International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 1, Jan 2022 pp: 1179-1188 www.ijaem.net ISSN: 2395-5252

Computation of Losses in Primary and Secondary Distribution System - A Case Study

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Submission: 18-01-2022 Revised: 28-01-2022 Acceptance: 31-01-2022

ABSTRACT
The developing country like India faces shortage of electrical power. Power distribution utilities in India are facing many problems like commercial loss due to various inefficiencies, and high technical losses. This has a very bad effect on the economic growth of our country. Power system losses in India comprises of technical losses, non-technical losses & revenue losses. So, there is a need of proper energy accounting and audit in the power distribution system that helps the power distribution utilities to compute the energy losses. This paper aims at the estimation and computation of technical losses in the power distribution system. For this, the calculation of the technical losses for HT feeders, power transformers, and secondary distribution system using load factor and loss load factor approaches.
Keywords: technical losses, power transformer, loss load factor, HT feeder), secondary distribution etc.

I. INTRODUCTION

Energy has always been an integral part of mankind civilisation historical as well as present day scenario, and there is no reason to abide that in future our existence will be more and more dependent on energy. Electrical energy finds innumerable uses in houses, industries, agriculture sector, commercial sector and in transport sector. Electrical energy is a convenient form of energy because it can be generated centrally in bulk and transmitted economically over a long distance and then finally distributed at the consumer level by the utilities. The economy of the power system is affected by certain factors mainly transmission and distribution losses commonly known as T&D losses.

India experiences severe endemic electric energy and peaking electric power shortage. Power system is paralysed with huge mounting commercial losses due to various inefficiencies, technical losses and increasing subsidy burden on state. This shortfall of power has a very detrimental effect on the country`s economic growth. As the total distribution losses equal to the technical, non –technical and revenue losses hence, it is very important to firstly understand the nature, causes & the impact of technical losses in both primary and secondary distribution system in detail to proceed further in the work.

The World Resources Institute estimates electricity transmission and distribution (T&D) losses in India to be 27 percent - the highest in the world. [2]. The T&D losses are due to a variety of reasons, viz., substantial energy sold at low voltage, sparsely distributed loads over hip hazard rural electrification, low investment in distribution system, improper billing and high energy pilferage.

In general, the cost of electricity per consumer is increased by system losses as these losses increase the operating cost of the electric utilities.

The main objective of this dissertation is to estimate and compute the technical losses in the power primary and secondary distribution system. Firstly, the technical losses for HT feeders, power transformers are calculated and then secondary distribution system technical losses are computed based on feeder data and load profile of transformers using load factor and loss load factor approaches.

Section-2 gives a brief description about the measurement of technical loss. Then, the approach for computing the power losses of the network is given in section-3. Lastly, in section-4 a case study is implemented using load factor and load loss factor to calculate the technical losses of the network. Conclusion is put forth in section-5.

II. MEASUREMENT OF TECHNICAL LOSS

System loss is basically arithmetic difference between the units purchased from bulk suppliers and the units billed to consumers in the respective period. The total system loss for any given period is expressed as percentage of total energy input in the system and is computed as follows [9]:

Total distribution loss = (Energy input- Energy sold)/ Energy input/ 100

The total losses comprises of technical loss and commercial loss. The commercial loss mainly consists of losses due to theft of energy and unrecovered billed amount [3-4]. While, technical losses are the losses occurred in the electrical elements during transportation of energy from the source to consumer end and mainly comprises of ohmic and iron losses. Technical loss is an inevitable consequence of transfer of energy across transmission and distribution networks.

2.1 Loss due to lines/feeders

Line losses occur due to loss in conductors/cables where lower size conductors are used. This causes sags and temperature rise in conductors which further aggravate the loss. Loss in higher loaded phase wire occurs due to unbalanced loading. Losses in the feeder occur due to current in neutral wire of lower size conductor [5-6]. Sometimes loosening of strands may cause of losses in cable. Loss in the feeder is calculated as below:

$P_{loss}=I*(I*r/l*L)=I^2R$

Where,

I is current

r/l is resistance / Kilometre

L is length of cable in Kilometres

For a 3-phase system, the losses for each phase are calculated separately according to the measured current as:

