Estimation of Electricity Network Loss Targets in Sri Lanka

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Abstract

This study estimated loss targets for the transmission licensee and the five distribution licensees of Sri Lanka over the period 2016 – 2020. Both technical losses and the non-technical losses at each component of the network were estimated largely using the data received from all the licensees, and the targets were set mainly considering the reduction of non-technical losses in the system.

Introduction

Sri Lanka electricity tariff methodology requires to specify an annual regulatory allowance for losses for the transfer of energy over the Transmission Licensee's network as well as through the Distribution Licensees' networks. Each licensee should abide by the loss target set by the regulator, the Public Utilities Commission of Sri Lanka (PUCSL). If the actual losses are lower than the allowed target loss, licensees can retain the corresponding income, but if the actual losses are higher than the target loss, the licensee has to finance such losses from internal funds.

The total energy loss in both transmission and distribution were reported to be 11.5% of net generation in 2014, whereas the target set by PUCSL was 12.4%. In 2014, PUCSL observed that the allowed loss targets from 2011-2015 do not match with the recorded loss levels, and there exists a sizable margin between the values. Hence, a study was commissioned in 2014 to establish revised and more realistic targets for each licensee, for the period 2016-2020.

This study provides an in-depth analysis of transmission and distribution losses, to separate the technical and commercial losses in each segment of the network and its equipment to establish reasonable losses to be allowed for each licensee, over the period 2016-2020.

Objective

The main objective of this study was to conduct a comprehensive analysis and to derive the annual loss targets for the transmission licensee and for each distribution licensee for the period 2016-2020, with the ultimate intention of

improving the fairness of the technical and economic regulatory activities of PUCSL, both to licensees and to customers.

Methodology

It was assumed that the present principles, policies and practices in planning and developing the transmission and distribution network by the licensees will remain unchanged. Features of customer demand, too, was expected to remain unchanged over the period of analysis. Information required for the analysis such as planning reports, network data, customer load profiles, sales information, transformer load profiles and case studies on distribution networks were provided by the licensees to a considerable extent. The study methodology adopted matched the limited information and data made available by the licensees.

Transmission Losses

Figure 1 shows the boundaries associated with the transmission system in Sri Lanka.

Figure 1 - Typical Boundaries of the Transmission System

Generator output is metered as follows:

Type 1: gross power output at the generator terminal (M_{1G}) and power input to auxiliaries (M_{2G}) are measured. Power input to transmission network is given by ($M_{1G} - M_{2G}$ - generator transformer loss).

Type 2: power input to the transmission network is directly measured. (M_{3G})

Most of the generators using renewable energy resources are directly connected to the MV network (embedded generation) and therefore, energy does not flow into the transmission system, unless at low power demand at distribution level or high renewable resource availability.

Technical Losses

Technical loss of the transmission system depends on; (a) configuration of the network, (b) parameters of the network elements, (c) dispatch of power plants, and (d) features of the demand served to distribution licensees (DLs) at each grid substation.

The following procedure was used to estimate the technical losses in the transmission system.

Step 1: Days in the period (a year) were divided into two dispatch scenarios and two demand patterns

Step 2: Representative days for each dispatch scenarios and demand pattern were selected.

Step 3: Load flow studies were conducted for selected days and the peak-time loss for each scenario was calculated.

Step 4: For each dispatch scenario, the maximum peak-time loss was obtained by considering the day peak and the night peak.

Step 5: Daily load factor (LF) was calculated using demand curves of weekdays and weekends, using the formula below.

$$LF = \frac{1}{P_{rate} d \times T} \times \int_{t=0}^T P(t) dt \dots\dots\dots (1)$$

Step 6: Daily loss load factor (LLF) for different scenarios were calculated using one of the following methods:

(i) using the formula,

$$LLF = (p \times LF) + [(1 - p) \times LF^2] \dots\dots\dots (2)$$

(ii) by obtaining the loss curve over a day

Step 7: Technical energy loss in the transmission network was calculated after obtaining all the above parameters.

Non-Technical Losses

Non-technical losses for the base year (2014) was calculated using the following formula.

$$\text{Non - Technical Loss} = \text{Total loss of TL} - \text{Technical loss} \dots\dots\dots (3)$$

Distribution Losses

Figure 2 shows the simplified MV and LV networks and the metering points.

Figure 2 - Simplified MV and LV Systems and Metering Points

Technical Losses in MV Network

The following methodology has been adopted by each distribution licensees (DLs) of CEB (DL1 – DL4) in the preparing Distribution System Development Plans to assess the MV network technical losses from 2016 – 2020.

