2.3.1 Technical losses

Technical losses are internal to the power system. Technical losses in the system are inherently influenced by components and system designs. A list of such components in the local distribution system where power dissipation occurs is mentioned below.

- MV distribution lines
- Transformers supplying to low voltage heavy consumers
- Distribution transformers
- Low voltage distribution lines
- Consumer service lines
- Voltage regulators
- Capacitors
- Electrical burdens in metering equipment
- All other electrical devices necessary for the operation of the distribution system

The losses in the power distribution lines, including service lines, are due to conductor loss. There are energy losses in electricity meters too. Further, higher level of harmonics in a distribution system also increases losses. Technical losses can be accurately computed provided the load conditions in the power system are known. Typically, load flow studies or network simulations are used to calculate technical losses.

2.3.2 Non-technical losses (NTLs)

NTLs are due to actions external to the power distribution system. NTLs are often unaccounted by utilities due to unavailability or lack of information. Hence, it is extremely difficult to have an accurate estimation of NTL in distribution systems. The general practice is to derive NTL after estimating technical losses.

NTLs represent an avoidable financial loss for the utility. It is the amount of energy not billed but consumed. NTLs also reflect a social issue. The consumers who are accurately metered and billed are subsidizing those who do not pay for the electricity consumed. In general, NTL in the electricity distribution is high in countries where Gross Domestic Product (GDP) per capita is low. However, there are exceptions such as Thailand and Indonesia who have achieved very low levels of NTL irrespective of lower GDP per capita [5].

2.3.3 Electricity theft

Electricity theft can be defined as a conscious attempt by a person to eliminate or reduce the amount of money that he or she will owe the utility for electrical energy consumed. It is generally viewed as the major source of NTL by the electricity utilities worldwide. Two main forms of electricity theft can be identified, namely, directly connecting an unmetered load to a power line and tampering with the electricity meter in order to reduce, or stop recording the actual energy consumed.

Direct connections to power lines are much easier and safer in low voltage electricity distribution systems. Illegal direct connections are mostly detected in rural and shanty areas. Tampering with electricity meters is probably the most common form of electricity theft in Sri Lanka. The present technology of electro-mechanical meters used for metering low voltage electricity consumers is very old. The public is familiar with the technology and working principle of electro-mechanical meters.

2.3.4 Other forms of Non-technical losses

Whilst electricity theft is considered as the major form of NTL, the other forms of NTL are,

- Defective energy meters
- Un-metered connections
- Errors and delays in meter reading
- Arranging false meter readings by bribing utility staff
- Errors in billing
- Assessed meter readings
- Errors in estimation of technical losses

2.4 Economic Impact of Losses

Energy losses represent losses in revenue for utilities. To recover costs involved in the supply of electricity and to fill the utility viability gap, costs of losses should be covered by paying users or by the Government via targeted output-based subsidies.

Loss reduction and improvement on energy efficiency would partially cover the expected demand rise offsetting the need to increase the installed capacity. On the supply side, the impact on the utility to finance new generation capacity can be delayed or avoided if reduction in demand can be achieved by implementing good demand side management measures. The use of energy efficient compact fluorescent lamps (CFLs) in place of conventional incandescent lamps at large scale for domestic and other lighting applications is a typical example of such a demand side management measure.

Table 3 - Consumer details and energy sales in WPN [6]

No. of Consumers	Energy Sales (GWh/Yr)			Revenue
	LV consumers	MV & LV bulk consumers	Total	Million LKR/Yr
542,942	606	1,104	1,710	25,765

2.5 Reduction of distribution losses

Reduction of losses in electrical power systems is vital because of the ever increasing demand for energy and the fast depletion of energy sources. It benefits the consumer, utility and country as a whole. However, in order to implement loss reduction measures effectively, it is essential to segregate the distribution losses with sufficient accuracy.

Increased revenue through reduction of NTL is a financial boost for any utility since the investments involved in implementing NTL reduction programmes are much less than implementing technical loss reduction programmes. Further, when the consumers who consume electricity illegally have to pay for their actual consumption, they will adjust their consumption to match their capacity to pay. This reduces the energy demand, which will create the same effect as reducing technical losses.

2.6 Case Study of Western Province North (WPN)

2.6.1 Overview of distribution system in WPN

Western Province North (WPN) is one of the three provinces in the Distribution Division 2 (DL 2) of Ceylon Electricity Board. The distribution system of the WPN spreads geographically over Gampaha district in Sri Lanka. Important facts about the province are shown in Table 4.

