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Modelling of Distribution Losses in an Urban Environment and Strategies for Distribution Loss Reduction

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Minimising distribution losses shall be one of the key objectives of a distribution electric utility, even though they do not constitute major operational or quality of supply problems. The negative impact of distribution losses on the economics of utility operation is often passed down as costs to customers. The percentage of distribution losses is one of the important indicators to evaluate the performance of a distribution electric utility, network.

Distribution losses in an electric utility are two fold viz. technical losses(TL) and non-technical losses (NTL). Technical and non-technical losses require continuous efficient management by utilities to ascertain the factors responsible for them and to take corrective actions to minimize them. The investment needed to reduce technical losses is significantly high compared with investment needed to reduce non-technical losses. This implies that the utilities may have to concentrate on non-technical loss reduction prior to reducing technical losses.

The main scope of this paper is to formulate a strategy to minimize distribution losses in the Electricity Distribution Network of an Urban Environment. This paper, describes the causes for the distribution losses and quantifies technical losses and non-technical losses at each level of the distribution network with the development of an energy flow diagram. Computation of the optimum level of distribution losses for an urban distribution network has also been presented, with the barriers and the strategies for distribution loss reduction, are discussed.

1. Introduction

One of the main issue in distribution systems or rather more appropriately the issue confronting the power sector as a whole, is the reduction of Transmission and Distribution (T & D) losses to an acceptable level. In Sri Lanka, the percentage of system losses has been reduced from 21% to14.5%[1]within the last decade. While the losses in the transmission network are about 3%-4%[2] bulk of the losses occur in the distribution system. T&D losses in developed countries are around 7-8% [3].

In general, distribution losses increase the operating costs of electric utilities and typically result in higher cost of electricity. The increase in the electricity price to customers will be affected by the regulatory treatment of the losses in the tariff. The reduction of system losses in any utility is important because of its economic, financial and social repercussions for the electric utility, the customers and even the operating country. Distribution losses pose a major challenge for regulatory agencies. Depending on the regulatory arrangement, losses can have adverse and varying levels of financial effects on the customers and the utility. Although some distribution losses are inevitable, steps can be taken to ensure that they are minimized. By identifying the importance of distribution loss reduction, Ceylon Electricity Board (CEB), the main power utility in the country, has initiated the distribution loss reduction programs. In order to carry out successful distribution loss reduction programs, it is required to identify the causes and measures and also the magnitude of distribution losses of the system.

The main objectives of this paper is to formulate a strategy to minimize distribution losses in an electricity distribution network of an urban environment. In order to achieve the main objective, the following methodology has been formulated.

- Identify the causes of the distribution losses in an urban environment.
- Model distribution losses in each level of the distribution network and develop an energy flow diagram for an urban environment.

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- Design of new programs for further reduction of technical and non-technical distribution losses & computation of optimum distribution loss levels.
- Discuss the barriers and propose strategies for reduction of distribution losses in an urban environment.

2. Distribution Losses

Distribution loss is the difference between units injected into the medium voltage distribution system by the transmission network and the units billed to the ultimate consumer and is generally expressed as a percentage of units injected. Distribution 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 transmission to the point of billing. Distribution losses occur on account of both technical and non-technical reasons. The losses occurring on account of technical factors are known as technical losses (TL). The losses occurring on account of non-technical factors or commercial factors are known as non-technical losses (NTL). It is required to clearly identify and separate technical losses from non-technical losses.

2.1 Technical Losses

Technical loss is inherent in electrical systems, as all electrical devices have some resistance and the flow of currents causes a power loss (I^2R loss). Integration of this power loss over time, i.e.$\int I^2R.dt$ is the energy loss.[4] Every element in a power system (a line or a transformer) offers resistance to power flow and, thus, consumes some energy while performing the duty expected of it. The cumulative energy consumed by all these elements is classified as "Technical Loss" are due to energy dissipated in the conductors and equipment used for transmission, transformation, sub-transmission and distribution of power. These occur at many places in a distribution system such as in lines, mid-span joints and terminations, transformers, service cables and connections, etc.

<u>Factors contributing to high technical losses</u>

- The low investment on T&D systems.
- Giving new connections without adequate reinforcement.
- Large scale rural electrification program resulting in long LT lines and extension of exiting distribution networks.
- Due to pumping loads in rural areas, and air conditioners, coolers and industrial loads in urban areas, the system has a low power factor which results in higher losses.
- Poor workmanship.
- Poor quality of equipment.

2.2 Non-technical Losses

NTL are not inevitable. They must be identified and fought with eradication objectives by all electricity distribution companies concerned about sound management. The problems caused by NTL are, in many cases, so serious that it is a major, even vital, priority for the companies involved. To determine the level of NTL, one starts with the energy supplied to the distribution network from which TL on the same network are subtracted. Thus we reach the notion of effectively consumed energy. Part of this consumed energy is not invoiced. The unbilled consumed energy is the primary component of NTL.

