Energy flow models for the estimation of technical losses in distribution network

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Abstract. This paper presents energy flow models developed to estimate technical losses in distribution network. Energy flow models applied in this paper is based on input energy and peak demand of distribution network, feeder length and peak demand, transformer loading capacity, and load factor. Two case studies, an urban distribution network and a rural distribution network are used to illustrate application of the energy flow models. Results on technical losses obtained for the two distribution networks are consistent and comparable to network of similar types and characteristics. Hence, the energy flow models are suitable for practical application.

1. Introduction

The amount of energy losses 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. Energy losses in distribution system can be attributed to technical losses and non-technical losses. Technical losses refers to energy losses resulting from the heating of electrical distribution components such as cables/lines and transformer windings, whereas non-technical losses is associated with the energy unaccounted for due to consumer pilferages, faulty energy meters, incorrect billing, etc. Therefore, technical losses in distribution systems are primarily dependent on network topology, system voltages, and electrical loading. Hence, the accuracy in estimating technical losses in a distribution system would require extensive network and load data for modeling. A variety of approaches to calculate energy losses in distribution system have been reported. Some of the variables commonly used to estimate energy losses in distribution network are load factor, loss factor and load curves/profile.

One of the earliest references on calculating energy loss in distribution system is written by Flaten [1] where percent loading of every distribution components in the distribution system and numerous other related variables, such as power factor, temperature correction, squares correction, load profile correction, etc. are used in the calculation. With numerous input parameters, the approach is seen to be extremely rigorous and requires tremendous effort and resources particularly in dealing with large utility distribution systems. In [2] Grainger presented a simplified approach using load loss factor and diversity factor to calculate energy loss in distribution system. However, the methodology involves a large amount of measured load data as well as network data to establish statistical and physically based models. In reference [3], Shenkman proposed an algorithm for energy loss calculation in network elements using statistical moments obtained by considering statistical daily load curves (DLC) as a set of random variables. Taleksi [4] further improved on the methodology by taking into account element ordering, power calculation with average loads at nodes and applied it to calculate...
energy loss in radial distribution network. More recent reference on estimating technical losses in distribution system is proposed by Dortolina, et al [5] where energy losses are computed in relative accuracy for specific distribution systems or feeders (known as bottom up approach) 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 the top down/bottom up approach is that it can handle varying degrees of data availability.

It can be seen from the various references [1-5] that the approach taken to estimate technical losses is generally dependent on the amount of data available, distribution system size and the accuracy required for each case. Generally, there is a trade off between amount of data available to estimate technical losses and the required accuracy of its results. With regards to data, most utility companies do maintain records of network data such as medium voltage feeder cable length and types, maximum demand, load profiles, and distribution transformers loading. Based on network information typically available such as those mentioned, this paper presents a methodology to estimate technical losses of utility distribution network using energy flow models associated with each medium and low voltage feeder, and average transformer loading. The approach is applied to estimate technical losses of a distribution system supplying loads to an urban and rural area and found to be efficient and practical. Additionally, the results obtained are within acceptable range which provides an indication of the level of technical losses to be expected from the particular distribution network.

2. Energy losses in network components

2.1. Underground cables and overhead lines
Power losses in underground cables and overhead lines are primarily due to load losses (\(P_{\text{Loss}} = I^2R\)). As the power losses varies with the square of current, the amount of current flowing in the cable will have the highest impact on the energy losses in cables and overhead lines. Typically, load losses of feeders are calculated under peak demand condition using load flow simulation. The energy losses over a specified period (one month) is then calculated using Loss Factor as follows,

\[
\text{Energy Loss} = P_{\text{Loss}} \times \text{Loss Factor} \times 24 \times 30 \quad (1)
\]

Loss Factor is calculated from Load Factor using the expression,

\[
\text{Loss Factor} = \alpha \times \text{Load Factor} + \beta \times (\text{Load Factor})^2.
\]

Where \(0 \leq \alpha \leq 0.35\), and \(\alpha + \beta = 1.0\).

Input energy to the feeder can be calculated as follows,

\[
\text{Input Energy} = \text{Peak Demand} \times \text{Load Factor} \times 24 \times 30. \quad (3)
\]

Technical Losses of the Feeder (%) = \((\text{Energy Loss} \times 100) / \text{Input Energy}\) \quad (4)

2.2. Power and distribution transformers
Power losses in transformers are contributed by load loss and core loss. Load loss varies with the square of transformer load current, whereas core loss is fixed loss resulting from magnetization and hysteresis loss. The expression to calculate total power loss in a transformer is given as,

\[
P_{\text{TX_Loss}} = P_{\text{NL_Loss}} + (CF)^2(P_{\text{FL_Loss}}) \quad (5)
\]

Where \(CF\) is the capacity factor defined as the ratio of peak load current over full load current of transformer.

Similarly, following which energy losses in a transformer over a specified period can be calculated using Loss Factor as given in (1) and (2).

3. Energy flow models
In general, the amount of technical losses in distribution systems is influenced by a number of factors such as:

- The geographical size of the network (related to feeder length),
- Quantity of electricity distributed against the capacity of distribution infrastructure, i.e, number of feeders and transformers, and their capacity (capacity factor),
- Ratio of MV network to LV network,
- Load profile (peak demand and load factor),
- Reactive power flow (power factor),
- Dispersion of loads in the network,

For utility distribution systems fed from grid system, energy meters are installed at main in-take substations to record the amount of energy supplied to the whole distribution network. For economic reasons, energy meters are usually not installed at individual outgoing distribution feeders to record its energy flow. Besides the energy meters installed at main in-take substations, other points of energy metering are at bulk customers substations to record energy sold to the respective customers.