Table 4 - Statistical data on WPN distribution system [6]

Land area	1,387 km^2
Population	2.29 Million
No. of Households	475,929
Percentage of Electrified Houses	100%
Peak Power Demand	456 MW
Energy Demand (Sales)	2,146 GWh/Yr

A noticeable fact in the distribution system in WPN is that approximately 65% of electricity sales are from heavy or bulk consumers. Only 35% of energy is sold to low voltage ordinary consumers. However, there were only 1,200 bulk consumers in WPN.

2.6.2 Distribution losses in WPN

The electricity distribution losses in WPN as a percentage of energy input to the system have been at 7.7%, 7.6% and 7.3% in 2010, 2011 and 2012 respectively [6][7]. Table 5 presents results of meter testing programme carried out in the province during the recent past.

Table 5 - Results of meter testing in WPN

	Number of meters	Percentage of meters tested
Tested	53,818	100.0
Accuracy acceptable	48,300	89.7
Accuracy not acceptable (Defective)	3,914	7.3
Physical adjustments done	826	1.5
By-passed	76	0.1
Meters damaged	629	1.2
Direct connections before meter	73	0.1
Total cases for NTL	5,518	10.3

The presence of defective meters is quite significant. More than 10% of the meters tested contributed to NTL.

3. Modelling and Estimation of Distribution Losses

Medium voltage network, power distribution transformers and low voltage network are three major components of concern. There are different models and techniques which can be used for the estimation of losses with acceptable level of accuracy. Some of the commonly applied models and techniques are discussed in detail in this section.

3.1 Medium Voltage Network

The peak power loss of the MV network is calculated through load flow studies. The loss of energy in any electricity network varies with time. A hypothetical time known as 'Utilization time of losses' or 'UTL' is defined such that losses during UTL with a continuous load equal to the peak power loss is the same as the loss with actual loading over the day[12], [13].

An empirical formula known as Jung's formula is used to calculate UTL [7], [8].

$$\text{Load Factor(LF)} = \frac{\text{Average Demand}}{\text{Peak Demand}}$$

$$\text{Utilization Time of Loss (UTL)} = \frac{LF^2(2 + LF^2) \times 8760}{(1 + 2.LF)}$$

$$\therefore \text{Annual Energy Loss} = (\text{Peak Power Loass}) \times \text{UTL per year}$$

3.2 Power Distribution Transformers

3.2.1 Load loss factor and estimation of energy loss

Energy loss of a transformer depends on how it is loaded over a period of time. The following terms are important in understanding the energy loss of transformers.

$$\text{Load loss factor (LLF)} = \frac{\text{Average power loss}}{\text{Peak power loss}} = \frac{\text{Actual loss (kWh) during the period}}{\text{Loss at maximum current during the period in kWh}}$$

The average power loss of a transformer is given by,

$\text{Power loss} = \text{LI} + \text{LC}$ [9]

Where,

LI - Iron loss of the transformer
LC - Copper loss of the transformer

Utilization Factor (UF) of a transformer is defined as follows.

$$\text{UF} = \frac{\text{Maximum demand}}{\text{Rated capacity}} = \frac{\text{Current at maximum demand}}{\text{Current at rated capacity}}$$

When the copper loss at the rated full load capacity of the transformer is denoted by LC_R, copper loss at maximum demand (LC_m) of the transformer is given by,

$LC_m = LC_R \times (UF)^2$

Therefore, the average variable loss of a transformer (LC) is given by,

$LC = LC_m \times LLF$

Therefore, energy loss of the transformer can be calculated. The relationship between load factor and load loss factor is explained by the following empirical formula [10], [11].

$$\text{LLF} = k \times \text{LF} + (1 - k) \times \text{LF}^2,$$
$$\text{where} \quad 0.15 < k < 0.3$$

The value of coefficient k can be assumed or replaced with calibrated factor if metered data is available. Generally k= 0.2 is used by utilities to calculate losses of distribution transformers [9], [10], [11].

3.2.2 Calculating energy loss of a large number of transformers

Instead of calculating the losses of individual transformers, a statistical method can be applied to approximately calculate the total loss of all the transformers under consideration. However, the following details of the transformers are required for the calculation.