<u>**Causes for non-technical loss**</u>

<u>Non-performing and under-performing meters</u>

The main reasons for this are:

- meter tampering by consumers (accuracy adjustments)
- meter tampering in connivance with the CEB employees
- pilferage by manipulating or bypassing of meters
- intentional damages to meters.
- faulty / inaccurate meters (old, poor quality, incorrect rating, etc)

<u>Errors in meter reading</u>

At the beginning it was noted that some of the meter readers do not care about issuing correct bills. Identified problems in the meter reading system were;

- assessed readings (defective meters, inaccessibility, meter readers involvement)
- non-reading of meters (unbilled consumers)
- reading errors

Theft by direct tapping
Direct tapping of electricity lines at following places in the distribution system have been identified

- cut-out
- service wire- exposed connections/joints in service cables,
- overhead bundled conductors
- overhead "bare" conductors.
- street lamps
- open junction boxes (in cable systems),

Energy accounting system (billing system)

- unauthorized street lamps and other public illuminations
- unbilled supplies
- temporary supplies
- intentional issuing of incorrect bills.

Bulk supply consumers' contribution in NTL is low as meter tampering is very rare at these places.

- meter errors -low accuracy of meters
- wrong application of multiplying factors
- defects in CT and PT circuitry (loose connections)

2.3 Benefits of Distribution Loss Reduction

The reduction of TL leads to a real gain in energy and reduced capital-intensive investments. It, therefore benefits the country's economy.
The main benefits may be as follows:

- reduction of unit cost.
- improvement in financial performance of electrical utilities.
- improvement in the quality of supply and service offered to customers.
- optimization of investments and improvement of the environment (reduction of the pollution of power plants, more efficient use of financial resources, rational use of energy and tracking down customers' waste of energy).

The economic and financial gains can be classified into two types:

- with constant consumption, the reduction of TL makes it possible to cut down generation, and therefore save on investments and fuel (with constant generation).
- with constant generation and consumption, the reduction of NTL helps to increase the sales revenue.

3. Variation of System Losses in Sri Lanka

The variation of system losses during the last fourty years is shown in Figure 3.1 below. Both increase and decrease of system losses could be noted until the year 2000[2]. After initiating loss reduction programs within the CEB in year 2000, a continuous reduction of system losses could be noted.

System Loss can be calculated as;

$$SL\ (\%) = \frac{(A-B)*100}{A}$$

SL - System Loss
A - Energy Generated
B - Energy Sales

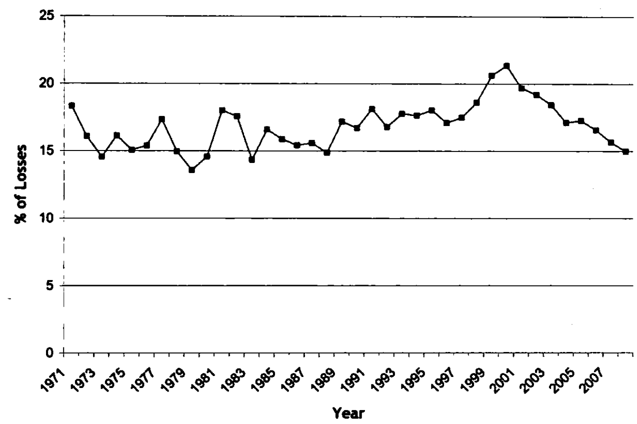

Figure 3.1 - Variation of system losses In Sri Lanka

The system loss is the sum of losses incurred in the generation, transmission and distribution systems. The generation loss is mainly the auxiliary supply of the station and can be measured using energy meters fixed at the point of generation and at the point of exit from the power station. Sometimes if one of the above meters is defective, energy for auxiliary services are estimated based on the equipment connected. The generation loss is generally less than 1%[2]. This loss includes technical losses of the transformers and switchgear, and the consumption of the power stations.

Transmission losses cannot be measured directly. In the Long Term Transmission

Expansion Plan, the transmission losses are calculated using network analysis software. The losses in the transmission system are completely TL as there is no avenues for NTL due to extra high voltage in the system. Transmission losses could be calculated monthly from the energy data obtained from the power stations and the grid substations. At the grid substations energy meters have been fixed for all the 33kV medium voltage feeders in order to measure the energy delivered to distribution system.

4. Variation of Distribution Losses in Sri Lanka.

Total distribution losses in Sri Lanka were not measured directly but used to be calculated by reducing the generation and transmission losses from the system losses. The distribution provinces calculated the individual provincial losses, but the accuracy of the figures were doubtful as the boundary meters were not available at most feeders which crosses the provincial boundaries. After the distribution division was divided in to Regions in year 2002, more efforts were made to obtain accurate figures for the losses of each province, and as such boundary meters were fixed wherever required.

4.1 Distribution Losses in Urban Environment

In urban areas, both high voltage and low voltage distribution systems are mainly underground, but in some areas, low voltage overhead lines too are available. The advantages of underground power cables are the fact that they are less subject to damage from severe weather conditions (mainly lightning and wind). The technical loss component of the urban areas are lower due to underground MV and LV distribution systems and short feeders with high consumer densities. However, due to high density of consumers and the condensed houses NTL are high.

