

**COST EFFECTIVE RELIABILITY IMPROVEMENTS IN
33kV/11kV ELECTRICITY DISTRIBUTION NETWORKS –
A CASE STUDY IN WESTERN PROVINCE SOUTH 1,
CEYLON ELECTRICITY BOARD, SRI LANKA.**

Degree of Master of Science in Electrical Engineering

Department of Electrical Engineering

University of Moratuwa

Sri Lanka

APRIL 2021

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Dissertation submitted in partial fulfillment of the requirements for the
Degree Master of Science in Electrical Engineering

Department of Electrical Engineering

University of Moratuwa

Sri Lanka

APRIL 2021

DECLARATION

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Date:

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Prof. W.D.A.S Wijayapala

Late Prof. H Y Ranjit Perera

ABSTRACT

Electricity Distribution system in Sri Lanka consists of 33kV, 11kV and Low Voltage (400V/230V) networks. Providing reliable supply to the end user is a challenging task to any utility. Therefore, utility is trying to develop their network to provide a highly reliable supply to user by investing in system developments.

In this research, a method is introduced for selecting a cost-effective solution to improve the reliability of the 33kV and 11kV distribution systems among different proposals. Improvement of conductor, its insulation and protection of short duration faults are focused to develop in this research. Part of the method developed in this research, includes the software tool (DisFeeRIA) to analyze the reliability indices and cost for the relevant proposal. Data Base of the DisFeeRIA software tool includes failure rate improvement, mean time to repair, costing of each option considered etc. The analysis is done using user input of the particular feeder, data base of the software which are the part of outcome of the research.

Medium Voltage Underground cable (MVUGC), Medium Voltage Aerial Bundle Conductor (MVABC), Medium Voltage Covered Conductor (MVCC), Room Temperature Vulcanizing (RTV) Si-R coating on existing bare line ceramic insulators are considered as options for improving conductor and its insulation. One of the latest & innovative technologies used in distribution network, Pulse closing technology is used to reduce momentary interruptions and enhance the life time of the equipment which used in distribution network.

Developed software and method were tested by case study done for Distribution network in Western Province South – 01 of Ceylon Electricity Board (CEB). Three (03) feeders were selected in different areas from Urban, Coastal & Rural.

The method that is introduced in this research is very important to utilities for planning of Electricity Distribution network.

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LIST OF ABBREVIATIONS

CEB	- Ceylon Electricity Board
LECO	- Lanka Electricity Company
MV	- Medium Voltage
LV	- Low Voltage
MVBOH	- Medium Voltage Bare Overhead
MVUGC	- Medium Voltage Underground Cable
MVABC	- Medium Voltage Aerial Bundle Conductor
MVCC	- Medium Voltage Covered Conductor
RTV	- Room Temperature Vulcanizing
Si-R	- Silicon Rubber
UV	- Ultraviolet
HDPE	- High Density Poly Ethylene
MDPE	- Medium Density Poly Ethylene
RMU	- Ring Main Unit
GSS	- Grid Sub Station
PSS	- Primary Sub Station
F	- Feeder
LBS	- Load Break Switch
DDLO	- Drop Down Lift Off
FSD	- Fuse Switch Disconnecter
HRC	- High Rupturing Capacity
MCCB	- Miniature Current Circuit Breaker
CT	- Current Transformer
PT	- Potential Transformer

ACSR	- Aluminium Conductor Steel Reinforced
AAAC	- All Aluminium Alloy Conductor
SAIDI	- System Average Interruption Duration Index
SAIFI	- System Average Interruption Frequency Index
MAIFI	- Momentary Average Interruption Frequency Index
yr	- Year
hr	- Hour
int	- interruptions
Cust.	- Customer
FOB	- Free on Board
MTTR	- Mean Time to Repair
GUI	- Graphical User Interface
GDP	- Gross Domestic Product
SPP	- Simple Payback Period
IRR	- Internal Rate of Return
BCR	- Benefit to Cost Ratio
MLKR	- Million Sri Lankan Rupee

OBJECTIVE

“Specific objective of this research is to develop a methodology for economic evaluation of reliability improvement options for 33kV/11kV Distribution Networks.”

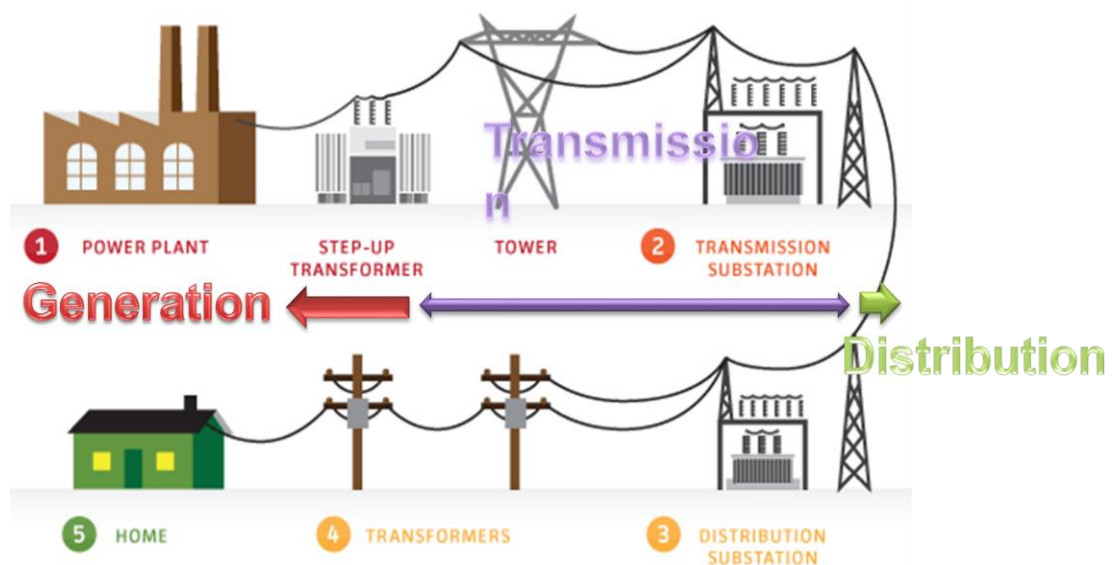
1 INTRODUCTION

Sri Lanka is one among the few countries that have reached 100% electrification level. In the present context, consumers always expect a highly reliable power supply. Hence, electricity is an essential commodity of people and therefore, utility has responsibility and prioritized targets to maintain the supply of the end user with high reliability level.

Supplying electricity supply to door step of customer has mainly three stages.

1. Generation
2. Transmission
3. Distribution

Figure 1: How Electricity transmits to end user from generation stage.



Therefore, reliability of electricity supply depends on the reliability of the above three stages. In the generation stage, it depends on Turbine, Fuel feeding system, Generator, Power transformer which is used to convert generation voltage to Transmission voltage (In Sri Lanka 132kV or 220kV), protection equipment etc. At transmission level, it depends on transmission line, Grid Sub Station components (Power transformers, protection equipment, Isolators, Breakers etc). Finally, at Distribution

level, the system reliability depends on Distribution line (33kV, 11kV & low voltage line), Primary substation (33kV/11kV power transformer, Isolators, Breakers, protection equipment etc), Distribution Transformers, switches (Load break switches, Drop down Lift Off (DDLO) fuses etc.

It is clearly seen and can be identified that ensuring the reliability of power supply from generation station to the door step of consumer is a challenging target to any utility. Therefore, utility should identify each stage of reliability level and have clear vision to achieve predefined well communicated SMART (Specified, Measurable, Achievable, Realistic, Time defined) target. There are multiple ways to achieve one target. Therefore, utility should not only look at this target and drive blindly any one of solution to achieve target. These solutions/proposals involve many technical & economic aspects.

In this research, improvement of reliability of the 33kV & 11kV Distribution Networks is targeted. Studying the reliability of 33kV/11kV medium voltage line and improvement of the reliability at the conductor and its insulation is mainly focused. Moreover, reducing no of short duration faults (impulses) have been focused. To achieve this, there are many solutions. Out of these many solutions, one is selected based on economic aspects.

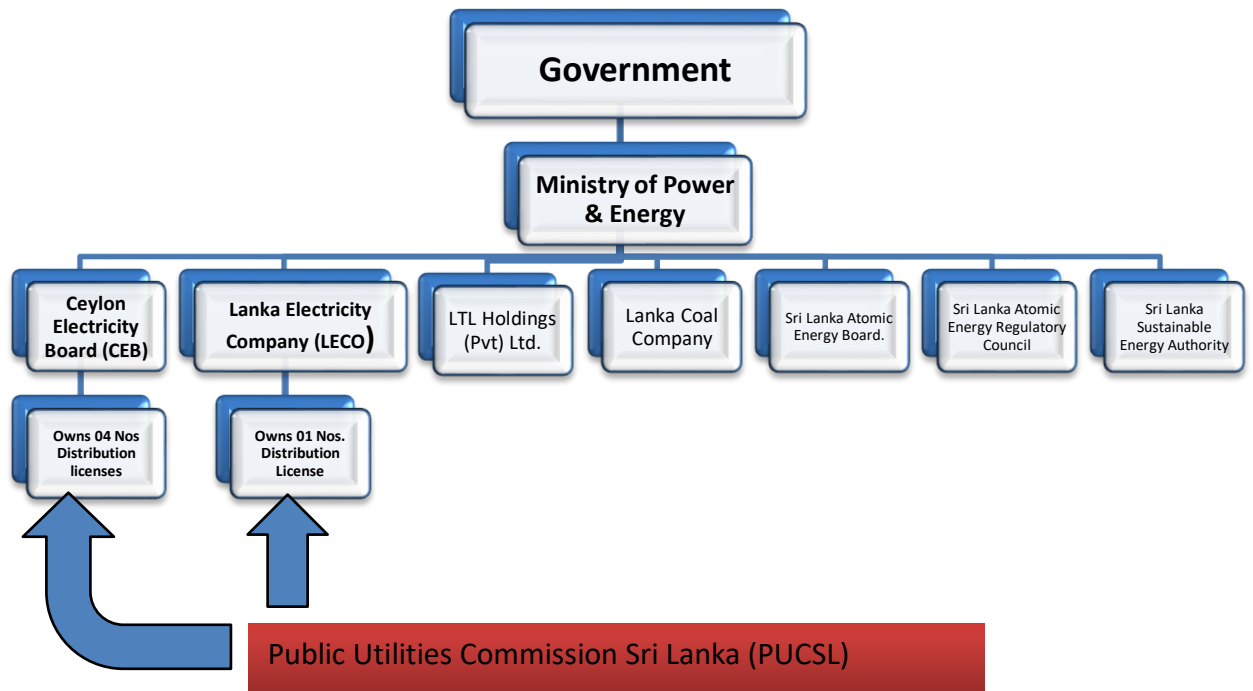
1.1 ELECTRICITY DISTRIBUTION IN SRI LANKA

33kV and 11kV are the voltages used in Medium voltage level and 400V/230V is the low voltage used for distributing electricity in Sri Lanka.

At present there are five (05) licensees issued for distributing electricity by Public Utilities Commission of Sri Lanka (PUCSL). PUCSL is the regulator of the electricity utilities in Sri Lanka. Distribution license holders are listed following.

1. Distribution Division -1 (Ceylon Electricity Board)
2. Distribution Division -2 (Ceylon Electricity Board)
3. Distribution Division -3 (Ceylon Electricity Board)
4. Distribution Division -4 (Ceylon Electricity Board)
5. Lanka Electricity Company (LECO)

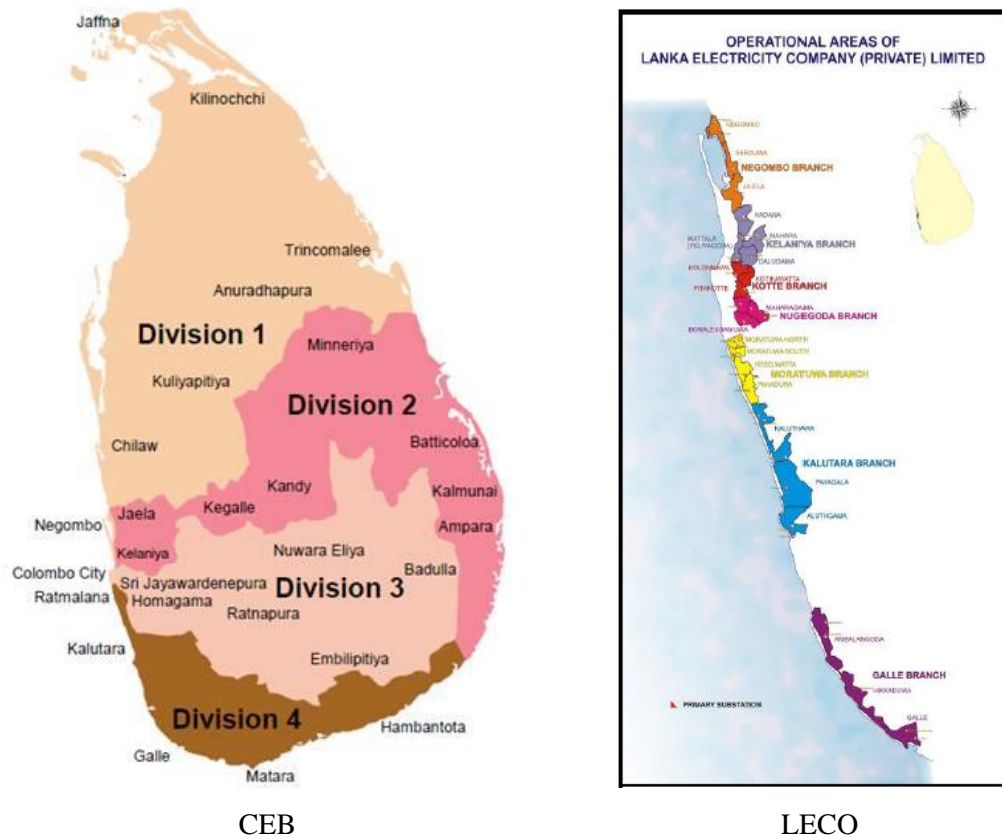
Figure 2: Structure of the Sri Lankan Power Sector & regulatory



These five licensees have dedicated & designated areas in Sri Lanka, to distribute electricity up to door step of the consumer. Ceylon Electricity Board (CEB) and Lanka Electricity Company (LECO) are two owners of these licensees.

End user receives the supply as 400V/230V, 33kV or 11kV supply as consumer requirement. Most of customers receive 400V/230V and a small number of customers (Demand is more than 1MVA) receive 33kV or 11kV supply.

Figure 3: Areas owned by Distribution Divisions of CEB & Areas owned by LECO.



1.1.1 Ceylon Electricity Board (CEB)

Ceylon Electricity Board is the one of the largest and important Government institute in Sri Lanka which has 20,512 employees, by November 2020.

CEB has total six (06) of licenses from PUCSL and out of them, four (04) are distribution licenses. Other two (02) are for Generation & Transmission. CEB owns 2953 MW (70%) out of the 4217 MW of installed capacity of generation. It consists of Hydro, Thermal (Oil & Coal) and Other Renewable Energy (ORE).

Major statistics are shown in Table 1.

Table 1: Statistical information of CEB [12]

Description	Value
No of employees	20,512 Nos.
CEB own installed capacity	2953 MW
Total installed capacity (with IPP)	4217 MW
Maximum demand	2669 MW
Total Transmission line length	3090 km
Total GSS	75 Nos
Total 33kV/11kV line length	34,994 km
Total LV line length	150,169 km
No of Consumer Service Centers	231 Nos
Total consumers	6,500,641 Nos.
No of consumers per employee	317 Nos.
Total Gross energy sold	14,611 GWh
Transmission & Distribution losses (On net generation)	8.23 %

Distribution licensees of CEB purchase power at 33kV from transmission licensee and operate their system with 33kV and 11kV voltage levels as medium voltage distribution and 400/230V for low voltage distribution. Three phase 3-wire (Delta Configuration) is used for 33kV and 11kV distribution system and Three phase 4-wire system (Star Configuration) is used for low voltage distribution network.

CEB is serving 92% of consumers in Sri Lanka and has 6.5 million consumer accounts. These consumers are categorized to seven (07) sub groups based on the tariff. Furthermore, CEB provides 11kV bulk supply to Lanka Electricity Company (LECO).

Table 2: Consumer accounts data of CEB [12]

Consumer Category	Consumer Accounts (Sales GWh)	% of accounts (% of sales)
Domestic	5,651,452 (4777 GWh)	87% (32.7%)
General purpose	739,122 (3089 GWh)	11% (21.1%)
Industrial	64,241 (4392 GWh)	1% (30.1%)
Religious	40,724 (87 GWh)	1% (0.6%)
Government	4574 (201 GWh)	0.1% (1.4%)
Hotel	470 (273 GWh)	0.007% (1.9%)
Agriculture	56 (0.05 GWh)	0.001%
LECO (Bulk supply as 11kV)	1 (1684 GWh)	- (11.5%)
Street Light	1 (108 GWh)	- (0.7%)
Total	6,500,641 (14611 GWh)	

These distribution networks consist of both overhead (OH) and underground (UG) systems. Bare overhead, Aerial Bundle Conductors (ABC), Covered Conductors are used for overhead distribution system. Out of them Covered conductor is only used for 33kV & 11kV networks.

Table 3: 33kV & 11kV line route owned by CEB [12]

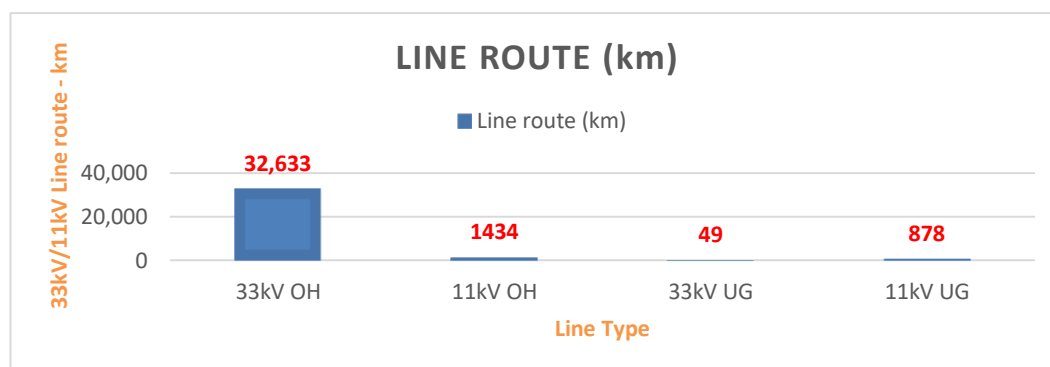
Distribution Division	33kV route (km)	11kV route (km)	Total route (km)	MV LV circuit route (km)
Division 1	11,070	1374	12,444	47,425
Division 2	9768	580	10,348	42,348
Division 3	7240	45	7285	32,189
Division 4	4604	313	4917	28,207
Total	32,682	2312	34,994	150,169

Underground networks are used for both Medium voltage (33kV/11kV) and Low voltage distribution systems in CEB. Out of total MV line route of 34,994km, 97% is overhead. Out of Overhead MV lines, approximately 99.9% is Bare Overhead conductors and the balance is Aerial Bundle conductors and Covered conductors.

Table 4: OH & UG line route in CEB MV distribution network [12]

Description	Line route (km)	Subtotal (km)
33kV OH	32,633	34,067
11kV OH	1434	
33kV UG	49	927
11kV UG	878	
Total	34,994	34,994

Figure 4 : Line route 33kV & 11kV network. [12]



1.1.2 Lanka Electricity Company (LECO)

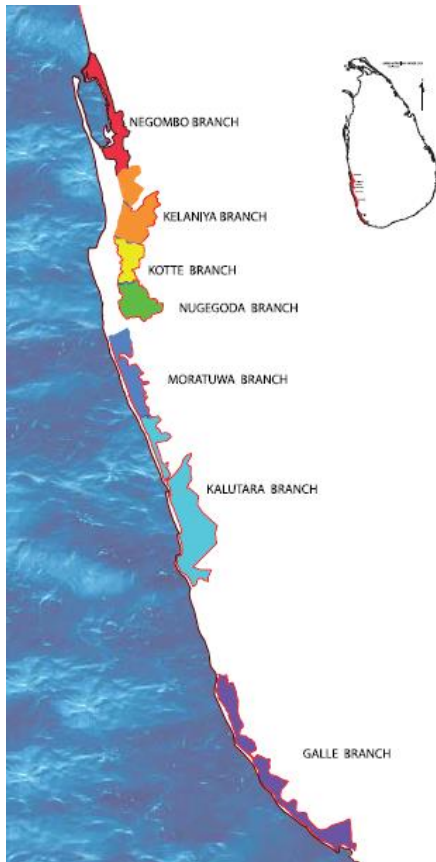
LECO was established in 1984 by taking over Kotte area for distribution network with 12,000 customers. LECO is the only distribution licensee owner other than CEB. LECO is distributing electricity using 11kV as Medium voltage and 400/230V as Low voltage through Southern – Western coastal belt such as Moratuwa, Panadura, Negombo, Galle etc. and urban areas such as Nugegoda, Maharagama, Kotte, Rajagiriya, Kelaniya etc.

LECO purchase 11kV bulk supply through Primary Sub Station (PSS) owned by CEB and distribute in their authorized areas. As per statistical digest 2019, LECO has sold a total of 1629 GWh electricity energy among 588,879 consumers (8% of total consumer accounts).

Table 5: Statistical information of LECO [13]

Description	Value
No of total Consumers	588,879 Nos
Total 11kV line length	1011 km
Total LV line length	3812 km
Total energy sale (2019)	1629 MWh
Total Consumer Service Centers	23 Nos.
No of consumers per employee	381 Nos.
Total network loss	3.98 %

Figure 5 : Distribution Area of LECO [13]



Distribution network of LECO also consists of both overhead & underground network.

1.1.3 Features of Distribution Network

Distribution network mainly consist of following components.

1. 33kV/11kV medium voltage line
2. Low voltage (LV) line
3. Protection equipment
4. Distribution Transformers (MV to LV).
5. Metering equipment.

Medium voltage line consists of conductor, insulation medium, medium to lay conductor/cable and supporting equipment for laying conductor/cable.

As an example, bare overhead line consists of the following,

- Conductor – *Raccoon/Lynx conductor*
- Insulation – *Insulators & Air*
- Medium of laying – *Air*
- Supporting equipment – *Concrete pole, insulator, stay, strut etc.*

Insulator of Bare Overhead Line has the dual function where Insulation & providing mechanical support with pole.

Low voltage configuration is the same as medium voltage elements. As an example, low voltage 5 core Aerial Bundle Conductor line consists of the following.

- Conductor – *All Aluminum Conductor (AAC)*
- Insulation – *XLPE (Cross Link Poly Ethylene)*
- Medium of laying – *Air*
- Supporting equipment – *Concrete pole, Wedge type Clamp, stay, strut etc.*

Load break switches, Auto Reclosers, DDLO, Surge arrestors are commonly used in medium voltage lines as protection equipment and for the LV lines distribution, fuses and breakers are used as protection equipment.

Three phase 33 kV or 11kV/ 415V Dy11 hermetically sealed type with the capacities of 100 kVA, 160 kVA, 250 kVA, 400 kVA, 630 kVA, 800kVA & 1000kVA distribution transformers are used. Following protections are used by utilities for Distribution transformers.

- Over current protection of MV side – *DDLO*
- Surge protection of MV side – *Surge Arrestor*
- Over current protection of LV side – *Fuse Switch Disconnecter (FSD)/MCCB*

Utilities use metering equipment in both Medium and Low Voltage levels. CT/PT combined units are commonly used in medium voltage lines, especially at boundaries between Divisions, Provinces, Areas and Consumer Service Centers (CSC) etc. Energy meters installed in distribution substations and consumer end energy meters are the two types used in distribution network to measure the energy.

1.2 POWER SYSTEM RELIABILITY

There are main six (06) desirable aspects that can be identified with a power system.

1. Reliability
2. Accessibility
3. Availability
4. Quality
5. Affordability

Reliability is the probability for the system to be still functioning at any given time or that the system would not fail during any given interval. Power system reliability covers the percentage duration in which adequate supply is available to meet the demand or quality of constancy of service (failure frequency) or percentage duration one can depend on the system to supply an incremental demand.

Quantification of the reliability is very important, to study the system issues. Reliability is the key factor that the utility has to track the performance of the system. Moreover, from consumer side, it is a very crucial factor for an investor to decide the location for the investment and domestic consumers to decide the location of the residence. Regulator of the power system is using reliability values to penalize or reward the utilities, in Sri Lanka; this has started with the implementation of Distribution Performance Standards Regulations (2016).

