International Journal of Recent Advances in Multidisciplinary Topics
Volume 3, Issue 1, January 2022
https://www.ijramt.com | ISSN (Online): 2582-7839

Statistical Approach to Estimate Energy Losses in Power Distribution System

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***Abstract*: Power system losses comprises of technical losses caused due to lack of inadequate T&D capacity, too many transformation stages, improper load distribution and extensive rural electrification etc., non-technical losses due to inaccurate meter reading, unmetered supplies, theft and pilferage etc.& revenue losses due to non-realization of energy. So, accurate and proper evaluation of these losses in the power distribution system plays an important role in terms of technical and economic factors for power distribution utilities. This research paper aims at the estimation of total losses in the distribution system based on statistical approach. This statistical approach not only helps in the identification of technical and non-technical losses but also gives a direction to the utilities to reduce these losses and improve the overall health of their power distribution system.**

***Keywords*: Consumer energy, distribution transformer (DT), hypotheses, statistical, transmission and distribution loss.**

1. Introduction

In order to study non-technical losses, which constitute a portion of the total losses in electrical power systems, the logical first step is to understand the complete picture of power systems losses. Power system losses can be divided into three categories namely as technical losses, non-technical losses and revenue losses. Technical losses on distribution systems are the losses due to physical aspect. These are mainly due to heat dissipation resulting from current passing through conductors and from magnetic losses in transformer. Technical losses occur during transmission and distribution and involve substation, transformer, and line related losses. These include resistive losses (resistive lose in winding and the core loses) resistive losses in the secondary network, resistive loses in service drop and loses in kWh meters [1].

The reported losses are under estimated in India and cover up large commercial losses (theft), actual figure are very high and bulk of loss occur in the sub-transmission and distribution systems. Inefficiency, frequent interruption, flicker, and poor voltage also characterize the poor health of the distribution systems. In addition, the billing and revenue collection are very tardy leading to utility financial losses of Rs. 26,000 crores approx. every year. If the current trend continues, in another three years, utility financial losses will reach Rs. 45,000 crores every year [2-3]. It is therefore necessary to bring about improvement in planning implementation and operation of T&D to network development should be replaced by an approach based on technical and reliability requirements, economic consideration of cost of energy loss and expansion of the system to meet the growth of prospective demand with least cost. The main objective of this paper is to estimate and compute the technical losses based on the statistical approach in the secondary power distribution system. The technical losses will be estimated based on the statistical approach using paired P-test & F-test when a complete set of data is not available.

The paper provides a brief description of theoretical aspects of energy losses in Section-2. We then give a statistical approach to estimate energy losses in Section-3. Section-4 reports the results. Conclusions and future directions are put forth in Section-5.

2. Theoretical Background

1) Transmission and Distribution Loss and AT&C loss

The energy losses occurring in the Transmission and Distribution system are known as T& D loss. T&D loss is the difference between units injected into the system and the units billed to the ultimate consumer and generally expressed as percentage of units injected:

$$\text{T\&D Loss (\%)} = \frac{(energyinput - energybilled) \times 100}{energyinput}$$

T&D loss is generally calculated for a period of one year, which is usually the financial year. It accounts for the loss of energy in this period from the point of generation to the point of billing [5]. The continued rising trend in the losses is a matter of serious concern and all out efforts are required to contain them. AT&C losses to the utility are the sum total of technical losses, commercial losses and losses due to non-realisation of total billed demand.

2) Statistical Evaluation Techniques

Most commonly used statistical techniques for comparing interrelated (before and after observation) data on the same subjects are Paired t-test [4]. A paired t-test is used to compare two population means where you have two samples in which observations in one sample can be paired with observations in

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the other sample. Examples of where this might occur are:

- Before-and-after observations on the same subjects (e.g. students' diagnostic test results before and after a particular module or course).
- A comparison of two different methods of measurement or two different treatments where the measurement/treatments are applied to the same subjects (e.g. blood pressure measurement using a stethoscope and a dynamap).

This approach consists of four steps:

- State the hypotheses,
- Formulate an analysis plan,
- Analyze sample data, and
- Interpret results

3. Statistical Approach for Estimating Power Losses

There are various type of losses in secondary distribution system. Figure 1 below gives the schematic diagram of all such type of losses.