Accounting of distribution losses in urban environments are more easier compared to rural environments as the area is smaller compared to rural areas. Implementation of programs for distribution loss reduction is more difficult in urban areas mainly due to the underground electricity system. Energy auditing which pinpoints the losses in the distribution system is difficult in urban areas as more than 90% of distribution system is underground.

Due to high density of buildings and due to the existence of underground systems, it is very difficult to identify unauthorized connections. The consumers in urban areas are not scared to do meter tampering and direct tapping are more common compared to the consumers in rural areas. Even though these consumers are taken to courts, they start consuming electricity using un-authorised connections after paying fines.

5. Management of Distribution Losses in Colombo City

The electricity distribution systems in Colombo City and Kandy City can be considered as the only two entirely urban distribution networks in Sri Lanka. Both these systems mostly consist of underground distribution networks. Out of these two networks , the network of Colombo City was taken for the case study as it is comparatively the larger one. The distribution losses in the Colombo City at the end of year 2004 was around 12.2% of which, it was estimated that 7.0 % was non-technical and 5.2 % was technical. The capital investment required to reduce NTL is bear minimum compared with TL. Hence Energy Management Unit (EMU) was formed in the Colombo City in the year 2004 mainly to address the problem of NTL. This unit was developed with the addition of new staff and various programs were introduced for non-technical loss reduction. As a result, losses of the distribution system have been reduced by 5.8% within the last 7 years. Figure 5.1 gives the variation of Colombo City distribution losses from 2002 to 2010 . Energy meters have been installed at all 9 primary substations to measure energy received by Colombo City and energy sales figures are taken from the revenue unit.

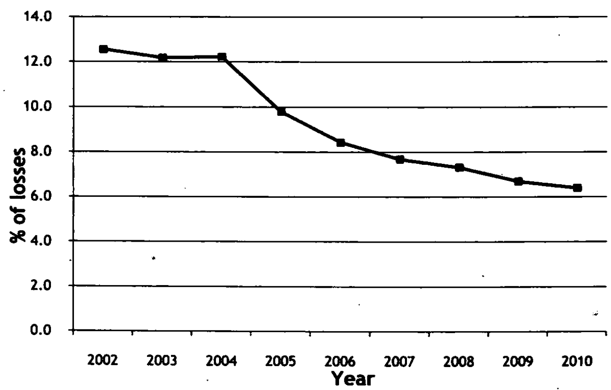

Figure 5.1 - Variation of Colombo City distribution losses

5.1 Technical Loss Reduction

The technical loss component of the distribution loss in the Colombo City has been addressed by;

- Adopting system improvement measures with the implementation of medium voltage development proposals. These proposals include the installation of new primary substations, new distribution substations, feeder cables and feeder pillars and upgrading of substations and cables.
- Implementation of system augmentation proposals (short term proposals-i.e. installation of substations, feeder cables and feeder pillars and upgrading of substations and cables) by spending around Rs.50 million annually.
- Fixing of capacitors to feeder pillars has been initiated in order to reduce the reactive current drawn within the distribution system.
- Improvement of workmanship and introduction of proper materials and tools which reduce most of TL (such as looseness of contacts of joints due to improper installation, loose connections in fuses and joints of service cables at the poles/junction boxes).

5.2 Non - Technical Loss Reduction

Measures taken for reduction of non-technical losses are;

- Investigations on the complaints received from meter readers and general public with and without police support.
- Investigations were carried out at the following places
  - Places where electricity consumption is zero.
  - Finalized accounts with bill arrears
  - Selected areas where unauthorized connections were suspected.
- Testing of bulk supply meters once a year and three phase meters once in three years
- Replacement of Meters (defective, tampered, old, etc)
- Rehabilitation of meter rooms
- Rehabilitation of LV network of estates (slum colonies) with Ariel Bundled Conductors and GI pipes
- Fixing of meter enclosures. (1 ph, 3 ph and bulk).
- Implementation of seal management system.
- Statistical monitoring of energy consumption
- Auditing meter readings.

Raids were carried out by EMU to detect consumers who use electricity illegally. Since year the 2005, 1277 cases of bill revisions and disconnections of ordinary supply have been done out of the 33943 places where EMU staff has visited for investigation. Generally, during these investigations if any illegal tappings are observed, the meters are tested for accuracy. If any illegal tapping or meter adjustment is noted, the electricity supply is disconnected and the bill revision is estimated as per the equipment available with the consumer or the genuine accuracy of the meter in case of an adjustment of the accuracy. Electricity supply is reconnected only after the consumer pays 50% of the revised amount and agrees in writing to settle the balance in a maximum of three instalments.

Table 5.1 gives the number of investigations with the number of defective meters and unauthorised usages found. As per the results approximately 10% of meters were defective, and out of them 4% used electricity illegally.

Table 5.1- Results of the Investigations

Year	Total investigated	Defective meters	Unauthorised supplies
2005	1263	162	94
2006	3823	307	379
2007	8146	587	328
2008	8244	869	220
2009	9361	806	170
2010	4947	572	120
Total	35784	3303	1311
%		9.2 %	3.7 %

Table 5.2 gives the analysis of information gathered on investigations carried out during the period from the year 2005 to 2010 tariff category wise. This information shows that most consumers who used electricity in unauthorized manner are in the domestic category.

