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A Practical and Novel Method for Power Loss Calculation in Distribution Networks

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Abstract - **In recent years, by the construction of electricity market and introduction of electric energy as a commodity, power loss reduction is of paramount importance for utilities. Distribution system losses are comprised of technical and non-technical parts. Technical and non-technical losses are related to physical features and impermissible use of electricity, respectively. The first step toward power loss reduction is to determine the reasons behind power loss and its quantity. Recent researches mainly focused on overall power loss in a wide region. However, it is required to initiate with partial power loss of a transformer and reach a large region step-by-step in order to determine the contribution of each part. In this paper, methods are proposed to calculate power loss in a typical distribution transformer feeder and then the obtained results are compared with actual measurements. Therefore, a distribution transformer equipped with a data logger (DL) in Mashhad City (Ommat 9-region) is selected. Results show that the computational method can easily and appropriately compute power loss using available and typical network data.**

Index Terms - Efficiency, distribution feeder, data logger, technical power loss calculation, non-technical power loss.

I. Introduction

Energy is vital for economic progress [1]. Recently, with the increase in cost of energy as well as formation of electricity market, in which electric power is offered as a commodity, power loss issue and its reduction are appeared in a novel form [2].

The aim of distribution system is to supply customers with electric power delivered from transmission system [3]. However, all the power cannot be consumed by end consumers, and a great share of generated power by power plants are wasted during distribution process [4]. Even though much efforts have been done national-wide (IRAN), there exists a significant gap between Iran and developed countries such as USA and Korea in terms of distribution power loss reduction [5], [6]. According to the reports by Tavanir Company in Iran, totally 60% of power loss in Iran is related to power distribution networks [7].

Power distribution losses are mainly obtained by getting the difference between purchased power from wholesale power suppliers and that of sold to the consumers [8]. In general, distribution power loss is composed of two parts: technical and non-technical power loss [9]; both components are important and system efficiency increases by the decrease of each component [10], [11]. Technical power losses are related to physical features and system components' nature, including power loss due to line resistance and climate condition. On the other hand, non-technical power losses are due to factors such as impermissible use of electricity and/or malfunction of measurement devices [12]. Non-technical power loss should be avoided in any condition. Implementation of novel technologies in load site such as capacitor placement for power factor correction [13] may reduce electric power losses [14]. The first step toward power loss reduction is determining why it occurs and how much it is. Then, appropriate measures could be employed.

Power system losses are calculated by two methods of realistic readings and analytic computations [15]. Various methods have been proposed by researchers to calculate power loss in distribution networks. In [16], power loss evaluation is done by neural networks (NN). In [17], a mathematical analysis is used for power loss calculation. In [18], mesh in power distribution system is detailed and points are examined as normally opened and normally closed modes. In [19], an adaptive genetic algorithm is proposed for power loss calculation. In [20], a power loss calculation model is described based on load flow; while in [21], power loss estimation is completed using load loss coefficient. Ref. [22] used state estimation and Ref. [23] computed power losses and load in a wide network through power factor correction.

In all of the researches reported above, power loss calculation has been done in whole size and for a wide region. However, power distribution is composed of numerous components and while each component may have low power losses, overall power loss will be huge [24]. It is required to start with initial power loss of a transformer and reach a wide region step-by-step to determine participation of each part in total losses.

The aims of research on power loss reduction is to suggest an approach based on technical and reliability requirements, economic considerations of power loss, and response to demand in future with the lowest cost [25]. The methods used depends on the research goals [26].

In this paper, a mathematical method is employed to calculate power loss in a typical feeder of a distribution transformer. Then, the obtained results are compared with those obtained from measurements. For this purpose, one distribution

transformer equipped with data logger (DL) installed in Electric Region-6 of Mashhad City (9st, Ommoat Blvd.) is selected. Loads supplied by this transformer are mainly of residential and commercial types. And, power loss computation is completed for one year.
Results show that computational method is able to accurately obtain power loss by current and typical data of the network.