- Capacity rating of each transformer
- Peak loading of each transformer
- Fixed and variable losses of the transformers of each rating
- Load factor

Table 6 is used to approximately determine the total losses of the transformers of a given rating.

Table 6 - Calculation of losses in transformers

Percentage Loading (X)	No. of transformers (f)	(X/2)	(X/2)*f
0 – 20		10	
20 – 40		30	
40 – 60		50	
60 – 80		70	
80 – 100		90	
Total	$\sum f =$		$\sum(X/2 *f) =$

The average loss of a transformer of a given rating such as 100 kVA, 250 kVA etc. is given by,

Average loading of a transformer or average,

$$\text{UF} = \frac{\sum (X/2) \times f}{\sum f}$$

When LF is known, LLF can be calculated using value k= 0.2 which is generally accepted. Then, average power loss of a transformer can be calculated. Then the total power loss of all the transformers of a given rating is calculated by multiplying average power loss of a transformer by the number of transformers. The calculations are repeated for each available rating of the distribution transformers.

3.3 Low Voltage Distribution Network

3.3.1 Overview of low voltage network

LV feeders consist of un-transposed three phase, two phase or single phase line segments. They supply electricity to balanced or unbalanced three phase loads, two phase loads and single phase loads. As a result, almost all LV feeders have unbalanced voltages and currents and non-zero neutral currents.

3.3.2 Uniformly distributed loads

When loads are uniformly distributed along a feeder it is not necessary to model each load to determine voltage drop or power loss in the feeder. Figure 2 shows a generalized line with *n* uniformly distributed loads.

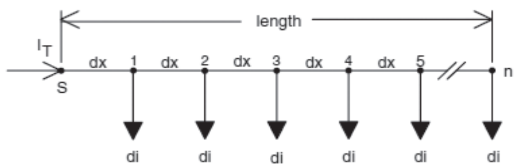

Figure 2 - Uniformly distributed loads [17]

The voltage drop along the line can be derived and shown that,

$$V_{drop} = \mathrm{Re}\left\{\frac{1}{2}.Z.I_T\right\}$$

The power loss in feeder can be analysed under three models.

When the model in Figure 3 is used to calculate the three phase power loss down the line, the result is,

$$P_{loss} = 3.\left|I_T\right|^2.\frac{R}{2} = \frac{3}{2}.\left|I_T\right|^2.R$$

Figure 3 illustrates the model where the load is lumped at mid point.

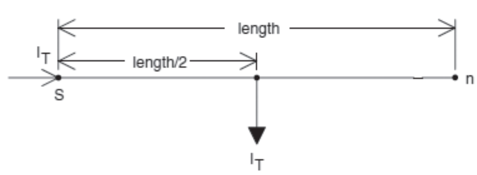

Figure 3 - Load lumped at midpoint [17]

When the model (One-half load lumped at the end) in Figure 4 is used to calculate the three phase power loss down the line, the result is,

$$P_{loss} = 3.\left|\frac{I_T}{2}\right|^2.R = \frac{3}{4}.\left|I_T\right|^2.R$$

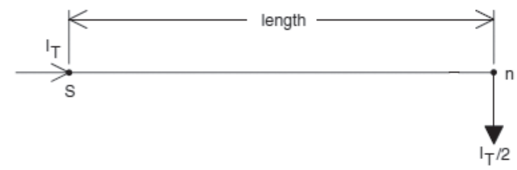

Figure 4 - One-half load lumped at end point

The two models in Figures 3 and 4 give two results for the power loss. In order to have correct results for the voltage drop as well as power loss, the exact lumped load model shown in Figure 5 can be used.

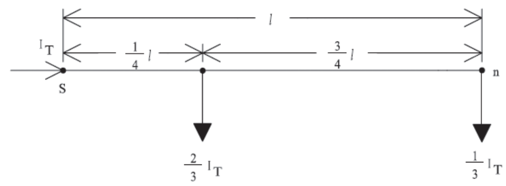

Figure 5 - Exact lumped load model [12]

4. Estimation of Distribution Losses in WPN

Estimation of provincial electricity distribution losses was done based on the data available in the planning division of the province. The focus in this section is to estimate the losses in the medium voltage network and the distribution transformers.

4.1 Medium Voltage Network

Based on the Medium Voltage Development Studies Region 2, 2012 – 2021[11], the provincial energy and power demands are as follows.