Tariff Code	Tariff Category
11	Domestic
31	General purpose (Commercial)-1phase
32	General purpose (Commercial)-3phase
21	Industrial purpose-1phase
22	Industrial purpose-3phase

Table 5.2 - Results of the Investigations (tariff category wise)

Year	Total investigated	Defaulters by Tariff Category						Total
		11	31	32	51	21	22	
2005	1263	58	28	8	0	0	0	94
2006	3823	284	71	19	1	2	2	379
2007	8146	253	51	22	0	0	2	328
2008	8244	184	25	10	1	0	0	220
2009	9361	144	11	14	0	0	1	170
2010	4947	95	14	9	0	0	1	120
Total	35784	1018	200	82	2	2	6	1311
	%	2.84	0.56	0.23	0.01	0.01	0.02	3.66

Table 5.3 gives the analysis of information gathered during inspections and meter testing of bulk supply installations. As per this information, it is clearly noted that unauthorized usages within bulk supply consumers are a minimum. Out of all 26 bill revisions which were carried out due to meter errors, so far only 4 cases have been identified for tampering of meters. Some of these bill revisions have been done due to disconnection of one current transformer(CT) wire or one voltage terminal, which is due to bad workmanship in giving meter connections.

Table 5.3 - Results of Bulk supply meter testings

Year	Tested (Numbers)	Faulty (Numbers)
2006	87	8
2007	985	7
2008	908	1
2009	1661	5
2010	1552	6
Total	5193	27
%		0.52

5.3 Socio Economic Reasons for Non-Technical Losses

In Colombo City, out of retail sales, 44% of the load is utilized by small scale commercial establishments. The cost of a unit of electricity in general purpose tariff is Rs. 19.50[5].This is a fairly high rate compared to the electricity tariffs in other South Asian countries. A small scale shop or hotel, without air conditioning, has an average consumption of 250kWh(units) and the average bill comes to around Rs.5000.00 per month, which is an unaffordable amount for most of such businesses. The consumption of shops which uses air-conditioners get an average of 600-700kWh (units) per month amounting to a monthly bill of around Rs 13,000.00. As per the statistics, 0.59% of cases where fines have been imposed for unauthorized consumption were small scale commercial establishments which comes under GP1 tariff. The main reason for high tendency in illegal tapping of electricity by consumers in this tariff category is due to the unbearable cost of electricity.

Most of the places where unauthorized electricity is used, were in the domestic category. This is mainly due to the electricity bill being not affordable for them. Most houses in the slum colonies do not have proper ventilation or proper natural lighting. Therefore, even during the day time, lights and fans are used resulting in a higher usage. In general, a small shanty house which have only two rooms consumes around 120kWh and the bill comes to around Rs1,500.00. Most of these occupants do not have permanent jobs and find difficulty to afford the electricity bill and tend to use electricity illegally. Without proper knowledge, the public tend to tamper meters. In some instances, workers attached to the CEB and electricians encourage consumers for meter tampering. Without knowing the gravity of the offence they tend to get their meters adjusted.

6. Modelling of Distribution Losses in Colombo City

The details of components of Colombo City distribution system are given in Table 6.1. The schematic diagram of this distribution model with the components and losses is given in Figure 6.1.

Energy flow diagrams are useful for visualizing where energy comes from and where it goes. In this study, energy flow of Colombo City from the PSS to LV consumers is developed at each level of the distribution system together with the energy loss at each level in order to compute the NTL of the system. The main purpose of developing the energy flow for Colombo City is to compute the NTL of the system. The accuracy of the NTL depends on how the TL of the system are computed. The TL have to be calculated separately for each level of distribution system. Methodology of computation of TL in each level is given below.

Primary substations

Energy inflow to Colombo City is taken from the energy meters fixed at the 11kV side of the 132/11kV or 33/11kV transformers in the PSS. So energy loss of PSS is not taken for the development of energy flow diagram.

11kV UG system

In the medium voltage distribution system development study, which is carried out once in two years, load flow run is done for the 11kV distribution system for peak and off peak loads. Power loss is calculated for both loads. Since there is no unique method to calculate energy loss in the system , most of the time empirical formulae based on load factors are used. The empirical formula known as "Jung's formula" is used in this study to calculate energy losses.

Data: Annual energy consumption - 1202GWh
Maximum demand - 250MW
Peak power loss -2029kW

Calculation:

Jung's formula $UTL = \frac{LF^2(2+LF^2) x 8760}{(1+2LF)}$ ..... (1)

where, LF= Load factor =>

$\frac{\text{Total energy consumption of the year}}{\text{(Peak load of the system} x 8760)}$ ...... (2)

$= \frac{1202*1000}{250X8760} = 0.55$

$UTL = \frac{(0.55)^2 [2+(0.55)^2] x 8760}{[1+2(0.55)]}$

= 2905hrs.

