

Reliability Improvement of the Medium Voltage Distribution Network Owned by Lanka Electricity Company: A Case Study in Kalutara Area

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Abstract – This paper presents the reliability and quality improvement of the medium voltage (MV) electricity distribution network owned, operated and maintained by Lanka Electric Company (LECO) in Kalutara area. MV distribution network established in Kalutara area is found to be rapidly growing owing to the load growth and hence a reliable and quality distribution network is required to meet the challenges in upcoming years 2022-2025. Therefore, modern technical evaluation methods are used to carry out the required study to reach techno-economically attractive optimal solution. An Artificial Neural Network based short term load forecasting method is used to predict the demand followed by Monti-Carlo simulation approach to ascertain the most appropriate distribution reliability model. Thereafter, OpenDSS software package in association with MATLAB based randomized load flow analysis is carried out to check the system performances of the proposed network configurations. Finally, the Cost of Energy Not Served (ENS) is used to evaluate the optimal network configuration.

Keywords: Medium Voltage Distribution, Artificial Neural Network, Distribution Reliability, Monti-Carlo simulation, Randomized load flow, Energy Not Served

Nomenclature

ANN - Artificial Neural Network

MC - Monti Carlo

SAIDI - System Average Interruption Duration Index

SAIFI - System Average Interruption Frequency Index

ENS - Energy Not Served

1 INTRODUCTION

Sri Lanka has faced an economic collapse in the years 2019–21 and worsened the situation owing to the locally affected Easter Sunday attack and globally affected corona pandemic. Subsequent effects have slackened the expansion of electrical distribution networks to meet the growing power and energy demand at medium voltage distribution levels. Under the circumstances, forecasting power and energy demand, which enables to maintain existing distribution networks and future expansions while minimizing the forced outages and network losses, in the upcoming era will be a major challenge that must be thoroughly examined. Moreover, the changes that must be made to improve the network performance should be more economically attractive as well. This research study carried out to improve the existing medium voltage (MV) distribution network reliability and quality in Kalutara area of LECO franchise as a case study, using the system elements currently in use or to

add an optimum number of new elements if there is any, that yield towards a better techno-economical solution. MV distribution network in Kalutara owned/maintained by LECO covers many urban and critical areas. Reliability of the said network is considered as an important factor owing to compaction of commercial buildings, district government offices and industrial consumers. MV network consists of three Primary Substations (PS). Molligoda PS emanate three feeders: Pirivena Road (PVR), Pothupitiya (POP) and Wadduwa (WAD). Kalutara North PS emanate three feeders: Hotel (HOT), Nagas Junction (NAG) and Waskaduwa (WAS). Fullerton PS emanate four feeders: Hillside (HIS), Kalutara North (KTN), AMW and Payagala (PAG). Payagala (PAG) feeder is not considered in this study since PAG feeder is owned by Payagala Customer Service Center (CSC). Study focuses on developing an ANN short term load forecast model and subsequently a reliability model to improve reliability and quality of the distribution network. Initial investigation consists of observing the system performance of existing electrical distribution network and thereafter remedial measures are proposed with an intension to improve the same.

2 LOAD FORECAST

Initially, a short-term load forecast is carried out to identify the maximum demands of each distribution feeder. In here, multi regression statistical analysis and artificial neural network methods are used. IBM Statistical Package for the Social Sciences (SPSS) software is used for multi regression analysis whereas MATLAB 2018Ra software is used for ANN method as depicted in Figure 1.

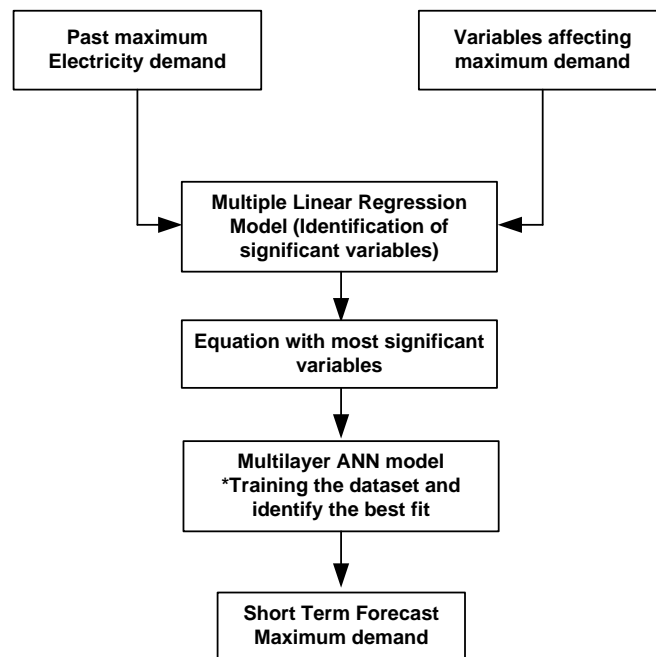


Fig. 1. Flow Chart showing demand forecasting method

MATLAB ANN toolbox is used for demand forecasting with Multilayer Feed Forward Neural Network structure. The multi-layer ANN model as shown in Figure 2 is used to construct the most appropriate architecture for ANN. Gross Domestic Product (GDP), Gross Domestic Product Per Capita (GDPPC), Population, Total number of consumers, Tourist Arrivals, Average Temperature (TMP) and Average Relative Humidity (RH) data are used as dependent variables to construct the ANN model. GDP and GDPPC forecast and historical data are taken from the International Monetary Fund database. TMP and RH

data are taken from the Department of Meteorology. Population and consumer count are taken from the Department of Census and Statistics and LECO database. The consumer count is statically forecasted with combination of population growth. Further World Tourism Organization forecasts are taken to modify the tourist arrival data.