II. Problem Description and Required Data

Issues raised in power loss computation in a transformer feeder is to have no data related to equipment, network operation, as well as customer demand. The first issue is solved by comprehensive atlas; the second one is obviated by DL device; and the last issue is solved by Ranir website.
Comprehensive atlas: this atlas prepared by Power Distribution Company of Mashhad City includes detailed data of the network such as supply region of each transformer, the number of consumers, reading method of meters on daily basis, consumers' serial number, cross section of conductors in supply route, the number of phases in supply route, data related to lighting, etc. The important note regarding this atlas is its applied and convenient use. Most data used in this research is obtained from this atlas.

A. Data logger(DL)

DL is a small device installed in transformer panels and stores operational data related to transformers, including voltage and current of phases, active and reactive power of each phase, temperature, etc. examples of data logger usage are given in table1 and figures 1-3. in pre-defined intervals. By conveying these data to a computer, one can apply these data for power loss measurement.

B. Ranir data

Ranir is a website that stores customers' demand in distinct intervals. And, required data are extracted conveniently by customer verification number and reading date of meter stored in the atlas. An example of this data is shown in Table2.

Table 1
Example of the information obtained from DL in the test period

Season	Maximum Consumption	Minimum Consumption
Spring	Wednesday 18 June 21:30	Friday 4 April 7:00
Summer	Friday 1 August 21:00	Saturday 21 September 7:00
Autumn	Wednesday 1 November 19:30	Saturday 5 October 6:30
Winter	Wednesday 29 December 19:30	Sunday 19 March 11:00

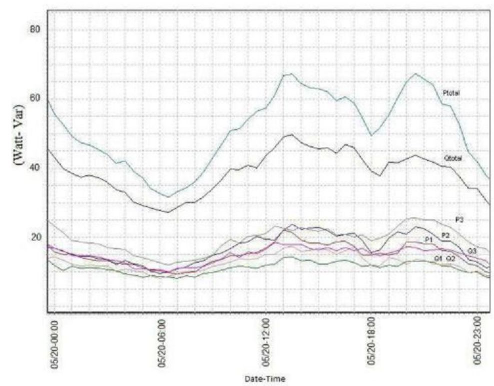

Fig 1. Daily power diagram plotted by the DL information

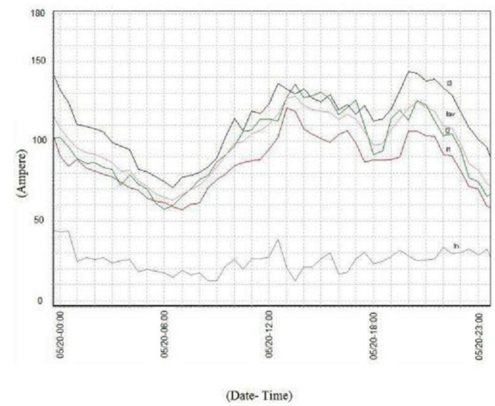

Fig 2. Daily current diagram plotted by the DL information

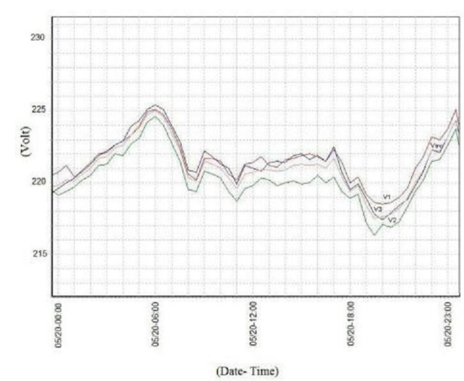

Fig 3. Daily voltage diagram plotted by the DL information

III. Power Loss Measurement

The transformer under study has a rated power of 100 KVA that is supplied two feeders. Overall, 130 customers mainly of residential type are supplied. For the measurement purposes, one-year time period should be considered for extracting dependable data.
Customer meters are read in two 20 and 21 work-days. Total reading time of meters in a work-day is 7 hours. When this time is divided by the number of customer meters that should be read in one day, average time is obtained for reading each meter. Now, with regard to meter reading route and that the customers in 20th day of test region are placed at the end of this route, required time of reading is subtracted from 14:00,

resulting in beginning time of reading for customers in 20th workdays in test region. For 21st workday, because test customers are positioned at the beginning of reading route, required time of reading is added to 07:00 to get finish time of meter reading for customers in test region.