$P_{loss}total=P_{loss-a}+P_{loss-b}+P_{loss-c}$

$=I^2R_a+I^2R_b+I^2R_b$

2.2 Loss in Transformers

Distribution transformers are expected to convert up to 95-98% of input power into usable output power [1]. The distribution transformer installed in the distribution system gets overloaded. Oversized transformer can contribute to inefficiency, but when the transformers are appropriately matched to their loads, efficiency increases. However, when the transformer is lightly loaded, no load losses of the transformer become a prominent part of input energy and leads to a high percentage energy loss. Factors contributing towards losses in transformer are:

- Oversized transformers operating at low loading: improper selection of transformer based on its expected load and day efficiency result in high no-load losses. Losses are high on weekend.
- Undersized transformers: this causes higher loading on the transformer, resulting in high operating losses.
- Unbalanced load in secondary side: there can be a significant unbalance in the system due to load balance in different phase, as more consumers may be connected to a particular phase. This results neutral shifting. This cause the over fluxing due to higher voltage on a certain limb which result in technical losses.
- Low oil level/oil leakage: oil serve as dual purpose of insulation and cooling. Leakage and contamination of oil with moisture can reduce the insulation resistance of oil. Sludge formation in oils can adversely affect the cooling and lead to higher temperature and losses.

III. APPROACHES FOR CALCULATION OF LOSS

3.1 Load Factor

The ratio of the average load during a designated period to the peak or maximum load occurring in that period. [8]

LF=Averageload/Maximumload

3.2 Load Loss Factor

The actual losses of the circuit / plant item is calculated by applying a factor to the total losses assuming maximum current to flow through that circuit / plant item during the whole period. This factor is called as Load Loss Factor (LLF) which is defined as:

Load Loss Factor = Loss at maximum current (kWh) /Actual loss (kWh) during period

There are methods giving the relationship between the Load Loss Factor (LLF) and the Load Factor (LF). The formulae used for the calculations are shown below. The methods outlined in this document are to be used to calculate the Loss Components for the various categories in the distribution network. These Loss Components will then be used to calculate the overall LLF's for the various customer connections [7-8].

This part gives the relation between load factor and load loss factor via an empirical equation. As loss is an approximate square function of the demand as given in the equation above, it is required to calculate exact relation between load factor and load loss factor for calculation of the losses. The empirical equation given below gives relationship between load factor and load loss factor.

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$LLF = k * LF + (1-k) * LF^2$ or $LLF= 0.2* LF+0.8*LF^2$

Where k = coefficient.

$K = \frac{LLF - LF^2}{LF - LF^2}$

It can be proved that coefficient k varies from consumer to consumer depending upon type and class of the consumer which can be derived from the following equation.

IV. CASE STUDY

The utility taken for the case is BSES Rajdhani power limited, a power distribution company that supply power to west and south Delhi. BSES Rajdhani power limited is broadly divided into west and south circle. The west circle of this utility comprises of 10 divisions, namely, Dwarka, Janakpuri, Vikaspuri, Palam, Mundka, Jaffarpur, Najafgarh, Tagore garden, Punjabi Bagh and Nangloi. Here, we considered Janakpuri division of west circle, BSES Rajdhani power limited. The Janakpuri division includes various categories of consumer like, industrial, domestic and commercial. This division serves approx. 1, 24,000 consumers with consumption of around 470 units per consumer per month for domestic and commercial consumers and around 3000 units per industrial consumer per month. A total of 64 outgoing 11 kV feeders that supply power to the areas of Mayapuri industrial area, Janakpuri, Rajouri garden, Sagarpur etc.. The details of 11 KV feeders that supply power to the consumers in the Janakpuri division are as:

S.NO.	Name of 11 KV feeder	No. of consumers (Approx.)	Category of consumer
1	AJANTA F. D.	195	Industrial
2	C-88 MAYAPURI	151	Industrial
3	D BLOCK KHAZAN BASTI	226	Industrial
4	D-1 JKP	3466	Domestic
5	DDU HOSPITAL	172	Commercial
6	DDU STAFF QRS.	3225	domestic
7	F BLOCK MAYAPURI	295	Industrial
8	FACILITY CENTER	181	Industrial
9	KACHHA TIHAR	3961	Domestic
10	MAHARANI S/STN.	1838	Commercial+ Domestic
11	MIG RAJOURI GARDEN	3455	Domestic
12	POLICE CHOWNKI HARI NAGAR	2380	Domestic +Commercial
13	O/H SHIV N.G.R	3575	Domestic
14	PUMPING STN., SWARG ASH.,SUBHASHNGR	1731	Commercial+ domestic
15	SELF FINANCE S/STN.	246	Industrial
16	TIHAR JAIL	3761	Domestic
17	AJANTA S/STN.	3788	Domestic
18	FATEH NAGAR	2993	Domestic
19	SUBHASH NAGAR S/STN.-2	2627	Domestic
20	GURUDWARA S/STN	2835	Domestic
21	J-3 RAJOURI GARDEN	3692	Domestic
22	LIG RAJAURI GARDEN+TDI MALL	1895	Domestic+ commercial
23	14 BLOCK SUBHASH NAGAR	2687	Domestic
24	CET PLANT MAYAPURI	194	Industrial
25	FATEH NAGAR	3721	Domestic
26	G BLOCK HARI NAGAR	1527	Domestic+ commercial
27	GANDHI PARK I/D S/STN.-1	3263	Domestic
28	GURUDWARA R/GARDEN	1422	Domestic + commercial
29	J BLOCK RAJOURI GARDEN	1825	Domestic+ commercial
30	LIG RAJOURI GARDEN	3311	Domestic
31	MIG RAJOURI GARDEN	3556	Domestic
32	MTNL FDR NO. II	1688	Commercial
33	MTNL NO-1 & AJANTA INDOOR	1824	Commercial
34	TIKONA PARK ASHOK NAGAR	2951	Domestic
35	B -II S/STN JKP	2833	Domestic
36	C - 1 S/STN JKP	3145	Domestic
37	C BLOCK DABRI MOD	2664	Domestic
38	O/G TO C-II BLOCK JKP	2884	Domestic
39	OG TO A-4 S/STN JKP	3056	Domestic
40	P&T QUARTERS	375	Commercial
41	B-2 BOOSTER PUMP-JKP	1791	Domestic +Commercial
42	BOOSTER PUMP DELHI 43CANTT.	1655	Domestic +Commercial
43	C- 4 JANAKPURI	3235	Domestic
44	C-3 COMPLAINT CENTER JKP	2488	Domestic
45	C.C.R.A. S/STN JKP	2491	Domestic
46	COMM. CENTER S/S NO. 1 PETROL PUMP	1672	Commercial
47	D -2 JANAKPURI	2789	Domestic
48	D-1 S/STN JKP	2579	Domestic
49	D.D.U. HOSPITAL NO II	1661	Commercial
50	D.D.U. HOSPITAL NO-I	1769	Commercial
51	INSTUTIONAL AREA	246	Commercial
52	M S BUILDING (COMM. CENTER JKP)	325	Commercial
53	MUSICAL FOUNTAIN JKP	2874	Domestic
54	TIHAR JAIL NO.-5	2945	Domestic

55	GOPINATH BAZAR	1524	Domestic+ commercial
56	BOOSTER (JANAKPURI)	2864	Domestic
57	DISTT., SRVC CNTR JKP	1445	Commercial
58	JYOTI SHIKHAR	251	Commercial
59	NANGLI ZALIB	3281	Domestic
60	PLOT NO. 11, D.C. DDA	1456	Domestic+ Commercial
61	PLOT NO. 13 LIC BLDG.	358	Commercial
62	B-3 S/STN JANAKPURI	3411	Domestic
63	PLOT NO.-7 DISTT. CENTRE	189	Commercial
64	Rewari MYP	820	Industrial

Table No. 4.1 Details of Janakpuri Division 11 KV feeders

From table no.4.1 shown above, the Janakpuri division is divided into four clusters, namely, domestic, industrial, commercial and domestic + commercial. The domestic cluster comprises maximum no. of domestic consumers, similarly, commercial cluster comprises of maximum commercial activity and commercial + domestic contains mixed bag of domestic and commercial consumers. From these 64 HT feeders, 32 HT feeders mainly consist of domestic consumers, i.e., majority of the consumers in these feeders are domestic ones. Similarly, eight 11 KV feeders belong to industrial consumers, thirteen feeders belong to commercial consumers and eleven feeders belong to commercial + domestic consumers.