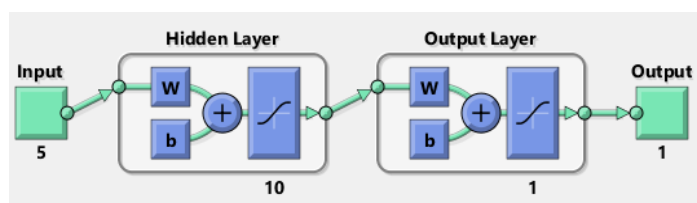


Fig. 2. Multilayer ANN model

Table 1 ANN structure

Description	ANN structure
No of hidden layers	1
No of Hidden neurons	10-13 varies for feeders
Activation function of hidden layer	Tan sigmoid
Activation function of output layer	Pure linear
No of neurons in the output layer	1
Training function	Trainbr

Kalutara Hotel, Molligoda Wadduwa, Molligoda Pirivena Road and Fullerton AMW feeders are forecasted with ANN. Kalutara Waskaduwa and Molligoda Pothupitiya feeders are observed as small feeder sections with saturated peak loads and cannot be forecasted with ANN. Fullerton Hill Street, Fullerton KTN and Kalutara Nagas junction feeder data are severely fluctuated owing to re configuration after 2018 and 2019 years. Therefore, those feeders are not forecasted with ANN and the load growth is separately modified with other feeder ANN forecast growth and statistical growth of the same feeder. Moreover, the correlation coefficients between distribution feeders are calculated up to 2019 and 2021 years separately. Growth of the network demand is observed to be changed after 2020 year owing to pandemic situation and economic crisis. Variables which have strong positive correlation coefficient up to the year 2021 are used by regression analysis while ANN utilized all the strong positive variables until 2019. Correlation coefficients of the variables with respect to all the feeders are shown in Table 2.

Table 2 Correlation coefficients of variables with respect to the feeders

Dependent variable	Variables	Correlation Coefficient							
		Hotel Feeder		AMW Feeder		Wadduwa Feeder		Pirivena Road Feeder	
		Up to 2019	Up to 2021	Up to 2019	Up to 2021	Up to 2019	Up to 2021	Up to 2019	Up to 2021
Maximum demand (Amps)	GDP	0.914	0.825	0.981	0.963	0.911	0.901	0.935	0.841
	GDPPC	0.838	0.836	0.944	0.935	0.840	0.769	0.864	0.628
	Population	0.982	0.444	0.932	0.615	0.970	0.811	0.987	0.953
	Total consumers	0.988	0.427	-	-	0.973	0.800	0.990	0.946
	Tourist arrivals	0.926	0.787	-	-	-	-	-	-
	TMP_ average	0.681	0.283	0.453	0.233	0.543	0.506	0.551	0.666
	RH_ average	-0.274	-0.178	-0.234	-0.149	-0.135	-0.183	-0.200	-0.309

2.1 Kalutara PS to Hotel feeder maximum current demand forecast

GDP, GDPPC, Population, Total consumers and Tourist arrivals data are used for ANN and GDP, GDPPC and Tourist Arrival data are used for Regression analysis respectively. Demand forecast is as shown in Figure 3. Table 3 shows the tested Mean Square Error.

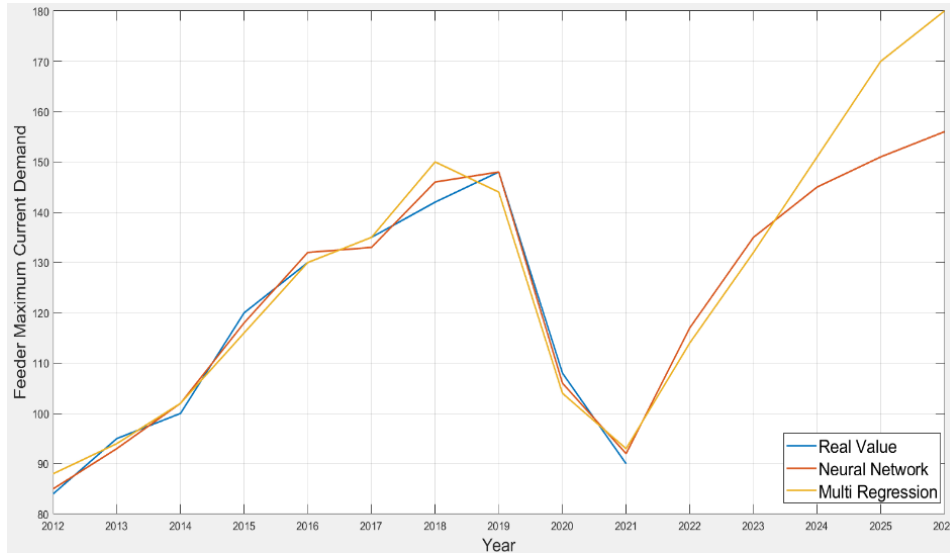


Fig. 3. Hotel feeder maximum current (Amps) demand forecast

Table 3 Tested mean square error

Hidden Layers	MSE (ANN)	MSE (Multi Regression)
13	4.71	13.99

2.2 Fullarton to AMW feeder maximum current demand forecast

GDP, GDPPC and Population data are used for ANN forecast. Only GDP and GDPPC data are used for Regression analysis. This is shown in Figure 4. Table 4 shows the tested Mean Square Error.

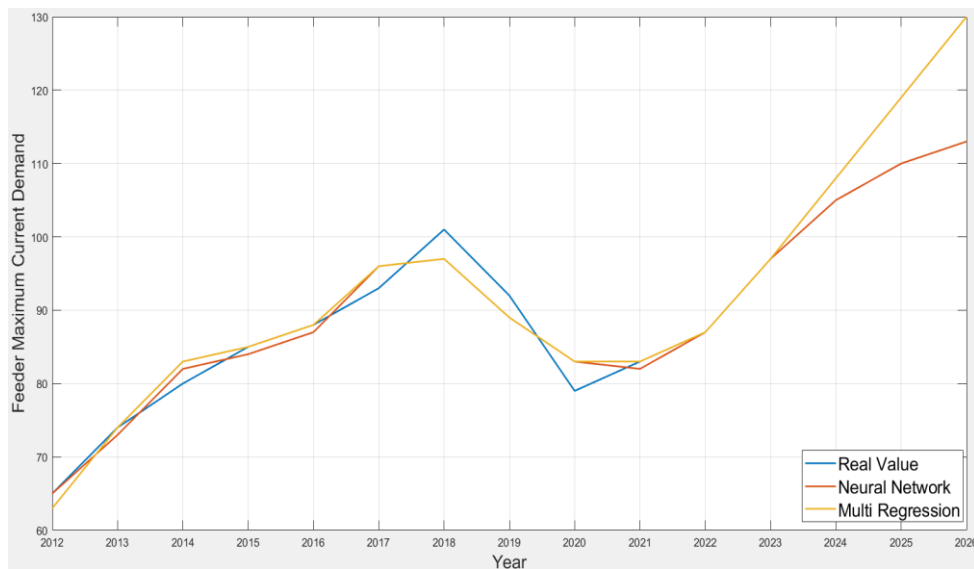


Fig. 4. AMW feeder maximum current (Amps) demand forecast

Table 4 Tested mean square error

Hidden Layers	MSE (ANN)	MSE (Multi Regression)
10	5.57	6.43

2.3 Molligoda to Wadduwa feeder maximum current demand forecast

GDP, GDPPC, Population and Total consumer count data are used for ANN forecast. GDP, Population and Total consumer count data are used for Regression analysis. This is shown in Figure 5. Table 5 shows the tested Mean Square Error.