Energy loss=(Peak Power Loss)xUTL kWh.(3)

=2029 x 2905 = 5.9 GWh

Thus, the energy loss of the medium voltage network of the Colombo city was estimated at 5.9GWh.

Table 6.1 - Components in electricity distribution system of Colombo City(As at August 2010)

Level	Component	Description
1	Primary Substation(PSS)	4 numbers of 132/33kV PSS, 5 numbers of 33/11kV PSS
2	11kV Under Ground(UG) system	572km of 11kV Cu cables
3	HT bulk supplies,	67 HT supplies with annual energy consumption of 282.82GWh
4	11kV/0.4kV transformers,	1297 with total capacity of 808MVA
5	LV bulk supplies above 112kVA from Substations(SS)	673 LT sub bulk supplies with annual energy consumption of 303GWh
6	Feeder cables from SS to Feeder Pillars,(FPs)	240sqmm/4C/UG/XLPE/AL
7	Feeder Pillars,	1688 numbers
8	Bulk supplies from FPs	867 LT Bulk Supplies with annual energy consumption of 87.5GWh
9	LV distribution from FPs	286km of LV over head & 518km of LV Under Ground
10	1 ph and 3ph LV consumers from distributors.	151,801 LT Supplies with Annual energy consumption of 447GWh

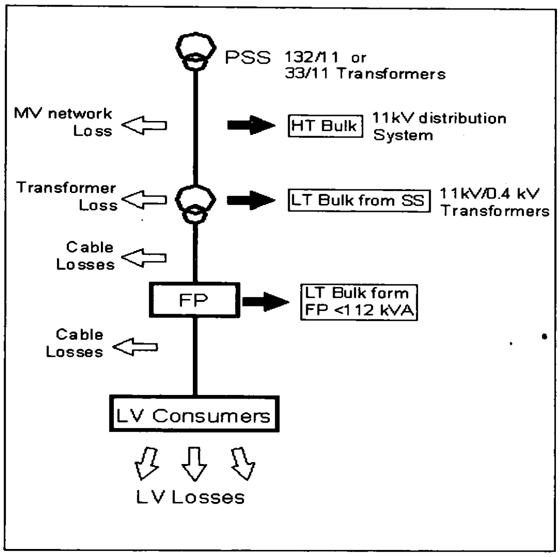

Figure 6.1 - Schematic diagram of electricity distribution system of Colombo City

HT bulk consumers

As the metering is done on the HT side no technical losses are involved. But metering errors which would be accommodated in NTL could be present. Once a year, meter testing is carried out in order to avoid metering errors.

11kV /0.4kV transformers

Colombo City has 1297 distribution transformers with total capacity of 808 MVA. The details of transformers such as capacity, peak load, no load and full load losses and year of manufacture were collected. All transformers were grouped into 5 groups as per the peak load of the transformers and the average peak load of all transformers were calculated. The peak power loss of different capacities of transformers was calculated for the average peak load. Table 6.2 gives the number of transformers in Colombo City with the percentage of loading.

Table 6.2- Number of transformers with percentage loading

% load (X)	No of T/f (f)	X/2
0-20	427	10
20-40	493	30
40-60	239	50
60-80	118	70
80-100	20	90
Total	1297	

Mean $=\sum(X/2)f/\sum f$ .... (4)
= 41,070/1297
= 31.7%

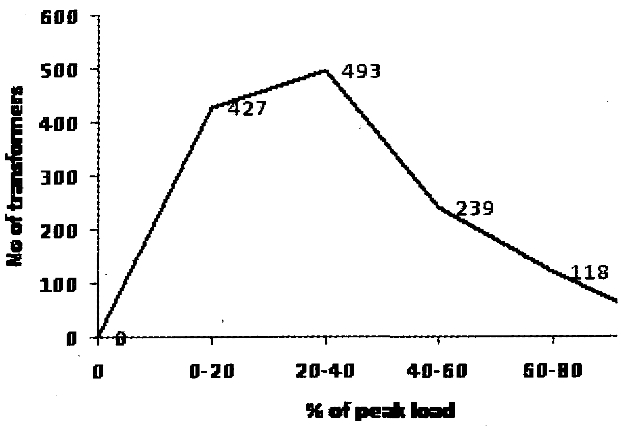

Figure 6.2 - Number of transformers with percentage peak loading

Table 6.3-Summary of transformers in Colombo City

Capacity kVa	No of transformers	Total capacity (MVA)	NL Loss W	FL Loss W	Loss per transformer W	Total loss kW
250	72	18	540	3550	842	60
400	312	125	755	4925	1174	366
500	120	60	885	5870	1386	166
630	373	235	1040	6950	1634	609
800	250	200	1265	8740	2016	504
1000	170	170	1390	11010	2357	403
	1297	808				2109

Calculation
As per Figure 6.2 the average peak load is 31.7%.
Assume the average peak load of all the transformers as 31.7%
For 400kVA transformers
No Load Loss = 755W
Full Load Loss =4925W
Peak load is = 400x 0.31.7 = 126.8 kVA
Current at peak load (I_P)
= (126.8x1000)/(Γ3x415)
= 176.4A
Full load current (I_{FL})= (400x1000)/(Γ3x415)
= 556.5A

Power Loss= Loss $_{NL}$+ Loss $_{FL}$ $x(I_P)^2 / (I_{FL})^2$..(5)
= 1174W
No of 400kVA transformers = 312
Total power loss = 366kW
Similarly total power loss of all transformers are given in the Table 6.3
From equation (1) and (2) UTL = 2905hrs.
From equation (3) energy loss = 2109 x 2905 kWh = 6.1 GWh

The total peak energy loss of all transformers were obtained using Jung's formula and it comes to around 6.1GWh.