(a) Data collection

- Geographical maps showing MV distribution lines and distribution substations
- Ratings and setting of network components.
- Network data
- Operational data
- Load data of distribution transformers, bulk supply transformers and primary substations
- Load transfers at divisional and provisional boundaries
- Data on Non-conventional Renewable Energy (NCRE) power plants
- Committed network development proposals
- Expected loads

(b) Modelling of the existing MV network using Syner GEE.

(c) Network load assessment and load forecasting based on time trend and analysis of special requirements.

(d) Modelling of future network and loss estimation based on short term, and medium to long term proposals.

As this methodology is acceptable, energy loss targets given in the Medium Voltage Distribution System Plans published by DL1-DL4 were adopted.

Transformer Losses to Serve LV Bulk Customers

The following procedure was adopted to calculate the transformer losses to serve LV

bulk customers who are metered at the LV side of the transformer.

1. Transformer test reports which provide the iron loss and full load copper loss were obtained.
2. From daily load curves of 253 transformers, energy transferred were obtained.
3. LF was calculated using the following formula:

$$LF = \frac{\text{Daily energy (kWh)}}{\text{Peak demand (kW)} \times 24} \dots \dots \dots (4)$$

4. Cu loss at each time interval was calculated using following:

$$Cu\ loss = \left[\frac{\text{Demand}}{\text{Rated capacity}} \right]^2 \times \text{Full load } Cu\ loss \dots \dots \dots (5)$$

5. LLF associated with the Cu loss was calculated using following:

$$LLF = \frac{\text{Daily energy loss } Cu\ loss (kWh)}{\text{Peak } Cu\ loss (kW) \times 24} \dots \dots \dots (6)$$

6. Using curve fitting, approximate value of p in equation $LLF = (p \times LF) + (1 - p) \times LF^2 \dots \dots \dots (2)$ was obtained for working days and holidays separately.
7. For transformers for which only billing data were available, monthly LF was calculated.
8. LLF for working days and holidays were then calculated using LF and previously estimated values of p.
9. Following ratios between average peak demand (working days) and average peak demand (holidays) were established using the load profiles available.
 - a. General purpose (GP2/GV2) = 2.5
 - b. Hotels (H2) = 1.2
 - c. Industry (I2) = 3.5
10. Number of working days and holidays were counted for the calendar year 2014 for each customer category.
11. The following formula was used to estimate the annual energy loss of all the LV bulk customer transformers of each DL.

$$\begin{aligned} \text{Energy Loss} = & (\text{Iron Loss} \times 8760) + \left\{ \left[\frac{\text{Average peak demand (working days)}}{\text{Rated capacity}} \right]^2 \times \right. \\ & \text{Cu loss}_{\text{full load}} \times \text{LLF (working days)} \times \text{No of working days} \times 24 \Big\} + \\ & \left\{ \left[\frac{\text{Average peak demand (holidays)}}{\text{Rated capacity}} \right]^2 \times \text{Cu loss}_{\text{full load}} \times \right. \\ & \text{LLF (holidays)} \times \text{No of holidays} \times 24 \Big\} \dots \dots \dots (7) \end{aligned}$$

12. Percentage loss was the calculated based on the total energy input to the transformers feeding LV bulk customers. **Percentage loss** =

$$\frac{\text{Energy loss} \times 100}{(\text{Energy sold} + \text{Energy loss})} \% \dots \dots \dots (8)$$

Losses in Distribution Transformers and the LV Network

It was assumed that the total load on the LV network is uniformly distributed on each pole (Figure 3)

Figure 3 - LV Distribution Network with Uniform Loading

The following equation was derived to calculate the peak-time loss in the network.

$$P_{NW,peak} = 3 \times k \times R \times \left(\frac{I_{MD,k}}{q} \right)^2 \times \left[\frac{q(q+1)(2q+1)}{6} \right] \dots \dots \dots (9)$$

Where

k = no. of LV feeders per transformer

R = line resistance between two poles

I_{MD} = current at maximum demand

$I_{MD,k}$ = current in each feeder ($\frac{I_{MD}}{k}$)

N = no. of customers

n = no. of customers per pole = $\frac{N \times \text{Distance between poles}}{\text{Total LV network length}}$

Average diversified maximum demand

$$(ADMD) = \frac{\text{Maximum demand}}{N}$$

$$q = \frac{\text{Maximum demand}}{3 \times ADMD \times n \times k}$$

Peak time Cu loss in the transformer;

$$P_{Cu,tf} = \text{Cu loss}_{\text{rated capacity}} \times$$

$$\left[\frac{\text{Maximum demand}}{\text{Rated capacity}} \right]^2 \dots \dots (10)$$

Energy loss in the transformer and the LV network can be calculated using the following formula;

$$E_{loss} = [P_{NW,peak} + P_{Cu,tf}] \times \text{LLF} \times T + [P_{iron,tf} \times T] \dots (11)$$

where, $P_{iron,tf}$ is the transformer iron loss.