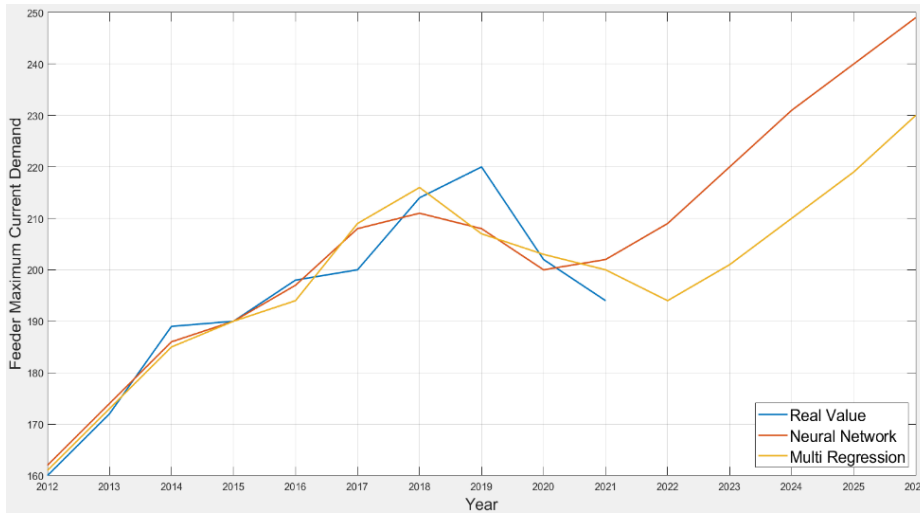


Fig. 5. Wadduwa feeder maximum current (Amps) demand forecast

Table 5 Tested mean square error

Hidden Layers	MSE (ANN)	MSE (Multi Regression)
15	30.84	32.38

2.4 Molligoda to Pirivena road feeder maximum current demand forecast

GDP, GDPPC, Population data and Total consumer count data are used for ANN forecast. GDP, Population data and Total consumer count data are used for Regression analysis. This is shown in Figure 6. Table 6 shows the tested Mean Square Error.

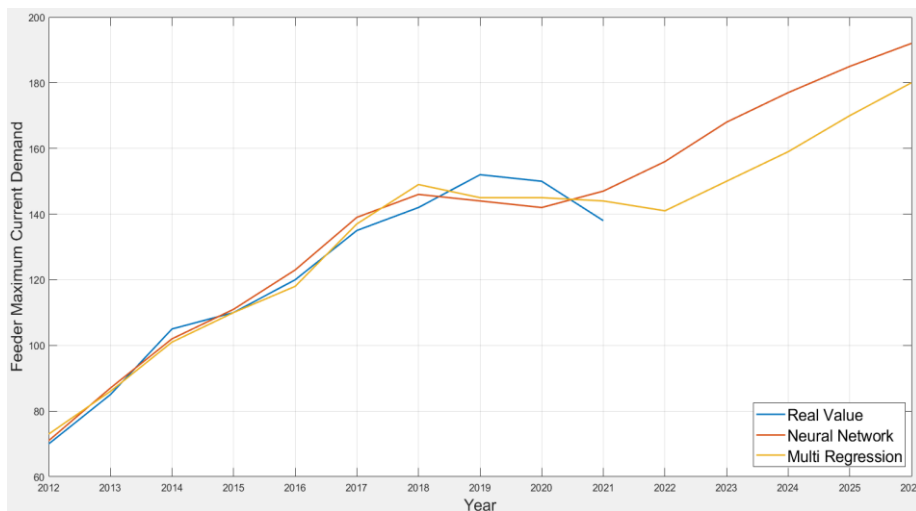


Fig. 6. Pirivena road feeder maximum current (Amps) demand forecast

Table 6 Tested mean square error

Hidden Layers	MSE (ANN)	MSE (Multi Regression)
10	25.69	20.47

3 QUANTITATIVE ANALYSES

OpenDSS Version 9.3.0.1 distribution analysis software package supported by MATLAB 2018Ra is deployed to carry out load flow simulations to arrive at technically feasible solution. In here, load points are randomly varied to catch the maximum feeder current. As such, two thousand (2000) randomizations of loads followed by associated load flow simulations are carried out for a single network configuration. Variation of load demand is randomized between 20-40% of maximum demand and the feeder maximum demand. The planning criteria applied to verify and reach the best network configuration is:

- Voltage at loads should not be greater or less than 4% of its rated operating voltage
- Line losses should not be greater than 1% of the total delivery
- Lines are not overloaded (not more than 50% the thermal rating)
- Primary Substation should not be overloaded (not more than 60% of its rated capacity)

OpenDSS and MATLAB-Com interfaces are used to establish connection between MATLAB and OpenDSS. Figure 7 shows data feeding from MATLAB through Com interface and data returning from OpenDSS.