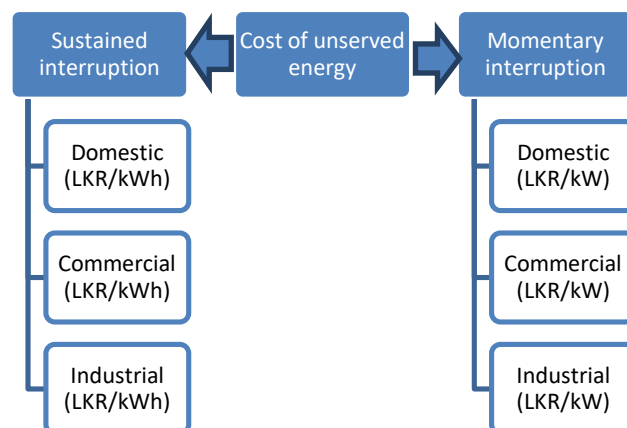
Evaluation of the reliability depends on main three (03) aspects.

1. Outage frequency
2. Outage duration
3. Cost of outage

For evaluation of outage frequency, System Average Interruption Frequency Index (SAIFI), Momentary Average Interruption Frequency Index (MAIFI), Customers Experiencing Multiple Interruptions (CEMI) and Average System Interruption Frequency Index (ASIFI) etc. are used. MAIFI is the index which is used to evaluate the momentary interruption frequency which occurs because of the operation of Auto Reclosers. Simply said, short duration faults such as due to touching of tree branches etc.

System Average Interruption Duration Index (SAIDI), Customer Average Interruption Duration Index (CAIDI), Average System Interruption Duration Index (ASIDI) etc. are used for evaluating outage duration. System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI) & Momentary Average Interruption Frequency Index (MAIFI) are commonly used reliability indices. Cost of unserved energy is the measurement used to evaluate the cost of outage. Unreliable supply causes to increase the investment on standby generation by consumers (indirectly increase the fixed asset cost and production cost), reduce the productivity, product wastage etc. Hence, cost of outage includes these costs. This value is changed based on the type of interruption (sustained or momentary) and nature of the consumer. Cost of unserved energy is typically categorized as follow.

Figure 6: Classification of Cost of Unserved Energy.



Cost of unserved energy is very important parameter to evaluate the reliability improvement proposals of the utility. Hence, up to date figures for above categories are very vital for an accurate decision. In addition, it shows the importance of the reliable supply.

Supply of reliable electricity supply to consumer has broad scope and reliability in distribution system is a subset of overall power system reliability. As discussed previously, reliability of each element in a distribution network is a subset of overall distribution system reliability. Distribution utilities (Distribution licensees) have prioritized responsibility to monitor each component reliability indices and take necessary action to improve the reliability.

As an example, low voltage bare conductors are being replaced by low voltage Aerial Bundle Conductors by CEB, because of the reliability and safety improvement of the LV network.

1.3 CLASSIFICATION OF INTERRUPTIONS.

Interruption is defined as an event where supply voltage is drop down to less than 0.1 pu. If the voltage is within 0.1 pu to 0.9 pu is called as voltage sag (dip) and if the voltage greater than 1.1pu is called as voltage swell.

The time frame of the interruption duration is used to define the interruption. Following are the three categories.

- *Instantaneous* – less than 0.6 s
- *Momentary* - between 0.6s to 3s
- *Temporary* - 3s to 1min

In a distribution system, most of the time, entries of the interruption are recorded manually and it is very difficult to segregate the duration below 1min. Hence, more than 1-minute interruptions are considered as sustain interruption and less than 1 min interruptions are considered as momentary interruptions.

2 PROJECT OVERVIEW

2.1 PROBLEM STATEMENT

In present context, electricity is an essential commodity for human beings. Besides, majority of the functions related to country's security, health sector, production and all others run on the platform of reliable electricity supply. Hence, highly reliable power supply to the nation is a non-debatable responsibility of utility. Therefore, utility should take every possible attempt to enhance the system reliability. When, they take these actions, there is an economic aspect that needs to be considered. However, when considered at distribution level, there is a low level of concentration for economic aspects and much more concentration about the technical aspects.

Among the proposals for improving the reliability in distribution sector, proposals related to MV network (33kV and 11kV) are more important since, it is exposed to more natural environment and artificial conditions made by human intervention. Furthermore, investment on distribution medium voltage network is high when compared with other investments in distribution level. Therefore, utilities should pay more attention on the proposals in this subject.

Furthermore, life time costs such as maintenance cost is normally not considered when taking such a decision to select a proposal.

Therefore, a method is needed to be developed to identify the proposals to achieve reliability targets which give cost-effective solutions.

2.2 OBJECTIVE

Specific objective of this research is to develop a methodology for economic evaluation of reliability improvement options for 33kV/11kV Distribution Networks.

2.3 METHODOLOGY

1. *Identify the present condition/reliability level of the distribution network in CEB.*
2. *Categorize the feeder types.*
3. *Literature review.*
4. *Identify possible options to improve conductor and insulation.*
5. *Collect failure data of the above options and calculate the improvement in each option by comparing Medium Voltage Bare Overhead (MVBOH) lines.*
6. *Collect relevant data and calculate cost of investment and maintenance etc.*
7. *Formulate calculation to find out reliability indices and economic figures.*
8. *Prepare a software tool (GUI) to calculate the reliability indices and economic results with cost figures of proposed combination of proposals.*
9. *Develop a method to segregate the proper solution based on economic aspects.*
10. *Case study of three (03) different feeders in Western Province South 1 – CEB to validate the proposed methodology.*
 - a. *Collect feeder tripping data in each feeder type.*
 - b. *Calculate present reliability indices (SAIFI, SAIDI & MAIFI)*
 - c. *Collect data of consumers attached to each feeder.*
 - d. *Calculate cost of unserved energy for each selected feeder by considering the found load data.*
 - i. *Sustained interruption (Cost per minute)*
 - ii. *Momentary interruption (Cost per interruption).*
 - e. *Select the proper suitable options based on the feeder type, by segregating according to type of feeder as mentioned above.*
 - f. *Obtain result using developed GUI tool.*
 - g. *Using trial & error method, find the proper combination of option which achieve the all reliability targets with optimal economic result.*

3 LITERATURE REVIEW

Proper literature review is very important for identifying the specified scope of the research, collecting previous and ongoing findings related to the research. This is very critical to avoid repeat work.

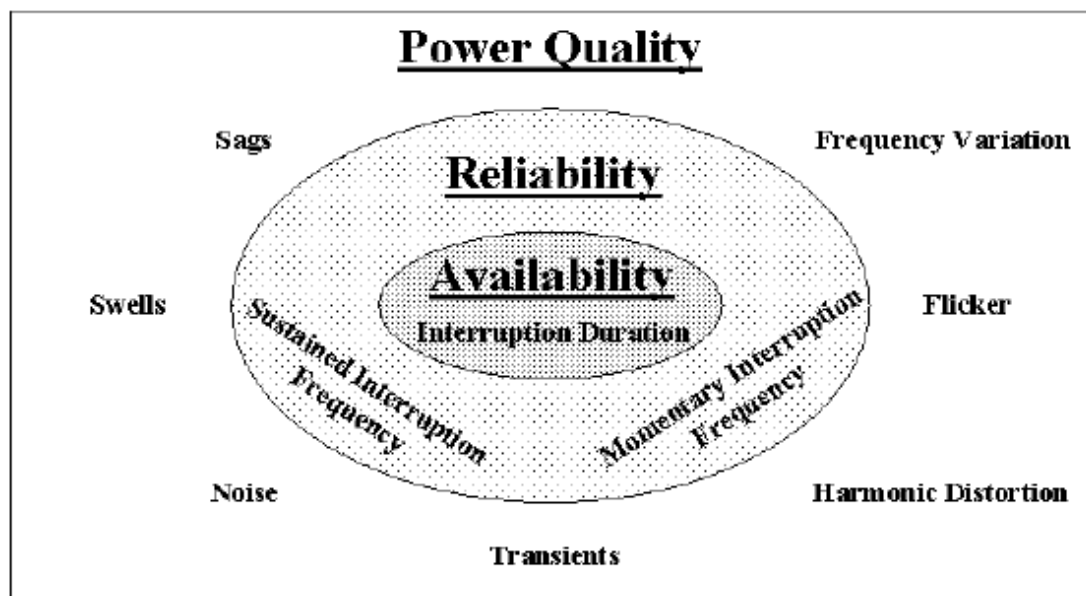
Accordingly, following areas were reviewed.

1. Reliability indices of distribution networks.
2. Methods that can be used to improve the reliability of distribution network.
3. Impact of high reliability of the distribution network.

3.1 RICHARD E. BROWN, “ELECTRICAL POWER DISTRIBUTION RELIABILITY”, 13: 978-0-8493-7567-5.

This reference is used to identify what is an interruption, types of interruptions and how those are measured. According to the reference, well defined measurable units are needed to analyze the distribution network.

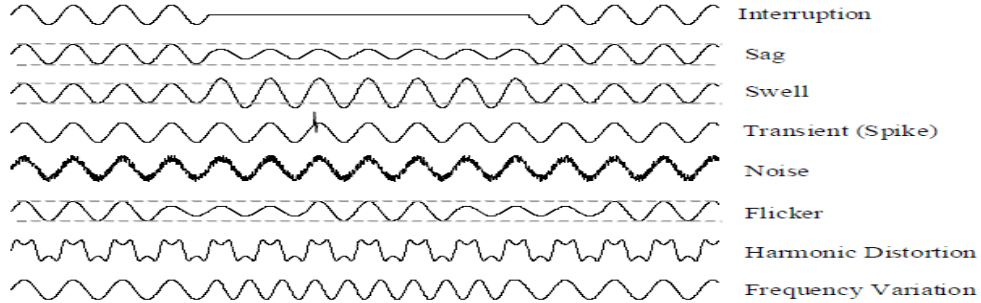
Figure 7 : Illustration of power quality and reliability



Power quality of the distribution system refers to the amplitude & frequency of the waveform. Distortion, variation in amplitude or change of the frequency is considered

as power quality issue and if these issues are beyond the defined limit it is considered as a reliability issue. Therefore, reliability is a sub set of the power quality.

Figure 8: Different type of power quality issues



Noise, Flicker, Harmonic distortion & frequency distortion are categorized as power quality issues. An interruption is a loss of voltage (to less than 0.1 pu) to customer more than 1 minute. This is also called as a sustained interruption (Non-momentary interruption). If the time is less than 1 minute it is referred as momentary interruption.

Quantification of the reliability has been done by using reliability indices. Customer based reliability indices are more popular. All customers are treated as same weight.

3.1.1 Reliability Indices for Sustained interruption

$$SAIFI = \frac{\sum \text{Total Number of Customer Interruptions}}{\text{Total Number of Customers Served}} \quad [\text{Interruption/year/consumer}]$$

$$SAIDI = \frac{\sum \text{Total Duration of Customer Interruptions}}{\text{Total Number of Customers Served}} \quad [\text{Hr/year/consumer}]$$

3.1.2 Reliability Indices for momentary interruption

$$MAIFI = \frac{\sum \text{Total Number of Customer Momentary Interruptions}}{\text{Total Number of Customers Served}}$$

[Momentary interruption/year/consumer]

Most of utilities are using SAIFI, SAIDI & MAIFI for quantifying the system reliability and set target to achieve the desired reliability levels. Improvement of SAIFI helps to improve the SAIDI level. However, SAIFI improvement might cause

an increase of MAIFI. As an example, adjustment of the traditional Auto Recloser settings may lead to improve the MAIFI value but, same attempt is caused to increase the SAIFI & SAIDI. Therefore, decision of investment related with reliability improvement based on SAIDI values may have a detrimental effect on MAIFI.

3.1.3 Mean Time to Repair (MTTR)

This is the average time that takes to restore the network. Mean time to repair depends on the type of the reason for the breakdown and skill of the allocated technical staff for repair.

3.2 D. PUNSARA COLAMBAGE, H.Y. R. PERERA," ASSESSMENT OF COST OF UNSERVED ENERGY FOR SRI LANKA", DEPT.ELECT. ENGINEERING, UNIVERSITY OF MORATUWA, MORATUWA.

Cost of unserved energy is an economic parameter, which measures the willingness of electricity customers to pay, to avoid period of time without power or willingness of consumer to accept compensation for period of time without power. This figure is very useful for investors to evaluate the proposals related with development in electricity network (Distribution, Transmission & Generation).

Consumer surveys have been used for evaluating the figure and it is considered as most common and preferred method to assess the cost of unserved energy.

This paper presents the cost of unserved energy for each domestic, commercial & industrial category. Furthermore, it has discussed about each category under cost for momentary & non-momentary interruption.

3.2.1 Cost of unserved energy for non-momentary interruption

Contribution to GDP by Domestic (3%), Commercial (20.96%) & Industrial (18.02%) sectors have been obtained based on Annual report of Central Bank – 2015. These values have been used as weight ages for the calculation.

Cost of unserved energy for non-momentary interruption of each category are given as both planned, unplanned interruption and merge it in to a one value based on the probability of occurrence.

Moreover, computation has been done under both financial and economic figures. Conversion factor of 0.76 is used to convert from financial to economic loss as per the calculation done by Ministry of Finance and Planning of Sri Lanka in early 1990s. (This figure has not been revised up to now).

Table 6 : Probabilities of occurrence non-momentary interruption categories.

Description	Probability						
	0.25hr	0.75hr	1.5hr	3hr	6hr	16hr	Total
Planned interruption	0.547	0.104	0.037	0.026	0.011	0.015	0.26
Unplanned interruption	0.151	0.005	0.008	0.014	0.050	0.032	0.74
Total	0.698	0.109	0.045	0.040	0.061	0.047	1.00

Table 7 : Combined cost of unserved energy for different categories.

Category	Financial Cost in LKR/kWh <i>(Economical Cost in LKR/kWh)</i>		
	Planned	Unplanned	Combined
Domestic	232.39 (176.61)	232.39 (176.61)	232.39 (176.61)
Commercial	453.49 (344.65)	418.19 (317.82)	427.37 (324.80)
Industrial	191.93 (145.87)	315.88 (240.07)	257.43 (195.65)

3.2.2 Cost of unserved energy for momentary interruption

Cost of unserved energy for momentary interruption has been calculated as LKR/kW, because of all losses happen during a very small time period and LKR/kWh does not interpret the exact picture. Same conversion factor (0.76) has been used to convert financial cost to economic cost.

Table 8 : Combined cost of unserved energy for non-momentary interruptions.

Sector	Financial cost in LKR/kW (Economic Cost in LKR/kW)
Domestic	0.00 (0.00)
Commercial	191.46 (145.51)
Industrial	78.62 (59.75)

3.3 D. M. A. K DISSANAYAKE, "TECHNO ECONOMIC ANALYSIS ON THE USE OF FULLY INSULATED CABLE FOR 33KV OVERHEAD POWER DISTRIBUTION SYSTEM IN SRI LANKA", MSC RESEARCH REPORT, UNIVERSITY OF MORATUWA, MORATUWA, 2017.

This research is based on techno economic analysis on the use of Medium Voltage fully insulated Aerial Bundle Conductor (MVABC). This discusses about the advantages and disadvantages of using MVABC.

There are main 03 issues that have been identified.

1. Stress crack on the outer sheath of the cable
2. Damaged copper screen
3. Burnt outer sheath

Stress cracks are developed due to the outer sheath material which is constructed from High Density Polyethylene (HDPE) that is less ductile, poor weathering resistance, low strength, stiffness. Hence, it will result in ingress water to core and premature failure. Therefore, two-layer design was introduced with PVC over Medium Density Polyethylene (MDPE). Effect from damage of the copper screen is reduced by introducing 15% overlapped two layer of copper tape. This also helps to improve the fault current carrying capacity and enhance the cable life time.

Because a damaged copper tape can lead to generate excess heat on insulation and outer sheath of the cable, this unpredictable heat can lead to burn the outer sheath.

Figure 9 : Crack built on outer HDPE Outer Sheath of MVABC

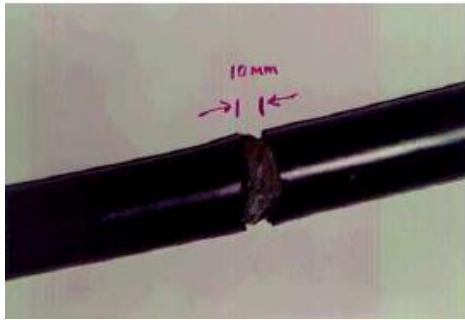


Figure 10 : Copper screen damage of MVABC



Figure 11 : Outer sheath damage of MVABC



Proper lightning protection mechanisms, Limitation of the circulating current by earthing of copper tape (metallic screen) at proper spacing are very important to follow when using MVABC.

Capital cost (investment) for MVBOH, MVABC & MVUGC have been calculated in this research and Summary of it is tabulated as following.

Table 9: Summary of Capital Cost Values

Description	MVBOH	MVABC	MVUGC
Cost in LKR/km (As per 2017 prices)	2,210,840 .00	6,796,594	54,904,012
Comparison with MVBOH	1	3.01	24.8

3.4 ROBERT BATTLE, RAJESH KHANNA, BLAISE BEAUGER," AERIAL MV COVERED NETWORKS: WORTH A NEW LOOK?" IN 25TH INTERNATIONAL CONFERENCE ON ELECTRICITY DISTRIBUTION MADRID, 3-6 JUNE 2019, 2016, PAPER NO 2316.

This paper discusses about the modified Medium Voltage Covered Conductor (MVCC). Developed MVCC has been constructed to eliminate the drawbacks, which had been identified in previous construction of cable.

- Electrical stress around unscreened conductors
- Corrosion related to water ingress
- Over voltage focal point.
- Cover materials and behavior with temperature
- Hotspots due to poor connections

Wrong construction of the MVCC causes cracking and eventual pin holing of the cables heating. Similarly, metallic parts close to energized MVCC lead for these results, because of such metallic parts seen as a “Floating earth”. Hence, there is a continuous voltage drop across cable which causes to end with cracking or pin holing of the cable sheath since, the insulation of the cable is not design for continuous voltage drop.

Figure 12: Excess voltage through insulation of MVCC

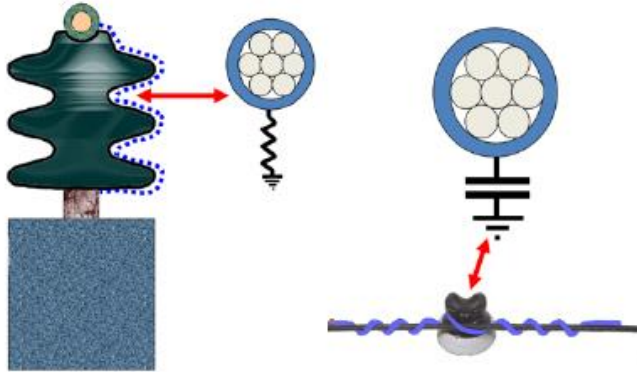


Figure 13: Pin holing of cable insulation from the use of “floating potential” metallic pre-form tie.



Figure 14: Cable insulation damage from use of metallic dead-end clamp.

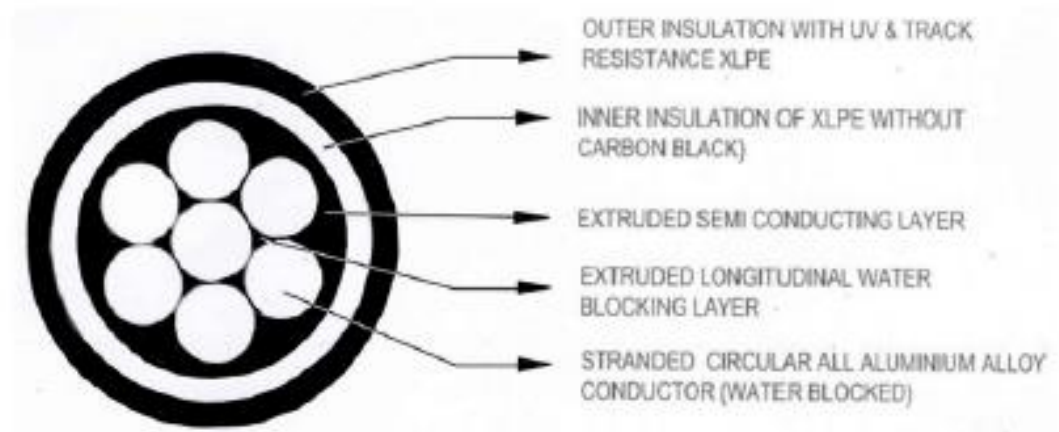


Therefore, the following common practices should be taken.

1. Do not use any metallic parts near MVCC.
2. Do not remove insulation.
3. Use sufficient over voltage protection.

New design has been introduced by adding extruded water blocking layer, Extruded semi-conducting layer & outer layer with UV & track resistance XLPE etc.

Figure 15: Cable construction of improved MVCC



Besides, cable supports have been modified by introducing new design of insulation piercing connectors, wedge type clamp for dead ends, UV stabilized cable tie etc.

Furthermore, sufficient surge protection has been added such as arc horn, surge diverters etc.

Change of the construction of the MVCC and the modification of used accessories, has been able to minimize most of drawbacks earlier occurred.

3.5 BRITISH STANDARD, “COVERED CONDUCTORS FOR OVERHEAD LINES AND THE RELATED ACCESSORIES FOR RATED VOLTAGES ABOVE 1 KV A.C. AND NOT EXCEEDING 36 K A.C.”, BS EN 50397-1:2006, 2006.

As per the standard “Covered conductors consist of a conductor surrounded by a covering made of insulating material as protection against accidental contacts with other covered conductors and with grounded parts such as tree branches, etc. In comparison with insulated conductors, this cover has reduced insulation properties, but it can be able to withstand the phase-to-earth faults by minimizing fault current.

Because of unavailability of the metallic screen, it is recommended to avoid touching the cable. Covered conductors are designed as per following definition of code.

Type code CC	- <i>Covered Conductor</i>
Covering material S	- <i>Semi-conductive conductor screen, if any</i>
X	- <i>Cross-linked polyethylene</i>
T	- <i>Thermoplastic polyethylene</i>
Conductor material and cross-section	- <i>According to EN 50182</i>
Conductor design W	- <i>Water tight.</i>
K	- <i>Compacted.</i>
Rated voltage U in kV	- <i>...kV.</i>

As an Example, “CCX 95-AL3 WK 36kV” is a XLPE-covered conductor with a rated voltage of 36 kV, longitudinal watertight compacted conductor of aluminum alloy AL3 and a nominal conductor cross-section of 95 mm².

Aluminum Conductor Steel Reinforce (ACSR) 50 mm² to 150 mm² or All Aluminum Alloy Conductors (AAAC) 35mm²to 240mm² can be used as conductor material.

Filling is added should be XLPE and thickness is decided as per the following formula.

$$S = 0.11 U$$

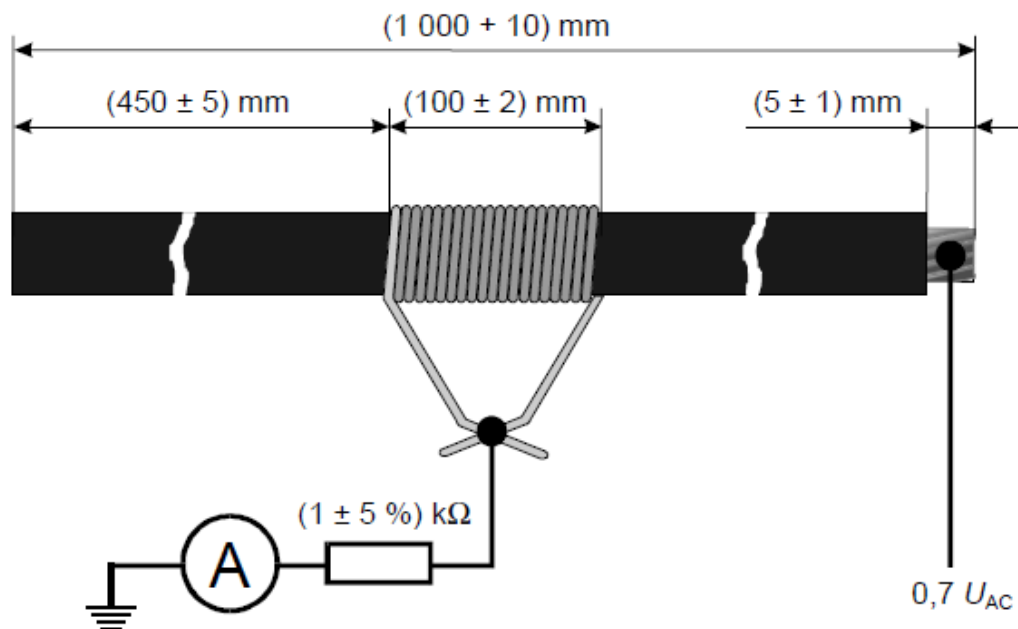
Where,

- S is the nominal thickness of the covering in mm (rounded to one decimal place);
- U is the rated voltage in kV

The nominal thickness of the covering shall be not less than 2.3 mm.

There is an important type test that has been listed in this standard. It is a test of leakage current. Maximum allowable value along 100mm length, through 1 kOhm resistance should be 1mA.