Total power supplied by the transformer;

$$P_{tf} = \sqrt{3} \times 400 \times I_{MD} \times 0.85^1 \dots (12)$$

For the y number of LV networks, the energy loss as a percentage of energy input to the distribution system was obtained by;

$$\% \text{Energyloss} = \frac{\sum_{j=1}^y [P_{NWpeakj} + P_{Cu.tfj} \times LLF + P_{iron.tfj}]}{\sum_{j=1}^y [(P_{tfj} \times LF) + (P_{Cu.tfj} \times LLF) + P_{iron.tfj}]} \times 100\% \dots (13)$$

Technical Losses in Metering MV Bulk, LV Bulk and LV Customers

This includes the standby power consumption of the CT/PT unit of the MV bulk customer meters and the power consumption of energy meters of the LV bulk and LV customers. Power consumption by each type of energy meter was obtained by the energy meter specifications of the meter manufacturers.

Non-Technical Losses in the MV Network

Ideally, there cannot be any non-technical loss in the MV network.

Non-Technical Losses to Serve MV and LV Bulk Customers

The following procedure was adopted to estimate the allowable non-technical losses associated with errors in the CTs and meters of MV bulk customers.

- For the entire sample, an error between $\pm 0.5\%$ was randomly assigned, separately for the CT and for the meter so that error distribution fits into a random distribution.
- Error was calculated using the following formulae;

If E_n = Annual energy transfer through the transformer

$$CTerror = \sum_{n=1}^N [err_{CT,n} \times E_n] \dots (14)$$

$$Metererror = \sum_{n=1}^N [err_{meter,n} \times E_n] \dots (15)$$

$$Totalerror = CTerror + Metererror \dots (16)$$

Non-technical loss due to CT and meter error was then estimated as:

$$\% \text{Error} = \frac{Totalerror}{\sum_{n=1}^N E_n} \times 100\% \dots (17)$$

Non-Technical Losses in LV Supply

This includes the error caused by meters of the LV customers. Percent errors for different currents passing through the meter for several

meters and load profiles of different customer categories were used to estimate the losses in metering LV customers.

Non-Technical Loss in the LV Network

After estimating all other losses, the residual loss was considered as the non-technical loss in the LV network.

Estimation of Losses

In accordance with the methodology described above, losses in each component of the network were calculated.

Losses in Transmission System

Estimation of Total Loss in Transmission

Using the monthly energy purchase and sales data of the TL, total loss for the duration May 2013 – April 2014 was estimated. Annual energy loss over one-year period was 294.3 GWh resulting in a total energy loss of 2.66% in the transmission system.

Estimation of Technical Loss

In accordance with the methodology explained, peak time loss was estimated for each dispatch scenario.

Table 1 – Estimated Parameters at each Dispatch Scenario

Dispatch Scenario		Number of Days	LF	LLF ²	Peak-time Loss (MW)
Hydro max, thermal balance	Weekday	$X_1 = 159$	0.677	0.458	$Z_1 = 45.3$
	Weekend	$X_2 = 84$	0.641	0.411	$Z_2 = 39.6$
Thermal max, hydro balance	Weekday	$X_3 = 35$	0.846	0.716	$Z_3 = 75.3$
	Weekend	$X_4 = 37$	0.789	0.622	$Z_4 = 68.8$

Thus, the technical energy loss in the transmission system for the period of one year (1st May 2013 to 30th April 2014) was 259,970 MWh, i.e. 2.37% of net generation.

Estimation of non-Technical Loss

Non-technical loss was calculated using equation (3) and was estimated to be 34,320 MWh i.e. 0.31% of net-generation.

Impact of Reverse Power flow into the Transmission Network

Generation from embedded generation can cause reverse power flow into the transmission

¹ Average power factor of LV networks was estimated to be 0.85

² LLF with p=0

network which can alter the losses. A case study was carried out to estimate the effect of reverse power. The date was selected was 22nd October 2014 to be the day in year 2014, with the highest recorded reverse power flows. Figure 4 shows the calculated transmission losses and reverse power on the selected date.