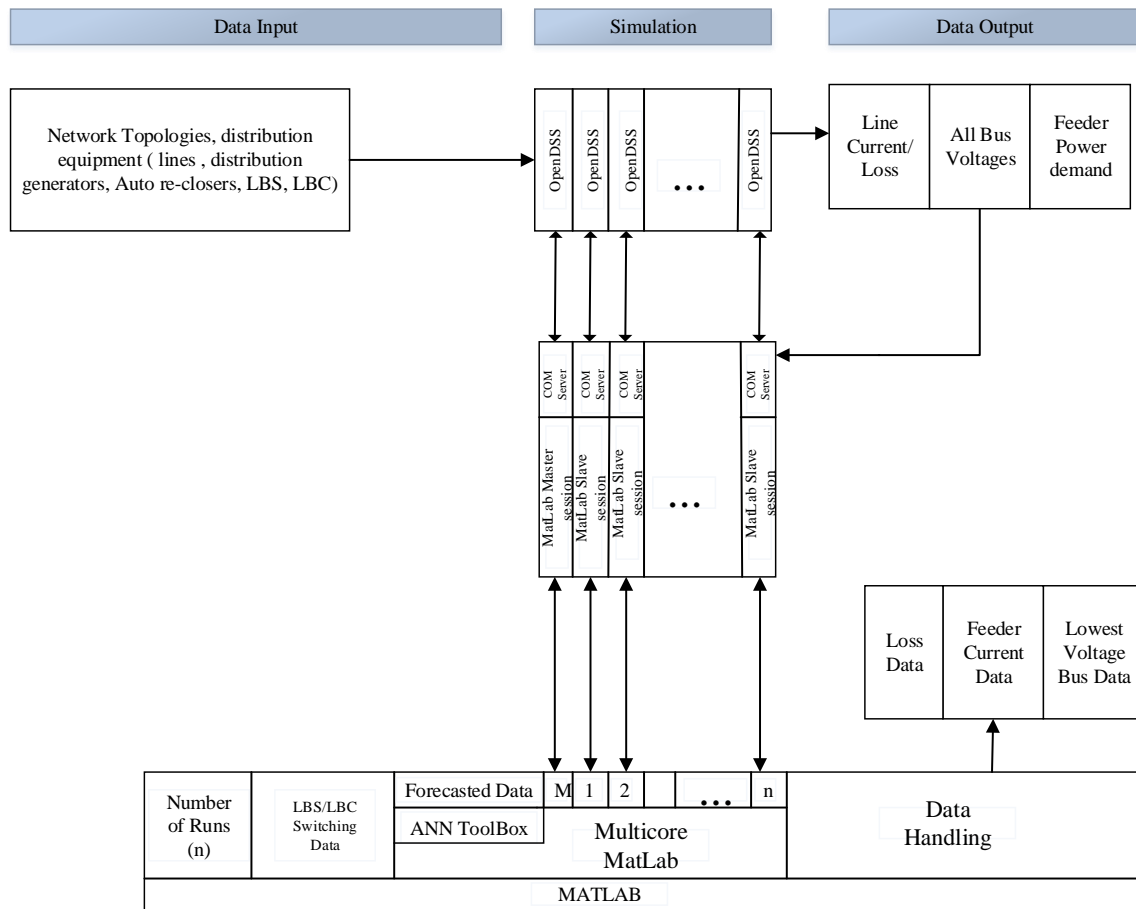


Fig. 7. OpenDSS and MATLAB interfacing

Flowchart showing the load randomization algorithm and load flow simulation handling is as shown in Figure 8. Two thousand randomized loads are generated for each node and feed to OpenDSS to get results in this process.

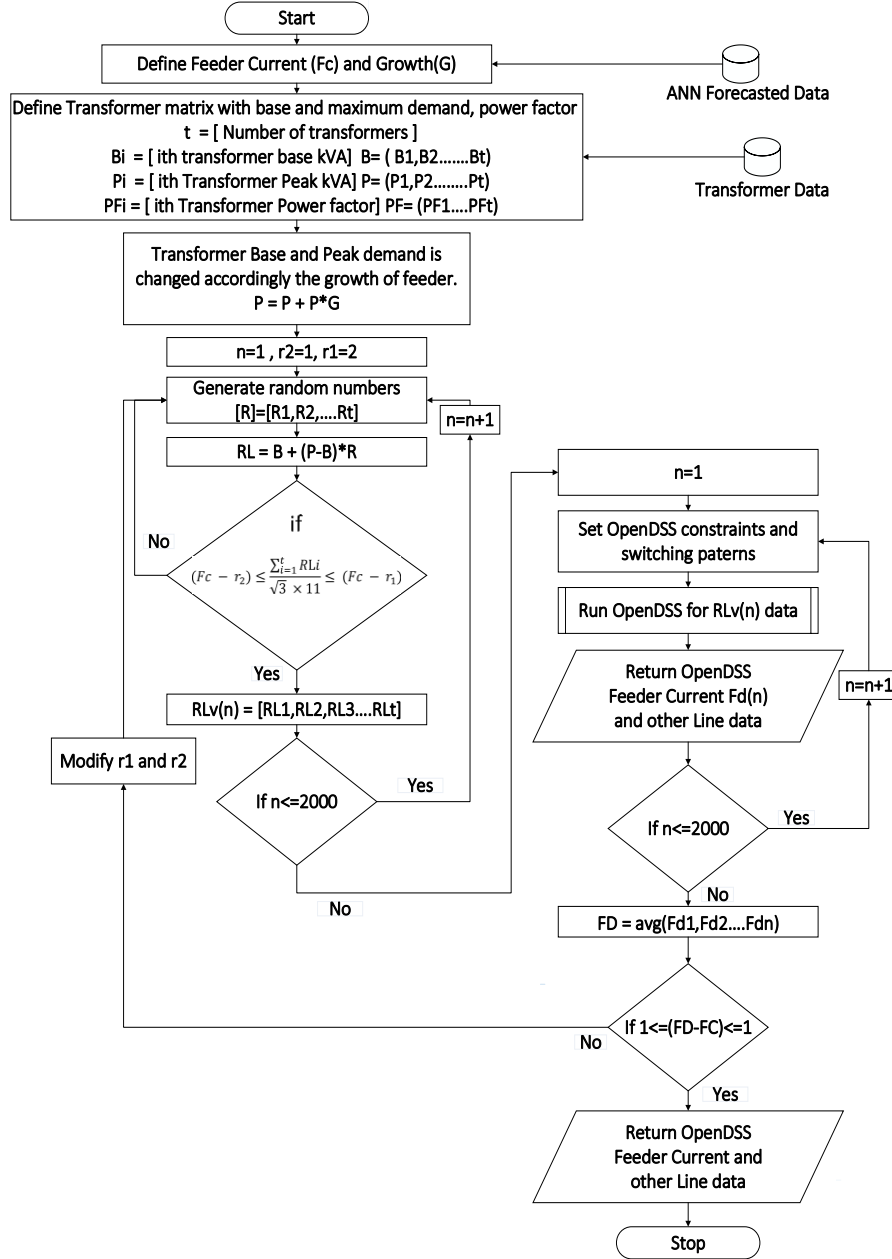


Fig. 8. Load randomization and load flow handling flowchart

1. Start
2. ANN forecasted data and growth data is taken. (*Feeder Current-Fc, Year Growth-G*)
3. Transformer base load and peak loads are defined. Transformer power factor and unique numbers are defined.