Figure 16 : Test setup of leakage current measurement of MVCC



3.6 SHUAIB MOHAMED BRAINI, "COATINGS FOR OUTDOOR HIGH VOLTAGE INSULATORS", PHD RESEARCH REPORT, CARDIFF UNIVERSITY, CARDIFF, 2013.

This reference is look at the method that can be used to improve the insulation in bare overhead lines. Insulators are the insulation medium of Bare overhead lines with structure which attached. Insulators are used for two (02) purposes.

1. Support with structure (Pole or tower)
2. Electrical isolation

Supporting capability is decided based on the force acting on the insulator, due to conductor weight, wind force on conductor etc. In addition, electrical isolation level depends on pollution & wetting level of the environment and need to maintain sufficient leakage length.

Porcelain and Glass are commonly used. However, both of these options don't have durable hydrophobic property on surface. Hence, polymer insulators (name as composite or Non-ceramic) are introduced.

Silicon rubber insulators are used to add the hydrophobic property to the insulation. High hydrophobic (Water repellent) property results in minimization of the surface leakage current & dry band formation on the surface. Polymer insulator has very weak bond with oxygen (chemical degradation) compared with porcelain.

Coating such as grease, Room Temperature Vulcanizing Silicon Rubber (RTV Si-R) and nano-coating are used for the purpose of adding the hydrophobic property to reduce the surface leakage current on insulators since silicone rubber insulators are not available to directly replace ceramic insulators. In this research, comparison has been done among uncoated insulator, coated insulator with silicon grease, RTV Si-R coating & nano-coating. Results were summarized as below.

Table 10: Summary of the features of different coating methods

	Suppressed leakage current	Reduce energy absorb	Flash over voltage compared with uncoated insulator	Hydrophobicity	Other
Grease coating	Yes	Yes	higher	-	-
RTV Si-R Coating	Yes	Yes	Higher (increases in flashover voltage of up to 30%)	Yes	1. High stability under UV exposure. 2. High resistance to tracking and erosion.
Nanocoating	Yes	Yes	Lower	Yes. But lost its when exposed to fog.	

3.7 ASHOK SUNDARAM, MARK MCGRANAGHAN, GEORGES SIMARD, "APPLICATIONS ASSESSMENT OF PULSE CLOSING TECHNOLOGY", ELECTRIC POWER RESEARCH INSTITUTE.

Pulse closing technology is the newest technology that is being used to replace the traditional Auto Reclosers. This paper is focused on elaborating the pulse closing technology and advantages of it.

Traditional Auto Reclosers identify the faults after allowing few attempts of reclosing (normally 3 or 4 times) full fault current to the system. Because of this, unwanted stress is applied on the system. This may cause reduction of life time of the equipment attached to system. Therefore, it is very important to minimize the unwanted number of tripping in the system.

Pulse closing technology use very low current to determine whether the fault remains in the system or not.

Figure 17: Current Vs Time of conventional Auto Recloser

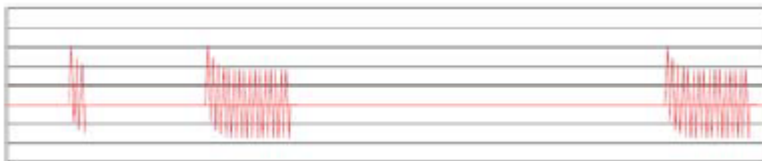


Figure 18 : Current Vs Time of Pulse Closing Technology



This technology is equipped with very short switching time, such that close and open contact before then first current zero crossing. Importance of this technology is that the closing point can be decided such that measure and analyze the fault by minimizing the let through energy low as possible. After voltage peak, interrupter is closed for creating an asymmetrical current within the first loop as a minor loop. Hence, only this minor loop of current is allowed to flow. Therefore, peak current is only limited to 3-8 ms, this minor loop of fault current is used to test the line.

Figure 19: Minor loop (Shaded in red) of fault current is allowed to flow.

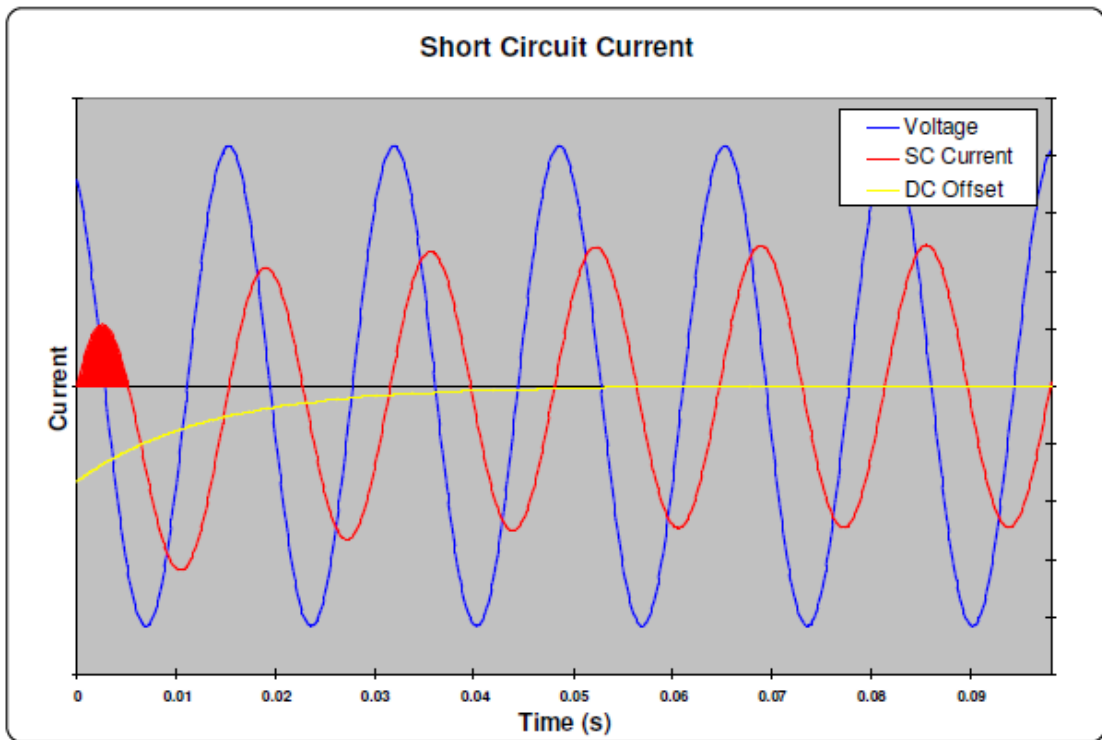
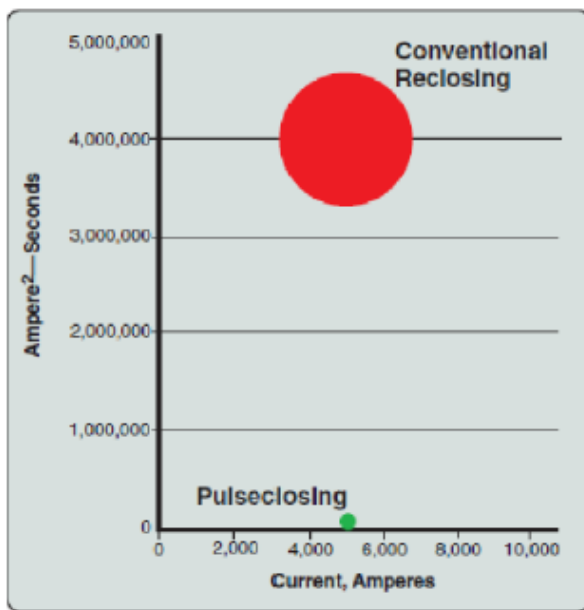


Figure 20: Relative let-through energy for a typical 5000 ampere fault.



3.8 MARTIN BISHOP, DONNA G. OIKARINEN, STEPHEN WILLIAMS, AND MIKE MEISINGER," FAULT DETECTION STRATEGY FOR DISTRIBUTION FEEDERS WITH OH AND UG MAIN LINE SECTIONS", S&CELECTRIC COMPANY, USA, FEBRUARY 4, 2019.

This paper discusses, the challenges that arise when there is hybrid network system consisting of bare overhead line and underground cable. To avoid unwanted stress on insulated cable such as UG and other distribution equipment, because of the transient faults of the bare overhead section, new protection system has been introduced. Pulse closing technology is ideal for above situation. It avoids the unwanted 2nd, 3rd & 4th electrical stresses, which are resultant due to allowing of full current to identify the fault by the traditional Auto Reclosers.

Comparison of reliability improvement has been done by adding Intellirupter Pulse Closers, which use pulse closing technology, to the hybrid network. Out of total line length of approximately 33.3 km, 12.7 km (38%) has been converted to the underground cable. Lateral parts of the networks are fed via cutout-mounted reclosing devices with enable of reclosing facility (Figure 21). After that, Intellirupter Pulse closers (03 Nos) have been introduced to a location which is upstream of the UG sections (Figure 22). Reliability indices MAIFI, SAIFI & SAIDI have been calculated. Summary is tabulated as follow.

Table 11: Summary of the result before and after adding pulse closing technology

No	Arrangement	SAIFI (int/yr/cust.)	SAIDI (min/yr/cust.)	MAIFI (int/yr/cust.)
01	OH & UG hybrid network with Added lateral devices at five locations with reclosing enabled.	7.63	13.85	18.84
02	OH & UG hybrid network with Added lateral devices at five locations with reclosing enabled & Main line device reclosing enabled using 3 <i>IntelliRupter</i> ® <i>fault interrupters</i> .	7.16	11.82	4.29 (77% <i>reduction</i>)

Figure 21: Initial set up before add pulse closing technology

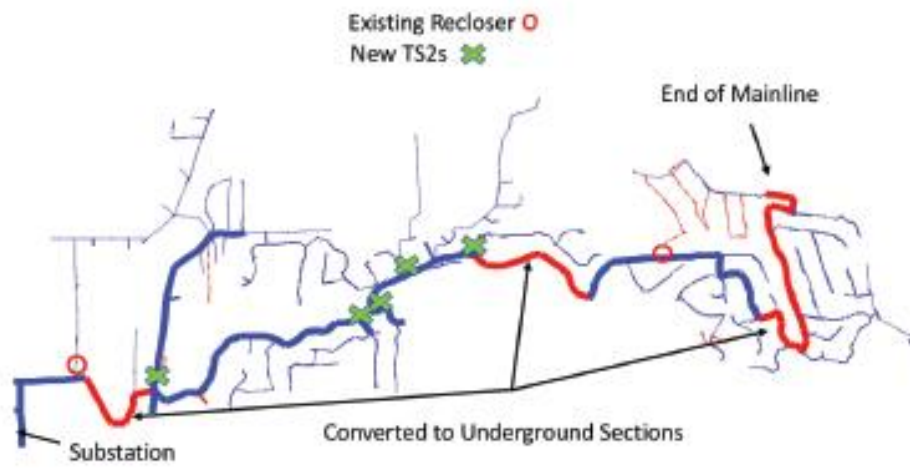
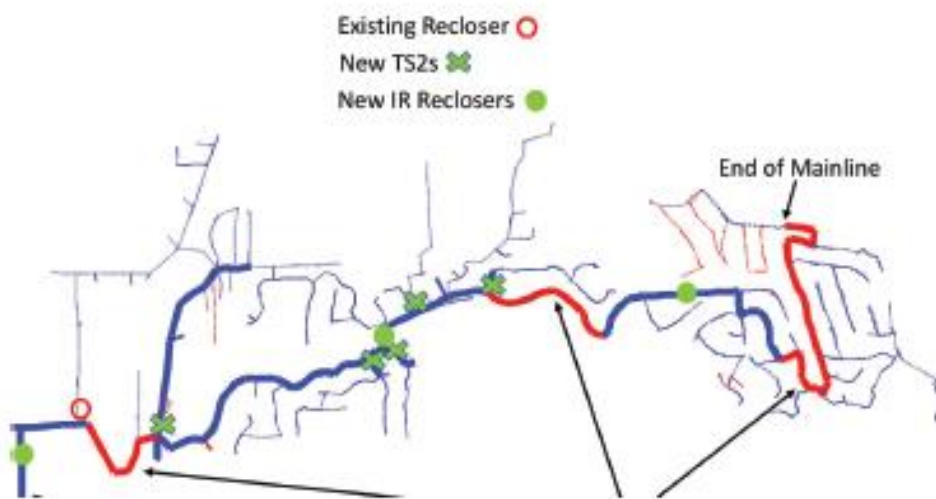


Figure 22: After adding pulse closing technology to the network



4 RELIABILITY IMPROVEMENT, MEAN TIME TO REPAIR & COST OF EACH OPTION PROPOSED TO BE USED FOR IMPROVING RELIABILITY IN DISTRIBUTION NETWORK

4.1 INTRODUCTION

This section elaborates the different options that can be considered for improvement of reliability of distribution network. Collecting actual data from real cases and calculations for failure rate improvement and costing of each option are included in this section.

As per the literature review, five options were studied to improve reliability of the conductor, insulation and protection.

- 1. Medium Voltage Underground Cable (MVUGC)*
- 2. Medium Voltage Aerial Bundle Conductor (MVABC)*
- 3. Medium Voltage Covered Conductor (MVCC)*
- 4. Room Temperature Vulcanizing (RTV) – SiR Coating to insulators*
- 5. IntelliRupter Pulse Closer.*

Among the above five (05) of options, first (03) three contribute to the improvement related with the conductor & insulation reliability.

Fourth option is a help to improve the insulation level of the conductor (MVBOH). Fifth option is introduced for improving the reliability of short duration earth faults (protection).

To obtain the comparative improvement percentage of each option, a comparison with the medium voltage bare overhead line, which is located in the same environment, was used. Failure rate per km per year of both of these has been used to calculate improvement percentage.

Mean time to repair of each option is calculated by considering one year of the studied period of failures and total down time.

Under cost calculation, capital cost was calculated per km and maintenance cost (Routine maintenance cost + Breakdown maintenance cost) was calculated per km per year.

4.2 MEDIUM VOLTAGE BARE OVERHEAD LINE (MVBOH)

Medium Voltage Overhead Lines are used commonly in Sri Lanka in distribution sector. Typically, in distribution sector following bare overhead conductors are being used.

Table 12: Details of MVBOH conductors

No	Name of BOH conductor	Size (No of strands/diameter of one strand)	Cross section	Current carrying capacity (A)
01	Raccoon (ACSR)	7/4.09 mm	92.0 mm ²	208 A
02	ELM (AAAC)	37/2.79mm	226.2 mm ²	405 A
03	LYNX (ACSR)	19/3.76mm	211.0 mm ²	335 A

According to the requirement of the site condition & current carrying capacity, above three types of conductors are used. When pole span is more than the standard span (50-60m), All-Aluminum Alloy Conductor (AAAC) is used, because it has low weight compare with LYNX (ACSR). For all other requirements, Aluminum Conductor Steel Reinforced (ACSR) conductors are used. According to the load of the connected, LYNX or Raccoon lines are selected.

4.2.1 Cost of Medium Voltage Bare Overhead Line (MVBOH)

Most of the distribution medium voltage lines are constructed with Raccoon conductor. Calculation for construction of new line and annual maintenance cost of bare overhead line was calculated based on Raccoon line. Annual maintenance cost was calculated based on routine maintenance such as line inspection (1 cycle per 2 years), way leaves clearance (2 cycles per year)& breakdown maintenance cost. Breakdown cost consists of abnormal breakdowns due to fallen of tree branches (33kV network -1 incident per 10 years), vehicle accidents (11kV network -1 incident

per 10 years) and flash over insulators (1 incident per 2 years for both 11kV & 33kV). Price List of CEB 2019[15] which used in 2020 is used for material cost. Furthermore, standard labour cost & transport cost used in CEB were used for calculation.

Cost for constructing 1km of 33kV Raccoon Line (Annex I)

- Material Cost = LKR 1,866,230.00
- Labor cost = LKR 546,490.00
- Transport cost = LKR 192,000.00
- Way leaves = LKR 100,000.00
- Total Cost = LKR 2,704,720.00**

Cost for constructing 1km of 11kV Raccoon Line (Annex II)

- Material Cost = LKR 1,683,620.00
- Labor cost = LKR 546,490.00
- Transport cost = LKR 192,000.00
- Way leaves = LKR 75,000.00
- Total Cost = LKR 2,497,110.00**

Maintenance Cost for 33kV Raccoon Line per year per km (Annex III)

- Routine maintenance Cost (A) = LKR 280,660.00
- Way leaves cost (B) = LKR 3480.00
- Breakdown maintenance cost (C) = LKR 25,960.00
- Total maintenance cost = $A/2 + B*2 + C$
= **LKR 173,250.00**

Maintenance Cost for 11kV Raccoon Line per year per km (Annex IV)

- Routine maintenance Cost (A) = LKR 119,300.00
- Way leaves cost (B) = LKR 3480.00
- Breakdown maintenance cost (C) = LKR 23,490.00
- Total maintenance cost = $A/2 + B*2 + C$
= **LKR 90,100.00**

4.3 MEDIUM VOLTAGE UNDER GROUND (MVUGC)

Out of the total distribution network, 2.7% (927 km) are underground cable [13]. At present, cross link poly ethylene (XLPE) insulated copper conductor cables are used. However, in early days, paper insulated, copper or aluminum cables were used.

In distribution systems, following cables sizes are commonly used.

Table 13: Current carrying capacity of MVUGC

No	Cable description	Current Carrying Capacity (A)
01	95sqmm/3C/XLPE/SWA cable	220 A
02	185sqmm/3C/XLPE/SWA cable	370 A
03	240sqmm/3C/XLPE/SWA cable	400 A

4.3.1 Cost of Medium Voltage Underground (MVUGC)

By considering the life time of the MVUG cable and, load growth, it was decided to select the 240sqmm size.

Annual maintenance cost was calculated based on routine maintenance such as service of RMU (Ring Main Units) & breakdown maintenance cost. Breakdown maintenance cost consists of abnormal breakdown cost due to faults of the UG cable (1 incident per 10 years). It is assumed and calculated that there are two (02) RMUs in 1km length of cable. Price List of CEB 2019 [15] which used in 2020 is used for material cost.

Cost for constructing 1km of 33kV 240mm²/Cu/XLPE/SWA Line (Annex V& VII)

- Material Cost = LKR 25,486,520.00
- Labor cost = LKR 3,678,630.00
- Transport cost = LKR 70,000.00
- Authority charges = LKR 5,787,170.00
- Total Cost = LKR 35,022,320.00**

Cost for constructing 1km of 11kV 240mm²/Cu/XLPE/SWA Line (Annex VI & VII)

- Material Cost = LKR 21,379,930.00
- Labor cost = LKR 3,678,630.00
- Transport cost = LKR 70,000.00
- Authority charges = LKR 5,787,170.00
- Total Cost = LKR 30,915,730.00**

Maintenance Cost of 33kV 240mm²/Cu/XLPE/SWA Line per year per km (Annex VIII)

- Routine maintenance Cost (A) = LKR 12,050.00 per RMU per year
- Breakdown maintenance cost (B) = LKR 696,060.00 per breakdown
- Total maintenance cost = A*2+ B/10
= **LKR 93,710.00**

Maintenance Cost of 11kV 240mm²/Cu/XLPE/SWA Line (Annex IX)

- Routine maintenance Cost (A) = LKR 12,050.00 per RMU per year
- Breakdown maintenance cost (B) = LKR 498,300.00 per breakdown
- Total maintenance cost = A*2+ B/10
= **LKR 73,930.00**

4.3.2 Improvement of failure rate of MVUGC compared with MVBOH

Comparison was done between MVUGC and MVBOH based on two feeders which are located in the same environment. Tripping data of following feeders have been collected and calculated independently. Improvement of failure rate was calculated as a percentage compared to MVBOH in the same environment.

Failure rate per km per year of MVBOH = FR_{BOH}

Failure rate per km per year of MVUGC = FR_{UGC}

Improvement % = (FR_{BOH}-FR_{UGC})/FR_{BOH} %

Dehiwala PSS Feeder 01 (MVUGC) and Dehiwala PSS Feeder 05 (MVBOH) were analyzed to calculate the failure rate improvement percentage. Detail of the calculation is in *Annex X* and summary is in Table 14.

Table 14: Comparison data of MVBOH & MVUGC

Construction	MVUGC	MVBOH
Feeder Name	Dehiwala PSS Feeder 01	Dehiwala PSS Feeder 05
Length	3.2km	2.9km
Line route	Dehiwala Galle road	Dehiwala Galle Road
Failures per year	03 Nos	14 Nos
Failure per year per km	0.94 Nos/year/km	4.83 Nos/year/km
Improvement	3.89 Nos/year/km	
Improvement %	$3.89/4.83 * 100 = 80.5 \% \sim \underline{\underline{81\%}}$	

By using medium voltage Underground Cable, failure rate can be improved by 81% compared with MVBOH.

4.3.3 Mean time to repair

Medium voltage failure report of Colombo city province of CEB was analyzed. Total no of failures and total down time during the period of November 2018 to October 2019 was used for calculations. (*Annex XI*)

- Total down time = 209,776 min
- Total failure = 632 Nos
- Mean time to repair = 209,776 min/632 Nos
- = 332 min per interruption

4.4 MEDIUM VOLTAGE AERIAL BUNDLE CONDUCTOR (MVABC)

Medium Voltage Aerial Bundle Conductor is generally called as MVABC. Appearance of it is same as low voltage ABC, but cable construction is totally different. Furthermore, the cable is suspended to the pole using suspension bracket or wedge type clamp (at tension point) using a separate messenger wire. But in LV ABC, neutral is used as messenger.

Simply, MVABC construction follows the MVUGC and the difference between MVABC & MVUGC is that each of the three phases of MVABC has been bundled together after the outer sheath of each core.

MVABC is the one and only option that can be laid overhead which is safe to touch. This is the option that CEB seeks when there are proximity issues due to a building. However, unexpected weight of the cable causes to maintain a low span between poles (around 35m – 40m). It is very inconvenient to erect the pole in a short span in highly congested areas. In addition, loosening of the cores from bundle, because of this weight, lead to an issue with visual pollution, especially in urban areas. Another drawback of the MVABC is rectifying a cable damage in middle of the span involves a high cost and long time to repair because of the comparably high cost of cable joints and because an additional support tray with new pole is needed to be installed. If it is not possible to erect a pole there, the relevant full span needs to be laid which involves two cable joints.

Advantages

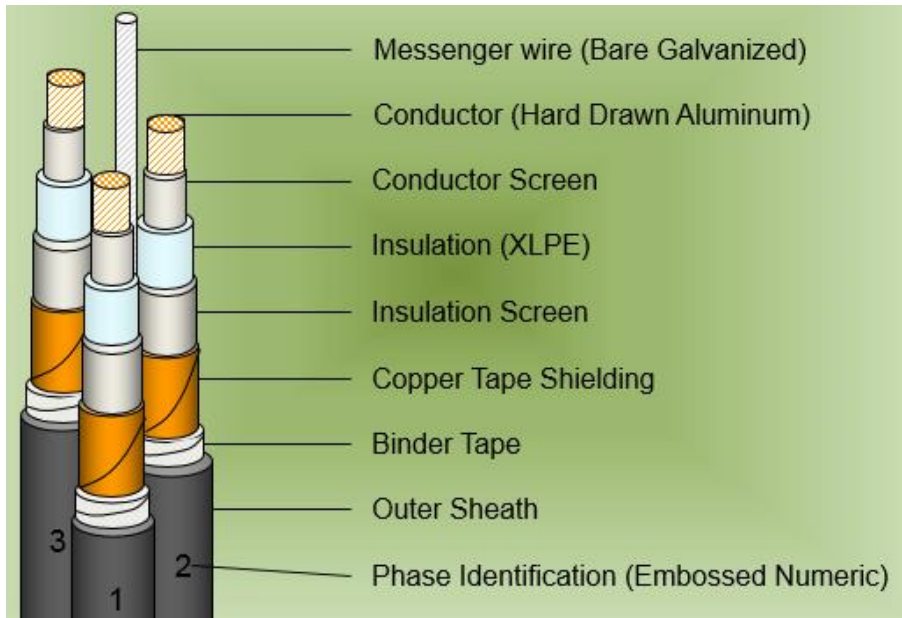
1. Safe to touch
2. No need of lighting protection (Lighting surges are arrested at interconnection with MVBOH).

Disadvantages

1. Loosening of cores from bundle causes visual pollution.
2. Mean Time to Repair is high.

3. Maintaining short spans between poles is very difficult.
4. Skilled labor is required for stringing and cable joints.
5. Cost of construction and breakdown maintenance is high.

Figure 23 : Construction of MVABC



At present, there are two sizes of MVABC cables that are being used in CEB. Both are constructed with Aluminum conductor and XLPE insulation.

