***% Technical Losses Estimated*** |
|---|---|
| 33 kV Feeders | 0.11 |
| 33/11 kV Transformers | 0.47 |
| 11 kV Feeders | 0.87 |
| 11/04. kV Transformers | 0.86 |
| Low Voltage Network | 0.90 |
| **Total** | **3.21** |

Table 2: Summary Results of Technical Losses Estimated for a Real TNB Distribution Network

## 5.0 Advantages of the Methodology

The main advantage of this methodology is that it is simple to use and it requires minimum set of input data which are commonly available in most utility distribution offices, while giving reasonably accurate results. It provides an indication of the overall technical loss level of a distribution system and identifies specific feeders/part of the distribution network with high technical losses where mitigation effort may be justified.

Additionally, the spread sheet developed based on the methodology is useful for someone who wants to do an energy audit to establish the technical loss level of a distribution system and identify MV feeders with high losses, or to evaluate the performance of the distribution network in terms of its technical losses.

## 6.0 Conclusion

This project presents a methodology to estimate technical losses of distribution network based on analytical method. Peak power loss functions of medium voltage distribution feeders based on different feeder characteristics are first established through simulation. Technical losses of each individual MV feeder is then estimated based on the respective peak power loss function and estimated feeder peak demand, length and load factor. To establish the technical losses of the complete MV network, normalized average of percent technical losses of each feeder is taken. Technical losses of distribution transformers are estimated based on transformer no load and load loss, average capacity factor, and loss factor. Finally, the technical losses of low voltage are estimated from the peak power loss function of LV network (classified as overhead or underground system), average percent loading, and loss factor. The estimation methodology is implemented using spread sheets. From the case studies, it is shown that results obtained based on the proposed approach are reasonably accurate.

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