The total annual energy demand= 2,314 GWh
Peak power demand = 456 MW
Peak power loss = 8.32 MW
Therefore, average load factor (LF)
= 2,314,000/ (456 x 24 x365)
= **0.579**

Using Jung's formula,
Utilization time of losses (UTL)

$$= \frac{0.579^2\left(2+0.579^2\right)\times 8760}{\left(1+2\mathrm{x}0.579\right)}$$

= 3,171.91 hrs per year
Therefore,
Energy loss per year
= 8.32 x 3,171.91/ 1000
= **26.39 GWh**

Annual energy loss as percentage of energy input to WPN,
= 26.39/2,314 x 100%
= 1.14%

4.2 Transformers of Low Voltage Bulk Consumers

The details of the LV bulk consumer transformers are shown in Table 7.

Table 7 - Details of LV bulk consumer transformers

Capacity in kVA	1,000	800	630	400	250	160	100
No. of units	118	22	159	174	190	141	260

The full load and no load losses of each transformer rating are shown in Table 8.

Table 8 - No load and full load losses of distribution transformers

Account Number	X_1	X_2	X_3~Xn
Monthly consumption kWh	4,348	3,052	
Maximum demand kVA	43	34	
Transformer capacity kVA	100	100	
Load factor	0.160	0.142	
Load loss factor	0.052	0.045	
Utilization factor	0.43	0.34	

Table 9 illustrates how the LF, LLF and UF are calculated for 2 low voltage heavy consumer transformers. The data in the first three rows were obtained from the CEB billing system. There were a total of 1,043 LV heavy consumer transformers in WPN for the month of January 2012. Therefore, there would be 1,043 records ('n' number of transformers) in the Table.

Table 9 - Calculation of LF, LLF and UF of transformers

kVA rating	No load loss in W	Full load loss in W
100	340	1,900
160	460	2,450
250	610	3,150
400	870	4,000
630	1,200	5,900
800	1,300	8,260
1,000	1,440	9,800

Table 10 illustrates how the rest of the calculations were done to find the average power loss of each heavy consumer transformer.

Table 10 - Calculation of monthly energy loss of transformers

Account Number	LI	LC_R	Energy loss in kWh
2779901918	340	1,900	267
2779903449	340	1,900	260

The calculations were repeated for all available bulk consumer transformers. Table 11 shows the results of calculations of monthly total energy loss of the LV heavy consumer transformers and the total energy loss.

Table 11- Energy loss of the LV bulk consumer transformers

Month	Energy loss in MWh
January	775
February	779
March	735
April	786
May	746
June	818
July	797
August	815
September	812
October	796
November	814
December	796
Total loss	**9,469**

From the provincial energy sales data, the total energy sales to LV bulk consumers was 485 GWh. Therefore, the energy loss as percentage of total annual energy input to the transformers was estimated to be 1.92.

4.3 Distribution Transformers (Supplying Low Voltage Consumers and Street Lamps)

The details of electricity distribution transformers are summarized in Table 12. Based on the annual peak time load readings taken by the provincial planning branch, distribution transformers were grouped into five ranges of loading. Accordingly, the number of transformers, falling into each range of loading against their rated capacities, is also shown in Table 12.

Table 12 - Average loading of distribution transformers

Percentage Loading/ Rating in kVA	630	400	250	160	100
100-80	1	10	50	186	77
80-60	7	11	88	235	77
60-40	1	20	93	273	74
40-20	2	15	59	136	65
0-20	7	24	26	43	48
Total	18	80	316	873	341

To calculate the losses, transformers of a particular capacity are first selected. Then the average loading of the selected transformers are calculated. The results of the calculation for 100 kVA transformers are shown in Table 13.

Table 13 - Calculation of average loading of transformers

Percentage Loading (X)	Number of transformers (f)	X/2	(X/2) x f
0 – 20	48	10	480
20 – 40	65	30	1,950
40 – 60	74	50	3,700
60 – 80	77	70	5,390
80 – 100	77	90	6,930
Total (∑f)	341	∑(X/2) f	18,450

Average loading of a 100 kVA transformer
= ∑(X/2).f / ∑f
= 18,450 / 341
= 54.1 kVA (54.1% of rated capacity)

The no load and full load losses of a 100 kVA transformer is 340 W and 1,900 W respectively (Ref. Table 8). The average system load factor of national grid is used for the calculations [13]. Therefore, taking LF = 0.57,

LLF = $0.2 \times 0.57 + 0.8 \times 0.57^2 = 0.37$

Average power loss of a transformer,
= No load loss + UF^2 x LLF x (Full load loss)
= $340 + 0.541^2 \times 0.37 \times 1{,}900$
= 546 W

Therefore,
Power loss of 100 kVA transformers
= 546 x 341
= 186 kW

The same calculations are repeated for the other available ratings of distribution transformers. The results are shown in Table 14.