Table 15: Current carrying capacity of MVABC

No	Cable description	Current Carrying Capacity (A)
01	Alu 3 x 95 + 50 sqmm	200 A
02	Alu 3 x 150 + 50 sqmm	350 A

4.4.1 Cost of Medium Voltage Aerial Bundled Conductors.

By considering the life time of the MVABC and load growth of the network, it is decided to select the 150 mm² size of MVABC for costing.

Annual maintenance cost was calculated based on routine maintenance and breakdown maintenance cost. Breakdown cost consists of abnormal breakdown cost due to fallen tree branches (33kV network -1 incident per 10 years), vehicle accident

(11kV network -1 incident per 10 years). Price List of CEB 2019 [15] which used in 2020 is used for material cost.

Cost for constructing 1km of 33kV Alu 3x150+50mm²ABC Line (Annex XII)

• Material Cost	= LKR	9,280,070.00
• Labour cost	= LKR	780,700.00
• Transport cost	= LKR	280,500.00
• Way leaves	=	-
Total Cost	=	<u>LKR10,341,270.00</u>

Cost for constructing 1km of 11kV Alu 3x150+50mm²ABCLine (Annex XIII)

• Material Cost	= LKR	7,622,820.00
• Labour cost	= LKR	780,700.00
• Transport cost	= LKR	280,500.00
• Way leaves	=	-
Total Cost	=	<u>LKR 8,684,020.00</u>

Maintenance Cost of 33kV Alu 3x150+50mm²ABC Line per year per km (Annex XIV)

• Routine maintenance Cost (A)	=	-
• Way leaves cost(B)	= LKR	3480.00
• Breakdown maintenance cost (C)	= LKR	1,016,830.00
Total maintenance cost	= B + C/10	
	=	<u>LKR 105,160.00</u>

Maintenance Cost of 11kV Alu 3x150+50mm²ABC Line per year per km (Annex XV)

• Routine maintenance Cost (A)	=	-
• Way leaves cost(B)	= LKR	3480.00
• Breakdown maintenance cost (C)	= LKR	928,790.00
Total maintenance cost	= B + C/10	
	=	<u>LKR 96,360.00</u>

4.4.2 Improvement of failure rate of MVABC compared with MVBOH

Comparison was done between MVABC and MVBOH based on two feeders which are located in the same environment. The 33kV MVABC line that was constructed by Wind Force (Pvt) Ltd located at Nirmalapura, Kalpitiya was used to analyze the tripping data of MVABC. Puttalam GSS feeder 03 which runs through Kalladiya, Palaviya, Palakuda junction, Kalawila, Kalpitiya was used to compare with MVABC. The calculated failure rate improvement percentage is as follows.

Failure rate per km per year of MVBOH = FR_{BOH}

Failure rate per km per year of MVABC = FR_{ABC}

Improvement % = $(FR_{BOH} - FR_{ABC}) / FR_{BOH} \%$

Feeder failure rate with data are annexed in *Annex XVI*.

Table 16: Comparison data of MVBOH & MVABC

Construction	MVABC	MVBOH
Feeder Name	MVABC line in Wind power plant at Kalpiyiya owned by WindForce (Pvt) Ltd.	Puttalam GSS Feeder 03
Length	22km	64.5km
Line route	Kalpitiya	Kalladiya, Palaviya, Palakuda junction, Kalawila, Kalpitiya
Failures per year	5.33 Nos	56 Nos
Failure per year per km	0.24 Nos/year/km	0.87 Nos/year/km
Improvement	0.63 Nos/year/km	
Improvement %	$0.63/0.87 * 100 = 72.4 \% \sim \underline{\underline{72\%}}$	

By using medium voltage Aerial Bundle Cable, failures can be improved by 72% compared with MVBOH

4.4.3 Mean time to repair

Failure data of MVABC line which is used by Wind force (Pvt) Ltd Wind power plant located at Puttalam was analyzed. Total no of failures and total down time during the period of December 2017 to May 2019 was used for calculation (*Annex XVI*).

- Total down time = 8760 min
- Total failure = 8 Nos
- Mean time to repair = 8760 min / 8 Nos
- = 1095 min per interruption

4.5 MEDIUM VOLTAGE COVERED CONDUCTOR (MVCC)

This is a partially insulated conductor, which is not safe to touch. MVCC has been modified from earlier construction that consists of only one insulation layer.

Medium voltage covered conductor has been introduced in 1980s and it has only an insulation layer and water blocking layer over the bare conductor. Later, it has been improved by adding semi conductive layer to equalize the electric field. Furthermore, outer layer over the insulation (XLPE) has been added to material which has made from HDPE for strengthening the cable.

Figure 24 : Single layer Medium Voltage Covered Conductor [18]



Figure 25 Three-layer Medium Voltage Covered Conductor [18]



By adding a semi-conductor layer, equalized electrical field is produced around the conductor and through insulation (XLPE). Uneven electric stress leads to reduced life time of the insulation.

Figure 26 : Comparison of voltage stress distribution with semi- conductor layer around conductor [18]



CEB has initiated a pilot project in southern province to check the improvement of failure rate of modified MVCC. A new line was constructed in Tangalle area along Mahawela road (Along the coastal belt). This line has been constructed with All Alloy Aluminum Conductor (AAAC) 80mm² MVCC.

Line has been constructed using recently re-designed 3-layer MVCC and accessories such as helical tie, wedge type clamp, composite insulators, lighting protection etc. Porcelain insulators, Aluminum binding have not been used, since it causes floating earth and continuous voltage across insulation to appear. Typical tension points are constructed with tension insulators and it has a groove made with metal (to hold the conductor). Hence, it also appears as floating earth and furthermore, it causes to damage to the insulation and allow ingress of water to conductor which causes corrosion. Therefore, wedge type clamps are used. Furthermore, the purpose of preventing the insulation removing, insulated piercing connectors (IPC) are used which can withstand voltage levels of 11kV & 33kV.

Lightning protection for line should be added, since covered conductors do not allow traveling the surges and there are many possibilities to burn the cable due to lightning. Therefore, dissipating surges is an important factor to consider.

Table 17: Current carrying capacities of MVCC

No	Cable description	Current Carrying Capacity [with 1m/s wind speed]
01	All Alloy 1120 / XLPE (CC) – 80mm ²	190 A [320A]
02	Al Alloy 6201 / XLPE (CC) – 95mm ²	211 A [360A]
03	Al Alloy 1120 / XLPE (CC) – 120mm ²	260 A [420 A]

4.5.1 Cost of Medium Voltage Covered Conductor

It is decided to select the 95 mm² size of MVCC for costing. Price of the conductor was taken from cable manufacture ACL cable (Pvt) Ltd and accessories cost was taken from Ensto, Finland. Covered conductors can be replaced directly from existing poles that are used of MVBOH line. Calculation of construction cost was done by assuming existing poles can be used. Therefore, MVCC construction cost does not include the pole cost and erection cost.

Annual maintenance cost was calculated based on routine maintenance, such as line inspection (1 cycle per 4 years), way leaves clearance (1 cycle per year) & breakdown maintenance cost. Breakdown cost consists of abnormal breakdown cost due to fallen tree branches (33kV network -1 incident per 10 years), vehicle accident (11kV network -1 incident per 10 years) and flash over insulators (1 incident per 5 years for both 11kV & 33kV). Price List of CEB 2019 [15] which used in 2020 is used for material cost.

Cost for converting 1km of 33kV 95mm² MVCC Line from MVBOH (Annex XVII)

• Material Cost	= LKR 4,300,620.00
• Labour cost	= LKR 468,420.00
• Transport cost	= LKR 105,000.00
• Way leaves	= LKR 50,000.00
Total Cost	= <u>LKR 4,924,040.00</u>

Cost for converting 1km of 11kV 95mm² MVCC Line from MVBOH (Annex XVIII)

- Material Cost = LKR 3,509,190.00
- labor cost = LKR 468,420.00
- Transport cost = LKR 105,000.00
- Way leaves = LKR 50,000.00
- Total Cost = LKR 4,132,610.00**

Maintenance Cost of 33kV 95mm² MVCC Line per year per km (Annex XIX)

- Routine maintenance Cost (A) = LKR 280,660.00 per km
- Way leaves cost (B) = LKR 3480.00 per km
- Breakdown maintenance cost (C) = LKR 28,880.00 per km
- Total maintenance cost = A/4 + B+ C
= **LKR102, 530.00**

Maintenance Cost of 11kV 95mm² MVCC Line per year per km (Annex XX)

- Routine maintenance Cost (A) = LKR 119,300.00 per km
- Way leaves cost (B) = LKR 3480.00 per km
- Breakdown maintenance cost (C) = LKR 20,900.00
- Total maintenance cost = A/4 + B+ C
= **LKR 54,210.00**

4.5.2 Improvement of failure rate of MVCC compared with MVBOH

Comparison was done between MVCC and MVBOH based on two feeders which are located in the same environment. Tripping data of following feeders have been collected and calculated independently. The calculated failure rate improvement percentage is as follows.

Failure rate per km per year of MVBOH = FR_{BOH}

Failure rate per km per year of MVCC = FR_{CC}

Improvement % = $(FR_{BOH}-FR_{CC})/FR_{BOH}$ %

Each feeder which is suitable for analyzing under same environment is analyzed and failure rate is annexed in *Annex XXI*.

Table 18: Comparison data of MVBOH & MVCC

Construction	MVCC	MVBOH
Feeder Name	Part of 0.66 km of Beliatta Feeder 01	Ratmalana GSS Feeder 09
Length	0.63 km	7.5 km
Line route	Tangalle- Matara road (Coastal belt)	Kaldemulla Road, Lunawa lagoon, Uyana Road
Failures per year	1 Nos	28 Nos
Failure per year per km	1.59 Nos/year/km	3.73 Nos/year/km
Improvement	2.14 Nos/year/km	
Improvement %	$2.14/3.73 * 100 = 57.4 \% \sim \underline{\underline{57\%}}$	

By using Medium Voltage Covered Cable, failures can be improved by 57% compared with MVBOH.

4.5.3 Mean time to repair

Failure data of MVCC line that was laid at Tangalle area is analyzed. Total no of failures and total down time during the period of January 2019 to December 2019 was used to calculate. (*Annex XXI*)

- Total down time = 25 min
- Total failure = 1 Nos
- Mean time to repair = 25 min per interruption

4.6 ROOM TEMPERATURE VULCANIZING [RTV (SI-R)] PAINTING ON PORCELAIN INSULATORS.

This is an option that can be used for existing MVBOH line to improve the life time of the insulation. In this method, coating is added, which results in hydrophobic qualities on the existing ceramic insulator. Polymer insulators such as those made from Silicon Rubber have same feature on the insulator surface. Because of this added feature on insulator, it helps to minimize the surface leakage current & reduce the dissipated energy on surface. Moreover, RTV coating has shown high resistance to the tracking & erosion when it was tested [06]. Furthermore, RTV coating reduces the possibility of dry band formation on insulator surface and it has shown higher stability than porcelain insulator when exposed to UV [06]. RTV coated insulators have shown higher flash over voltage than porcelain insulators [06].

4.6.1 Cost of RTV Si-R coating to the insulators.

CEB has initiated RTV coating in Southern Province of Distribution Division 04. Cost for material (RTV paint, equipment cleaner), equipment (air less spray unit) and labor cost spent for painting the insulator are used for calculating the cost for RTV coating. After that Labor cost for replacing existing uncoated insulator with RTV coated insulator is added. Annual maintenance cost was calculated based on routine maintenance such as line inspection (1 cycle per 4 years), way leaves clearance (2 cycles per year) & breakdown maintenance cost. Breakdown cost consists of abnormal breakdown cost due to fallen of tree branches (33kV network -1 incident per 10 years), vehicle accident (11kV network -1 incident per 10 years) and flash over insulators (1 incident per 4 years for both 11kV & 33kV).

4.6.1.1 Cost for painting insulator

• Material (paint + equipment cleaner)	= LKR 2,791,900.00
• Equipment cost (Airless spray unit)	= LKR 331,500.00
• labor cost	= LKR 208,800.00
• Transport cost	= LKR 25,000.00
• Contingency	= LKR 335,720.00
Total cost	= <u>LKR 3,692,920.00</u>

- No of coated pin insulators = 642 Nos
- No of coated shackle insulators = 613 Nos

Painting area of one number of Pin Insulator is equal to two numbers of Tension Insulators (Single Disks),

Therefore,

- Cost for paint on pin insulator = LKR 3893.43
- Cost for paint one shackle disk = LKR 1946.72

Based on costs for coating as above, replacement cost of insulators with coated insulator was calculated as below. Price List of CEB 2019 [15] which used in 2020 is used for material cost.

Cost for replacing of RTV Si-R coated insulators to existing 1km of 33kV BOH Line(Annex XXII)

- Material Cost = LKR 291,780.00
- Labour cost = LKR 78,070.00
- Transport cost = LKR 6000.00
- Total Cost = LKR 375,850.00**

Cost for replacing of RTV Si-R coated insulators to existing 1km of 11kV BOH Line (Annex XXIII)

- Material Cost = LKR 168,910.00
- Labour cost = LKR 78,070.00
- Transport cost = LKR 6000.00
- Total Cost = LKR 250,980.00**

Maintenance Cost of 33kV(RTV Coated)BOH line per year per km (Annex XXII)

- Routine maintenance Cost (A) = LKR 280,660.00
- Way leaves cost (B) = LKR 3480.00
- Breakdown maintenance cost (C) = LKR 21,060.00
- Total maintenance cost = $A/4 + B*2 + C$
= LKR 98,190.00

Maintenance Cost of 11kV(RTV Coated)BOH line per year per km (Annex XXIII)

- Routine maintenance Cost (A) = LKR 119,300.00
 - Way leaves cost (B) = LKR 3480.00
 - Breakdown maintenance cost (C) = LKR 18,710.00
- Total maintenance cost = $A/4 + B*2 + C$
= **LKR 55,500.00**

4.6.2 Improvement of failure rate of MVCC compared with MVBOH

RTV Si-R painted insulators have been used along the coastal belt at Dewinuwara to University of Ruhuna (Matara CSC), Mirissa to Thalaramba (Weligama CSC), Tangalla hospital to Parewella beach (Tangalla CSC) etc. RTV Si-R coated insulators are not used continuously in these lines and used in ad-hoc manner. Therefore, it is very difficult to sort the breakdown details of RTV coated line. As per the reference [06], flash over voltage is increased by 30% when compared with uncoated porcelain insulator. Hence, failure rate is assumed to be reduced by the same percentage (30%).

4.7 PULSE CLOSING TECHNOLOGY FOR RECLOSERS

This technology is used to limit the short time duration interruptions. Traditional Auto Reclosers are used to avoid human intervention for restoring interruptions, which occurs due to short duration faults such as tree branch touching, animal touching etc. Auto Reclosers are reclosing the circuit after a defined time period, after which it allows the flow of full load current to check whether the fault has been cleared or not. If it is not cleared, the Auto Recloser disconnects the circuit again and recloses. This cycle is repeated for a pre-defined number of times and if it goes beyond, Auto Recloser lockout. But this process causes a minimum three (03) times of momentary interruptions with switching surges to identify sustained faults. These surges produce unwanted electrical & mechanical stresses on equipment (Distribution transformers, cable etc.) in distribution network. Also these rapid change of load, because of the sudden & several number of tripping of feeder section may cause to experience voltage sags (specially, if reactive power dominant system) for consumers who are in

upstream of the point of common coupling (PCC) of the fault, especially which is at low fault level & reactive power dominant network. Pulse technology is used to avoid unwanted surges and it uses only less than 5% of the usual energy to check whether the system has been cleared from fault. Technology and function were elaborated in the literature review section. This technology is especially applicable to hybrid networks, which consist of insulated cables such as Underground cable, Aerial Bundle Conductors, Covered Conductors etc. Furthermore, this is enhancing the life time of equipment used in network.

4.7.1 Cost of Pulse Closing Technology (Intellirupter Pulse Closer).

This is not used in Sri Lanka up to now and cost evaluation was calculated as per FOB price of IntelliRupter Pulse Closer, received from manufacturer. Tax and transport cost are added on this equipment unit cost. Finally, labour, additional accessories cost etc. were added to calculate the total installation cost of Intellirupter Pulse Closer. Maintenance cost consists of inspection and testing the battery of RTU unit (2 cycles per year) and service of the equipment (1 service in every 2 year). Price List of CEB 2019 [15] which used in 2020 is used for material cost.

Cost for installation 33kV Intellirupter Pulse Closer (Annex XXIV)

• Cost for Intellirupture pulse closer	= LKR 7,427,190.00
• Other material cost	= LKR 642,980.00
• Labor cost	= LKR 156,140.00
• Transport cost	= LKR 29,000.00
Total	= <u>LKR 8,255,310.00</u>

Cost for installation 11kV Intellirupter Pulse Closer (Annex XXV)

• Cost for Intellirupture pulse closer	= LKR 6,253,140.00
• Other material cost	= LKR 547,170.00
• Labor cost	= LKR 156,140.00
• Transport cost	= LKR 29,000.00
Total	= <u>LKR 6,985,450.00</u>

Maintenance Cost of 33kV Intellurupter Pulse Closer (per year per km (Annex XXV))

- Cost for Condition Monitoring (A) = LKR 7740.00
- Cost for Routine maintenance (B) = LKR 26,000.00
- Cost for Battery (C) = LKR 20,000.00
- Total = $A*2 + B/2 + C/5$
= **LKR 32,480.00**

Maintenance Cost of 11kV Intellurupter Pulse Closer (per year per km (Annex XXVI))

- Cost for Condition Monitoring (A) = LKR 7740.00
- Cost for Routine maintenance (B) = LKR 21,590.00
- Cost for Battery (C) = LKR 20,000.00
- Total = $A*2 + B/2 + C/5$
= **LKR 30,280.00**

4.7.2 Improvement of failure rate (momentary interruption) by adding IntelliRupter Pulse Closer

Main purpose of adding the intellirupter Pulse Closer is to reduce failures that happen due to momentary interruptions. As per the literature review followings results have been obtained.

Table 19: Comparison of data before & after introducing “Pulse Closing Technology”.

Table 19:	Arrangement	MAIFI
01	OH & UG hybrid network with Added lateral devices at five locations with reclosing enabled.	18.84
02	OH & UG hybrid network with Added lateral devices at five locations with reclosing enabled & Main line device reclosing enabled using 3 <i>IntelliRupter® fault interrupters</i> .	4.29
	Improvement	$= (18.84 - 4.29) / 18.84 \%$ = <u>77%</u>

By using pulse closing technology, momentary failures can be reduced by 77% compared with traditional Auto Reclosers.

4.8 SUMMARY OF RELIABILITY IMPROVEMENT, MEAN TIME TO REPAIR & COST OF THE METHODS WHICH ARE USED FOR IMPROVING RELIABILITY IN DISTRIBUTION NETWORK

Capital costs have been rounded up nearest LKR 100,000 and Maintenance costs have been rounded up to nearest LKR 1000.00.

Table 20: Summary of costs, failure improvement & MTTR.

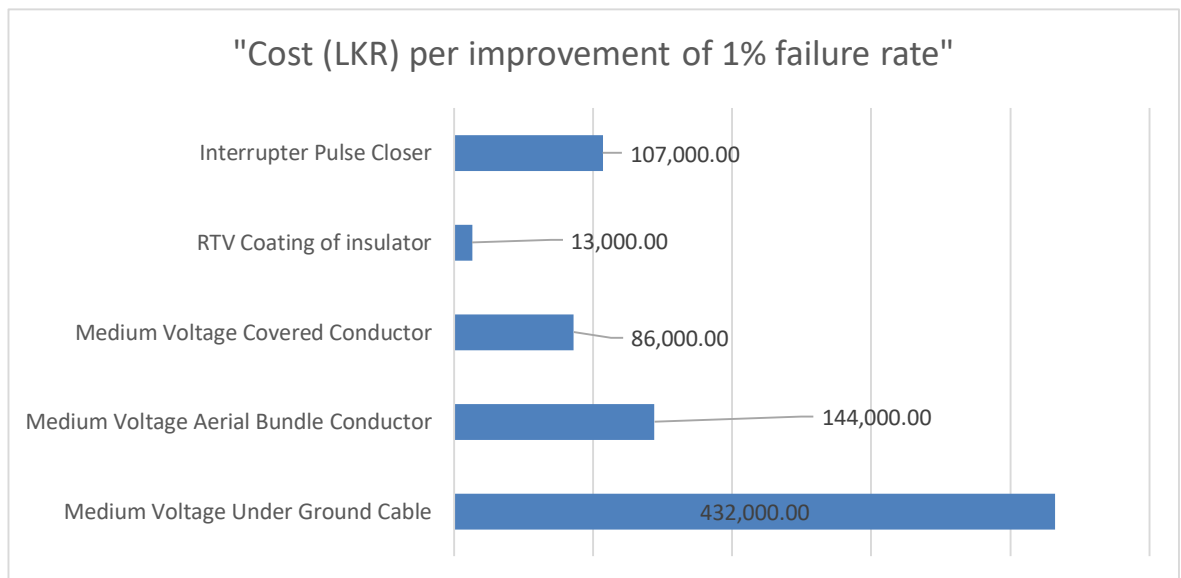
Option	Capital Cost (per km)		Maintenance Cost (per km per year)		Failure rate improvement	Mean time to repair
	33kV(MLKR)	11kV(MLK)	33kV(LKR)	11kV(LKR)		
MVBOH	2.7	2.5	173,000.00	90,000.00	N/A	
MVUGC	35.0	30.9	94,000.00	74,000.00	81%	332 min
MVABC	10.3	8.7	105,000.00	96,000.00	72%	1095 min
MVCC	4.9	4.1	102,000.00	54,000.00	57%	25 min
RTV Coating	0.4	0.3	98,000.00	56,000.00	30%	Same as BOH
IntelliRupter Pulse closer	8.3	7.0	32,000.00	30,000.00	77% (MAIFI)	N/A

4.8.1 Cost per improve failure rate by 1%

Table 21 : capital cost per 1% improvement of failure rate

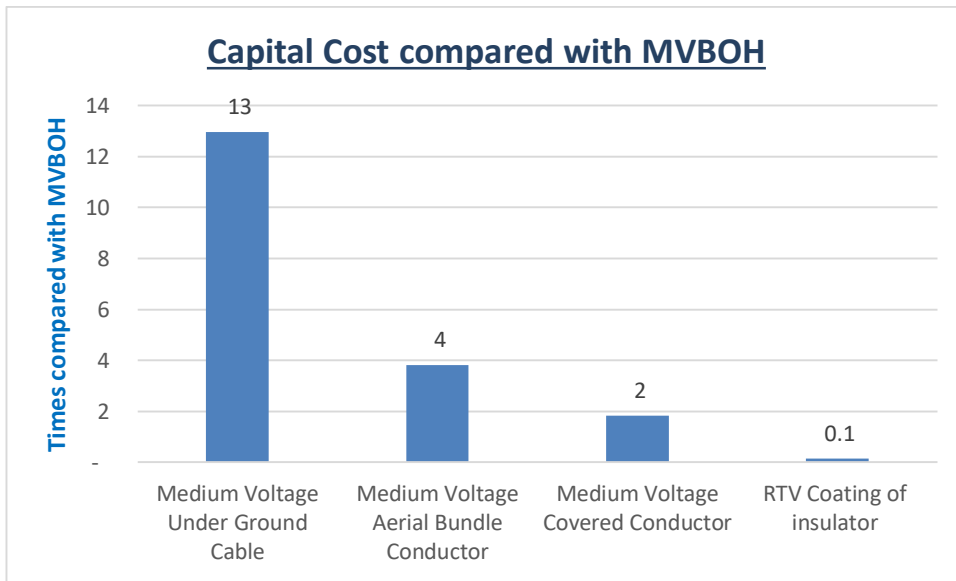
Method	Cost per 1% improvement of FR compared to BOH (LKR)
Medium Voltage Under Ground Cable	432,000.00
Medium Voltage Aerial Bundle Conductor	144,000.00
Medium Voltage Covered Conductor	86,000.00
RTV Coating of insulator	13,000.00
Interrupter Pulse Closer	107,000.00