$t = \text{number of transformers}$
 $B = [B1, B2, B3, \dots, Bt]$
 $P = [P1, P2, P3, \dots, Pt]$
 $PF = [PF1, PF2, PF3, \dots, PFt]$

$B_i = i^{\text{th}} \text{ transformer base demand kVA}$
 $P_i = i^{\text{th}} \text{ transformer peak demand kVA}$
 $PF_i = i^{\text{th}} \text{ transformer power factor}$
 $R_i = \text{Random number between } 0-1 \text{ for a node } i$

4. Set $n = 1$ and $r1=1, r2=2$

5. Peak load is modified according to yearly growth for next year.

$$P = P + P * G$$
6. Generate random numbers between 0 and 1

$$R = [R1, R2, R3, \dots, Rt]$$
7. Node loads are randomized $RLi = Bi + [Pi - Bi] * Ri$ & $RL = [RL1, RL2, RL3, \dots, RLt]$
8. Check loads are in between feeder current. Set variation in between $Fc - r1$ and $Fc - r2$.
 If $(Fc - r_2) \leq \frac{\sum_{i=1}^t Ri}{\sqrt{3} \times 11} \leq (Fc - r_1)$ go to step 9. Else go to step 6
9. Update the matrix with all randomized loads (RLv) with RL data $RLv(n) = RL$
10. If $n < 2000$ go to step 6 by incrementing n by 1. Else go to step 11
11. Set $n = 1$
12. Set OpenDSS constraints and run OpenDSS for RLv(n) data
13. Return OpenDSS feeder current (Fdn) and other line data
14. If $n < 2000$ got to step 12 by incrementing 1, else go to step 15.
15. Compute OpenDSS feeder current Average

$$FD = avg(F_{d1}, F_{d2}, \dots, F_{dn})$$
16. If OpenDSS average feeder current (FD) and actual feeder current (FC) variation is greater than 1, move to step 6 by modifying r_1 and r_2 . Else move to step 17.
17. Return OpenDSS feeder current and other line data.

Load flow studies are carried out for the year 2022 with the existing network condition and the study results are shown in Table 7. The system performance for the years 2022 and 2026 with the required modifications to the network to alleviate the limitations are shown in Table 8 and Table 9 respectively. Further, the developed load flow model is validated with the LECO load flow studies for better clarification.

Table 7 Load flow results for the existing network condition-Year 2022

Primary Sub Station	Feeder Current (ID)	Feeder Current (Amps)	OpenDSS-Load Flow Results					Planning Criteria (Violations)				
			Feeder Loss (MVA)	Feeder Loss (kW)	Feeder Loss (%)	Lowest Voltage (pu)	PS Loading (Diversified) (MVA)	PS Loading (%)	Line Loss (<1%)	Bus Voltage $0.96 < V < 1.04$	Feeder Loading (<50%)	PS Loading (<60%)
Kalutara 2×5 MVA	HOT	117.38	2.23	6.97	0.36	0.99						
	NAG	170.23	3.27	47.17	1.62	0.97			x			
	WAS	17.69	0.34	0.17	0.06	0.99						
							5.52	55.2				
Molligoda 2×5 MVA	POP	48.64	0.92	1.25	0.15	0.99						
	PVR	156.35	2.98	23.62	0.87	0.98						
	WAD	209.09	3.98	59.00	1.69	0.97			x		x	
							7.49	74.9				x
Fullerton 2×10 MVA	HS	221.08	0.93	1.21	0.14	0.99					x	
	KTN	93.96	1.79	11.63	0.69	0.98						
	AMW	87.34	1.66	3.9	0.27	0.99						
	PAG	105.01	2.00									
							9.18	45.9				

x = values exceeding the limits

Table 8 Load flow results after network modification-Year 2022

Primary Sub Station	Feeder (ID)	Current (Amps)	OpenDSS-Load Flow Results					Planning Criteria (Violations)				
			Feeder (MVA)	Feeder Loss (kW)	Feeder Loss (%)	Lowest Voltage (pu)	PS Loading (Diversified) (MVA)	PS Loading (%)	Line Loss (<1%)	Bus Voltage (0.96<V<1.04)	Feeder Loading (<50%)	PS Loading (<60%)
Kalutara 2×5MVA	HOT	117.38	2.23	6.97	0.36	0.99						
	NAG	57.06	1.09	2.61	0.26	0.99						
	WAS	17.69	0.34	0.17	0.06	1.00						
							3.48	34.8				
Molligoda 2×5MVA	POP	48.64	0.92	1.25	0.15	1.00						
	PVR	156.35	2.98	23.62	0.87	0.98						
	WAD	101.79	1.94	13.97	0.82	0.98						
							5.55	55.5				
Fullerton 2×10MVA	HS	133.70	2.55	18.97	0.83	0.98						
	KTN	122.83	2.34	21.47	0.99	0.98						
	AMW	87.34	1.66	3.9	0.27	0.99						
	PAG	105.01	2.00									
							8.12	40.6				
EUR 1×5MVA	EUR T	163.11	3.10	14.2	0.53	0.99	3.10	62.0				

Table 9 Load flow results after network modification-Year 2026

Primary Sub Station	Feeder (ID)	Current (Amps)	OpenDSS-Load Flow Results					Planning Criteria (Violations)				
			Feeder (MVA)	Feeder Loss (kW)	Feeder Loss (%)	Lowest Voltage (pu)	PS Loading (Diversified)	PS Loading (%)	Line Loss (<1%)	Bus Voltage (0.96<V<1.04)	Feeder Loading (<50%)	PS Loading (<60%)
Kalutara 2×5MVA	HOT	156	2.96	12.42	0.48	0.98						
	NAG	64.33	1.23	3.30	0.29	0.99						
	WAS	21	0.41	0.25	0.07	0.99						
							4.37	40.37				
Molligoda 2×5MVA	POP	59	1.12	1.85	0.18	0.99						
	PVR	192	3.66	35.35	1.06	0.97						
	WAD	122.56	2.33	19.89	0.97	0.98						
							6.76	67.6				68
Fullerton 2×10MVA	HS	161.07	3.07	28.19	1.03	0.97						
	KTN	148.25	2.82	31.14	1.18	0.97			1.2			
	AMW	113	2.15	6.60	0.36	0.99						
	PAG	127	2.42									
							9.94	49.7				
EUR 1×5MVA	EUR T	212	4.04	24.2	0.70	0.99	4.04	80.8				

4 SIMULATION STUDY FOR RELIABILITY ASSESMENT

4.1 Reliability indices and Monte Carlo simulation

Three basic parameters are defined for components such as Transformers, Auto reclosers, Load break switch, Load break cut outs etc. connected in series for reliability studies in distribution planning and they are: the failure rate λ (interruptions/year), the interruption duration r (hours/interruption), and the unavailability U (hours/year).

$$\lambda = \sum_{i=1}^N \lambda_i \quad (1)$$

$$U = \sum_{i=1}^N \lambda_i r_i \quad (2)$$

$$r = \frac{U}{\lambda} \quad (3)$$

Where N = Total number of components in the system and i = Index of the node.