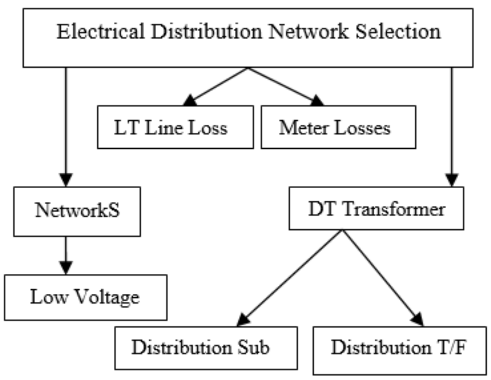

Fig. 1. Different Types of Secondary Distribution Losses

The schematic diagram is used to develop a strategy to minimize the electrical energy losses in an electrical secondary distribution network.

1) Methodology for Measured Distribution Losses

In the Case study considering the Mayapuri industrial area (MIA) phase 1 network. The power is fed to this network by 20 MVA Power T/F at Rewari Mayapuri 33 KV substation. There are 19 Distribution Transformers that fed power to Mayapuri Industrial consumers. For sake of simplicity the data of 7 DT`s is displayed as single line diagram as in Figure 2

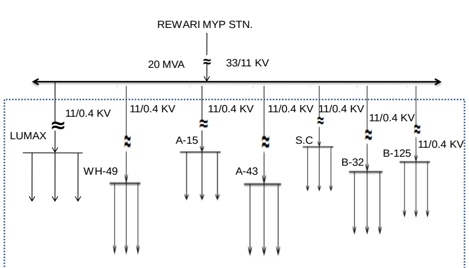

Fig. 2. SLD of 7 DT`s of Mayapuri Industrial Area

The next step in this approach is to do consumer tagging. For the sake of simplicity, the consumer tagging of only two DTs are shown in table no.1

Table 3.1
Consumer Tagging Data

S. no	Meter no.	Meter Type	March	April
1	27115299	Poly phase	1893	2386
2	27065154	Poly phase	1317	1369
3	E-993902	Single phase	39	39
4	27065252	Poly phase	1967	1434
5	24147462	Single phase	593	930
6	27016428	Poly phase	1232	1232
7	29001037	C.T	3472	3680
8	27045327	Poly phase	6469	5470
9	13468687	Single phase	25S2	392
10	27038175	Poly phase	1057	1250
11	29001065	C.T	1968	2320
12	27036094	Poly phase	1261	1114
13	27037778	Poly phase	1269	1601
14	29001063	C.T	3820	4024
15	DVBO3625	C.T	7581	8116
16	DVB0362	C.T	2396	3178
17	27016430	Poly phase	800	800
18	23822551	Single phase	53	73
19	22137976	Single phase	177	177
20	13090358	Single phase	165	195
21	23833429	Single phase	18	18
22	24157859	Single phase	24	24
23	9825087	Single phase	993	993
24	27110120	Poly phase	1223	988
25	27068494	Poly phase	1265	1296
26	27074855	Poly phase	2769	4556
27	27049235	Poly phase	4077	4489
28	27024217	Poly phase	1856	1856
29	27063169	Poly phase	1033	1153
30	27036503	Poly phase	2978	4287
31	DVB0292	C.T	31209	27602
32	27063243	Poly phase	212	275
33	27063308	Poly phase	175	268
34	29001038	C.T	4132	4024
35	DVB0292	C.T	12625	11098
36	29001035	C.T	1096	1280
37	29001034	C.T	1864	1752
38	22034943	C.T	1816	1628
39	27016837	Poly phase	706	706
40	22078151	Single phase	277	177
41	29001036	C.t	1788	1476
42	23767192	Single phase	124	124
43	29001029	Poly phase	280	232
44	27063097	Poly phase	335	702
45	22396747	Single phase	143	143

Table 3. 2 below gives the summary of measured percentage T&D Losses for selected segments of distribution network of 7 DT`s of MIA.

Table 3.2 (a)
Summary of Measured % T&D Losses

DT Name & Code	**Lumax (DT1)**	**WH-49 (DT2)**	**A-15 (DT3)**	**A-43 (DT4)**
Power absorbed (Consumer MR)	232500	192668	224558	328114
Power delivered (DT MR)	250000	216480	258112	431728
% difference of power absorbed	0.075	0.124	0.149	0.316
% difference of power delivered	0.070	0.110	0.130	0.240
Relative difference b/w power absorbed & delivered	0.53	1.36	1.94	7.58

Table 3.2(b)
Summary of Measured % T&D Losses

	Shopping complex (DT5)	**B-32 (DT6)**	**B-125 (DT7)**
Power absorbed (Consumer Meter Reading)	204161	314389	133317
Power delivered (DT Meter Reading)	224352	365568	145280
% difference of power absorbed by	0.099	0.163	0.090
% difference of power delivered	0.090	0.140	0.082
Relative difference b/w power absorbed & delivered	0.89	2.28	0.74