Now, the average of these two time intervals is obtained and considered as the start time of data extraction from DL. Because 20th workday in third time-period of 2014 is on August 11 and 21st workday is on August 24, the data extraction time of DL is on August 22 (22:00) if middle points are on August 11(10:00) and August 14 (10:00), respectively. Likewise, the finish time of data extraction time interval is obtained that is august 14 (22:00). Accordingly, power loss calculation is performed.

Table 2
Information of transformer consumers from Ranir in the test period

period	Consumption
5 year 2014	55342 Kwh
6 year 2014	49802 Kwh
1 year 2015	42565 Kwh
2 year 2015	55925 Kwh
3 year 2015	52977 Kwh
4 year 2015	68933 Kwh
total	298660 Kwh

A. Input power to Recorder

the recorder input power is stored hourly. By aggregation of these data in one year of test interval, input energy to the recorder will be 639947 kWh,

B. Customer demand

based on the results obtained from Ranir website, power consumption by customers is 307024 kWh between third quarter of 2014 and third quarter of 2015 [27].

C. Lighting demand

Lighting meter installed in transformer board records total 26 gas lamps and 3 incandescent lamps. According to the last reading time of the meter, overall 122018 kWh is obtained in 756 days. Thus, annual lighting demand (58910 kWh) is obtained by average daily consumption multiplied by the total number of days per year.

D. Measured power loss

by subtracting customers' demand and consumed lighting energy, measured power loss is 4012 kWh. The obtained results are provided in Table III.

IV. POWER LOSS COMPUTATION

Before addressing power loss computation, several parameters are introduced.

A. Normalized load curve

load variation representation as a time function is called load curve. If these variations are sorted from higher to lower quantity in terms of time, a sorted load curve is obtained. Now, once this sorted curve is converted into p.u. system through time and power peak values, normalized load curve will be obtained in which power and time is between zero and unity [28]. This curve is depicted in Fig. 4.

B. Sochinsky Function

each sorted and normalized load curve can be approximated by the following function [29]:

$$p = a - bt^{c} \qquad (1)$$

where P is the normalized power, t is the normalized time, and a, b, and c are degrees of freedom that can be calculated by:

$$a = 1, b = m_0 - 1, c = \frac{m - m_0}{1 - m} \qquad (2)$$

M=LF=load factor=average power/maximum power
m0=distortion ratio=minimum power/maximum power

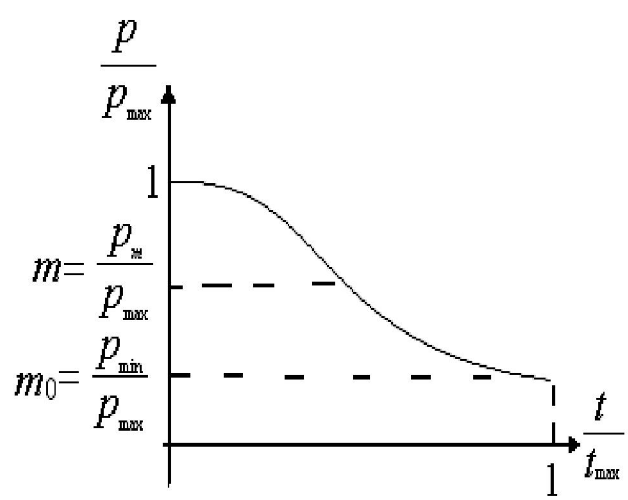

Fig 4. Normalized load curve and Concept of load factor and distortion factor

Now, line power loss of a single-branch in the network with resistance R and input power of Pin is obtained:

$$w_{cu3phase} = \int_0^{8760} 3RI^2 dt$$
$$= \frac{8760 R p_{max}^2}{(v_{line}\cos\varphi)^2}\int_0^1 (p(t))^2 dt$$
$$= 3RI_{max}^2 \int_0^1 (p(t))^2 dt \times 8760 \qquad (3)$$

$$w_{cu} = 8760 \times p_{cumax} \times m_{cu} \qquad (4)$$

Where m_{cu} is load loss coefficient, P_{cumax} is maximum power loss, $w_{cu3phase}$ is three-phase losses, v_{phase} is phase voltage and v_{line} is line voltage. Sochinsky function is obtained in order to get m_{cu}; while, recording data are used to get P_{cumax}.
Now, the method described above is generalized and then, it is used for power computation in the test region:

Considering each line length (L), cross-section of phase conductors (A), and cupper resistance coefficient (ρ_{cu}), the resistance of each circuit branch is obtained by:

$$R = \rho \frac{L}{A} \qquad (5)$$

Resistance graph of the test network is illustrated in Fig. 5. Single-phase and two-phase parts are denoted by one and two small lines on each related branch, respectively. Each branch resistance is shown in mΩ.

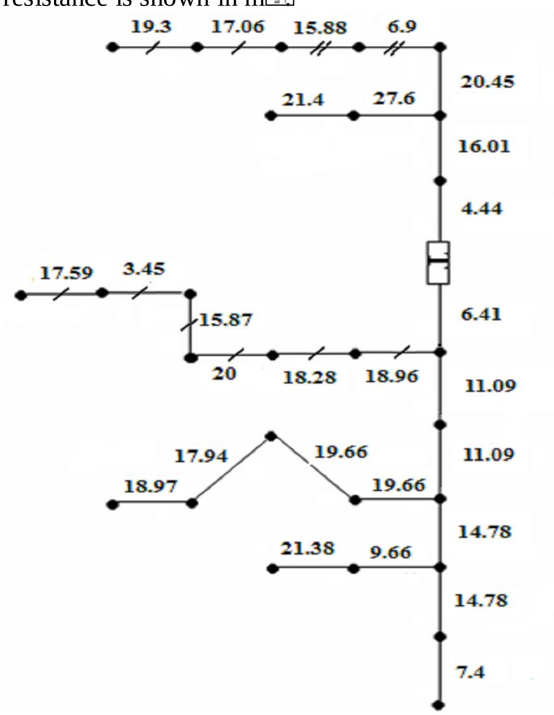

Fig 5. Resistive Graph of network (milliohms)

Considering the type of customers in the region, it is assumed that customers have equal power consumption. And a same current (I) is considered for each customer. Thus, current graph of the network is illustrated in Fig. 6.

C. *Calculation*

using recorded data and reports by operating and balance group, the maximum current, maximum output power, and minimum output power drawn from the transformer is 165 A, 84.1 kW, and 14 kW, respectively. Load factor (m) is defined based on experimental relationships for various customers and different regions. It is fixed on 0.5 because the region is of residential type [30].