Table 14 - Total power loss of the distribution transformers

Rating in kVA	630	400	250	160	100
Power loss per transformer in W	1,929	1,368	847	614	546
Total power loss in kW	35	109	268	536	186

Therefore, the total power loss of all the transformers = 1,134 kW
Annual energy loss of the transformers
= 1,134 x 24 x 365
= 9.9 GWh

4.5 Overall Energy Flow in the Distribution Network in WPN

Table 15 summarizes the energy flow in WPNup to the low voltage network level.

Table 15 - Summary of annual energy flow in the distribution system, WPN

	GWh	Percentage
Total annual energy input to WPN	2,314	100.0
Energy supplied to LECO	417	18.0
Energy supplied (sales) to HV bulk consumers	619	26.8
Medium voltage network loss	26	1.1
Energy supplied (sales) to LV bulk consumers	485	21.0
Energy loss in LV bulk consumer transformers	10	0.4
Energy loss in distribution transformers	10	0.4
Therefore, energy input to LV network	747	32.3

Energy loss in distribution network in WPN
= (Energy purchased) – (Energy sales)
= 2,314 – (417+619+485+606)
= 187 GWh

Energy loss as a percentage of energy input
= 187/ 2,314 x 100
= **8.1 %**

According to the decision on electricity tariffs, allowance of energy for street lighting for DL 2 is 1.37% of its energy sales [14]. The same basis is used to estimate the consumption of street lamps in WPN.

Estimated energy consumption of street lamps
= 1,710 x 1.37/100
= 23.4 GWh

Energy loss without street lamps
= 187 – 23.4 = 163.6 GWh

Percentage energy loss without street lamps
= 163.6/ 2,314 x100
= **7.1%**

Aggregate of losses of medium voltage network and all transformers,

= 26 + 10 + 10 = 46 GWh (2.0%)

Therefore, energy loss in low voltage network without consumption of street lamps (X)

= 163.6 - 46 = 117.6 GWh

Therefore, X as a percentage of total energy input to WPN = 117.6 / 2,314 x 100 = **5.1**%

Further, it is important to know how much of energy input to the low voltage network is lost.

X as a percentage of energy input to LV Network,
= 117.6 / 747 x 100
= **15.7 %**

Even though LV network loss in the overall provincial energy scenario is less, it is much higher in terms of energy input to the LV network. In order to further segregate the losses in the LV network, the power consumption of electricity meters can be estimated.

The power consumption of a typical single phase electro-mechanical meter used in CEB is around 1 W [15].

Number of ordinary consumers in WPN
= 541,700 [11]
Assuming each consumer is installed and measured through a single phase electro-mechanical meter,
Total power consumption of meters
= 541,700 W
Therefore, annual energy consumption
= 4.7 GWh

Therefore, the energy loss excluding the power consumption of electricity meters, as a percentage of total energy input to the low voltage network,

= (117.6 – 4.7)/ 747 x 100
= **15.1%**

5. Sample Study on Low Voltage Network Losses

Low voltage network supplies electricity to ordinary consumers. The ordinary consumers include those supplied under the domestic, religious, small scale industrial and general purpose tariff categories. Street lighting is also in the low voltage network. The share of ordinary consumer electricity sales is about 56% total electricity sales in the country. Table 16 shows the comparison of electrical energy consumption of the ordinary consumers and the low voltage distribution line lengths in the entire country and the provincial LV network of Western Province North, CEB for the two years.

Table 16 - Details of electricity sales and LV line lengths

	Sri Lanka		WPN	
Year	**2011**	**2012**	**2011**	**2012**
Electricity sales to LV ordinary consumers in GWh (A)	5,470	5,706	683	606
Total electricity sales in GWh (B)	9,972	10,389	1,735	1,710
A/B x100%	56.2	56.2	39.4	35.4
Total low voltage line length in km	108,886	112,995	8,121	8,329

The objective of this section is to further segregate the losses in a selected area of the LV network into technical and non-technical components.