The reliability indices considered for distribution planning in this research study are SAIFI, SAIDI and ENS and can be expressed as:

$$1) \text{ System average interruption frequency index: } SAIFI = \frac{\sum_i \lambda_i N_i}{\sum_i N_i} \quad (4)$$

$$2) \text{ System average interruption duration index: } SAIDI = \frac{\sum_i U_i N_i}{\sum_i N_i} \quad (5)$$

where N_i is the number of customers at load point i .

$$3) \text{ Energy not supplied: ENS (kWh/yr.) } ENS = \sum L_{a(i)} U_i \quad (6)$$

where $L_{a(i)}$ is the average load (kW) at node i

In here, N is the number of customers connected to the i^{th} node

The Monte Carlo (MC) method simulates the distribution system faulty situations in random manner. Probabilistic technique is used by MC simulation method to predict the behavior of the distribution system components. Sequential down status and up status of the components in distribution system can be simulated through MC simulation method. The time to failure (TTF) which is identified as time taken for a component to fail is randomly predicted by MC simulation as described in equation (7).

$$TTF = -\frac{1}{\lambda} \ln(u) \quad (7) \text{ where } u \text{ is a uniformly distributed random number (0 to 1).}$$

The time to repair (TTR) is defined as the time required to repair the failed component.

TTR is also estimated randomly using equation (8)

$$TTR = -\frac{1}{\mu} \ln(u) \quad (8) \text{ where } \mu \text{ is the repair rate of the component.}$$

The behavioral pattern for a single component is as shown in Figure 9.

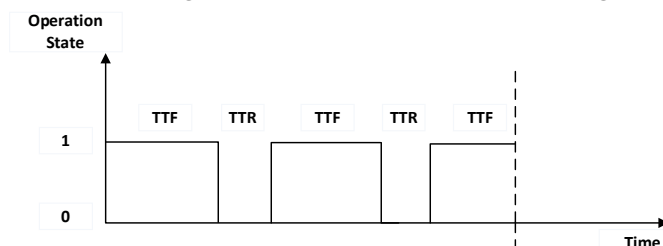


Fig. 9. A single component behavioral pattern

The time to switch (TTS) is separately modified for each feeder. A constant value is assumed for this figure after carefully observing historical outages. Both TTF and TTR are derived using exponential distribution. TTF and TTR for each component is created for one-year simulation period in sequential order. For better achievement of the results, MC simulation should be carried out for considerable number of simulation years, as such 5000 simulation years are considered in this research study.

4.2 Outages considered for MC simulation

There are three types of forced outages identified in LECO distribution system.

1. Repairable and Switchable outages (RS): Repair time and switching time are separately identified for those outages. In this case, section wise outages are modeled using components concentrated to one section.
2. Non repairable and non-switchable outages (NRS): Outages do not belong to RS are categorized under this section. Unknown cases and PS tripped cases are majorly found here. Those faults are factorized according to the affected consumer count to reach accurate reliability index.
3. Primary substation loss (PSL): Outage of the power supply connected to the PS are considered under this category and all the feeders connected to PS are on outage state.

In this research study, only the Repairable and Switchable cases are considered for system performance improvement and MC simulation. The rest of the two cases are considered to verify the results with historical data. NRS outages are factorized with the affected customers to build up the model for NRS outages. Finally, all the outages are simulated with the help of developed model and verified with historically recorded LECO data as shown in Figure 11,12 and 13.

4.3 Reliability data

Required basic reliability parameters for the system components and distribution lines obtained from 2015-2019 LECO outage report are depicted in Table 10 and Table 11 respectively.

Table 10 Reliability data for components

Fault type	Fault Type	Component No	Failures/yr.	Down Time /yr.	Failures/yr./unit	Down time/failure
Kalutara PS		1	73	43.90	73	0.6
Fullerton PS		1	43.4	14.23	43.4	0.33
Molligoda PS		1	74.6	32.24	74.6	0.43
AR	Faulty AR	23	2	7.29	0.0869	3.64
LBS	Faulty LBS	915	12	23.41	0.0131	1.95
LBC	Faulty LBC	586	4.20	2.85	0.0071	0.68
TF	Faulty TF	4387	18.4	21.53	0.0041	1.17
Arrestor	Burnt Arrestor	13161	18.8	53.64	0.0014	2.85
DDLO		13161	21.2	16.08	0.0016	0.76

AR - Auto Recloser LBS - Load Break Switch LBC - Load Break Cutout TF - Transformer
DDLO - Drop Down Lift Off

Table 11 Reliability data for distribution lines

Feeder name	Fault type	Length (km)	Failures/yr.	Failures/yr./km	Mean Repair Time (hr.)	Mean Switch Time (hr.)
Fullerton to Hillside	RS	4.48	13.20	2.94	0.87	0.5
Fullerton to Kalutara North	NRS	-	78.59	-	0.42	-
Kalutara North to Hotel	RS	12.54	21.4	1.70	0.79	0.5
Kalutara North to Hotel	NRS	-	75.40	-	0.45	-
Kalutara North to Nagas junction	RS	6.295	11	1.74	0.40	0.2
Kalutara North to Nagas junction	NRS	-	17.54	-	0.39	-
Kalutara North to Waskaduwa	RS	4.72	24.60	5.21	0.54	0.3
Kalutara North to Waskaduwa	NRS	-	35.37	-	0.38	-
Molligoda to Pothupitiya	RS	1.75	3.80	2.17	0.58	0.3
Molligoda to Pothupitiya	NRS	-	10.60	-	0.45	-
Molligoda to Pirivena	RS	2.38	7.60	3.19	0.53	0.5
Molligoda to Pirivena	NRS	-	24.40	-	0.48	-
Molligoda to Wadduwa	RS	11.02	22.40	2.03	0.70	0.5
Molligoda to Wadduwa	NRS	-	45.26	-	0.41	-
Wadduwa	RS	7.77	12	1.54	0.75	0.5
Wadduwa	NRS	-	28.43	-	0.44	-

* RS = Repairable and switchable outages * NRS = Non-Repairable and Non switchable outage

Components concentrated to one section is considered as one component in MC simulation. As an example, Table 12 shows the components concentrated in a single section between two Load Break Switches BT359 and BT824. Section which can be isolated through LBS or LBC is identified as one single component for MC simulation.