Figure 27: Cost (LKR) for improvement 1% of failure rate



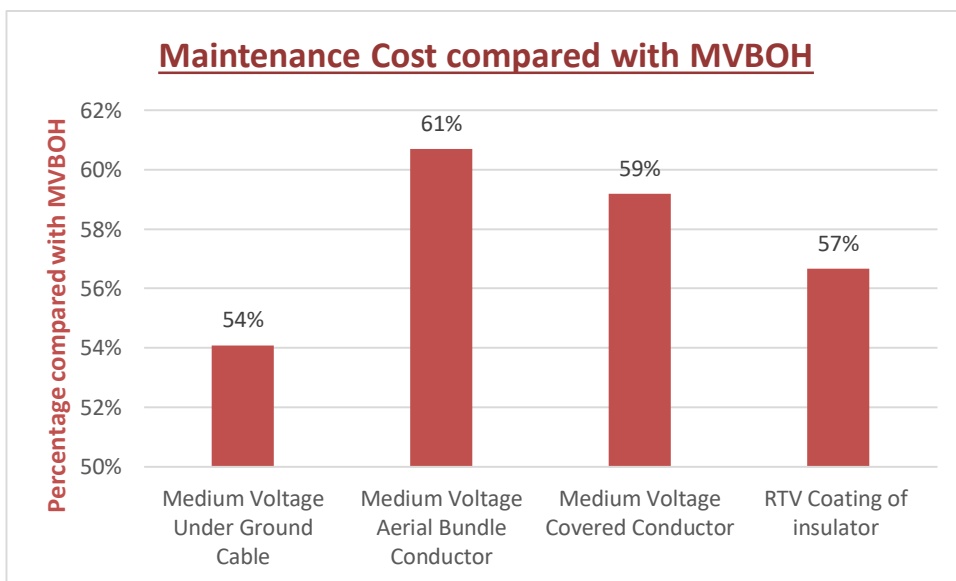
4.8.2 Comparison of Capital Cost

Figure 28: Comparison of capital cost



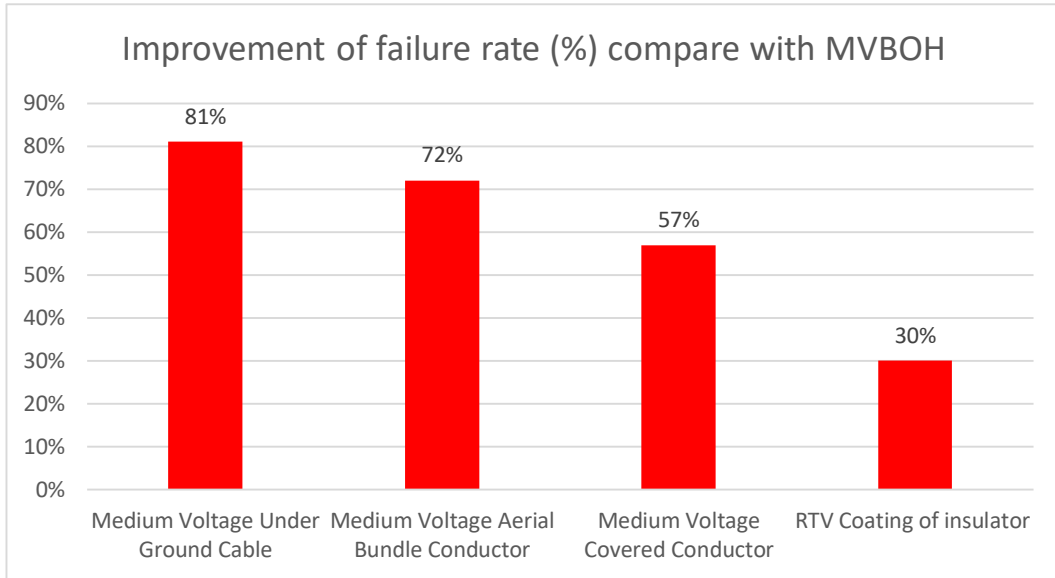
4.8.3 Comparison of Maintenance cost

Figure 29: Comparison of maintenance cost with MVBOH line



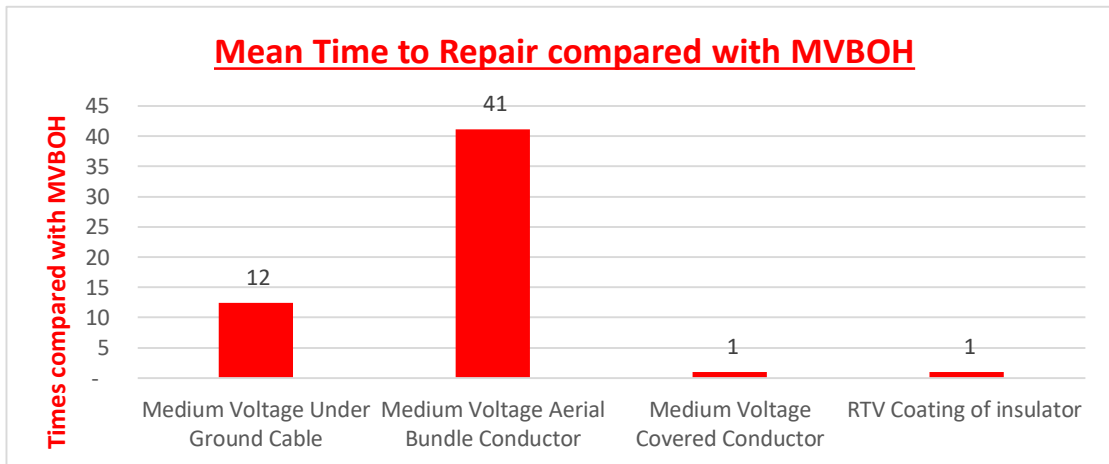
4.8.4 Improvement of failure rate compared with MVBOH

Figure 30: Failure rate improvement % compared with MVBOH



4.8.5 Comparison of Mean Time to Repair (MTTR)

Figure 31: Comparison of MTTR of each with MVBOH



5 METHOD OF ANALYSIS AND CALCULATION

This research is initiated to identify the cost-effective reliability improvement method for improving reliability of the 33/11kV Distribution network. As mentioned in the methodology, performance of the available options has been identified as mentioned in previously mentioned section 04.

Therefore, this section elaborates that how the cost-effective method is found.

5.1 IDENTIFY THE FEEDER TYPE AND PRELIMINARY FILTRATION

Distribution feeders of the network can be classified basically under following category based on the area that is fed.

1. Urban feeders
2. Rural feeders
3. Coastal feeders

Based on above feeder types, typically different priorities should be given consideration when there is a change in a distribution network.

For urban feeders, high priority should be given to the space available for the route, visual pollution etc. In rural area, there may be forests, ancient places etc. Furthermore, there are many momentary interruptions to be expected. Along the coastal area, salty wind, visual pollution (because of the tourism and sight of the beach), deposit of sand etc. should be considered.

Hence, available options must be sorted out depending on feeder type. Following table has summarized the preliminary filtration.

Table 22: Method of Preliminary filtration

Feeder Type	RTV coating for insulators	MVUGC	MVABC	MVCC	Interruption Pulse Closer
Urban	Yes	Yes	No	Yes	No
Rural	Yes	No	Yes	Yes	Yes
Coastal	Yes	Yes	No	Yes	No

MVABC option is not considered in urban and coastal feeders, since it causes the visual pollution after some duration of installation, because of the loosening of the cable from bundle. Furthermore, span between two poles should be maintained around 30-35m. Generally, MVBOH has 50 – 60m span. Therefore, if it is changed to MVABC, it is required to erect poles at extra locations between typical MVBOH lines. This is very difficult task in urban areas. By considering these, MVABC is not considered for urban feeders.

Same issue of visual pollution is there, when MVABC are considered for coastal feeders. Most of the coastal areas have now transformed because of tourism industry. Therefore, visual amenity and skyline of these areas have become very important to maintain the attraction for tourism. Therefore, MVABC should not be considered when selecting options along the coastal areas.

Laying MV underground cable, involves at least 1.1m depth and 0.5m width excavation. Backfilling is conducted according to the standard material such as sand, Poly-Ethylene warning tape, cement tile, quarry dust etc. for laying MVUG cable. Therefore, excavation along forest areas and backfilling like these materials will disturb the natural activities and there may be objections from relevant authorities and villagers. By considering all these, MVUG cable option is not considered for rural feeders.

5.2 CALCULATE RELIABILITY AND ECONOMICAL PARAMETERS.

Selected options after considering preliminary filtration are combined and checked on trial and error basis with combination of each other by checking percentage of the line section considered. Each section involves different figures for reliability and economical parameters. Therefore, final result of the combination should be calculated. Required parameters are listed out below.

Reliability parameters

- SAIFI
- SAIDI
- MAIFI

Economical parameters

- Investment cost
- Annual maintenance cost
- Simple payback period (SPP)
- Internal Rate of Return (IRR)
- Cost to Benefit Ratio (CBR)

5.2.1 SAIFI

[22]

$$\blacktriangleright \mathbf{FR}_i = \mathbf{FR}_{MVBOHX} (1 - \mathbf{impr}_i \%)$$

$$\blacktriangleright \mathbf{FR}_o = (\sum_{i=1}^n \mathbf{FR}_i \times \mathbf{pi}\%)$$

$$\blacktriangleright \mathbf{SAIFI}_o = \mathbf{FR}_o \times \mathbf{L}$$

$$= (\sum_{i=1}^n \mathbf{FR}_i \times \mathbf{Pi}\%) \times \mathbf{L}$$

$$= (\sum_{i=1}^n \mathbf{SAIFI} / \mathbf{L} \times (1 - \mathbf{impr}_i \%) \times \mathbf{pi}\%) \times \mathbf{L}$$

$$\mathbf{SAIFI}_o = \mathbf{SAIFI} \times (\sum_{i=1}^n (1 - \mathbf{impr}_i \%) \times \mathbf{pi}\%)$$

FR_i	= Failure rate of selected option [#int/year/km]
FR_{MVBOH}	= Failure rate of feeder that is analyzing [#int/year/km]
Impr_i%	= % of improvement of selected option compared to BOH
FR_o	= Failure rate of selected combination [int/year/km]
p_i%	= Proposed % of line section to be used [%]
L	= Line length [km]
SAIFI_o	= Improved SAIFI [# int/year/consumer]
SAIFI	= present SAIFI of the feeder [#int/year/customer]

5.2.2 SAIDI [22]

- ▶ $r_s = \sum_{i=1}^n (\lambda_i \times r_i) / \lambda_s$
- ▶ $SAIDI_o = r_s \times SAIFI_o$
- ▶ $\lambda_i = \frac{SAIFI}{L} \times p_i \% \times L \times (1 - impr_i \%)$
- ▶ Hence,
- ▶ $SAIDI_o = \sum_{i=1}^n (\lambda_i \times r_i) / \lambda_s \times SAIFI_o$
- ▶ $SAIDI_o = [\sum_{i=1}^n [(\frac{SAIFI}{L}) \times p_i \% \times L \times (1 - impr_i \%) \times r_i] / SAIFI_o \times SAIFI_o$

$SAIDI_o = SAIFI \times \sum_{i=1}^n [(1 - impr_i \%) \times p_i \% \times r_i]$
--

r_s	= Resultant Repair time [min/int]
λ_i	= Failure rate (#int/year)
r_i	= Repair time of selected option [min/int]
λ_s	= Failure rate (#int/year)
SAIDI_o	= Improved SAIDI [min/int/consumer]
SAIFI_o	= Improved SAIFI [# int/year/consumer]

SAIFI	= present SAIFI of the feeder [int/year/customer]
L	= Line length [km]
n	= No of options
Impr_i%	= % of improvement of selected option compared to BOH
p_i%	= Proposed % of line section to be used [%]

5.2.3 MAIFI [22]

$$\text{MAIFI}_0 = \text{MAIFI}_x (1 - \text{impr}_{PC} \%)$$

5.2.4 SAVING

$$\text{SAV}_{\text{CoUsE,Non-Mom}} = (D_{nm} * \text{LOAD}_D + C_{nm} * \text{LOAD}_C + I_{nm} * \text{LOAD}_I) * (\text{SAIDI} - \text{SAIDI}_0) * 60$$

$$\text{SAV}_{\text{CoUsE,Mom}} = (D_m * \text{LOAD}_D + C_m * \text{LOAD}_C + I_m * \text{LOAD}_I) * (\text{SAIFI} - \text{SAIFI}_0)$$

$$\text{SAV}_{\text{CoUsE}} = \text{SAV}_{\text{CoUsE,Non-Mom}} + \text{SAV}_{\text{CoUsE,Mom}}$$

$$\text{SAV}_T = \text{SAV}_{\text{CoUsE}} + \text{SAV}_{\text{MC}}$$

SAV_T	= Total saving per year [LKR/year]
SAV_{CoUsE}	= Saving from Cost of Unserved Energy [LKR/year]
SAV_{MC}	= Saving from Maintenance Cost [LKR/year]
SAV_{CoUsE,Non-Mom}	= Saving from Cost of Unserved Energy of Non-momentary interruption [LKR/Year]
SAV_{CoUsE,Mom}	= Saving from Cost of Unserved Energy momentary interruption [LKR/Year]
D_{nm}	= Cost of unserved energy of Domestic sector non momentary interruption [LKR/kWh]
C_{nm}	= Cost of unserved energy of Commercial sector non momentary interruption [LKR/kWh]
I_{nm}	= Cost of unserved energy of Industrial sector non momentary interruption [LKR/kWh]
LOAD_D	= Connected load of under Domestic sector [kW]

LOAD _c	= Connected load of under Commercial sector [kW]
LOAD _I	= Connected load of under Industrial category [kW]
D _m	= Cost of unserved energy of Domestic sector momentary interruption [LKR/kW]
C _m	= Cost of unserved energy of Commercial sector momentary interruption [LKR/kW]
I _m	= Cost of unserved energy of Industrial sector momentary interruption [LKR/kW]

5.2.5 SIMPLE PAYBACK PERIOD & IRR%

- ▶ $SPP = C_t / SAV_{CoUsE}$
- ▶ **IRR is found such that,**
- ▶ $0 = NPV = \sum_{i=1}^n \left(\frac{SAV T}{(1+IRR)^t} \right) - CCt$

SPP	= Simple Pay Back Period [year]
NPV	= Net Present Value [LKR]
IRR	= Internal Rate of Return [%]
N	= Life time of line [Years]
Sav _T	= Total saving per year [LKR/year]
Sav _{CoUsE}	= Saving from Cost of Unserved Energy [LKR/year]

Present value is calculated using discount rate.

5.2.5.1 BENEFIT TO COST RATIO (BCR)

$$BCR = \sum_{i=1}^n (PV \text{ of } SAV \ i) / \text{Investment}$$

BCR = Benefit to Cost ratio

$PV \text{ of } Sav_i = \text{Net Present Value of saving each year [LKR]}$

$n = \text{Life time of line [Years]}$

5.3 RELIABILITY TARGET

Target values of the reliability indices should be decided in this stage. This target is varied according to the vision of the utility or pre-defined target by regulator. In Sri Lanka, the regulator is in the first stage of implementing Distribution Performance Standards Regulations (2016) where distribution licensees are in the first stage of compiling reliability data which will be incorporated into the Distribution Development plans in future for each Distribution utility, which serves as the regulator approved investment plan.

5.4 CHECK INRELIABILITY RESULTS BY CHANGING DIFFERENT LENGTH OF THE CABLE.

According to the calculation of reliability indices in section 5.2, improved values are calculated based on the percentage length of the options that are selected (according to the feeder type and preliminary filtration) and resultant value of failure rate improvement, mean time to repair etc. Then check whether the results are within the targets. If it is not satisfied, percentage length of the option should be changed till the target is achieved. Range of the percentage length that satisfies reliability target is then determined. Limit (percentage length of options) of this range will be one of following points.

1. Point at reliability target.
2. Point at maximum or minimum use of the option.

Pulse closing technology is used in “IntelliRupter Pulse Closer”, to reduce the momentary interruptions. Therefore, it only uses in the rural feeders based on the usage of the cable (MVUGC, MVABC, MVCC).

5.5 SELECT COST EFFECTIVE SOLUTION BASED ON ECONOMICAL ANALYSYS

At this stage, there is a set of range which meet reliability target. If in urban feeder, there are 03 options that should be considered. Therefore, maximum there are 04 sets of ranges that meet the reliability target. Some of the combinations will not meet the target, therefore, such combinations are not considered further. *Considered options in urban feeder,*

1. MVBOH with RTV Coating
2. MVUGC
3. MVCC

Possible four (04) Combinations

1. MVBOH with RTV Coating, MVUGC & MVCC
2. MVBOH with RTV Coating & MVUGC
3. MVBOH with RTV Coating & MVCC
4. MVUGC & MVCC

Economic evaluation and optimization are done by changing the percentage of the options within range, which give required reliability target. Out of this ranges, further sorting is done such that IRR is more than discount rate. Then the point, which gives maximum IRR of each combination, is selected. Finally, the maximum IRR among each combination is selected.

If there is no range that gives $IRR > \text{Discount rate}$, then the range which gives IRR more than zero ($IRR > 0\%$) is selected. The same procedure is followed, for all options.

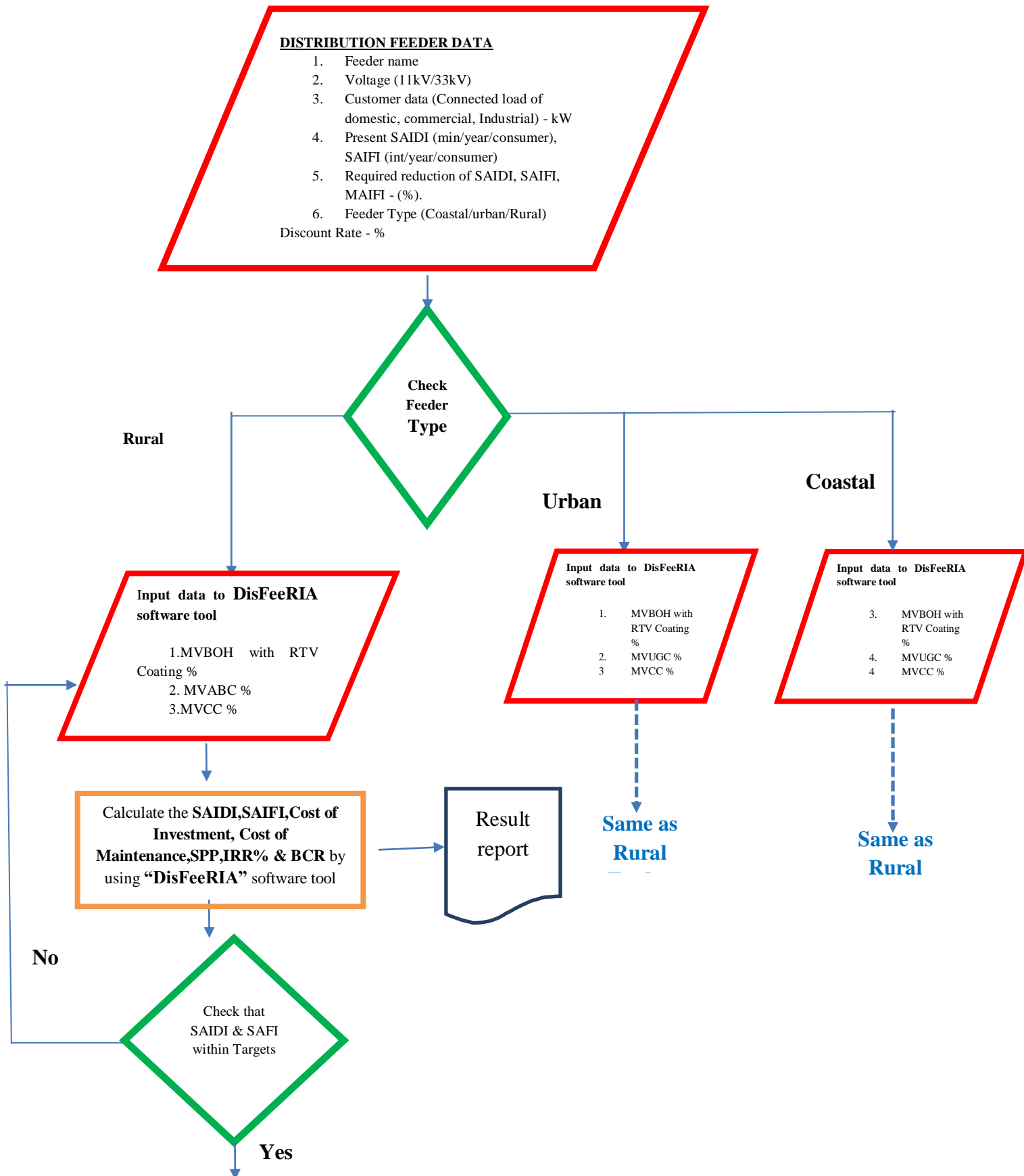
5.6 FINAL RESULT

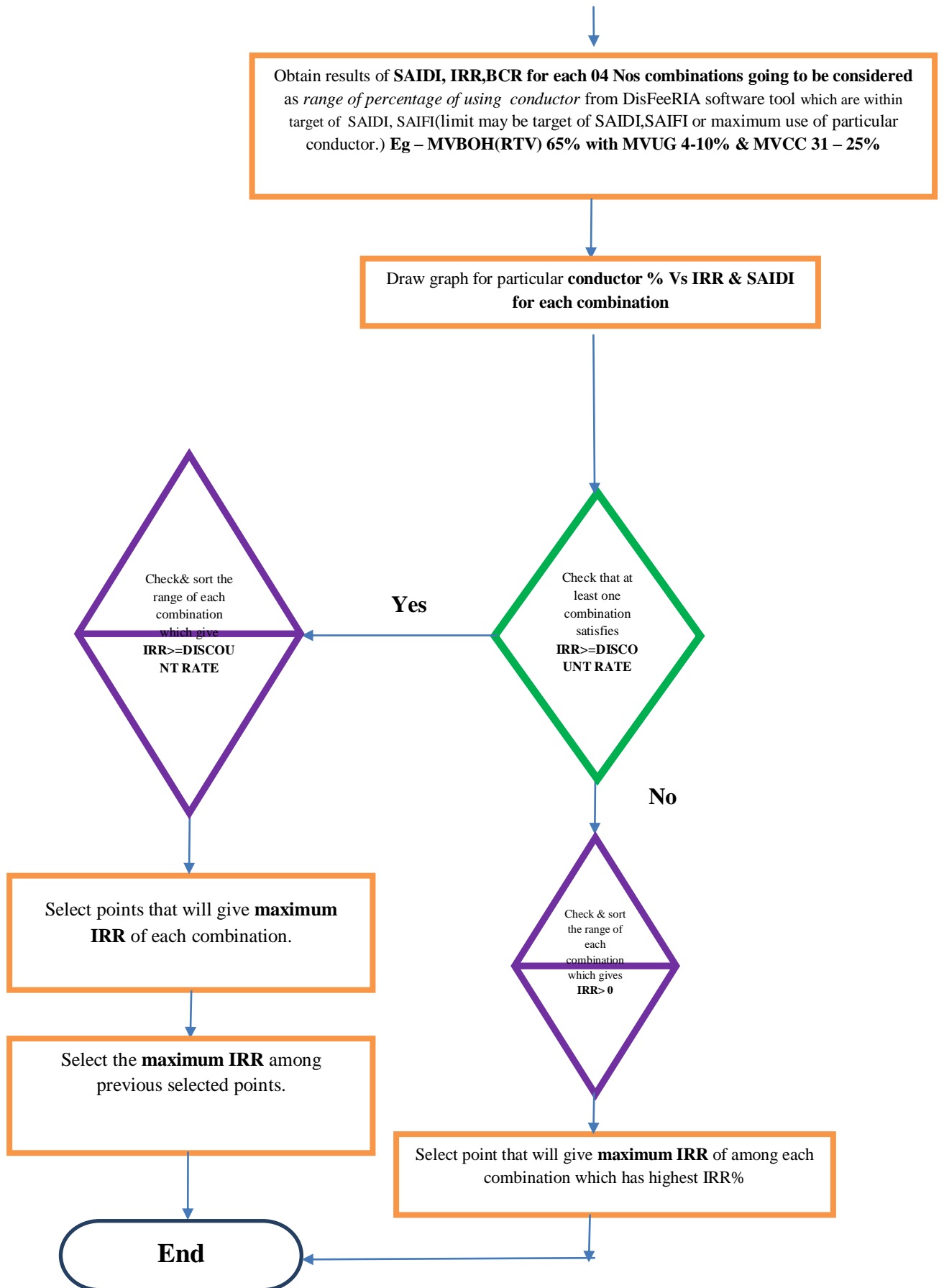
By using selected cost-effective solution, following results can be given to user to get an assessment of the proposal with economical consideration.

- *Expected SAIFI, SAIDI and MAIFI*
- *Investment* - *MLKR*
- *Annual maintenance cost* - *MLKR/Year*
- *Simple payback period* - *Years*
- *IRR* - *Percentage*
- *Benefit to Cost Ratio* - *ratio*
- *Savings* - *MLKR/Year*

5.7 FLOW CHART

Figure 32: Flow chart





6 DEVELOPMENT OF A SOFTWARE TOOL FOR ANALYSIS

Method elaborated in section 05 of this report, involves trial and error method to find the results. Therefore, it is very difficult to calculate these indices manually. A Graphical User Interface (GUI) is developed for this purpose. This tool is required a set of user inputs.

Then calculation is done as per user inputs and stored data of software (Data that was found in this research as discussed in section 5.6) to calculate the reliability indices and economic indications for evaluation. It has the facility to store the result as MS Excel file.