Bulk consumers from substations.
As the energy meters are fixed inside the SS, the service cables are very short. Hence the TL could be taken as negligible. But metering errors which would be accommodated in NTL could be present.

Feeder cables from SSs to FPs
1688 FPs are used in Colombo City distribution system, and 604 GWh of energy passed through the FPs during the year 2009. 240sqmm/4C/XLPE Aluminium cables have been used as feeder cables which have been laid from SSs to FPs. Load curves of 10 FPs were obtained and the distances from the SS to each FP were measured. Power loss curves were developed using the cable loss (I^2R) of the feeder cable. The energy losses of each feeder cable were calculated from the power loss curves.

Feeder pillar No. selected for sample calculation.-06S086

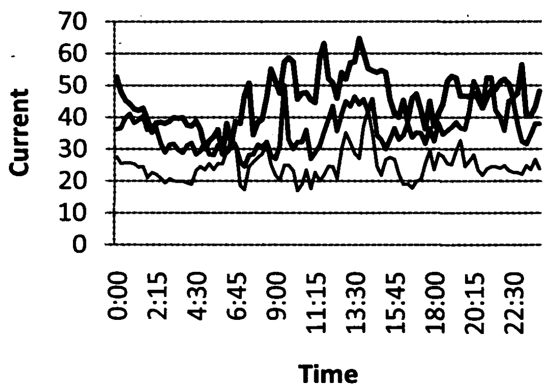

Figure 6.3 - Current of Three Phases of Feeder Pillar 06S086

Data:
Resistance of 240 sqmm/4C/UG/XLPE Al = 0.125 Ω/km
Distance from SS to FP (06S086) = 157m

Calculation
Resistance per phase for 157m of cable
= 0.0196 Ω

As per Figure 6.3 at 9.00a.m,

Power loss = $I^2 R$= (27^2+22^2+51^2) x0.0196
=75W
Similarly for a 24 hour period the power loss was calculated, and it is given in Annexure 1. Total energy consumed during 24 hour period
= 553kWh

Energy Loss during 24 hour period
From the area of power loss curve = 1.94kWh.
Energy loss % = 0.35%
From UTL method(LF= 0.74) = 1.88kWh
Energy loss % = 0.34%

Table 6.4 -Loss from Feeder cables from Substations to Feeder Pillars

Name of FP	Distance from SS m	Energy consump kWh	Load Factor	Energy Loss kWh	
				Power loss curve	UTL method
06S097	20	1057	0.68	1.1	1.0
06S086	157	553	0.74	1.9	1.9
06S089	184	589	0.72	2.7	2.7
11W023	81	210	0.28	0.4	0.2
11W024	84	1875	0.4	20.3	12.5
11W025	26	475	0.41	0.4	0.3
11W027	58	1849	0.4	13.7	8.6
11W030	99	2106	0.42	27.2	17.5
11W032	134	1986	0.43	32.0	21.5
11W059	81	580	0.39	2.3	1.3
Total		11280		102	67.4
Average				0.9	0.6

Table 6.4 gives the energy loss calculated using power loss curve and UTL method for 10 nos feeder cables from substations to feeder pillars.

For 10 FPS for 24 hrs. period:
Total Energy consumption = 11280kWh
Total Energy loss
From the area of power loss curves
= 1021kWh
% of energy loss= 0.9%
From UTL method = 67.4kWh
Energy loss % = 0.6%

The energy loss using power loss curve and UTL method is same only if the LF is above 0.5. The average % of loss for all 10 nos FP from both methods have two different values due to having 7 nos FPs with LF less than 0.5. For the calculation of technical losses of the system the energy loss calculated using power loss curve is taken as it calculates the actual loss during the 24 hour period.The average energy losses for all 10 sample feeder cables is 0.9%(5.4GWh) and is taken as the energy loss of feeder cables from distribution transformers to FPs.

Feeder Pillars (FPs)
1688 FPs are available in the system. Energy loss due to contact resistance is considered to be negligible.

Bulk Supplies (BSs) from FPs
867 LT bulk supplies which have an annual energy consumption of 87.5GWh are supplied from FPs. Data on monthly energy consumption, cable length from FPs to BSs and the cable sizes of 17 bulk supplies were obtained. As per the monthly maximum demand, maximum current drawn was calculated. Cable loss and the LF for each BS were calculated and using Jung's Formula energy loss of each bulk supply was calculated. From the total energy consumption and total energy loss of 17 BS average energy loss value of 0.3%(0.3GWh) was obtained and this figure was taken as the average energy loss in the cables from FPs to 867 nos BSs.