Table 3.3 Consumer Connection Losses

DT Code	**No. of Consumers**	**Line Losses (%)**	**Total Power Flow**	**Total Energy Loss**
DT1	49	1.30	250000	3250.00
DT2	64	1.60	216480	3463.68
DT3	105	2.30	258112	5936.58
DT4	83	1.80	431728	7771.10
DT5	85	1.85	224352	4150.51
DT6	98	2.20	365568	8042.50
DT7	17	0.90	145280	1307.52

As per standards, the difference in power absorbed and delivered must be less than two percent. From the table 3.2, if the difference is less than two percent then it is an acceptable loss value otherwise is unacceptable. From table 3.2, it can be concluded that A-43 & B-32 needs investigation and the remaining are acceptable.

Applying the statistical approach gives an estimate of commercial losses so here we give a brief introduction about the source of non-technical losses. The main sources of nontechnical losses are:

- Deficiencies in the commercial cycle, including unread or improperly read meters and/or inaccurate logging of readings;
- Non-metered supply, due to a lack of meters (in these cases, consumption is often estimated);
- Inaccurate meters;
- Meter tampering and meter bypass;
- Illegal connections (theft), i.e., energy diverted by illegal taps in the network.

Nontechnical losses in distribution systems generally occur in the LV network. In this last case, nontechnical losses are normally associated with meter inaccuracy or meter tampering or, more properly, with tampering with the measurement transformers. Once total distribution losses (D_L) and the technical distribution losses (D_{LT}) are known, non-technical losses (D_{LNT}) are easy to compute, as follows:

$$D_{LNT} = D_L - D_{LT}$$

Therefore, a Statistical approach is proposed for accurately estimating technical losses in power distribution system and identifying the commercial losses based on this approach.

2) Methodology for Estimating Projected Distribution Losses

The actual losses of secondary distribution network can be verified by comparing the actual measured data of the network with projected loss data. For calculation of projected loss of the network, the main parameter that should be considered are as:

- Customer Connection Losses
- Distribution transformer Losses
- Meter Inaccuracy

The discussion of each parameter in detail is as:

3) Customer Connection Losses

These losses are those occurring in the circuit between distribution transformers to consumer premises. In Indian distribution system usually power is distributed through a single distribution transformer to a single society/locality with inclusion of many consumers based on DT capacity. This type of arrangements lead to the power loss due to low power factor, due to presence of many joints and loose connections, high resistive circuits at low voltage profile etc. These losses depend upon many factors but mainly depend upon number of consumer fed through that particular feeder. Based upon experience it has been found that customer connection losses are proportional to number of customers and varies between

Table 3.4
Distribution Transformer losses

T/F Name	T/F Rating (KVA)	T/F Losses (%)	DT Energy Reading	Total T/F Loss
Lumax	1000	1.60	250000	4000.00
WH-49	1000	2.30	216480	4979.04
A-15	990	2.20	258112	5678.46
A-43	1000	1.40	431728	6044.19
Shopping complex	990	1.90	224352	4262.69
B-32	1000	2.50	365568	9139.20
B-125	1000	1.30	145280	1888.64

Table 3.5
Meter Losses

Feeder Name	Consumer Reading	Total Energy Loss
Lumax	232500	116.25
WH-49	192668	96.334
A-15	224558	112.279
A-43	328114	164.057
S. Complex	204161	102.0805
B-32	314389	157.1945
B-125	133317	66.6585

Table 3.6 (a)
Statistical Evaluation of 7 DT`s Losses of MIA

DT Name	Lumax	WH-49	A-15	A-43
Determine P value for paired t-test	0.036842	0.013956	0.01962	0.000279
Significance (f test)	0.1051	0.20372	0.02767	0.00903
Standard deviation of Population	6616.43	9274.95	13533.79	49775.88
Confidence interval for Population Mean	13887	19467	28406	104473
Measured value of Bus	232500	192668	224558	328114

Table 3.6 (b)
Statistical Evaluation of 7 DT`s Losses of MIA

DT Name	Shopping complex	B-32	B-125
Determine P value for paired t-test	0.045786	0.013507	0.003217
Significance (f test)	0.04258	0.07506	0.19909
Standard deviation of Population	7800.82	20513.65	4998.58
Confidence interval for Population Mean	16373	43056	10492
Measured value of Bus	204161	314389	133317

1.3% - 2.6%. Table 3.3 gives the consumer connection losses for Mayapuri Industrial area along with number of consumer’s connection.