Table 11 Components concentrated in a section for MC simulation

Components concentrated between Load break switches BT359-BT824					
	km or #of Unit	Failures/yr./km or Failures/yr./unit	r repair time hours	λ failures/yr.	U Unavailability hours
Line	3.23	2.94	0.87	9.50	8.27
LBS	2	0.0131	1.9508	0.0262	0.0511
DDLO	21	0.0016	0.7588	0.0338	0.0256
LBC	4	0.0071	0.6785	0.0286	0.0194
Arrestor	21	0.0014	2.8535	0.0299	0.0855
TF	7	0.0041	1.1701	0.0293	0.0343
			0.8795	9.6478	8.4859

4.3 Fault isolation and restoration procedure

1. After Identifying the faulty component, the fault section is isolated using $n \times r$ matrix to store failed nodes. (n: faulty components, r: nodes effected)
2. Thereafter, observe the switching matrix. Nodes which can be switched on to restore power are stored here. It requires $n \times s$ matrix to store switchable nodes. (n: faulty components s: nodes switchable)
3. After restoration of the fault as described in 1 & 2, normal operational matrix is restored.

4.4 Monte Carlo simulation procedure. [algorithm & flowchart]

Time sequential Monte Carlo simulation algorithm is used to develop the MATLAB program for the determination of distribution system reliability and is as follows:

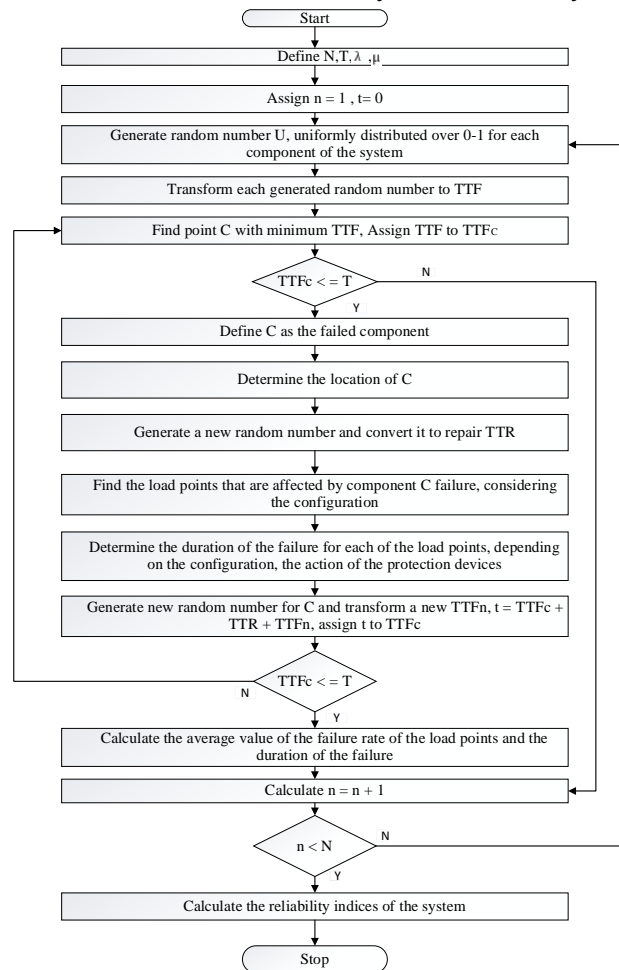


Fig. 10. Flow chart showing time sequential Monte Carlo simulation

- Step 1:** Define the system variables. Failure rate λ , repair rate μ of each component. Number of sample years (N), simulation period (T).
- Step 2:** Simulation starts, $n = 1$, $t = 0$.
- Step 3:** Generate random number [0-1] for each component of the network and compute TTF (time to failure) for each component.
- Step 4:** Find the component with minimum TTF and set it as TTF_c
- Step 5:** Generate random number and convert it to TTR (Time to Repair) of failed component.
- Step 6:** Find the load points that are affected by the failure of this element considering the configuration and status of breakers, disconnects, fuses and alternate supply and record a failure for each of these load points.
- Step 7:** Find the switching time by considering affected components.
- Step 8:** Determine the failure duration depending upon the configuration and status of breakers, disconnects, fuses and alternate supply and record the outage duration for each failed load point.
- Step 9:** Generate a random number and convert it to TTF_n . $t = TTF_n + TTF_c + TTR$.
- Step 10:** Go to Step 4 if the simulation time is $<$ mission time. Else go to step 11.

Step 11: Calculate the average value of the load point failure rate and failure duration for the sample years

Step 12: Calculate the system indices for the sample years

Step 13: Return to Step 3 if the simulation time is less than the total simulation period. Otherwise, print the results

4.5 Verification of the results obtained from the model with historical data

Comparison of recorded SAIFI, SAIDI values for feeders by LECO and simulated results for the same in this research study are shown in Figure 11,12 and 13 respectively.