5.2 Selection of Substations and Low Voltage Network for Sample Study

Two substations and the low voltage networks fed by those two substations were selected for the sample study. The details of the substations are in Table 17. The substations have multiple feeders with three phase and single phase feeder segments. The substation is identified in the utility context by its unique Substation Identification Number (SIN).

Table 17 - Substations selected for the sample study

Feeder	SIN & Area	No. of consumers	Length of feeder sections (3- Ph.) (m)	Length of feeder sections (1- Ph.) (m)
F1	G 011, Gampaha,	190	1,500	100
F2		155	1,400	1,000
F3		187	1,600	500
F4		238	2,000	300
F1	H 048, Veyangoda	230	2,800	400
F2		124	1,400	300
F3		11	100	-

Table 18 - Calculation of total energy loss of the LV feeders – Substation 1

Substation	H048, Veyangoda		
Feeder	F 1	F 2	F3
Energy consumption – feeder meter	14,925	7,092	673
Energy consumption – Individual meters	13,311	6,349	636
Energy consumption of street lamps in kWh	275	118	15
Total energy loss in kWh (Including street lamps)	1,614	743	37
Percentage energy loss (Incl. street lamps)	10.8	10.5	5.5
Total energy loss(Excluding street lamps)	1,339	625	22
Percentage energy loss (Excluding street lamps)	9.0	8.8	3.3

All the feeders were bare All Aluminium Conductors (AAC, 7/3.40 mm). The total three phase and single phase line lengths were 10.8 km and 2.6 km respectively. There were a total of 1,135 consumers in the two substations.

5.3 Methodology

In order to find the electrical energy loss in the LV network selected, the methodology adopted is explained below.

- Energy meters were installed near the substation at the beginning of each feeder. The initial active energy reading of each meter was noted.
- Meter readings of all consumers on each LV feeder were obtained.
- A survey was carried out to obtain details of street lamps connected to each feeder.
- The distance of each feeder and spur lines connected were measured.
- The individual service connections and consumer meters on each feeder were inspected and tested.
- After a certain period of time (one month), consumer meter readings on each feeder were obtained.
- The load profile data or averaged over 15 minute time spans were downloaded from the digital meters installed at the feeders. The profiles covered the whole period of measurement.

5.4 Calculation of Losses

Initially, the total distribution loss of each feeder was calculated. Then the technical loss (I^2R loss) of each LV feeder was estimated. The non-technical loss of each feeder was derived by subtracting the technical loss from the total loss of each feeder. The calculation of energy losses of the two substations are shown in table 18 and 19, respectively.

5.4.1 Calculation of technical losses

The meters of the individual consumers were electro-mechanical and of accuracy class 2. The electronic or programmable poly-phase meters installed at the feeders were of accuracy class 1. The outdoor type current transformers used to provide secondary current output to the feeder meters were of accuracy class 1. The average peak load on each feeder during the period of measurement was obtained from the relevant load profiles downloaded from the feeder meters. The average peak current per phase of each feeder was also calculated. Table 20 shows the results.

Table 19 - Calculation of total energy loss of the LV feeders – Substation 2

Substation	G 011, Gampaha			
Feeder	F 1	F 2	F 3	F 4
Energy consumption – feeder meter	23,688	17,578	18,923	22,166
Energy consumption – Individual meters	20,383	13,431	15,560	17,637
Energy consumption of street lamps in kWh	1,071	896	978	946
Total energy loss in kWh (Including street lamps)	3,305	4,147	3,363	4,529
Percentage energy loss (Incl. street lamps)	14.0	23.6	17.8	20.4
Total energy loss(Excluding street lamps)	2,234	3,251	2,385	3,583
Percentage energy loss (Excluding street lamps)	9.4	18.5	12.6	16.2

Table 20 - Peak loading of the feeders

Feeder Identification	SIN & Area	Average daily peak load (kW)	Average daily peak load (kVA)	Average peak current (Amp.)
F1	G 011	67.3	71.6	103
F2		65.5	74.4	107
F3		59	65.6	95
F4		69.3	79.7	115
F1	H 048	62.5	65.8	95
F2		30	31.8	46
F3		3.3	3.5	5

Under the uniform load distribution model, a load flow analysis was done for each feeder to determine the peak power loss. The software programme "SynerGEE Electric 3.5" was used for the analysis.

Figure 6 shows a screen shot of the load flow analysis results for the feeders. The peak power loss as a percentage of the input peak power demand is indicated in the last column.