Figure 4 - Transmission Losses and Reverse Power Flow on 22nd Oct 2014

It was estimated that the LF on the selected date was 0.698 and the LLF was 0.539. If 5% of days in the year, reverse power flows occur on the system, the technical loss changed from 2.35% to 2.42% only. As the planned additional embedded generation is expected to be small compared with the demand growth, it was concluded that the effect of reverse power flows on transmission loss targets is negligible.

Assessment of Losses in Distribution System

Technical Losses in the MV Network

Based on the analyses by each DL, Table 2 below shows the summary of loss targets for the MV network from 2016-2020.

Table 2 - Targets for MV Network Technical Losses of Distribution Licensees

DL	Energy Losses (%)				
	2016	2017	2018	2019	2020
DL1	1.00	0.87	0.81	0.83	0.84
DL2	1.45	0.90	0.87	0.89	0.89
DL3	1.10	1.00	1.00	0.80	0.90
DL4	1.48	1.30	1.52	1.46	1.55
DL5	0.44	0.55	0.55	0.51	0.57

Source: Distribution Development Plans of each CEB Licensee, 2014, Load Flow Analysis Report, LECO, 2015

Transformer Losses to Serve LV Bulk Customers

For the sample of 600 LV bulk customer load profiles, $p = 0.4$ for working days and $p = 0.355$ for holidays were selected. The percent loss was calculated using equation (8) and the results are shown in Table 3.

Table 3 - Calculated Percent Loss of LV Bulk Customer Transformers

DL	Energy Loss (%) 2014
National average	2.06
DL1	2.38
DL2	1.93
DL3	1.94
DL4	2.12
DL5	2.00

It was observed that about 72% of the LV bulk customer transformers are loaded less than 50% of the transformer capacity, causing a considerable iron loss.

Losses in Distribution Transformers and LV Network

Methodology described was followed and following assumptions were made.

Power factor = 0.85

Resistance of LV feeders = $0.4487 \Omega/\text{km}$ (conductor type: FLY, $R = 0.4487 \Omega/\text{km}$ and for 70 mm^2 ABC, $R = 0.443 \Omega/\text{km}$)

No. of feeders per transformer = 3

Average LF = 0.47

Table 4 below shows the calculated distribution transformer loss and LV network loss for each licensee assuming $p = 0.25$ and $LF = 0.5$

Table 4 - Calculation of Energy Loss in Distribution

DL	Distribution Transformer Loss	LV Network Loss	Total Transformer and LV Network Loss
DL1	2.22%	4.64%	6.75%
DL2	1.85%	7.74%	9.44%
DL3	4.61%	4.56%	8.95%
DL4	2.10%	4.86%	6.86%
DL5	1.80%	1.87%	3.64%

Technical Losses in the MV bulk, LV Bulk and LV Customers

MV bulk: CT/PT units and energy meters have a standby power consumption of about 120W. Annual energy loss owing to power consumption of the CT/PT unit was thus calculated.

LV bulk: Three phase electronic energy meters used for LV bulk metering have a standby power consumption of 0.7 W. Calculated

percentage loss due to this was very small and therefore neglected.

LV: Power consumption of single phase electro-magnetic meters is 1 W and 3 phase customers usually have electronic meters with standby power consumption of 0.7 W. Annual energy loss due to LV metering was therefore calculated for the total number of LV customers.

Results are shown in Table 5.

Table 5 - Technical Loss and MV Bulk and LV Metering

DL	MV Bulk		LV	
	No. of customers	Energy Loss as % of Input	No. of customers	Energy Loss as % of Input
DL1	116	0.02%	1,501,127	0.79%
DL2	138	0.02%	1,870,131	0.97%
DL3	50	0.02%	1,104,691	1.02%
DL4	25	0.02%	932,693	0.94%
DL5	14	0.04%	515,414	0.56%

Non-Technical Losses to Serve MV Bulk and LV Bulk Customers

The procedure explained was followed for 138 number of MV bulk customers. For a random distribution of CT and meter errors it was found that the maximum possible error is $\pm 0.05\%$. Therefore, the allowed non-technical loss for all licensees to serve MV customers was fixed at 0.05%. A sample of 1,352 LV bulk customer transformers was considered in estimating the non-technical loss of serving LV bulk customers. The maximum possible error was estimated to be 0.012%.

Non-Technical Losses in LV Supply

Using the representative daily load curves of each LV customer category, the current passing through the meter at each 15-minute interval was obtained and for each current value, an error was assigned using the meter test data. Estimated percent meter error for different customer categories are shown in Table 6.

Thus, the non-technical loss in LV supply for each licensee are DL1: 0.41%, DL2: 0.36%, DL3: 0.36%, DL4: 0.38%, DL5: 0.45%.