4.1 HT feeder data and power transformer load profile

This sub-section comprises of computation of power losses of the network based on the approach of load factor and load loss factor. For the sake of simplicity, four 11 feeders are taken one from each cluster of Janakpuri division. Firstly, the feeder data for 24 hours for these four 11 kV feeders is shown in Table nos. 4.3 and 4.4 respectively. Then, LF, LLF and K are calculated for these feeders based on the feeder data. Table no.4.2 shows the load variation of 24 hours of Commercial and Industrial 11 KV feeder of Janakpuri Division.

Feeder Name/Type of Feeder	JYOTI SHIKHAR Commercial	Rewari MYP Industrial
Size of Cable	300 Sqmm	300 Sqmm
Time	Amp	Amp
1	75	243
2	76	244
3	78	250
4	77	239
5	80	240
6	84	230
7	102	254
8	295	263
9	315	299
10	314	357
11	316	394
12	320	409
13	285	335
14	297	342
15	323	359
16	354	398
17	367	415
18	373	388
19	380	386
20	365	334
21	294	307
22	124	263
23	96	248
24	88	244

Table No. 4.2 Load variation of 24 hours of Commercial and Industrial 11 KV feeder

Similarly, table no. 4.3 shows the load variation of 24 hours of remaining two clusters, domestic and domestic + commercial 11 KV feeder of Janakpuri Division.

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Feeder Name	GOPINATH BAZAR (Domestic + Commercial) Cluster	MIG RAJOURI GARDEN Domestic Cluster
Size of Cable	240 Sqmm	300 Sqmm
Time	Amp	Amp
1	98	86
2	96	93
3	87	87
4	98	87
5	115	102
6	211	124
7	223	236
8	239	228
9	241	238
10	194	151
11	180	114
12	180	116
13	164	116
14	177	123
15	280	125
16	285	128
17	290	188
18	240	212
19	245	221
20	232	218
21	196	198
22	132	146
23	124	112
24	102	98

Table No. 4.4 Load variation of 24 hours of domestic and (domestic + commercial) feeder

4.2.1 Load curve and load duration curve of 11 KV feeders

This part of the section gives the load curve and load duration curve of the feeder data. Figs. 4.1 to 4.4 gives the load curve of the 11 KV feeders based on the feeder data given in table nos. 4.2 to 4.3.

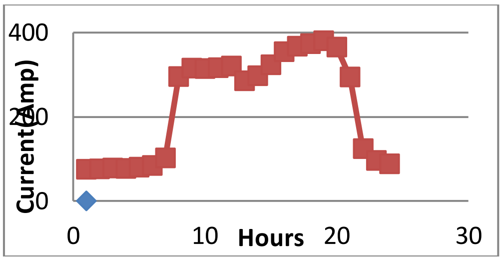

Fig 4.1 Load curve of JyotiShikhar commercial feeder

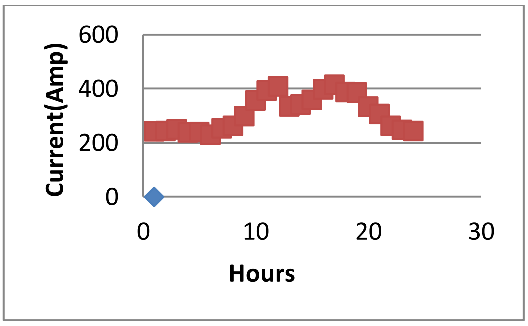

Fig.4.2 Load curve of Rewari MYP industrial

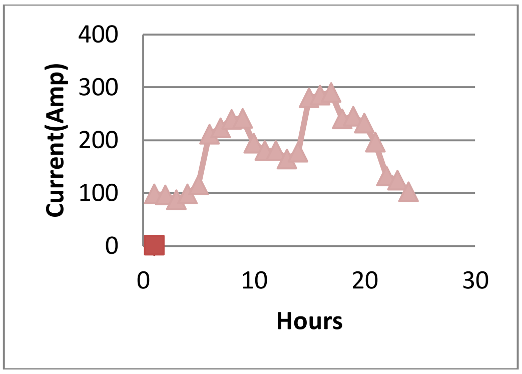

Fig.4.3 Load curve of Gopinath Bazar domestic + commercial area

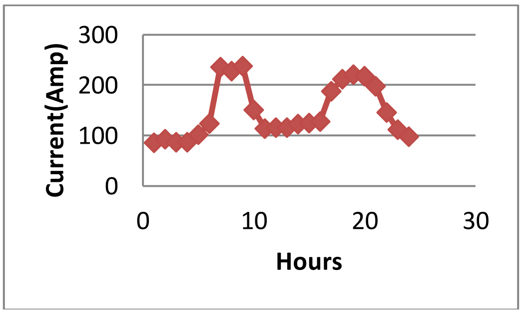

Fig. 4.4 Load curve of MIG Rajauri Garden domestic area

Similarly, Figs. 4.5 to 4.8 give the load duration curve of the 11 KV feeders based on the feeder data given in table nos. 4.2 to 4.3.