Feeder / Subtran	kW Losses A	B	C	Tot	Pct
Feeders for Substation G 011					
G 011_Feeder 1	1	1	1	4	5.0%
G 011_Feeder 2	5	2	2	8	11.4%
G 011_Feeder 4	3	2	2	6	8.5%
G 011_Feeder 3	3	2	2	7	10.1%
G 011 Fdr Totals	12	6	6	25	8.7%

Figure 6 - Percentage peak power losses of the Gampaha G 011 substation

A similar analysis was done for the 3 feeders in the other substation.

Figure 7 shows a screen shot of the load flow analysis results. The peak power loss as a percentage of input peak power demand is indicated in the last column.

Feeder / Subtran	kW Losses A	B	C	Tot	Pct
Feeders for Substation H 048					
H 048 Feeder 2	0	0	0	1	3.1%
H 048 Feeder 3	0	0	0	0	0.1%
H 048 Feeder 1	3	2	2	7	11.2%
H 048 Fdr Totals	4	2	2	8	8.3%

Figure 7 - Percentage peak power losses of the Veyangoda H 048 substation

It was required to calculate the average power loss of each feeder. For this, the average load factors and thereby the loss of load factors of the feeders were calculated. Table 21 elaborates the calculation of LF and LLF of the feeders.

Table 21 - Calculation of load factors and loss of load factors of the feeders

Feeder	Average Daily Peak Demand (kW)	Energy consump-tion (kWh)	Period of measure-ment in days	LF	LLF
F1	67.3	23,688	27	0.543	0.344
F2	65.5	17,578	27	0.414	0.220
F3	59.0	18,923	27	0.495	0.295
F4	69.3	22,166	27	0.494	0.294
F1	62.5	14,925	21	0.474	0.274
F2	30.0	7,092	21	0.469	0.270
F3	3.3	673	21	0.405	0.212

The calculation of the LLF for the feeder 1 of the G011 substation is shown.

$$LLF = 0.2 \times 0.543 + 0.8 \times (0.543)^2 = 0.344$$

Finally, the energy loss of each feeder under the four models was calculated. The equation below was used for the calculation of energy loss once the peak power loss of each feeder had been calculated.

Energy loss = Peak power loss x LLF x period of measurement in hours

The results of the calculations are shown in Table 22.

Table 22 - Calculated energy loss (Technical) of the feeders

Feeder	Substation	Energy loss	
		kWh	%
F1	G 011, Gampaha	827	3.5
F2		1,074	6.1
F3		1,139	6.0
F4		1,121	5.1
Total		4,161	5.1
F1	H 048, Veyangoda	968	6.5
F2		126	1.8
F3		0	0.1
Total		1,095	4.8

5.4.2 Derivation of non-technical losses

The non-technical loss of each feeder in terms of energy in kWh and as a percentage of total energy input to the feeder is shown in Table 23.

Table 23 - Non-technical losses of the feeders

Feeder	No. of meters tested	No. of accur--atemeters	No. of Defec--tive meters	No. of tampered meters	Total cases of NTL
F1	192	176	12	4	16
F2	155	137	13	5	18
F3	189	180	8	3	11
F4	240	214	22	9	31
Total	**776**	**707**	**48**	**21**	**76**
%	**100.0**	**91.1**	**7.1**	**1.8**	**9.8**
F1	230	213	14	3	17
F2	124	117	5	2	7
F3	11	11	0	0	0
Total	**365**	**341**	**19**	**5**	**24**
%	**100.0**	**93.4**	**5.2**	**1.4**	**6.6**

Table 24 - Results of meter testing

Feeder	SIN	Energy input in kWh	Total energy loss in kWh	Technic-al loss in kWh	Non-techni-cal loss in kWh
F 1	G 011	23,688	2,234	827	1,407
F 2		17,578	3,251	1,074	2,177
F 3		18,923	2,385	1,139	1,246
F 4		22,166	3,583	1,121	2,462
Total		**82,355**	**11,453**	**4,161**	**7,293**
%		**100.0**	**13.9**	**5.1**	**8.9**
F 1	H 048	14,925	1,339	968	371
F 2		7,092	625	126	498
F 3		673	22	0	22
Total		**22,690**	**1,986**	**1,095**	**891**
%		**100.0**	**8.8**	**4.8**	**3.9**

The NTL components tabulated above include any errors in the estimation of technical losses, energy losses at service drops and joints, losses in the electricity measuring instruments etc. However, the losses in the electricity meters can be estimated in order to further consolidate on the levels of NTL. Assuming that the power loss of a single phase active energy meter is 1 W [20].