LV Distribution from FPs
286 km of LV OH and 518 km of LV UG distribution systems are available in Colombo City and NTL and TL are present in both these distribution systems. Energy meters were installed for 4 FPs in order to obtain the amount of energy delivered. The energy consumption of the consumers who are fed from the particular FP during the same period were obtained and the energy loss of the FP was calculated. Using the power analyzer the load curve was obtained. Then the distribution network of the FPs was drawn and Load flow was run (Using SynerGEE Software) for the peak load of the FP and power loss was obtained. In order to calculate the technical energy loss for the same period, Utilisation Time of Losses (UTL) method was used. The difference between the total energy loss and the technical energy loss is the NTL. The average technical energy loss value 5.7% for all 4 FPs was taken as the percentage of TL of LV distribution from FPs. The percentage of TL in LV distribution system 5.7% is the theoretical loss of the LV distribution system as under the computation only line losses have been taken into consideration. The losses due to contact resistance and the losses in the service wires will come into the NTL of the system.

LV consumers

Losses due to contact resistance and NTL are available at LV consumer installations. Figure 6.4 shows the Energy flow of Colombo City for the year 2009. The 3.9% technical loss is the theoretical technical loss which includes only line losses and transformer losses. Table 6.5 gives the technical loss at each level of distribution in GWh and as a percentage. The loss due to contact resistance and bad workmanship which is not possible to be computed fall into NTL.

Table 6.5-Technical losses at each level of distribution

Location	% of TL	TL in GWh
11kV UG system	0.5	5.9
11kV/0.4kV Transformers	0.7	6.1
Feeder cables from SS to FPs	0.9	5.4
Bulk supplies from FPs	0.2	0.3
LV Distribution from FPs	5.7	28.9
Total (Average)	3.9	46.6
Total Distribution Loss	6.7	81.1
Total Non-technical Loss	2.8	34.5

As per the energy flow of Colombo City for the year 2009, 2.9% of NTL is present and it is required to develop programs for reduction of this NTL and to find out the optimum level of distribution losses that can be achieved economically for a distribution system of an urban environment.

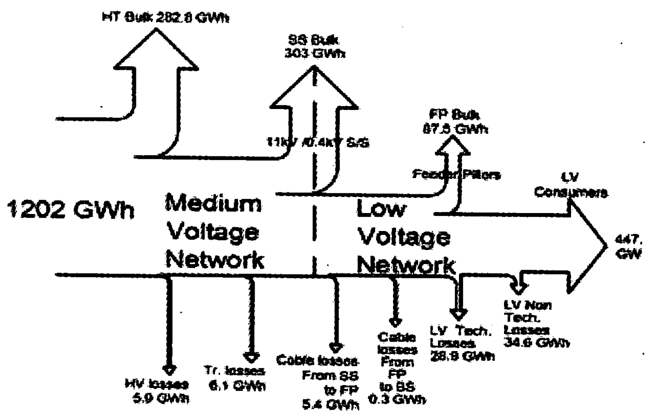

Figure 6.4 -Energy flow diagram of Colombo City for the year 2009

7. Development of New Programs for Colombo City for further reduction of Distribution Losses

In the year 2010, the EMU of Colombo City carried out activities similar to the year 2009 and only 0.3% reduction of loss was possible. This shows that improvement during the year 2010 is marginal, and a fresh approach is required to reduce distribution losses to a challenging figure of 5.5%. A few possibilities of implementing new techniques/ methodologies required to reduce NTL and TL further in Colombo City are discussed below.

7.1 Reduction of Technical Losses

(a)Rehabilitation of LV network of estates (slum colonies) with Aluminium bundled conductor (ABC) and GI pipes.

In many underserved settlements, meters have been fixed inside the houses and service wires are drawn along the walls of the houses. This has led to easy tampering of electricity lines and higher losses. Therefore it is required to draw bundled conductor overhead lines and to provide each house with a separate service connection. Thereafter meters should be shifted outside and the enclosures should be fixed. This will avoid tampering of the cut-out, and the service wire, and also high line losses due to small service wires.

(b) Phase balancing

Unbalanced phase loadings have been noted and this creates high neutral currents which tend to increase losses in the system. The phase balancing is an important measure that is required to be implemented in order to reduce the technical losses. In UG system it is very difficult to implement as all the cable connections are not visible. Mainly consumers should be encouraged to balance their loads by publicity campaigns as well as inspecting their premises.

(c) Fixing of capacitors for feeder pillars and government installations in order to improve power factor.

It has been estimated that 40kVar or 20kVAr capacitors are suitable to be fixed for all the feeder pillars depending on the load of the feeder pillar. This would reduce the technical loss of the system.

(d)Replacing low accuracy CT's with high accuracy CT's of bulk supplies with high consumption

At present, CTs with 0. 5 accuracy class are installed for bulk supplies. Accuracy class of most CTs available in old bulk supplies are of Class 1 or above. Therefore it is proposed to replace the CT's of Accuracy Class above 0.5 with the CT's of accuracy class 0.5 or 0.2. This would reduce the technical loss of the system.