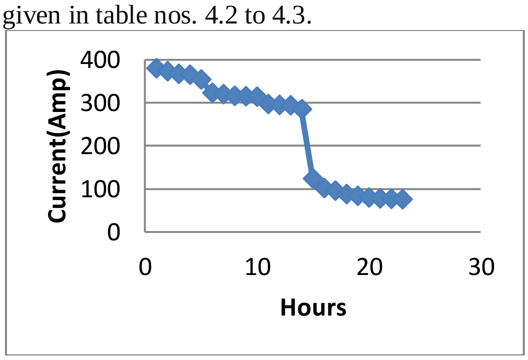

Fig 4.5 Load duration curve of JyotiShikhar commercial feeder

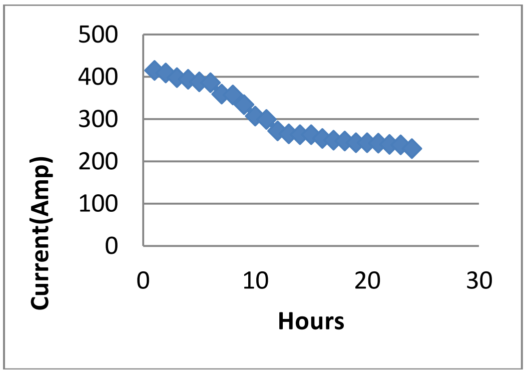

Fig.4.6 Load duration curve of Rewari MYP industrial area

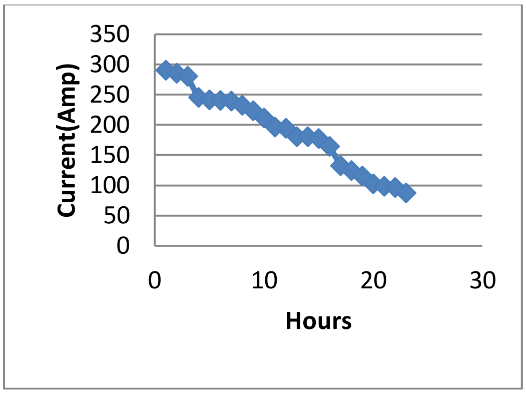

Fig.4.7 Load duration curve of Gopinath Bazar (domestic + commercial Cluster) 11 KV feeder

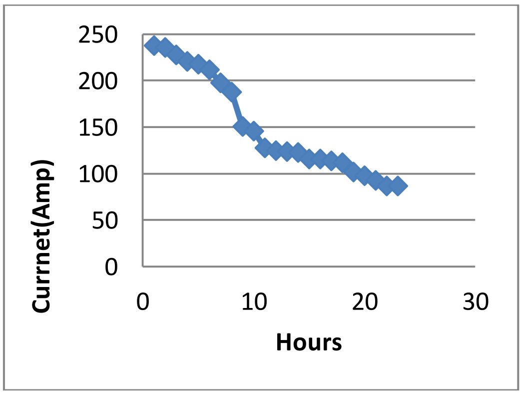

Fig. 4.8 Load duration curve of MIG Rajauri Garden domestic 11 KV feeder

Transformer name	Rewari Substation
Time	Amp
1	521
2	522
3	494
4	446
5	444
6	466
7	472
8	494
9	456
10	658
11	688
12	714
13	752
14	690
15	782
16	782
17	778
18	756
19	834
20	796
21	720
22	680
23	666
24	614

4.2.2 Load Profile of Power Transformer

This sub-section deals with the have the load profile of power transformer of 33 KV grid Rewariline that serves the industrial consumers of Mayapuri Phase-1, Janakpuri division. The power transformer of 20MVA that supplies power to industrial consumers of Mayapuri phase is considered. Table no. 4.4 gives the load profile of 24 hours load variation of 20 MVA power transformer.

Table No. 4.4 Load variation of 24 hours of power transformer

Similarly, Figs. 4.9 to 4.10 give the load curve and load duration curve respectively of the 20MVA Power Transformer based on data given in table no. 4.5.