Power loss of meters in G 011 substation
= (Number of meters) x 1 W
= 770 x 1 W
= 0.77 kW

Energy loss for 27 days
= 499 kWh
Energy loss as percentage of energy input
= (499/ 82,355) x 100%
= 0.6%

Similarly, for the substation in Veyangoda,
Energy loss in 375 consumer meters
= (365 x 1 x 24 x 21/1000) kWh
= 184 kWh
Energy loss as percentage of energy input
= 184/22,690 x 100%
= 0.8%

Therefore, NTLs as a percentage of energy input excluding the power consumptions of the meters are 8.3% and 3.1% for Gampaha and Veyangoda substations, respectively.

5.5 Meter Testing Results

All the consumer meters in the selected two LV networks were tested by CEB staff. The results of the meter testing are shown in Table 24.

The number of defective meters in the entire sample is 74 and it is 6.5% of the total number of meters tested. The number of cases contributing to non-technical loss is 100 and it is 8.8% of the total number of meters tested.

6. Conclusions and Remarks

Losses in electrical power systems have become a serious problem to utilities worldwide. Amidst the escalating global crisis for energy, the attention of utilities has shifted towards reduction of losses. The economic, financial and social consequences of power system losses are being gradually understood. As such, utilities and countries as a whole are devising various measures to arrest losses in electrical power systems. However, an initial and essential step towards reduction of losses is accurately estimating losses.

Losses in electricity distribution represent dominant part in the overall power system losses. In the Sri Lankan context, losses in the distribution system are around 10% of gross electricity generation when the total losses in generation, transmission and distribution amount to 14% in 2012. Though this can be viewed as a reasonably good level, when compared with the power system losses in rest of the developing countries in the region, country need long strides to reach the levels achieved by the developed countries.

In any efforts to arrest losses, it is of paramount importance that the losses are estimated accurately. It is a pre-requisite before developing strategies to counter losses. It is required to segregate distribution losses to identify the losses at different levels.

WPN is a key area in the distribution system of CEB which generate 16% of its revenue. There are 12 such provinces in the distribution system of CEB. The total energy loss as a percentage of energy input to the province was 7.1%. The medium voltage network loss was 1.14% of energy input. The losses in the power distribution transformers were at 0.8%. The low voltage network loss as percentage of energy input to the province was 5.1%. However, the same as a percentage of energy input to the low voltage network was 15.7%. This implies that losses in the low voltage network are considerably high, even though its true gravity is not reflected in the overall picture. The situation was subjected to further analysis segregating low voltage network loss into technical and non-technical components. This was done in a selected area of the network, since it was practically difficult to handle the entire network.

The sample study showed an interesting picture which was an eye opener for the utility. Total energy loss in the two substations selected, Gampaha and Veyangoda, were 13.9% and 8.8% respectively and technical losses were calculated to be 5.1% and 4.8% respectively tow areas. Non-technical losses accounted to 8.9% and 3.9% respectively of the energy input to the two substation networks, viz., Gampaha and Veyangoda. Interestingly, the consumption of street lamps was estimated to be 4.8% and 1.8% respectively for Gampaha and Veyangoda. Since all consumer meters in the selected networks were tested, test results are interpreted with a view of understanding the contribution of metering problems to non-technical losses. Following important conclusions can be drawn with regard to the sample study.

- Street lamp consumptions can be very high as they are not metered or billed properly. Therefore, it is recommended to adopt suitable methods to monitor and record the consumption of street lamps.
- Presence of defective meters contributes significantly to NTL. Well organized regular meter testing and replacement programmes are essential to overcome the problem.
- Utility must adopt proper seal management systems, and refurbish meter installation fully without correcting only the meter, to prevent or minimize avenues for unauthorized access.
- Proper sealing and installation practices should be used right at the time new connections are given to prevent addition of new cases which might contribute to NTL.
- Set up standards for regular meter testing programmes at utility or regulator level.
- It is required to device programmes to analyse consumer consumption patterns to identify power pilferages.

It is recommended to have broader surveys to determine low voltage network losses such that entire network can be modelled with sufficient accuracy. It will enable the utility to implement loss reduction measures very effectively.

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