In this paper, energy flow models developed to estimate technical losses of the whole distribution network are based on the constraint that only two sources of actual energy and peak demand data are available; that is, the total input energy and peak demand of the whole distribution system, as well as total bulk customers energy and peak demand fed from the distribution system.

Besides the energy and peak demand data set, the energy flow models require realistic distribution network data in order to estimate technical losses in the distribution system.

The network data are:- total numbers of medium voltage (e.g. 33 kV, 22 kV, and 11 kV) feeders, total length of medium voltage feeders according to voltage level, total number of low voltage feeders, and total installed capacity of power and distribution transformers (e.g 33/11 kV and 11/0.4 kV transformers) in the distribution system. In this energy flow model, the average length of low voltage feeders is fixed at 1 km.

The energy flow model then distribute the total input energy and peak demand accordingly to each medium voltage feeder, power and distribution transformer, and low voltage feeder, and calculates the amount of energy (technical) losses at each voltage level and for each components.

4. Case studies
Two case studies are presented in this paper. The first case is a 11/0.4 kV distribution system of an urban area, and the second case is a 33/11/0.4 kV distribution system of a rural area.

4.1. Case I – Urban distribution network
The characteristics of the urban distribution network are:- relatively short feeders, highly load feeders and transformers, and a significant proportion of its energy being sold to customers in bulk at medium voltage. Hence, technical losses of the urban network are expected to be lower.

4.2. Case II – Rural distribution network
The characteristics of the rural distribution network area:- relatively long feeders (two medium voltage level, 33 kV and 11 kV), lightly load feeders and transformers, and a small proportion of its energy being sold to customers in bulk at medium voltage. Hence, technical losses of the rural network are expected to higher.

The network data used to calculate technical losses of the networks are given in Table 1. The results of technical losses calculated based on the energy flow models are given in Table 2.

Technical losses for the rural distribution network are 5.4% compared to 4.97% for the urban network. The higher percentage in technical losses of the rural network is due primarily to technical losses at the medium voltage system (33 kV and 11 kV) where there are long feeders with an additional voltage transformation at 33/11 kV.

5. Conclusions
Energy flow models developed for the estimation of technical losses in distribution network produced results that are consistent with the characteristics of the respective distribution system and comparable with other models. The energy flow models have proven to be practical and efficient, and a useful tool that could be applied to estimate technical losses of distribution system which are in operation as well as for planning future network.
Table 1. Energy, Demand, and Network Data

| Network Parameters | Case I           | Case II          |
|--------------------|------------------|------------------|
| Energy Supplied    | 125,000 MWhr     | 98,000 MWhr     |
| Peak Demand        | 250 MW           | 230 MW           |
| Power Factor       | 0.9 lagging      | 0.9 lagging      |
| Load Factor        | 0.69             | 0.59             |
| Energy Sold at 33 kV Bulk Cust. | -               | 0.0              |
| Energy Sold at 11 kV Bulk Cust. | 35,000 MWhr     | 8,000 MWhr      |
| Total Peak Demand of 11 kV Bulk Cust. | 61 MW           | 13.9 MW         |
| Total number of 33 kV Feeders | -               | 16               |
| Average Length per Feeder (33 kV) | -               | 30 km            |
| Total Installed Transformer Capacity (33/11kV) | -               | 800 MVA          |
| Total number of 11 kV Feeders | 80              | 300              |
| Average Length per Feeder (11 kV) | 15 km           | 25 km            |
| Total Installed Transformer Capacity (11/0.4 kV) | 600 MVA         | 500 MVA          |
| Average % Loading of LV Feeders | 50 %            | 40 %             |

Table 2. Results on Technical Losses

|                         | Case I    | Case II   |
|-------------------------|-----------|-----------|
| Energy Supplied (Input) | 125,000 MWhr | 98,000 MWhr |
| Total Energy Loss in 33 kV Feeders | -         | 1,341 MWhr |
| Total Energy Loss in 33/11 kV Transformers | -         | 233 MWhr   |
| Total Energy Loss in 11 kV Feeders | 2,285 MWhr | 630 MWhr   |
| Total Energy Loss in 11/0.4 kV Transformers | 770 MWhr   | 460 MWhr   |
| Total Energy Loss in LV Feeders | 3,160 MWhr | 2,633 MWhr |
| Total Energy Loss in Distribution System | 6,215 MWhr | 5,297 MWhr |
| Percentage of Technical Losses | 4.97 %    | 5.41 %    |

References
[1] David L Flaten 1988 Distribution system losses calculated by percent loading IEEE Transactions on Power Systems Vol. 3 No. 3.
[2] Grainger J and Kendrew T 1989 Evaluation of technical losses on electric distribution systems CIRED.
[3] Shenkman A 1990 Energy loss computation by using statistical techniques IEEE Transactions on Power Delivery Vol. 5 No. 1.
[4] Taleski R and Rajicic D 1996 Energy summation method for energy loss computation in radial distribution network IEEE Transactions on Power Systems Vol. 11 No. 2.
[5] Dortolina C and Nadira R 2005 The loss that is unknown is no loss at all: A top-down/bottom up approach for estimating distribution losses IEEE Transactions on Power Systems Vol. 20 No. 2.