Figure 33: Calculation of GUI tool

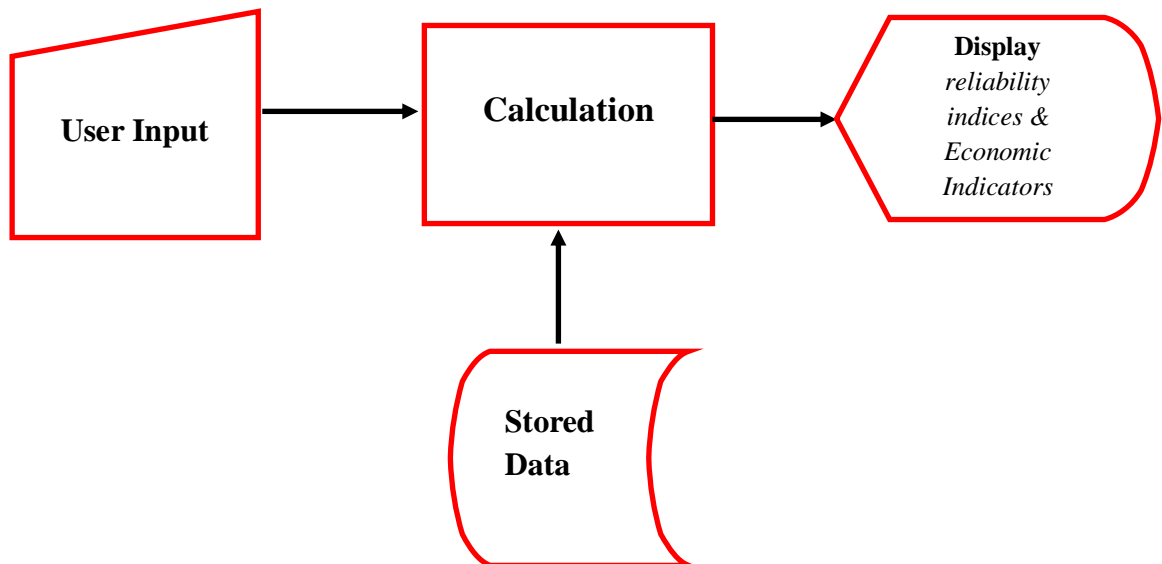


Table 23: Data category

User Input	Feeder Name
	Feeder Length
	Load of Domestic, Commercial & Industrial sector. [kW]
	Feeder type (Urban, Coastal, Rural)
	Voltage level (33kV/ 11kV)
	Present values of Reliability indices (SAIFI – #int/year/consumer, SAIDI - min/year/consumer, MAIFI - # int/year/consumer)
	Target of Reliability indices [%]
	Discount rate use for economic analysis [%]
	Proposed feeder length as % to be consider among selected options (MVBOH with RTV coating, MVUGC, MVABC, MVCC)
Stored data	% of improvement of failure rate compared with MVBOH in each option.
	Mean Time to repair of each option which analyze.
	Cost of unserved energy in Domestic, Commercial & Industrial sector.
	Capital cost (Investment) of each option which analyze.
	Maintenance cost of each option which analyze.
Display Results	Expected SAIFI, SAIDI, MAIFI
	Target is achieved or not
	Total Investment
	Annual maintenance cost`
	Annual maintenance cost
	Simple payback period
	IRR %
	Cost to Benefit ratio
	Saving
Proposed line sections length and Number of IPC to be used	

Figure 34: Input interface of DisFeeRia

The screenshot shows the input interface of the DisFeeRIA software. The window title is 'DisFeeRIA'. At the top, there is a decorative image of a city skyline at night. Below the image, the interface is organized into several sections with input fields and dropdown menus:

- Feeder Name:** Dehiwala PSS F5
- Length:** 2.90 km
- Load Data:**
 - Domestic: 751.47 kW
 - Commercial: 925.97 kW
 - Industrial: 56.29 kW
- Feeder Type:** Coastal (dropdown menu)
- Voltage:** 11kV (dropdown menu)
- Economic Analysis:**
 - Discount rate: 7.50 %
- Reliability Indices:**
 - SAIDI: 730.33 min/year/consumer
 - SAIFI: 20.33 int/year/consumer
 - MAIFI: 0.00 int/year/consumer
- Urban/Coastal:**
 - MV BOH (RTV): 65.00 %
 - MV UGC: 10.00 %
 - MV CC: 25.00 %

Figure 35: Output interface of DisFeeRia

The screenshot shows the output interface of the DisFeeRIA software, titled 'Reliability Analyze Report of Dehiwala PSS F5'. The report is presented in a table format with three columns: Index, Description, and Value. The data is categorized into three main sections: Reliability Indices, Economical Indices, and a summary of savings.

Index	Description	Value
	MVBOH(RTV Coating)	65 % 1.89 km
	MVUGC	10 % 0.29 km
	MVABC	0 % 0 km
	MVCC	25 % 0.73 km
Reliability Indices		
1	Expected SAIFI :	11.98 int/year/consumer
	Target SAIFI :	12.20 int/year/consumer
		Target Achieved
2	Expected SAIDI :	437.74 min/year/consumer
	Target SAIDI :	438.18 min/year/consumer
		Target Achieved
Economical Indices		
	Expected Investment :	12.39 MLKR
	Maintenance Cost :	0.20 MLKR/Year
	Simple Payback Period(SPP) :	5.72 Years
	IRR :	9.96 %
	Benefit to Cost Ratio :	2.16
	Investment per 1% improvement of SAIFI :	0.30 MLKR/1% of SAIFI
	Total Saving :	2.27 MLKR/Year
	Saving from unserved energy :	2.17 MLKR/Year
	Saving from Maintenance :	0.10 MLKR/Year

At the bottom of the window, there are three buttons: 'Download Report', 'Back', and 'Close'.

7 CASE STUDY

Case study was done in a one of the provinces in which Ceylon Electricity Board operates. Data of the one feeder in each type (Urban, Coastal, and Rural) were collected. The following data is included,

1. Failure analysis - Calculated SAIFI, SAIDI, MAIFI
2. Analysis of consumer load. – Load of Domestic, Commercial & Industrial categories.

After that, collected and calculated data of above are used to find the cost-effective solution as per input data. Selected feeder in each feeder type is tabulated following.

Table 24 : Details of selected feeder in each feeder type

Feeder Type	Feeder Name	Voltage	Line length	Line route
Urban	Kalubowila PSS F6	11kV	6 km	Kalubiwila PSS to Kohuwala gantry, Dutugemunu street Mudali mawatha LBS, Peters lane to Nugegoda high level road, Sunethra Devi road to Woodland road and LBS at Cemetery Anderson road
Coastal	Dehiwala PSS F5	11kV	2.9 km	Galle road from Mihindu Mawatha to Dehiwala junction, Senanayaka road, fair line road and end at LBS DM003S1N near Dehiwala AGA office.
Rural	Matugama GSS F2	33kV	145 km	(i) Mathugama GSS to Kithulgoda Gantry(ii)(a)Kithulgoda gantry to Kalawana rd Athwelthota (Auto recloser KA083R3) (ii)(b) Lathpandura KA021R3 to Kukule (iii)Kithulgoda to Horana rd Kalumale (Auto Reclosers - KA082)

Failure data of three years were analyzed and furthermore, analysis was done for finding the total no of consumers in each sector by categorizing Domestic, Commercial & industrial and calculate load (kW) of each category. Data that was found in this case study is as follows.

Table 25: Calculated results of each feeder

Feeder Name	Feeder Type	Present reliability indices (per year per customer)			Load data (kW)		
		<i>SAIFI</i>	<i>SAIDI</i>	<i>MAIFI</i>	<i>Domestic</i>	<i>Commercial</i>	<i>Industrial</i>
Kalubowila PSS F6	Urban	24.7	531.7 min	13.8	578.3	1555.5	Nil
Dehiwala PSS F5	Coastal	20.3	730.3 min	12.5	751.5	926.0	56.3
Mathugama GSS F2	Rural	70.7	1872.8 min	464.0	3355.3	86.3	559.2

Method which is elaborated in section 06, was used to select the cost-effective solution for each of the above feeders.

Different percentages (%) of improvement from present value of reliability indices were selected as the reliability target for different cases.

7.5% is chosen as discount rate, as 7.25% is the maximum fixed deposit interest rate given by government banks for corporate sector.

7.1 URBAN FEEDER – KALUBOWILA PSS FEEDER 06

- ▶ *Selected options,*
 1. MVBOH RTV Si-R Coating
 2. MVUGC
 3. MVCC

- ▶ *Four combinations can be considered.*
 1. MVBOH RTV Si-R + MVUGC + MVCC
 2. MVBOH RTV Si-R + MVCC
 3. MVBOH RTV Si-R + MVUGC
 4. MVUGC + MVCC

- ▶ *Ranges of percentage of each 04 options which are within defined reliability target.*

- ▶ *Three cases were studied for Kalubowila PSS Feeder 06 based on the target of the reliability as reduction of 40%, 42% & 36% from present reliability level.*

7.1.1 Target (40% reduction of reliability target)

- SAIFI = 14.8 int/yr/cust.
- SAIDI = 319 min/yr/cust

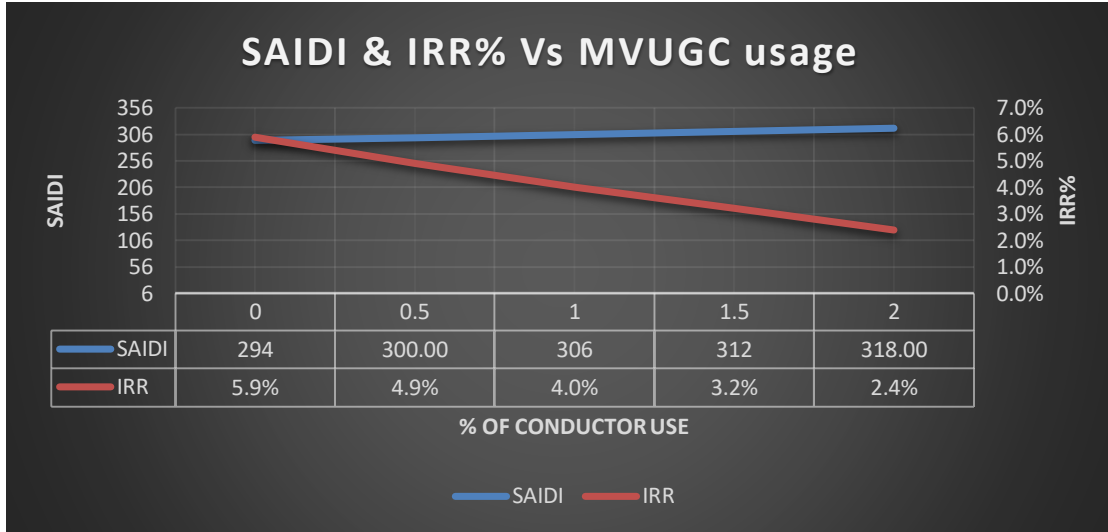
Table 26: Summary of obtained result using DisFeeRIA tool - Kalubowila PSS F6

	Combination	Expect SAIFI (int/yr/Cust.)	Expected SAIDI (min/yr/Cust.)	SPP (Year)	IRR %	BCR	Investment (MLKR)	Maintenance cost (MLKR/year)
1	BOH(RTV) 25%, UG 2%, CC 73%	12.2	318	10.3	2.4%	1.26	22.2	0.33
	BOH(RTV) 27%, UG 0%, CC 73%	12.4	294	7.7	5.9%	1.67	18.5	0.33
2	BOH(RTV) 50%, CC 50%	14.0	319	6.1	9.6%	2.12	13.2	0.33
	BOH(RTV) 0%, CC 100%	10.6	266	9.2	3.5%	1.39	24.8	0.33
3	BOH(RTV) 80% UG 20%	14.8	609(not within target)	-	-	-0.2	38.3	0.36
4	UG 4% CC 96%	10.4	317	14.9	-1%	0.9	31.2	0.33
	UG 0% CC 100%	10.6	266	9.20	3.5%	1.39	24.8	0.33

- ▶ Graphical illustration of SAIDI & IRR vs usage % of option & Sort again the range that IRR % > Discount Rate 7.5%. if this is not existing all combination check that IRR% > 0%.

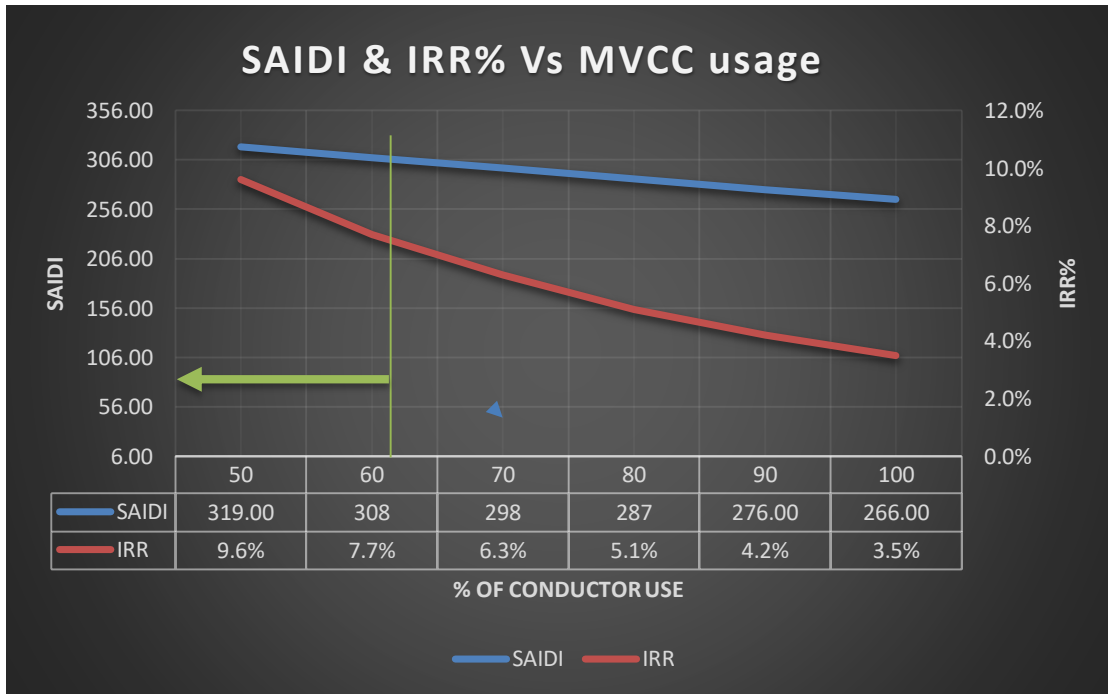
1. MVBOH RTV Si-R + MVUGC + MVCC

Figure 36 : Variation SAIDI & IRR% Vs MVUGC usage with RTV coating and MVCC- Kalubowila PSS F8



2. MVBOH RTV Si-R + MVCC

Figure 37: Variation SAIDI & IRR% Vs MVCC usage with RTV coating - Kalubowila PSS F8

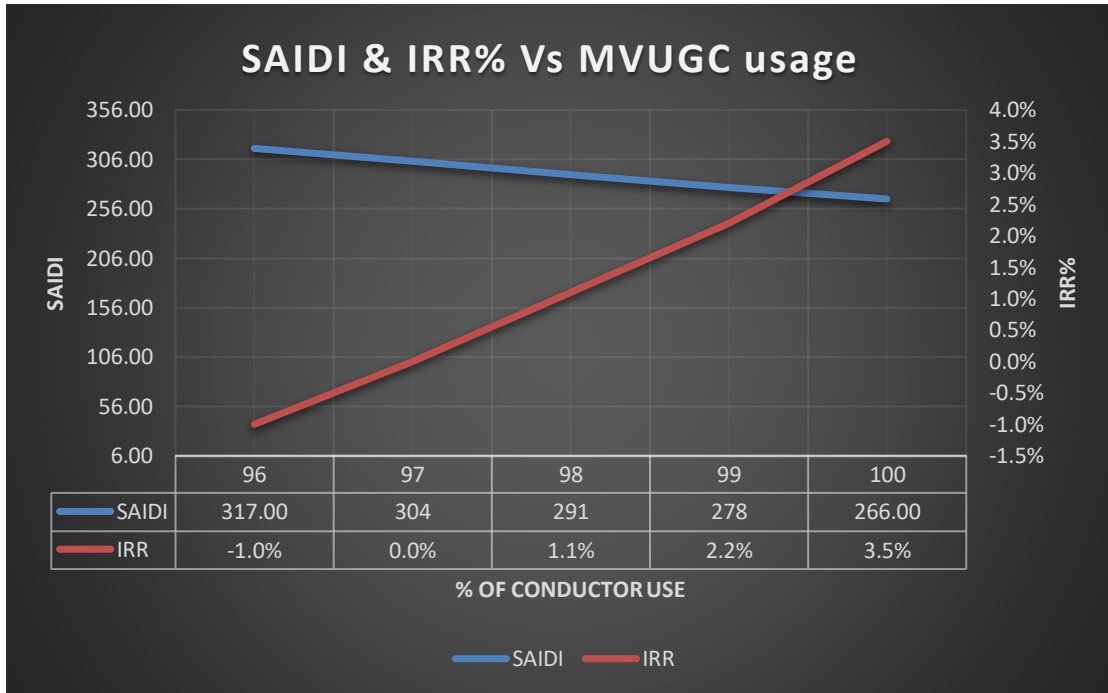


3. MVBOH RTV Si-R + MVUGC

Target SAIFI & SAIDI both could not be obtained simultaneously by using from this combination.

4. MVUGC + MVCC

Figure 38: Variation SAIDI & IRR% Vs MVCC use with MVUGC - Kalubowila PSS F8



► *Select the maximum IRR% combination each group of combination.*

Table 27: Selected results which have highest IRR% in each group of combination - Kalubowila PSS F6 –

(Target 40% reduction of reliability indices)

Combination	SAIFI(int/yr/ Cust.)	SAIDI(min/yr/ Cust.)	SPP (Year)	IRR %	BC R	Cost / 1% SAIFI improvement (MLKR/1%)
BOH(RTV) 27%, UG 0%, CC 73%	12.4	294	7.7	5.9%	1.67	0.37
BOH(RTV) 50%, CC 50%	14.0	319	6.1	9.6%	2.12	0.30
UG 0% CC 100%	10.6	266	9.2	3.5%	1.39	0.44

This is the most cost-effective solution to achieve 40% reliability target of Kalubowila PSS F6.

Total length of the feeder	= 6 km
Length need to paint insulator RTV coating Si-R	= 3 km
Length need be changed as MVCC	= 3 km
Expected SAIFI	=14.0 int/year/cust.
Expected SAIDI	=319 min/year/cust.
Total Investment	=13.2 MLKR
Annual Maintenance Cost	=0.33 MLKR/ Year
SPP	=6.1 Years
IRR%	=9.6%
Benefit to Cost Ratio	=2.12
Cost of improve 1% SAIFI	=0.3 MLKR

7.1.2 Target (42% reduction of reliability target)

- SAIFI = 14.33 int/yr/cust.
- SAIDI = 308 min/yr/cust

Table 28: Summary of obtained result using DisFeeRIA tool - Kalubowila PSS F6 (Target - 42% reduction of reliability indices)

Combination	Expect SAIFI (int/yr/Cust.)	Expected SAIDI (min/yr/Cust.)	SPP (Year)	IRR %	BCR	Investment (MLKR)	Maintenance cost (MLKR/year)	
1	BOH(RTV) 3%, UG 3%, CC 94%	10.6	308	12.74	0.1%	1.01	28.92	0.33
	BOH(RTV) 6%, UG 0%, CC 94%	11.0	272	8.90	3.9%	1.44	23.40	0.33
2	BOH(RTV) 40%, CC 60%	13.3	308	6.84	7.7%	1.89	15.48	0.33
	BOH(RTV) 0%, CC 100%	10.6	266	9.20	3.5%	1.39	24.80	0.33
3	BOH(RTV) 76% UG 24%	14.3	657	-	-	-0.28	45.70	0.36
4	UG 3% CC 97%	10.4	304	12.87	0.0%	1	29.60	0.33
	UG 0% CC 100%	10.6	266	9.20	3.5%	1.39	24.80	0.33

Table 29 : Selected results which have highest IRR% in each group of combination - Kalubowila PSS F6 – (Target - 42% reduction of reliability indices)

Combination	SAIFI (int/yr/Cust.)	SAIDI (min/yr/Cust.)	SPP (Year)	IRR%	BCR	Cost / 1% SAIFI improvement (MLKR/1%)
BOH(RTV) 6%, UG 0%, CC 94%	11.0	272	8.90	3.9%	1.44	0.42
BOH(RTV) 40%, CC 60%	13.3	308	6.84	7.7%	1.89	0.34
UG 0% CC 100%	10.62	267	9.2	3.5%	1.39	0.44

This is the most cost-effective solution to achieve 42% reliability target of kalubowila PSS F6

Total length of the feeder	= 6 km
Length need to paint insulator RTV coating Si-R	= 2.4 km
Length need be changed as MVCC	= 3.6 km
Expected SAIFI	=13.3 int/year/cust.
Expected SAIDI	=308 min/year/cust.
Total Investment	=15.5 MLKR
Annual Maintenance Cost	=0.33 MLKR/ Year
SPP	=6.8 Years
IRR%	=7.7 %
Benefit to Cost Ratio	=1.89
Cost of improve 1% SAIFI	=0.3 MLKR

7.1.3 Target (36% reduction of reliability target)

- SAIFI = 15.81 int/yr/cust.
- SAIDI = 340 min/yr/cust

Table 30: Summary of obtained result using DisFeeRIA tool - Kalubowila PSS F6 (Target - 36% reduction of reliability indices)

Combination	Expect SAIFI (int/yr/Cust.)	Expected SAIDI (min/yr/Cust.)	SPP (Year)	IRR %	BCR	Investment (MLKR)	Maintenance cost (MLKR/year)
1 BOH(RTV) 33%, UG 3%, CC 64%	12.6	340	11.27	1.5%	1.16	21.93	0.33
	13.0	304	7.12	7.1%	1.81	16.41	0.33
2 BOH(RTV) 70%, CC 30%	15.3	340	4.38	16.5%	2.99	8.49	0.33
	10.6	266	9.20	3.5%	1.39	24.80	0.33
3 BOH(RTV) 88% UG 12%	15.8	515	135.43	- 11.0%	0.18	23.58	0.35
4 UG 5% CC 95%	10.3	330	16.09	-1.9%	0.81	32.83	0.33
	10.6	265	9.20	3.5%	1.39	24.80	0.33

100%							
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Table 31 : Selected results which have highest IRR% in each group of combination - Kalubowila PSS F6 – (Target - 36% reduction of reliability indices)

Combination	SAIFI (int/yr/Cust.)	SAIDI (min/yr/Cust.)	SPP (Year)	IRR%	BCR	Cost / 1% SAIFI improvement (MLKR/1%)
BOH(RTV) 36%, UG 0%, CC 64%	13.0	304	7.12	7.1%	1.81	0.17
BOH(RTV) 70%, CC 30%	15.3	340	4.38	16.5%	2.99	0.09
UG 0% CC 100%	10.62	265	9.2	3.5%	1.39	0.44

This is the most cost-effective solution to achieve 36% reliability target of kalubowila PSS F6

Total length of the feeder	= 6 km
Length need to paint insulator RTV coating Si-R	= 4.2 km
Length need be changed as MVCC	= 1.8km
Expected SAIFI	=15.3 int/year/cust.
Expected SAIDI	=340 min/year/cust.
Total Investment	=15.5 MLKR
Annual Maintenance Cost	=0.33 MLKR/ Year
SPP	=4.4 Years
IRR%	=16.5 %
Benefit to Cost Ratio	=2.99
Cost of improve 1% SAIFI	=0.1 MLKR

7.2 COATSTAL FEEDER - DEHIWALALA PSS FEEDER 05

- ▶ *Selected options,*
 1. MVBOH RTV Si-R Coating
 2. MVUGC
 3. MVCC
- ▶ *Four combinations can be considered.*
 - MVBOH RTV Si-R + MVUGC + MVCC
 - MVBOH RTV Si-R + MVUGC
 - MVBOH RTV Si-R + MVCC

- MVUGC + MVCC
- ▶ *Range of percentage of each 04 option which are within defined reliability target.*
- ▶ *Three cases were studied for Dehiwala PSS Feeder 05 based on the target of the reliability as reduction of 40%, 45% & 35% from present reliability level.*

7.2.1 Target (40% reduction of reliability target)

- SAIFI = 12.2int./yr/cust.
- SAIDI = 438 min/yr/cust.