4) Distribution transformer Losses:

Table 3.4 gives the total energy loss for Mayapuri Industrial area Distribution Transformers.

5) Metering Inaccuracy

Losses due to metering inaccuracies are defined as the difference between the amount of energy actually delivered through the meters and the amount registered by the meters. All energy meters have some level of error which requires that standards be established. In India, the accuracy range is +/- 2.5 percent.

The accuracy class of CT Meter and DT meters is of 0.1 s. Generally an energy meter with accuracy class of 0.5s is mostly used. Table 3.5 give the energy meter losses for 7 DT`s of Mayapuri Industrial Area.

6) Projected Total Loss Calculation

The projected total loss can be calculated by sum of consumer connection losses, DT Losses and Meter Losses. Mathematically, the projected total loss is given by

Projected Loss = Consumer connection loss + DT Loss + Meter Loss

Projected power absorbed = Power Measured – Projected total Loss

This is the factor which determines probability of having non-technical losses in distribution system. Conclusions are drawn from these percentage differences. If percentage difference is less than 10% then it is normal. A percentage difference higher than 10 percent is assumed high and need further investigation.

7) Problematic Areas Identification using Statistical Approach

As we know that the calculation of the p value returns the two tailed p value of a paired t test. The t test generates a standard score value for each DT value with respect to the minimum, typical and maximum value of each of the different DT`s on the network. It returns a p value for each DT on the distribution using the two tailed probability for the normal distribution.

This function is used to assess the likelihood that

The actual measured electrical energy output for a specific DT and the estimated electrical energy for the same DT are derived from the same electrical energy input bus on distribution network.

The f test statistical function used in the model returns the one-tailed probability that the variances in the actual measured electrical energy and the estimated electrical are not significantly differently. This function is used to determine whether the measured and estimated electrical energy have significantly different variances. The confidence interval here calculates the mean of the DT of both the measured and estimated electrical energy. It is used here to determine, with a particular level of confidence the lowest and highest electrical energy level of use for a particular DT in the electrical distribution network. This level of confidence it compared to the actual measured value of the electrical energy used by DT and the confidence interval should be an order or more lower than the actual measured electrical energy to be assumed operating correctly. Table 3.6 (a&b) gives the statistical evaluation of the 7 DT`s of Mayapuri Industrial Area.

These four statistical calculations can be subdivided into two groups' namely statistical calculations and measured data verification group. The statistical evidence group contains the t-test and f-test whereas the measured data verification group consists of the standard deviation and the confidence interval. From these two groups the final potential area identification can be done in order of priority.

4. Results

Results obtained by the statistical approach are shown in table 1.by analyzing the statistical evidence group, A-43 and B-32 secondary distribution network are identified as problem area whereas by analyzing measuring data group the data integrity of LUMAX, WH-49, Shopping Complex and B-125 secondary distribution network have been verified. The data in the A-43, B-32 and A-15 secondary distribution network highlights inconsistencies.

By combining statistical and measured data tests the results are prioritized as;

- A-43 secondary distribution network – Problematic Area as known of huge commercial loss
- B-32 secondary distribution network – Problem Area
- A-15 distribution network – Problematic Area
- WH-49 secondary distribution network- No Problem Area i.e. very less commercial losses
- Shopping Complex distribution network- No Problem Area i.e. very less commercial losses
- LUMAX and B-125 distribution network – No Problem i.e. very less commercial losses

Once the identification of the problematic areas is done in term of huge commercial losses, inform the power utilities so that action can be taken to reduce these losses.

5. Conclusions and Future Directions

The power distribution utilities in India have huge amount of debt (approx. two lacs seventy five thousand crore rupees) due to high T&D loss% in the distribution sector. This results in poor customer satisfaction and unreliable power supply. The losses in the primary and secondary distribution system comprises of technical losses, non-technical losses & revenue losses. The reasons for the technical losses are lack of inadequate T&D capacity, too many transformation stages, improper load distribution and extensive rural electrification etc.

For the proper and accurate measurement of power losses in the power distribution utilities, we have to identify and found different power losses like technical and non-technical losses. The power distribution utilities should estimate the losses where the data for computing the technical and non-technical losses are generally not available. The statistical approach is used in this paper to estimate the total losses in the primary and secondary distribution system. This statistical approach not only helps in identification of technical and non-technical losses but also guide the utilities to reduce these losses and improve the overall health of their power distribution system. The utilities will have to concentrate on other mathematical approaches and advanced technologies for the accurate estimation and reduction of non-technical losses and the technical losses.

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