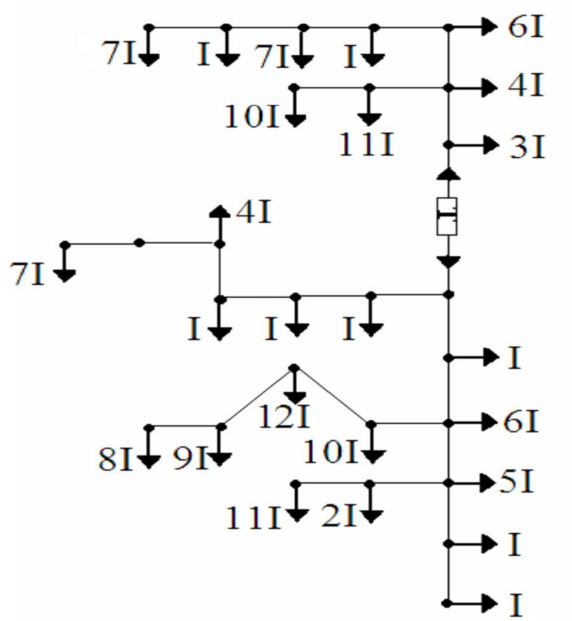

Fig 6. Network current flow graph

1) line power loss calculation: maximum current of each customer obtained by dividing total maximum power by total supplied customers is 1.27 A. Now, maximum power loss of each branch (P_{cumax}) is obtained considering current flowing through each part of the circuit and its resistance:

$$p_{cumax} = NRI_{max}^{2} \qquad (6)$$

where I_{max} is maximum current flowing through the branch of interest and N is the number of phases.
Considering available data, P(t) is obtained be Sochinsky approximation:

$$p(t) = 1 - 0.82t^{0.64} \qquad (7)$$

Subsequently, load factor of network losses (m_{cu}) is obtained:

$$m_{cu} = \int_0^1 p^2(t)dt = 0.295 \qquad (8)$$

Thus, line power loss can be obtained by following relationship (i is the number of each branch in the circuit):

$$w_{cu} = \sum_i w_{cui} = \sum_i 8760 \times m_{cu} \times p_{cumaxi} = 3504 kwh \qquad (9)$$

2) Neutral-line power loss calculation: Neutral-line power loss in a three-phase network is commonly 1% of total power losses. In this paper, this approximation is employed [30]. However, the procedure for single-phase and two-phase parts in network graph is done as follows: for a single-phase network, phase current that enters directly into the neutral phase is:

$$|I_n| = I \quad (10)$$

For a two-phase network, by assuming equal current for two phases, we have:

$$I_n = I\angle 0 + I\angle 120 \Rightarrow |I_n| = I \quad (11)$$

Therefore, using (4) and considering neutral-phase resistance in each single-phase and two-phase branch, we can calculate neutral-phase power losses accordingly. Total neutral-phase power loss is 421.4 kWh.

3) Calculation of output power of transformer:

$$w_{out} = \int_0^{8760} p'(t)dt = 8760\int_0^1 P_{max}\, p(t)dt \quad (12)$$

Where $p'_{(t)}$ is the sorted power curve and p(t) is normalized power curve (P(t) is obtained by Sochinsky approximation and Pmax is achievable by available data). Thus,

$$w_{out} = 8760 \times 84.1 \times 0.5 = 368358\, kwh \quad (13)$$

4) Lighting demand calculation:

Considering the number and type of lamps used in lighting related to test transformer and assuming that these lamps are in operation 12 hr/day, measured lighting demand is 58156 Kwh.

V. Comparison and Discussion

Results obtained from power loss measurements are provided in Table3. The difference between calculation and measurement also represents non-technical power loss that can be due to following reasons:

- Impermissible branching or meter manipulation
- Incorrect meter reading
- Having no access to customer meters or billing provisional consumption

By increasing cross-section of conductors or power factor via capacitor installation, once can reduce power loss and increase system efficiency.

Comparing results provided in this table revels that computational method offered in this paper can be used to get power loss with permissible accuracy using available data.

Thus, in this paper, not only a method is proposed to calculate technical power losses in a typical distribution transformer feeder, another technique is also proposed to measure power losses and separate technical and non-technical power losses.

Table 3
Results Comparison

	Calculation	Measurement	Difference	Difference percentage
Transformer output	368358 Kwh	369947 Kwh	1588 Kwh	0.43
lighting	58156 Kwh	58910 Kwh	754 Kwh	1.28
Total losses	3926 Kwh	4012 Kwh	86 Kwh	2.15
Losses divided by input	%1.27	%1.29	%0.02	1.05

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