Table 6 - Percent Meter Error of LV Customers

Customer Category		Error in electro-magnetic meter *	Error in electronic meter*
Household - Single Phase	0-60	-0.05%	
	60-90	-0.23%	
	90-120	-0.41%	
	120-180	-0.96%	
	>180	-1.01%	
Household - Three Phase	>180		-0.91%
GP1	0-300	-0.18%	
	>301	-0.54%	-0.25%
I1	0-300	-0.49%	
	>301	-0.36%	-0.38%

* (-) error implies that the meter reads less than the delivered energy

Non-Technical Losses in LV Network

After determining all the technical and non-technical losses in distribution, residual loss was estimated as the non-technical loss in the LV network which mainly occurs owing to electricity theft.

Determination of Loss Targets from 2016 - 2020

Approach used to estimate the loss targets for each licensee is described below and the results are shown in Table 7 and Table 8.

Transmission: According to the CEB Long Term Generation Expansion Plan 2013-2032, future generation additions were considered and the number of days for each dispatch scenario was calculated for the forecast years. Peak losses were obtained by PSS/E simulations carried out for representative years. It was assumed that the daily load factor gradually increases by 10%.

Table 7 - Recommended Transmission Loss Targets for 2016 - 2020

Year	Technical Loss (%)	Non-Technical Loss (%)	Total Loss (%)
2016	2.75%	0.51%	3.26%
2017	2.13%	0.28%	2.41%
2018	1.84%	0.24%	2.08%
2019	1.59%	0.21%	1.80%
2020	1.53%	0.18%	1.71%

Distribution:

- Forecast of MV network loss for each licensee was obtained from the MV Development plans.
- It was assumed that the load profiles and the loading levels of the LV bulk customer transformers will remain unchanged, and therefore, the percent loss will not be changed.
- Distribution transformer loss was forecast by accounting for change of the load profile owing to growth of customers.
- As planned LV network improvements cannot be predicted, LV network loss was fixed at the estimated value.
- Technical losses in metering MV bulk, LV bulk and LV customers were forecast by considering the electricity market forecast of each distribution licensee.
- Non-technical loss of LV network and LV supply were estimated to progressively reach to 0.1% by 2020 such that the total loss in 2020 of the entire transmission and distribution network would be 7.5% of net generation.

Table 8 - Recommended Distribution Loss Targets for 2016 - 2020

DL	Year	Loss Target (as a % of Purchase by each DL)		
		Technical	Non-Technical	Total
DL1	2016	5.88%	2.32%	8.20%
	2017	5.64%	1.77%	7.41%
	2018	5.54%	1.21%	6.75%
	2019	5.51%	0.66%	6.18%
	2020	5.48%	0.12%	5.60%
DL2	2016	6.99%	3.01%	10.00%
	2017	6.35%	2.23%	8.57%
	2018	6.12%	1.45%	7.58%
	2019	5.99%	0.75%	6.74%
	2020	5.85%	0.10%	5.94%
DL3	2016	7.01%	1.19%	8.20%
	2017	6.71%	0.92%	7.64%
	2018	6.65%	0.65%	7.30%
	2019	6.39%	0.38%	6.78%
	2020	6.43%	0.11%	6.54%
DL4	2016	6.82%	1.78%	8.60%
	2017	6.55%	1.37%	7.92%
	2018	6.72%	0.95%	7.67%
	2019	6.63%	0.54%	7.17%
	2020	6.68%	0.12%	6.80%
DL5	2016	3.80%	1.19%	5.00%
	2017	3.89%	0.93%	4.81%
	2018	3.88%	0.66%	4.54%
	2019	3.83%	0.39%	4.23%
	2020	3.89%	0.13%	4.02%

Resultant targets for the total Transmission and Distribution system of Sri Lanka for the period of 2016 - 2020 is shown below.

Table 9 - Recommended Total Loss Targets for 2016 - 2020

Year	Sales to end-use customers (GWh)	Net Generation (GWh)	Sri Lanka Total T&D Loss (as a share of net generation)		
			Technical	Non-Technical	Total
2016	11,985	13,536	8.87%	2.59%	11.46% ¹
2017	12,781	14,175	7.97%	1.86%	9.84%
2018	13,622	14,959	7.62%	1.31%	8.94%
2019	14,518	15,795	7.29%	0.80%	8.09%
2020	15,475	16,730	7.21%	0.29%	7.50%

¹Note: This study was conducted over 2015 - 2016. The loss target for 2016 was decided to be fixed at the actual reported loss of year 2014. However, provisional generation and sales data for 2016 available at the time of this publication, indicate that the actual total loss in year 2016 was 10.3% of net generation.

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