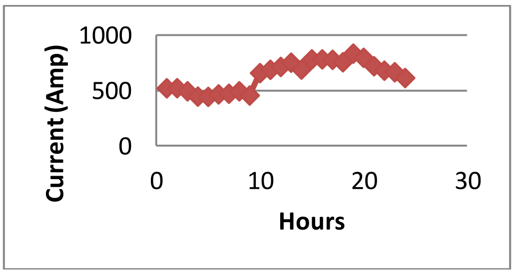

Fig.4.9 Load curve of Rewari power transformer

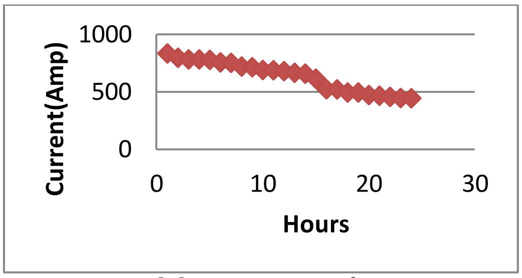

Fig. 4.10 Load duration curve of Rewari power transformer

4.3 Computation of Power Losses of the Network

Lastly, the technical losses in the 11 KV feeders of four clusters and 20 MVA power transformer of Janakpuri division, BSES Rajdhani power limited are calculated.

4.3.1 Losses in Feeders

Loss in a feeder for a given period (which is one month in this case) is given by the equation below.

Technical loss in MU = $I^2 \times R \times L \times LLF \times 24 \times 30 \times 10^{-9}$

I = Load in amp.

R = Resistance of the conductor in ohms/ kilometre

L = Length of the feeder in kilometres

LLF = Load loss factor

The technical losses of these four 11 KV feeders in million units (MUs) are shown in table No.

	JyotiShikhar CX	Rewari MYP IX	GopinathDX+ CX	MIG Rajauri Garden DX
Size of conductor	300 Sqmm	300 Sqmm	300 Sqmm	240 Sqmm
Length	3 KM	2 KM	3.5 KM	5 KM
Peak load	380	415	245	238
LF	0.76	0.68	0.72	0.76
LLF	0.61	0.50	0.55	0.64
K	0.17	0.17	0.12	0.34
Loss in MU	0.06 MU	0.05 MU	0.01 MU	0.03 MU
Technical Loss in %	1.9	1.3	2.3	2.6

Table No. 4.5 Technical loss in MU for 11 KV feeders

In the similar manner, technical loss in MU can be calculated for remaining feeders.

4.3.2 Loss in power transformer

Loss in power transformer can be calculated by equation for calculation of technical loss is given under:

Technical loss of Transformer in MU for month = {No load loss + [(% loading) 2 * rated Cu. loss *LLF]}*24*30/10^6

The technical losses of power transformer in million units (MUs) is shown in table no. 4.6

4.4 Computation of Power Losses in Distribution Transformers

This section gives the load profile of distribution transformer as well computation of losses in distribution. There are nineteen distribution transformers in the Mayapuri industrial area phase-1 that supply power to nearly 820 industrial consumers.

Table 4.6 Technical Loss of Power Transformer

Power transformer (20 MVA)	
Peak load	834
Full load	1250
% loading	71.21
LF	0.76
LLF	0.61
K	0.18
No load loss	1.72 KW
Full load loss	7.3KW
Loss in MU	0.002 MU
Loss in %	0.9

Sr. No.	Feeder Name	Transformer Rating (KVA)	No. of consumers
1	A-8, S/STN, MAYAPURI PH-1	630	30
2	A-23, S/STN, MAYAPURI PH-1	630	20
3	A-15, S/STN, MAYAPURI PH-1	990	105
4	A-4, S/STN, MAYAPURI PH-1	630	20
5	A-43, MAYAPURI, PH-1	1000 & 630	83
6	COMMUNITY CENTRE, MAYAPUURI, PH-1	1000 & 630	77
7	A-42, MAYAPURI PH-1	400	8
8	B-138, MAYAPURI PH-1	990	20
9	B-75, MAYAPURI PH-1	1000	10
10	POLICE STATION,	400	6