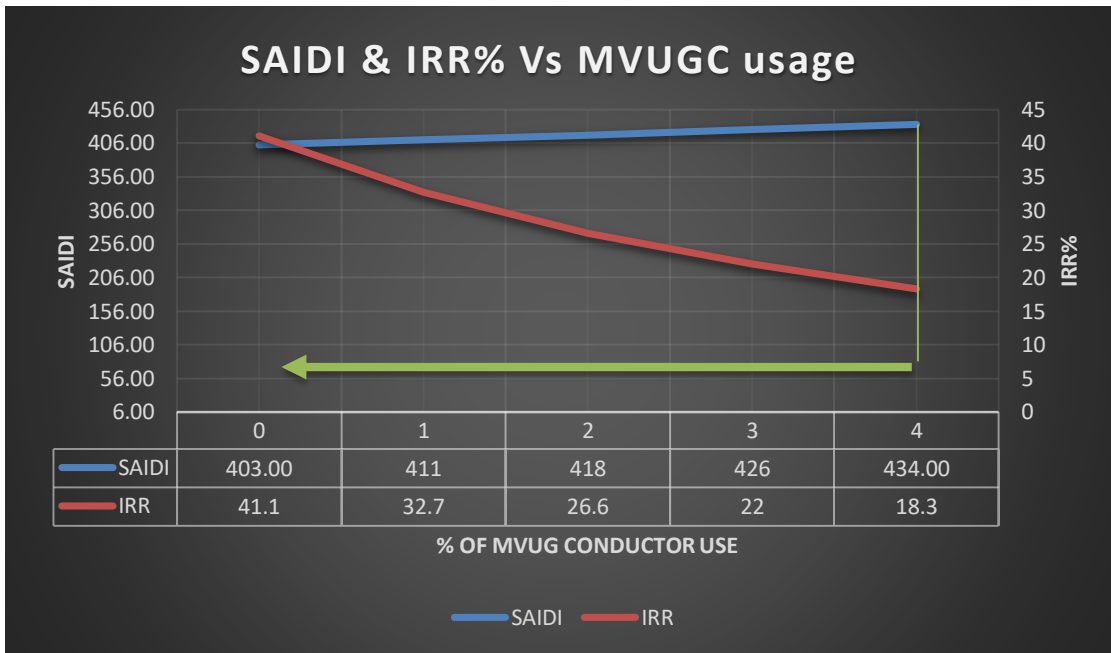
Table 32: Summary of obtained result using DisFeeRIA tool - Dehiwala PSS F5

	Combination	Expect SAIFI (int/yr/Cust.)	Expected SAIDI (min/yr/Cust.)	SPP (Year)	IRR %	BCR	Investment (MLKR)	Maintenance cost (MLKR/year)
1	BOH(RTV) 59%, UG 4%, CC 37%	11.8	434	3.8	18.3%	3.2	8.45	0.16
	BOH(RTV) 63%, UG 0%, CC 37%	12.2	403	2.0	41.1%	6.1	4.90	0.16
2	BOH(RTV) 63%, CC 37%	12.2	403	2.0	41.1%	6.1	4.90	0.16
	BOH(RTV) 0%, CC 100%	8.7	219	3.2	23.3%	3.84	12.0	0.16
3	BOH(RTV) 80% UG 20%	12.1	665(Not within the target)	38.3	-7.4%	0.37	18.5	0.17
4	UG 20% CC 80%	7.8	431	12.4	-0.1%	0.99	27.5	0.17
	UG 0% CC 100%	8.7	218	3.2	23.3%	3.84	12.0	0.16

- ▶ *Graphical illustration of SAIDI & IRR vs usage % of option & Sort again the range that IRR % > Discount Rate 7.5%. If this is not existing all combination check that IRR% > 0%.*

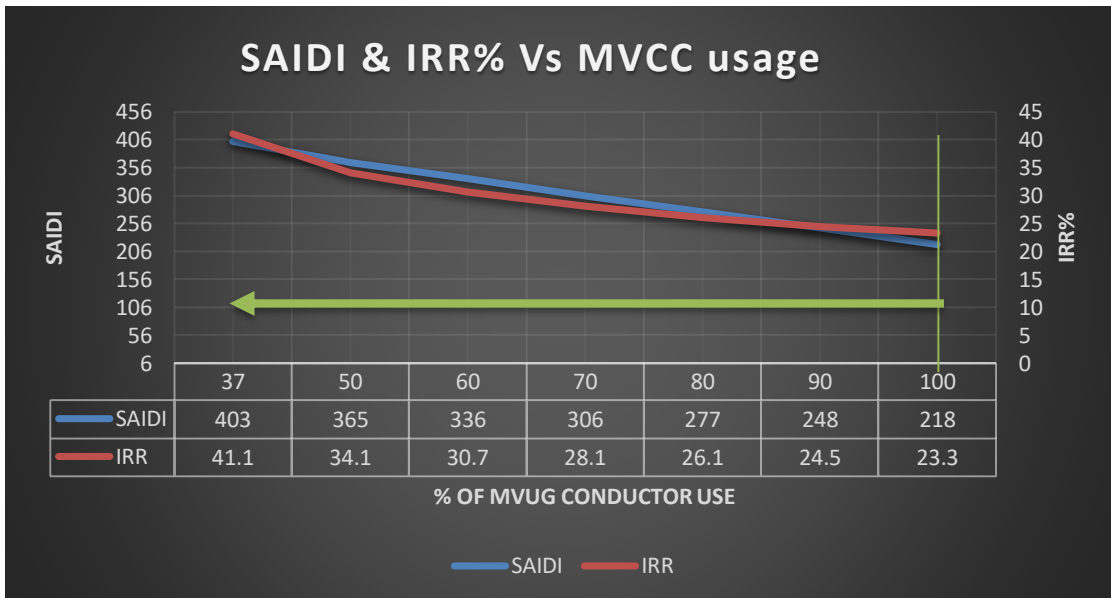
1. MVBOH RTV Si-R + MVUGC + MVCC

Figure 39: Variation SAIDI & IRR% Vs MVUGC usage with RTV coating and MVCC-Dehiwala PSS F5



2. MVBOH RTV Si-R + MVCC

Figure 40: Variation SAIDI & IRR% Vs MVCC use with RTV coating -Dehiwala PSS F5

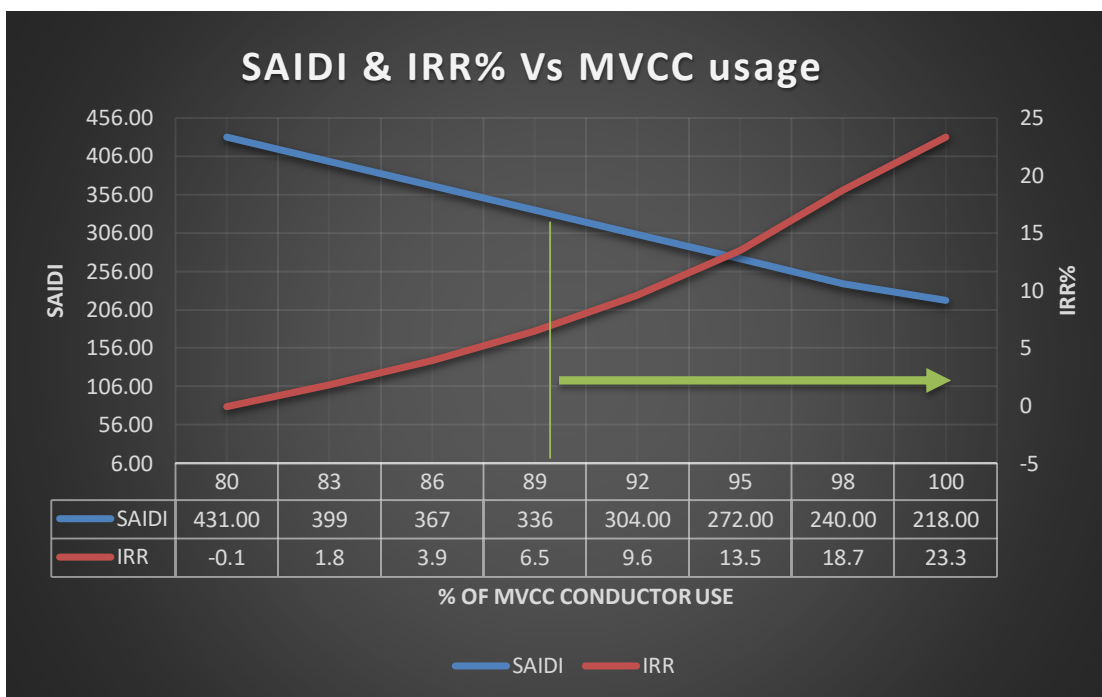


3. MVBOH RTV Si-R + MVUGC

Target of SAIFI & SAIDI both could not be obtained simultaneously by using from this combination.

4. MVUGC + MVCC

Figure 41 : Variation SAIDI & IRR% Vs MVCC use with MVUGC -Dehiwala PSS F5



► Select the maximum IRR% combination.

Table 33: Selected results which have highest IRR% in each group of combination - Dehiwala PSS F5

Combination	SAIFI (int/yr/Cust.)	SAIDI (min/yr/Cust.)	SPP (Year)	IRR%	BCR	Cost / 1% SAIFI improvement (MLKR/1%)
BOH(RTV) 63%, UG 0%, CC 37%	12.2	403	2.0	41.1%	6.10	0.12
BOH(RTV) 63%, CC 37%	12.2	403	2.0	41.1%	6.10	0.12
UG 0% CC 100%	8.7	219	3.2	23.3%	3.84	0.21

This is the most cost-effective solution to achieve 40% reliability target Dehiwala PSS F5.

Total length of the feeder	= 2.9km
Length need to paint insulator RTV coating Si-R	= 1.8 km
Length need be changed as MVCC	= 1.1 km
Expected SAIFI	=12.2 int/year/customer
Expected SAIDI	=403 min/year/customer
Total Investment	= 4.9 MLKR
Annual Maintenance Cost	=0.16 MLKR
SPP	=2 years
IRR%	= 41.1%
Benefit to Cost Ratio	= 6.1
Cost of improve 1% SAIFI	= 0.12 MLKR

7.2.2 Target (45% reduction of reliability target)

- SAIFI = 11.17 int/yr/cust.
- SAIDI = 402 min/yr/cust

Table 34: Selected results which have highest IRR% in each group of combination - Dehiwala PSS F5 (Target - 45% reduction of reliability indices)

Combination	SAIFI (int/yr/Cust.)	SAIDI (min/yr/Cust.)	SPP (Year)	IRR%	BCR	Cost / 1% SAIFI improvement (MLKR/1%)
BOH(RTV) 44%, UG 0%, CC 56%	11.1	347	2.48	32%	4.94	0.16
BOH(RTV) 44%, CC 56%	11.1	347	2.48	32%	4.94	0.16
UG 0% CC 100%	8.7	218	3.16	23%	3.84	0.21

This is the most cost-effective solution to achieve to achieve 45% reliability target Dehiwala PSS F5.

Total length of the feeder	= 2.9km
Length need to paint insulator RTV coating Si-R = 1.3 km	
Length need be changed as MVCC	= 1.6 km
Expected SAIFI	=11.1 int/year/customer
Expected SAIDI	=347 min/year/customer
Total Investment	=7.0 MLKR
Annual Maintenance Cost	=0.16 MLKR
SPP	=2.5 years
IRR%	=32%
Benefit to Cost Ratio	=4.94
Cost of improve 1% SAIFI	=0.16 MLKR

7.2.3 Target (35% reduction of reliability target)

- SAIFI = 13.12 int/yr/cust.
- SAIDI = 475 min/yr/cust

Table 35: Selected results which have highest IRR% in each group of combination - Dehiwala PSS F5 (Target - 35% reduction of reliability indices)

Combination	SAIFI (int/yr/Cust.)	SAIDI (min/yr/Cust.)	SPP (Year)	IRR%	BCR	Cost / 1% SAIFI improvement (MLKR/1%)
BOH(RTV) 81%, UG 0%, CC 19%	13.2	456	1.41	62%	8.8	0.08
BOH(RTV) 81%, CC 19%	13.2	456	1.41	62%	8.8	0.08
UG 0% CC 100%	8.7	218	3.16	23%	3.84	0.21

This is the most cost-effective solution to achieve to achieve 35% reliability target Dehiwala PSS F5.

Total length of the feeder	= 2.9km
Length need to paint insulator RTV coating Si-R	= 2.3 km
Length need be changed as MVCC	= 0.6 km
Expected SAIFI	=13.2 int/year/customer
Expected SAIDI	=456 min/year/customer
Total Investment	=2.9 MLKR
Annual Maintenance Cost	=0.16 MLKR
SPP	=1.4 years
IRR%	=62%
Benefit to Cost Ratio	=8.8
Cost of improve 1% SAIFI	=0.08 MLKR

7.3 RURAL FEEDER – MATHUGAMA GSS FEEDER 02

▶ *Selected options,*

1. MVBOH RTV Si-R Coating
2. MVABC
3. MVCC

▶ *Four combinations can be considered.*

- MVBOH RTV Si-R + MVABC + MVCC
- MVBOH RTV Si-R + MVABC
- MVBOH RTV Si-R + MVCC
- MVABC + MVCC

▶ *Range of percentage of each 04 option which are within defined reliability target.*

▶ *Three cases were studied for Mathugama GSS Feeder 02 based on the target of the reliability as reduction 40% & 32% from present reliability level.*

7.3.1 Target (40% reduction of reliability target)

- SAIFI = 42.4 int/yr/cust.
- SAIDI = 1124 min/yr/cust.

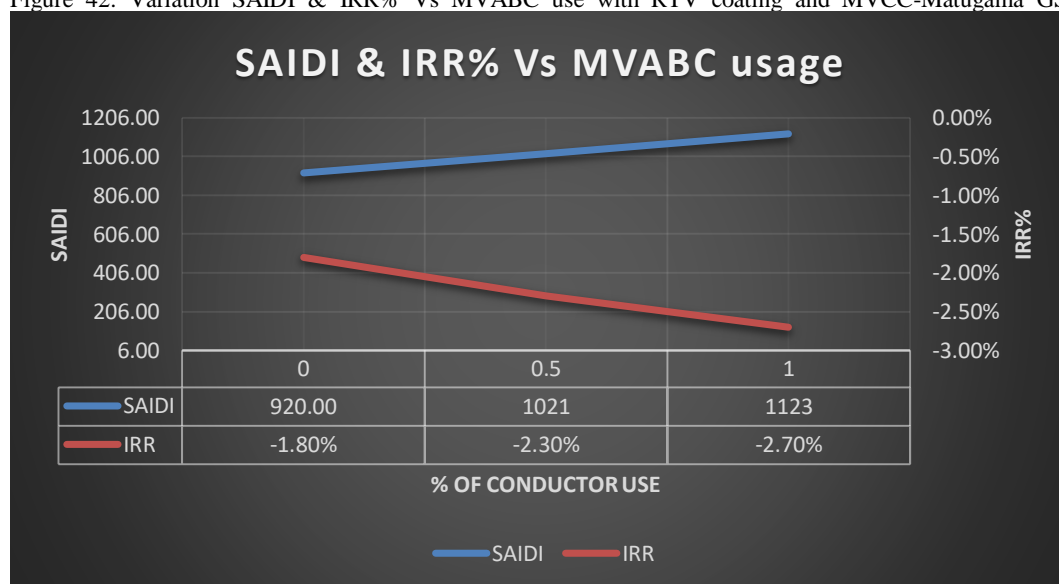
Table 36: Summary of obtained result using DisFeeRIA tool - Matugama GSS F2 (reduction 40% from present reliability level)

	Combination	Expect SAIFI (int/yr/Cust.)	Expected SAIDI (min/yr/Cust.)	SPP (Year)	IRR %	BCR	Investment (MLKR)	Maintenance cost (MLKR/year)
1	BOH(RTV) 28% MVABC 1% MVCC 71%	35.6	1123	22.3	-2.6%	0.74	570.2	14.8
	BOH(RTV) 29% MVABC 0% MVCC 71%	35.9	920	19.98	-1.8%	0.81	555.8	14.8
2	BOH(RTV) 62% MVCC 38%	42.2	1102	12.6	3%	1.33	321.6	14.5
	BOH(RTV) 0% MVCC 100%	30.4	760	25.5	-4%	0.62	763.5	15.1
3	BOH(RTV) 76% MVABC 24%	42.4	6198 (Not within the target)	-11.3	-	0.74	409.5	14.5
4	MVABC 1.5% MVCC 98.5%	30.2	1074	29.7	-4.8%	0.55	775.3	15.1
	MVABC 0% MVCC 100%	30.4	760	25.67	-4%	0.67	763.5	15.1

► Graphical illustration of SAIDI & IRR vs usage % of option & Sort again the range that IRR % > Discount Rate 7.5%. if this is not existing all combination check that IRR% > 0%.

1. MVBOH RTV Si-R + MVABC + MVCC

Figure 42: Variation SAIDI & IRR% Vs MVABC use with RTV coating and MVCC-Matugama GSS F2

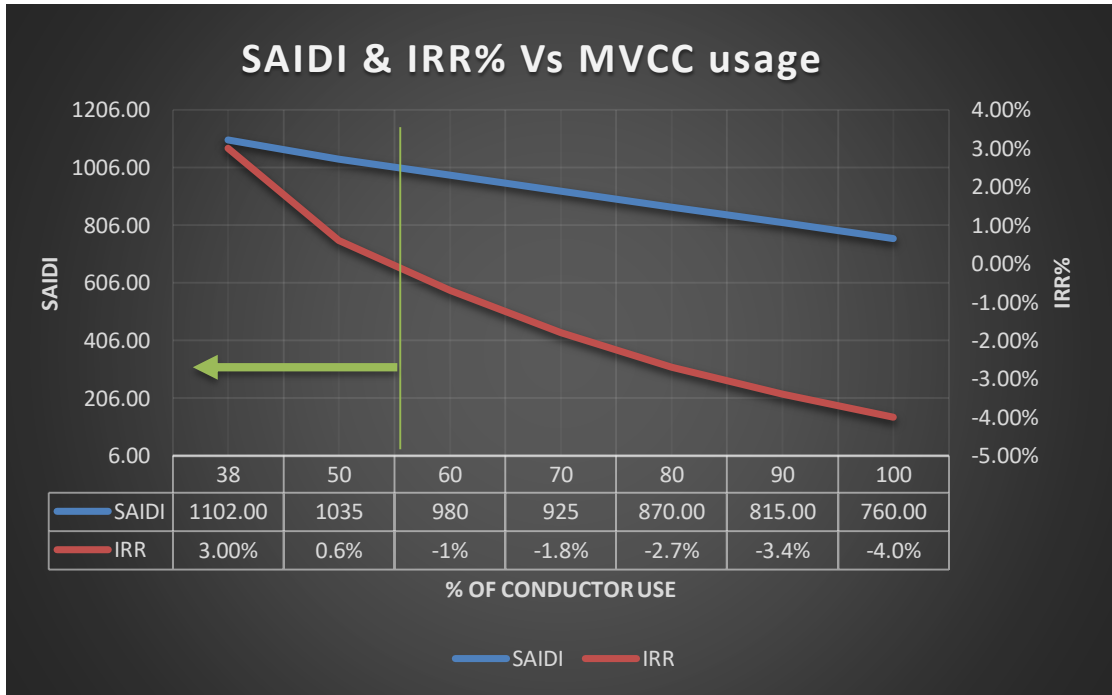


2. MVBOH RTV Si-R + MVABC

Target of SAIFI & SAIDI both could not be obtained simultaneously by using from this combination.

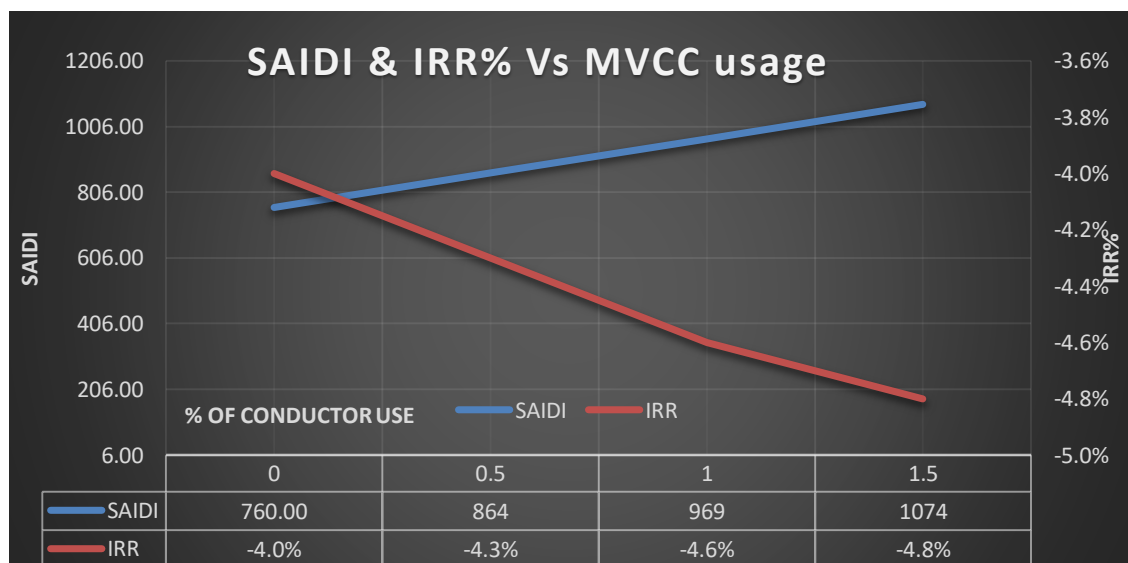
3. MVBOH RTV Si-R + MVCC

Figure 43: Variation SAIDI & IRR% Vs MVCC use with RTV coating – Mathugama GSS F2



4. MVABC + MVCC

Figure 44: Variation SAIDI & IRR% Vs MVABC use with MVCC – Matugama GSS F2



- ▶ *Select the maximum IRR% combination.*

Table 37: Selected results which have highest IRR% in each group of combination - Matugama GSS F2 (reduction 40% from present reliability level)

Combination	SAIFI (int/yr/Cust.)	SAIDI (min/yr/Cust.)	SPP (Year)	IRR%	BCR	Cost / 1% SAIFI improvement (MLKR/1%)
BOH(RTV) 62% MVCC 38%	42.2	1102	12.6	3%	1.33	7.98

This is the most cost-effective solution to achieve 40% reliability target Mathugama GSS Feeder 02.

Total length of the feeder	= 145 km
Length need to paint insulator RTV coating Si-R	= 89.9 km
Re-conductor with MVCC	= 55.1 km
Expected SAIFI	=42.2 int/year/customer
Expected SAIDI	=1102 min/year/customer
Total Investment	=321.6 MLKR
Annual Maintenance Cost	=14.5 MLKR
SPP	=12.6 years
IRR%	=3%
Benefit to Cost Ratio	=1.33

7.3.2 Target (32% reduction of reliability target)

- SAIFI = 48.1 int/yr/cust.
- SAIDI = 1274 min/yr/cust.

Table 38: Selected results which have highest IRR% in each group of combination - Matugama GSS F2 (Target - 32% reduction of reliability indices)

Combination	SAIFI (int/yr/Cust.)	SAIDI (min/yr/Cust.)	SPP (Year)	IRR%	BCR	Cost / 1% SAIFI improvement (MLKR/1%)
BOH(RTV) 55% MVABC 0% MVCC 44%	41.1	1069	14.09	1.6%	1.17	8.8
BOH(RTV) 92% MVCC 8%	47.96	1267	14.55	8.7%	2	3.3

This is the most cost-effective solution *to achieve 32% reliability target Mathugama GSS Feeder 02.*

- **Total length of the feeder** = 145 km
- **Length need to paint insulator RTV coating Si-R =133.4 km**
- **Length need be changed as MVCC** = **11.6 km**
- **Expected SAIFI** =48.0 int/year/customer
- **Expected SAIDI** =1267 min/year/customer
- **Total Investment** =107.3 MLKR
- **Annual Maintenance Cost** =14.3 MLKR
- **SPP** =14.6 years
- **IRR%** =8.7%
- **Benefit to Cost Ratio** =3.3

8 CONCLUSION

- ▶ *Most of the time, existing approaches to maintain a reliable supply by utilities are not economically oriented. However, most of approaches are required comparably high investment. Therefore, utilities should carefully invest on reliability improvement proposals in distribution networks.*
- ▶ *Methodology that is developed in this research can be used by utilities to reach the reliability target by improving the 33/11kV Distribution network conductors and its insulation.*
- ▶ *Developed software tool (DisFeeRIA – Distribution Feeder Reliability Improvement Analyzer) can be used for analyzing reliability improvement of any distribution feeder while considering economic aspects. (Especially in Divisional Planning of CEB).*
- ▶ *To find the cost-effective solution, Trial & Error method was used by alternating the percentage of conductor of each option in user input fields of DisFeeRIA software. Mathematical optimization of derived formula for Reliability indices and Economical indices have not been used in this study.*
- ▶ *Medium Voltage Covered Conductor and RTV Si-R coating for existing Medium Voltage Bare Overhead lines can be used for improving the reliability of Coastal, Urban & Rural distribution feeders in a cost-effective manner after proper analysis based on technical & economic aspects.*
- ▶ *However, depending on the safety concerns, Medium Voltage Underground Cable or Medium Voltage Aerial Bundle Conductor can be used irrespective of the economical aspect.*
- ▶ *Intelirrupter pulse closers can be used to replace traditional Auto Reclosers. (Especially with MVUGC, MVABC & MVCC) in rural feeders. It helps to reduce the momentary interruption failures and enhance the equipment lifetime by reducing thermal & mechanical stress on all distribution equipment & cables. Furthermore, it may help to improve the power quality of the system.*

9 FURTHER DEVELOPMENTS

This research output is produced with few limitations. Furthermore, some data need to be updated and analyzed to produce more accurate values. In this section, these areas are discussed.