7.2 Reduction of Non- Technical Losses

Energy Auditing

Energy auditing is an important measure that is required to be implemented in order to pinpoint the places where the losses are high. It is required to fix Poly Phase Programmable meters(PPM) for all the substations in order to calculate the energy delivered by the substation. The consumers who are fed from each substation are to be identified. As the distribution system is underground and the feeding arrangements of distributors and feeder pillars are changed at times during load transfers it is difficult to identify the exact substation which feeds a particular consumer. Therefore it is more appropriate to ascertain losses of a group of transformers and to pinpoint losses of the said cluster. Even though this exercise is rather complex and difficult, it would be very useful to pinpoint losses and to take corrective action. Once the losses of a cluster of transformers is identified, special program should be initiated to check installations which come under higher loss transformer clusters. Revenue officers should be made responsible for losses of each transformer cluster and they should take every action to maintain losses under a predetermined value.

Meter testing and replacement of defective meters and fixing meter enclosures

Testing of bulk meters at least once a year need to be carried out. An enhanced meter testing program to test all ordinary supply meters (150,000) within a two year period is required in order to reduce distribution losses further.

Publicity Campaign

An effective publicity campaign should be initiated to educate the public on repercussions of illegal electricity tapping and to promote the complaints made by the general public on illegal usage of electricity. Introduction of a rewarding system for the public as well as for the CEB staff is also appropriate.

8. Barriers to reduction of Non-Technical Losses

Reduction of NTL can be considered as a complicated task as most of the issues are interrelated to various socio- economic issues in the country. In addition to that, the process is closely interlinked with legal entities and other government agencies like local authorities. Hence a power utility cannot take measures to mitigate NTL in isolation and should have a very good rapport with other related systems and organizations. A utility should have a group of highly motivated employees to achieve its set targets on non-technical loss reduction. The employees who are engaged in these activities have to overcome a lot of barriers within and outside the environment, which may even go to an extent of life threat. These obstacles and other related issues should be properly understood in order to address the issue effectively. The barriers that requires to be overcome in carrying out non-technical loss reduction are illustrated below.

8.1 The influence from the legal framework in the Country (New Electricity Act)

As per Act No. 17 of 1969, CEB officers had the authority to visit consumer premises at any time, without a prior notice, in order to inspect the energy meter fixed by the CEB. If any illegal connection or meter tampering was noted, CEB officers had the authority to disconnect the power-supply and issue a revised (or estimated) electricity bill, in general for a period of 12 months. Due to the rigid legal framework in function during this period, there was a significant reduction in tampering and other illegal activities.

As at present, one of the main barrier for reduction of non-technical loss is being the Clause 8 of section 31 of schedule 11 in the New Electricity Act no.20 of 2009[6]. According to this clause the licensee has to give three days notice of the intended entry by stating fully and accurately as possible, the nature of the work that intended to be done. In case of illegal connections and meter tampering, consumers could remove or reverse the acts before the officer of the CEB visits the premises. This fact has been brought to the notice of all relevant authorities including the Ministry of Power & Energy and Public Utility Commission of Sri Lanka. The necessary amendments for the new act are under discussion.

8.2 Police support for legal procedure

Obtaining effective police support for raids is also a vital issue in carrying out loss reduction activities like raids.

8.3 Skills and capacity gaps of the staff

It is required to improve the soft skills like public relations of the employees to handle the customers carefully in case of a raid or an investigation.

8.4 Technical Constraints

Implementation of programs for distribution loss reduction is difficult in urban areas like Colombo city as its' distribution system is underground. In an underground system it is difficult to locate illegal tappings as most of them are not visible. Sometimes it is required to open break cement, concrete or tiled floors in order to locate illegal tappings.

9. Conclusion

Accurately estimating technical and non-technical losses in a distribution systems is becoming increasingly important, in order to develop programs for reduction of distribution loss. However, in general the hindrance for this is the non availability of the data needed for accurate estimating of total losses and particularly their breakdown into technical and non-technical components. Distribution losses experienced by electricity utilities have an impact on a number of areas, including financial and economic outcomes and social stability. Financial impacts are the most critical for many utilities as they involve a reduction in profits, a shortage of funds for investments in improving the power system and its capacity, and the necessity for implementing means to cope with the losses. The current methods of dealing with NTLs impose high operational costs and require extensive use of human resources. An urban environment, Colombo City was considered for the case study to model distribution loses in each stages of distribution and to identify the causes for distribution losses. This study revealed that approximately 10% of ordinary supply meters are defective and out of them 4% used electricity illegally. Unauthorized usage within bulk supply consumer groups are very low and out of a total of 26 cases detected for bill revisions due to meter errors, only 4 cases have been due to tampering of meters.

The barriers for reduction of distribution losses are identified and strategies are developed to achieve optimum level of distribution losses. **According to the analysis done, the information gathered and measurements obtained, it is possible to reduce distribution losses to below 5% in an urban environment by pin pointing losses, continuous monitoring and having the required technical, regulatory and legal support.**

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