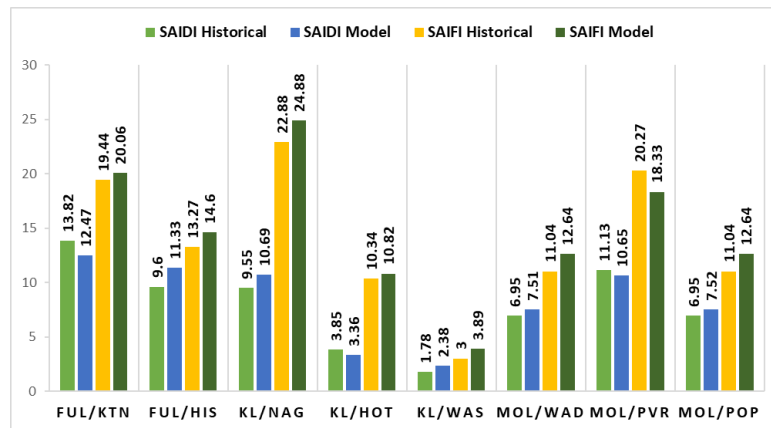


Fig. 11. Reliability Indices for the repairable and switchable outages

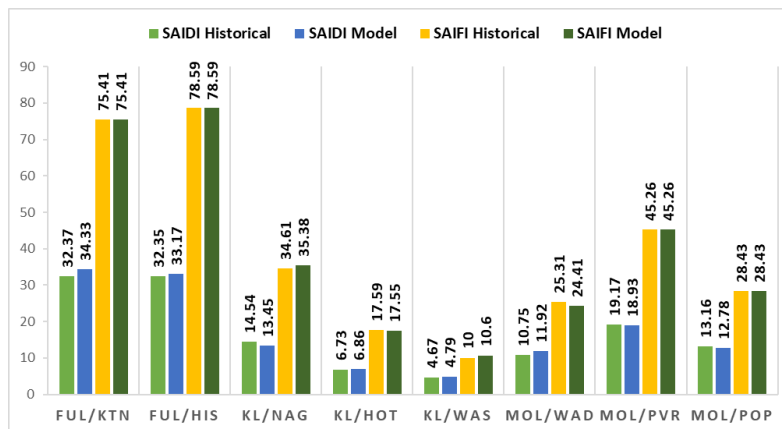


Fig. 12. Reliability Indices for the non-repairable and non-switchable outages

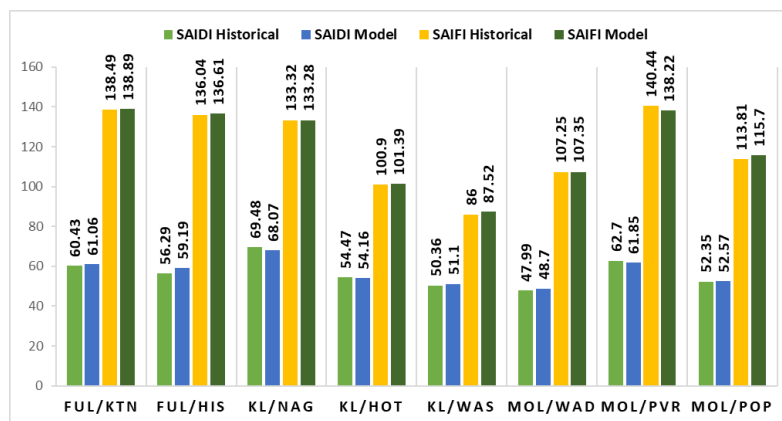


Fig. 13. Reliability Indices for all the outages as described in 4.2

4.6 Modified system reliability indices

Modification to the distribution system is done to achieve the maximum reliability indices by adding new LBSs, moving the existing LBSs to new position, adding new LBCs and reconfiguring the existing 11kV lines. Repairable and switchable outages are reduced through the modification done to the system. Figure 14 shows the repairable and switchable outage reliability indices before and after modifications done to the system.

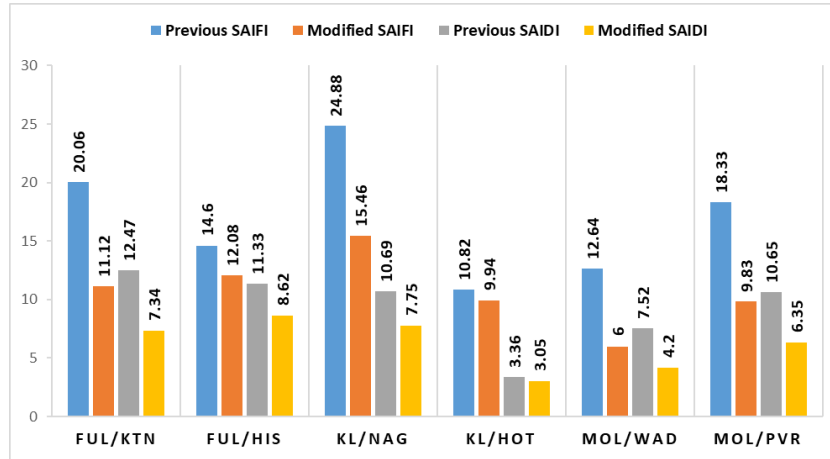


Fig. 14. Modified vs previous system reliability indices

4.7 Cost of energy not served and budget for modification

ENS (Energy Not Served) is calculated by using the mean value of node unavailability. Standard deviation of the data is checked further to verify the variation of taken mean value. Energy usage of single node cannot be found from the current system. So that whole feeder mean energy is taken for calculating ENS. Six-month average monthly energy demand is used for the calculation.

Total Energy Not Served = Mean unavailability of feeder × Mean energy demand of feeder. Cost of the energy is taken as 0.782USD/kWh which is already being used by LECO. 1USD = 202LKR rate is used for the calculations because LECO cost manual is published in first half of the 2022 year. Saved ENS and saved cost of ENS for modified system is tabulated under Table 13 and table 14 for budget of the purposed system. Simply the budget used for the modification of the system can be recovered within a 2.5-year period.

Table 12 Reduction of cost of energy not served by network modification

Primary	Feeder	Previous ENS (kWh)	Modified ENS (kWh)	Saved Cost of ENS (LKR)
Fullerton	HS	5496.03	5315.92	28450.17
	KTN	11696.13	7894.65	600481.78
	EUR_T	12799.98	1725.84	1749271.15
Molligoda	PVR	13567.71	8418.51	813367.63
	WAD	10229.86	6095.23	653106.15
	POP	1991.34	-	-
Kalutara North	NAG	13223.92	10090.59	494940.80
	HOT	6974.85	6427.80	86412.01
	WAS	961.91	-	-
Total Saved Cost of Energy Not Served				4426029.69

Table 13 Capital budget required for the modification

Primary	Feeder	LBS (New)	LBC (New)	LBS (Move)	AR (New)	Total Cost
Kalutara	NAG	1	-	-	-	1,749,833
	HOT	-	1	-	-	122,180
	WAS	-	-	-	-	-
Molligoda	PVR	-	-	2	-	273566
	WAD	-	-	-	1	2091770
Fullerton	HIS & Eur-Tec	-	2	1	1	5,728,219
	KTN	-	6	1	-	809863
Total Cost (LKR)						10,775,431

5 CONCLUSIONS

A reliable and quality electrical distribution network is one of the essential requirements to slacken the current economic crisis in Sri Lanka to a certain extent. This research, as a case study, found many technical drawbacks and limitations pertaining to the prevailing distribution network owned and operated by LECO in Kalutara area. Subsequently, by applying novel methods and technologies such as Monte Carlo simulation for network modification associated with OpenDSS and MATLAB load flow studies, considerable improvement to the said network is observed. The study revealed that the proposed network modification required only simple payback period of 2.5 years based on energy not served reliability improvement. It is also noted that in this research study, ANN method of demand forecasting produced better results compared to other statistical forecasting methods too.

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