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	MAYAPURI PH-1		
11	SHOPPING CENTER MAYAPURI PH-1	990 KVA	85
12	B- 80/1, MAYAPURI PH-1	630 KVA	14
13	LUMAX, MAYAPURI PH-1	1000 KVA	49
14	WH -38, MAYAPURI PH-1	1000 KVA	23
15	WH -49, MAYAPURI PH-1	1000 KVA	64
16	B-32 , MAYAPURI PH-1	1000 KVA	98
17	B-24 , MAYAPURI PH-1	990	37
18	B-125 , MAYAPURI PH-1, KIOSK S/STN.	1000	17
19	B-125 TRF NO-1,	1000	33

Table No. 4.7 Details of Mayapuri PH-1 DTs

Loss in the Distribution transformer can be calculated by the same formulae as for power transformer and is given below:
Technical loss of Transformer in MU for month = {No load loss + [(% loading) 2 * rated Cu. loss * LLF]} * 24 * 30 / 10^6 [25]
This part deals with the load profile of Distribution transformer that serves the consumers of Mayapuri, Janakpuri division. The Distribution transformer of rating 1000 KVA located at shopping center, Mayapuri is considered here. Table no. 4.8 gives the load profile of 24 hours load variation of this DT.

Transformer name	Shopping Center
Time	Amp
1	175
2	174
3	174
4	176
5	178
6	180
7	195
8	228
9	315
10	350
11	367
12	378
13	316
14	321
15	323
16	367
17	468
18	541
19	480
20	345
21	294
22	237
23	197
24	187

Table 4.8 Load variation in Shopping Center DT

Load curve and Load duration curve of distribution transformer are shown in fig.4.11 and 4.12 based on load profile of DT as given in table no. 4.9.

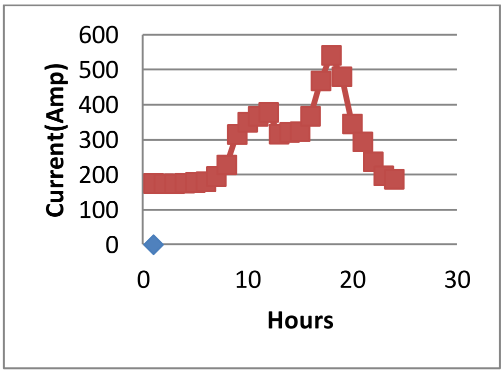

Fig.4.11 Load curve of Shopping Center DT

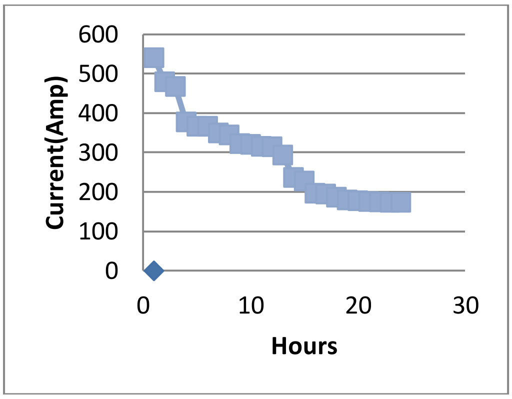

Fig.4.12 Load duration curve of Shopping Center

Lastly, the technical loss % based on load factor and load loss factor approach are computed.
The technical losses of Distribution transformer in million units (MUs) of these 7 DT's are shown in table no. 4.9

Table No. 4.9 Loss Calculation in Distribution Transformer

T.F Name	Peak Load in Amp	Full Load in Amp	% Loading	Value of "K"	Loss (MU)	Loss %
Lumax-85	1159	1250	92.72	0.17	0.0040	1.6
A-15	982	1237	79.38	0.18	0.0025	2.2
B-32	644	1250	51.52	0.19	0.0014	2.5
A-43	434	1250	34.72	0.18	0.0012	1.4
Shopping Center	541	1237	43.73	0.17	0.0013	1.9
WH-49	859	1237	69.44	0.16	0.0021	2.3
B-125	686	1237	54.45	0.18	0.0016	1.3

V. CONCLUSION

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% and AT&C loss % in the distribution sector. This results in the poor customer satisfaction, poor quality and unreliable power etc. The losses in the primary and secondary distribution system mainly comprises of technical losses, non-technical losses & revenue not realized. 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. The case study of Janakpuri division of BSES Rajdhani power limited, a power distribution utility of Delhi was considered and computed the technical losses for primary and secondary distribution system using load factor and loss load factor approaches.

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