9.1 LIMITED DATA

Medium Voltage Covered Conductors have been used from 1990s in CEB. Because of the failures of the earlier design, it had not been used anymore. But developed Covered Conductor (3-layer MVCC) is not yet used. It has been installed less than 1km length. Therefore, it is important to analyze more data after converting the 3 layer MVCC, to have more accurate value for failure rate improvement and Mean Time to Repair etc.

RTV coating of insulator have not been fixed in continuous section in present feeders. Therefore, it is very difficult to analyze the tripping data. Further analysis of failure improvement of RTV coating is very essential.

IntelluRupter Pulse Closer, which uses pulse closing technology is one of the emerging technologies in the world and is under developing stage. Therefore, further studies need to be conducted for obtaining more accurate value of improvement in MAIFI.

9.2 UPDATE THE DATA BASE

Technology is changing very fast. Therefore, living pattern of people, cost of production etc all are being changed every time. Cost of unserved energy, cost of investment & maintenance cost calculation figures should be updated at least once in two years.

9.3 ECONOMICAL EFFECT OF WAYLEAVES CLEARANCE TO ENVIRONMENT

Monetary value of tree, because of the way leave clearance is not included for cost element in this research. Furthermore, environmental effect is also not included in this value. Future studies should focus on these aspects.

9.4 ECONOMICAL EFFECT OF ENHANCED LIFE TIME OF EQUIPMENT & POWER QUALITY IN DISTRIBUTION NETWORK.

Reducing undesirable electrical stresses causes to enhance the life-time of distribution network equipment. Furthermore, it may enhance the power quality in the upstream network of the system by reducing momentary interruptions. These two aspects are not considered in the economic evaluation in this study. Therefore, future studies could focus on this topic.

9.5 OPTIMIZATION OF SOLUTION

Trial & error method was used to find the cost-effective solution to achieve the reliability target. However, future development can be considered for researchers to obtain the optimized solution by optimizing the mathematical formula, which used in this research to find the reliability indices & financial calculation.

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Cost for constructing 1km of 33kV Raccoon Line					<i>Annex I</i>
(a) Material cost as per PL price 2019 of CEB					
PL Code	Material	Unit	Qty	Unit Cost	Sub total
A 04 25	Poles - Concrete Pre-Stressed 11.0 m 350kg	Nos	8	33,380.00	267,040.00
A 04 30	Poles - Concrete Pre-Stressed 11.0 m 500kg	Nos	5	39,330.00	196,650.00
A 04 35	Poles - Concrete Pre-Stressed 11.0 m 850kg	Nos	4	52,320.00	209,280.00
A 04 37	Poles - Concrete Pre-Stressed 11.0 m 1200kg	Nos	1	77,040.00	77,040.00
B 04 10	Cross Arm - Pin G.S. 33 kV	Nos	11	8,660.00	95,260.00
B 04 20	Cross Arm - Tension G.S. 33 kV	Nos	4	16,870.00	67,480.00
B 05 15	Danger Boards - 33kV	Nos	15	513.00	7,695.00
B 07 10	Washer - G.I. 16 mm	Nos	127	29.00	3,683.00
B 07 40	Bolts & Nuts - G.I. 50 x 16 mm	Nos	49	74.00	3,626.00
B 07 55	Bolts & Nuts - G.I. 200 x 16 mm	Nos	40	152.00	6,080.00
B 07 70	Bolts & Nuts - G.I. 230 x 16 mm	Nos	20	200.00	4,000.00
B 07 75	Bolts & Nuts - G.I. 250 x 16 mm	Nos	8	224.00	1,792.00
B 07 85	Bolts & Nuts - G.I. 300 x 16 mm	Nos	8	285.00	2,280.00
B 07 90	Bolts & Nuts - G.I. 350 x 16 mm	Nos	2	340.00	680.00
B 08 15	Stay Wire - G.S. 7/4.00 mm - (Grade - 700)	kg	120	182.00	21,840.00
B 09 10	Stay Assembly Complete HT Galvanized 2.4 m x 20 mm	Nos	12	4,630.00	55,560.00
B 10 15	Thimbles - Galvanized 7/4.06 mm	Nos	12	27.00	324.00
B 02 50	Stay Clamps, G.I.	Nos	12	202.00	2,424.00
B 02 55	Strut Bracket - G.I.	Nos	3	666.00	1,998.00
B 03 70	Stainless Steel Straps, for Bundled Cable	Nos	10	148.00	1,480.00
B 07 05	Washer G.I. 12mm	Nos	12	18.00	216.00
C 01 20	Insulator - Stay HT	Nos	12	197.00	2,364.00
C 01 35	Insulator - Pin 33kV	Nos	42	3,930.00	165,060.00
C 01 40	Insulator Tension Set 36 kV with Hardware (Raccoon)	Nos	18	6,850.00	123,300.00
D 02 10	A.C.S.R. (Raccoon) - 7/4.09 mm - kg	kg	1005	443.00	445,215.00
D 06 05	Aluminium Binding Wire (No. 9) 3.6mm	kg	10	707.00	7,070.00
D 07 45	Compression Clamps Al/Al. 7/4.09(Raccoon) - 7/4.09(Raccoon) H Type	Nos	3	189.00	567.00
J 03 05	wire - G.S. (No. 6) 5 mm - kg	kg	152	202.00	30,704.00
J 03 40	Rods - Earth Steel Copper Clad 1.2m x 17 mm	Nos	4	3,020.00	12,080.00
J 03 50	Clips - Bull Dog 8 mm	Nos	4	285.00	1,140.00
W 07 05	Joint Compression Midspan (Raccoon) 7/4.09mm	Nos	3	2,770.00	8,310.00
W 07 30	Non Tension Sleeves (Raccoon) 7/4.09mm	Nos	9	696.00	6,264.00
D 07 45	Compression Clamps Al/Al. 7/4.09(Raccoon) - 7/4.09(Raccoon) H Type (For tapping ss)	Nos	6	189.00	1,134.00
Cost Summary					
A	TOTAL MATERIAL				1,829,640.00
B	WAYLEAVES				100,000.00
C	TOTAL TRANSPORT				192,000.00
D	LABOUR	Hrs	630	477.00	300,510.00
E	SUBSISTANCE	Hrs	70	400.00	28,000.00
F	CONTINGENCIES (2%) - Min LKR 3500.00				36,590.00
G	OVERHEAD	Hrs	630	346.00	217,980.00
I	OTHER COST				-
Construction Cost -33kV Raccoon Line					2,704,720.00
Reference					
1. Ceylon Electricity Board, "Construction standards for MV power distribution lines", Colombo, Sri Lanka, 1997.					
2. Ceylon Electricity Board, "Catalogue & Price List of Materials ", Colombo, Sri Lanka, 2019.					
Cost Summary					
• <i>Material Cost</i>				<i>1,866,230.00</i>	
• <i>Labor cost</i>				<i>546,490.00</i>	
• <i>Transport cost</i>				<i>192,000.00</i>	
• <i>Wayleaves</i>				<i>100,000.00</i>	
Total Cost				2,704,720.00	

Cost for constructing 1km of 11kV Raccoon Line					<i>Annex II</i>
(A) Material cost as per PL price 2019 of CEB					
PL Code	Material	Unit	Qty	Unit Cost	Sub total
A 04 25	Poles - Concrete Pre-Stressed 11.0 m 350kg	Nos	8	33,380.00	267,040.00
A 04 30	Poles - Concrete Pre-Stressed 11.0 m 500kg	Nos	5	39,330.00	196,650.00
A 04 35	Poles - Concrete Pre-Stressed 11.0 m 850kg	Nos	4	52,320.00	209,280.00
A 04 37	Poles - Concrete Pre-Stressed 11.0 m 1200kg	Nos	1	77,040.00	77,040.00
B 04 05	Cross Arm - Pin G.S. 11 kV	Nos	11	4,270.00	46,970.00
B 04 15	Cross Arm - Tension G.S. 11 kV	Nos	4	6,550.00	26,200.00
B 05 10	Danger Boards -11kV	Nos	15	513.00	7,695.00
B 07 10	Washer - G.I. 16 mm	Nos	127	29.00	3,683.00
B 07 40	Bolts & Nuts - G.I. 50 x 16 mm	Nos	49	74.00	3,626.00
B 07 55	Bolts & Nuts - G.I. 200 x 16 mm	Nos	40	152.00	6,080.00
B 07 70	Bolts & Nuts - G.I. 230 x 16 mm	Nos	20	200.00	4,000.00
B 07 75	Bolts & Nuts - G.I. 250 x 16 mm	Nos	8	224.00	1,792.00
B 07 85	Bolts & Nuts - G.I. 300 x 16 mm	Nos	8	285.00	2,280.00
B 07 90	Bolts & Nuts - G.I. 350 x 16 mm	Nos	2	340.00	680.00
B 08 15	Stay Wire - G.S. 7/4.00 mm - (Grade - 700)	kg	120	182.00	21,840.00
B 09 10	Stay Assembly Complete HT Galvanized 2.4 m x 20 mm	Nos	12	4,630.00	55,560.00
B 10 15	Thimbles - Galvanized 7/4.06 mm	Nos	12	27.00	324.00
B 02 50	Stay Clamps, G.I.	Nos	12	202.00	2,424.00
B 02 55	Strut Bracket - G.I.	Nos	3	666.00	1,998.00
B 03 70	Stainless Steel Straps, for Bundled Cable	Nos	10	148.00	1,480.00
B 07 05	Washer G.I. 12mm	Nos	12	18.00	216.00
C 01 20	Insulator - Stay HT	Nos	12	197.00	2,364.00
C 01 25	Insulator - Pin 11kV	Nos	42	1,800.00	75,600.00
C 01 30	Insulator Tension Set 11 kV	Nos	18	6,850.00	123,300.00
D 02 10	A.C.S.R. (Raccoon) - 7/4.09 mm	kg	1005	443.00	445,215.00
D 06 05	Aluminium Binding Wire (No. 9) 3.6mm	kg	10	707.00	7,070.00
D 07 45	Compression Clamps Al./Al. 7/4.09(Raccoon) - 7/4.09(Raccoon) H Type	Nos	3	189.00	567.00
J 03 05	wire - G.S. (No. 6) 5 mm	kg	152	202.00	30,704.00
J 03 40	Rods - Earth Steel Copper Clad 1.2m x 17 mm	Nos	4	3,020.00	12,080.00
J 03 50	Clips - Bull Dog 8 mm	Nos	4	285.00	1,140.00
W 07 05	Joint Compression Midspan (Raccoon) 7/4.09mm	Nos	3	2,770.00	8,310.00
W 07 30	Non Tension Sleeves (Raccoon) 7/4.09mm	Nos	9	696.00	6,264.00
D 07 45	Compression Clamps Al./Al. 7/4.09(Raccoon) - 7/4.09(Raccoon) H Type (For tapping ss)	Nos	6	189.00	1,134.00
Cost Summary					
A	TOTAL MATERIAL				1,650,606.00
B	WAYLEAVES				75,000.00
C	TOTAL TRANSPORT				192,000.00
D	LABOUR	Hrs	630	477.00	300,510.00
E	SUBSISTANCE	Hrs	70	400.00	28,000.00
F	CONTINGENCIES (2%) - Min LKR 3500.00				33,012.12
G	OVERHEAD	Hrs	630	346.00	217,980.00
I	OTHER COST				-
Construction Cost -33kV Raccoon Line					2,497,108.12
Reference					
1. Ceylon Electricity Board, "Construction standards for MV power distribution lines", Colombo, Sri Lanka, 1997.					
2. Ceylon Electricity Board, "Catalogue & Price List of Materials ", Colombo, Sri Lanka, 2019.					
Cost Summary					
• <i>Material Cost</i>				<i>1,683,620.00</i>	
• <i>Labor cost</i>				<i>546,490.00</i>	
• <i>Transport cost</i>				<i>192,000.00</i>	
• <i>Wayleaves</i>				<i>75,000.00</i>	
Total Cost				2,497,110.00	

Maintenance Cost of 33kV Raccoon Line per year per km					Annex III		
<i>MV line Maintenance Cost (Rural) - 33kV</i>							
No	Job description	km	Job No	Cost			
1	Maintenance of 33kV line at Gangalanga S/S to Puwakdola S/S - Reh 2km	2	5652	1,924,001.82			
2	33kV line at KB06D3 DDLO to Bandanagoda Sub (KB100)	3.5	5735	1,037,345.64			
3	Maintenance of 33kV line at Diganna DDLO to Harabakanada	6	5833	1,746,153.24			
4	Maintenance of 33kV line at Kapugedara DDLO	4	5918	319,503.00			
5	Maintenance of 33kV line at Jinaloka Mawatha S/S to Kuda Ambegoda	1.9	5919	182,464.00			
6	Maintenance of 33kV line at Ilukpotha DDLO(KA024D3N) to Ilukpotha S/S(KA092)	2	5920	298,123.00			
7	Maintenance of 33kV line at Naravila DDLO to Bopitiya S/S (KM011)	1.4	5949	694,864.84			
8	Maintenance of KM049D3N DDLO to KM064 S/S	3.5	6027	2,818,319.12			
9	Maintenance of 33kV line at KM034D3N DDLO to KM037 Makalamdawa S/S	1.3	6089	588,332.00			
10	Maintenance of 33kV line at KM050D3N DDLO to KM063 S/S	2.2	6121	328,293.00			
11	Maintenance of 33kV line at KM046D3N DDLO to Hallindola S/S(KM093)	3.5	6159	418,018.00			
12	Maintenance of 33kV line at Main line to Deegalla LBS	3.2	6160	347,175.00			
13	Maintenance of 33kV line at KMN006D3N DDLO to Deegalla LBS	2.7	6161	656,555.24			
14	Maintenance of 33kV line at KA010D3N DDLO to KA044 S/S	5.5	6163	623,112.08			
15	Maintenance of 33kV line at Thundola LBS to KM028 S/S	2.5	6234	1,673,912.56			
16	Maintenance of 33kV line at KM052D3N to KM101 S/S	1.8	6235	174,509.00			
17	Maintenance of 33kV line at KM051D3N to KM116 S/S	1.8	6237	173,476.00			
18	Maintenance of 33kV line at KM067D3N to KM122 S/S	1.5	6238	112,857.00			
		50.3		14,117,014.54			
	Annual Maintenance cost for 33kV line 1km [A] - 1 cycle per 2 year			140,330.00		LKR/km/year	
B	Way leave clearance cost per km			3,480.00		LKR/km	
	Annual Way leave clearance cost - 2 cycle per year			6,960.00		LKR/km	
C	Breakdown Cost - Natural due to fall of tree branch						
Material	Description	Unit	Quantity	Unit Price	Sub Total		
B 04 10	Cross Arm - Pin G.S. 33 kV	Nos	1	8,660.00	8,660.00		
C 01 35	Insulator - Pin 33kV	Nos	1	3,930.00	3,930.00		
D 06 05	Wire binding	kg	0.5	707.00	353.50		
W 05 30	Repair Sleeve Tension for ACSR 7/4.09mm	Nos	1	514.00	514.00		
A 04 25	PS pole 11m/350kg	Nos	1	33,380.00	33,380.00		
a	TOTAL MATERIAL					46,837.50	
b	WAYLEAVES						
C	VAN/D CAB	LKR/KM		40.00	-		
	CREW CAB/SMALL LORRY	LKR/KM	50	60.00	3,000.00		
	LARGE LORRY	LKR/KM		70.00	-		
	CRANE/AUGOR/BUCKET LORRY	LKR/KM	50	90.00	4,500.00		
	CRANE/BUCKET LORRY (LIFTING)	Hrs	4	1,500.00	6,000.00		
	AUGOR (WORKING)	Hrs	4	2,000.00	8,000.00		
	HIRED VEHICLE 1	LKR/KM		60.00	-		
	HIRED VEHICLE 2	LKR/KM					
		LKR/KM					

c	TOTAL TRANSPORT				21,500.00
d	LABOUR	Hrs	72	477.00	34,340.00
e	SUBSISTANCE	Hrs	8	400.00	3,200.00
f	CONTINGENCIES (2%) - Min LKR 3500.00				3,500.00
g	OVERHEAD	Hrs	72	346.00	24,910.00
i	OTHER COST				-
	Breakdown Cost - Natural due to fall of tree branch [C]				134,290.00
D	Breakdown Cost - Flash over of insulator				
Material	Description	Unit	Quantity	Unit Price	Sub Total
C 01 35	Insulator - Pin 33kV	Nos	1	3,930.00	3,930.00
D 06 05	Wire binding	kg	0.5	707.00	353.50
a	TOTAL MATERIAL				4,283.50
b	WAYLEAVES				-
c	TOTAL TRANSPORT				7,200.00
d	LABOUR	Hrs	12	477.00	5,724.00
e	SUBSISTANCE	Hrs	1	400.00	200.00
f	CONTINGENCIES (2%) - Min LKR 3500.00				3,500.00
g	OVERHEAD	Hrs	12	346.00	4,152.00
i	OTHER COST				-
	Breakdown Maintenace Cost due to flash over of insulatos (D)				25,060.00
Breakdown cost by assuming 1 fallen of tree per 10 years and insulator flashover per 2 year.					
(A+B+C/10+D/2) - LKR/km/year					173,250.00

Maintenance Cost of 11kV Raccoon Line per year per km					<i>Annex IV</i>
<i>MV line Routine Maintenance Cost - 11kV</i>					
No	Job description	km	Job No	Cost	
1	Kalubowila PSS to Wikies LBS	7.6	5748/2018D	886,170.00	
			5707/2018D	1,275,773.00	
2	Saranankara Police LBS to Pamankada SF6 LBS	3.75	5945/2018D	152,632.00	
3	Pamankada SF6 LBS to Mudali Mawatha SF6 LBS	3.1	5749/2018D	619,775.00	
4	Peters Lane LBS to Highlevel Road	3.2	5462/2018D	507,376.00	
5	Kalubowila PSS to Nelus ABS	11.6	5845/2018D	902,357.40	
6	Alubogahawaththa LBS to Kohuwala Gantry LBS	5.3		386,484.40	
7	Galvihara Road Junction to Municiple Council	4.7	5942/2018D	407,522.00	
8	AGA Office LBS to Wikies LBS	5.75	5866/2018D	857,665.00	
9	Karagampitiya Junction LBS to Galvihara Road Junction LBS	4.2	5960/2018D	227,186.00	
10	Station Road LBS to AGA Office LBS	3.95	5855/2018D	555,954.00	
11	Dehiwala PSS to Station Road LBS	2.15	5848/2018D	453,121.00	
12	Nadimala Gantry to Galle Road	4.8	5900/2018D	578,031.00	
13	Dehiwala PSS to Aurban's place LBS	1.3	5867/2018D	185,150.00	
14	Keselkotuwa DDLO to Galle Road	2.1	5844/2018D	223,193.00	
15	Dehiwala PSS to Telecom Gantry	2.55	6030/2019D	206,425.00	
16	Dehiwala PSS to Kaudana Broudway LBS	1.55	6076/2019D	147,766.40	
17	Flam Beach Hotel LBS to Telecom LBS	1.8	6014/2019D	193,434.40	
18	Suntel LBS to Hotel Road LBS	1.85	5984/2019D	249,346.40	
19	Mt- Lavinia Station Road LBS to Pham Beach Hotel LBS	0			
20	Attidiya PSS to Watarappala Road LBS and Kawdana Broadway LBS	5.3	5985/2019D	386,484.40	
21	Templers Road Junction to Suntel LBS	2.3	6074/2019D	260,546.00	
22	Templers Road Junction to Katukurunduwatta Junction LBS	2.55	5938/2018D	270,665.00	
23	Attidiya PSS to KALAPURA LBS & Katukurunduwatta LBS	2.7	6075/2019D	179,794.00	
24	Lake road LBS to Nadimala Gantry LBS & Alubogahawatta LBS	4.45	5946/2018D	274,787.00	
			5944/2018D	287,647.00	
25	Kalubowila PSS to Nadimala Gantry & Galvihara road LBS ,Dehiwala GSS to Balapokuna line End Dehiwala 1,3 (Combine 33kV and 11kV)	2.6	6197/2019D	714,806.80	
26	Athtidiya PSS to Nedimala Gantry 11kV F6 & Dehiwala 33kV F06 & F 08 From Dehiwala GSS to Attidiya PSS	5	6079/2019D	297,065.00	
27	Attidiya PSS to Katukurunduwatta LBS	1.4	RM/426D	249,346.40	
28	Attidiya PSS to Dehiwala PSS	1.3	6077/2019D	243,629.00	
		102.1		12,180,132.60	
Line Maintenance cost (A) - 1 cycle per 2 year				59,650.00	LKR/km/Year

B	Way leave clearance cost per km			3,480.00	LKR/km
	Annual Way leave clearance cost - 2 cycle per year			6,960.00	LKR/km
C	Breakdown Cost - Accident and pole damage				
Material	Description	Unit	Quantity	Unit Price	Sub Total
A 04 25	PS pole 11m/350kg	Nos	1	33380	33380
C 01 25	Insulator 11kV pin	Nos	1	1800	1800
D 06 05	Wire binding	kg	0.5	707	353.5
A	TOTAL MATERIAL				35,533.50
B	WAYLEAVES				
		LKR/KM			
C	TOTAL TRANSPORT				21,500.00
D	LABOUR	Hrs	72	477.00	34,344.00
E	SUBSISTANCE	Hrs	8	400.00	3,200.00
F	CONTINGENCIES (2%) - Min LKR 3500.00				710.67
G	OVERHEAD	Hrs	72	346.00	24,912.00
I	OTHER COST				-
	Breakdown Maintenace Cost due to accident (C)				120,200.00
D	Breakdown Cost - Flash over of insulator				
Material	Description	Unit	Quantity	Unit Price	Sub Total
C 01 25	Insulator 11kV pin	Nos	1	1,800.00	1,800.00
D 06 05	Wire binding	kg	0.5	707.00	353.50
A	TOTAL MATERIAL				2,153.50
B	WAYLEAVES				
C	VAN/D CAB	LKR/KM		40.00	-
	CREW CAB/SMALL LORRY	LKR/KM	20	60.00	1,200.00
	LARGE LORRY	LKR/KM		70.00	-
	CRANE/AUGOR/BUCKET LORRY	LKR/KM	0	90.00	-
	CRANE/BUCKET LORRY (LIFTING)	Hrs	4	1,500.00	6,000.00
	AUGOR (WORKING)	Hrs	0	2,000.00	-
	HIRED VEHICLE 1	LKR/KM		60.00	-
	HIRED VEHICLE 2	LKR/KM			
		LKR/KM			
C	TOTAL TRANSPORT				7,200.00
D	LABOUR	Hrs	12	477.00	5,724.00
E	SUBSISTANCE	Hrs	1	400.00	200.00
F	CONTINGENCIES (2%) - Min LKR 3500.00				3,500.00
G	OVERHEAD	Hrs	12	346.00	4,152.00
I	OTHER COST				-
	Breakdown Maintenace Cost due to flash over of insulatos (D)				22,930.00
Breakdown cost by assuming 1 vehicle accident per 10 years and insulator flashover per 2 year.					
(A+B+C/10+D/2) - LKR/km/year					90,100.00

Cost for constructing 240sqmm, 3C,XLPE,33kV UG cable					<i>Annex V</i>
Material					
PL code	Item Description	Unit	Qty	Unit Price	Sub Total
M 14 36	33kV/240mm2 /3C/CU/XLPE/SWA/UG Cable	m	1000	16,870.00	16,870,000.00
V 12 10	HT Cable Tiles	Nos.	3000	296.00	888,000.00
NPL	Warning Tapes	m	1000	21.00	21,000.00
N 19 15	End Termination Kit HS Outdoor - 33kV/240sqmm/3C/XLPE/SWA UG Cable (without Sockets)	Nos.	4	57,460.00	229,840.00
N 19 10	End Termination Kit HS Indoor - 33kV/240sqmm/3C/XLPE/SWA UG Cable (without Sockets)	Nos.	6	48,510.00	291,060.00
N 11 12	Straight Through Joint HS- 33kV/240mm2 /3C/CU/XLPE/SWA	Nos.	3	111,110.00	333,330.00
P 01 99	Ferrules Cu. Crimp type for (10KV - 30KV) - HV/240sqmm		9	2,810.00	
G 03 10	Surge Arrestors 33kV - 10 kA	Nos.	6	9,650.00	57,900.00
	Sand	cube	124	18,000.00	2,224,824.00
	Quarry dust	cube	43	8,000.00	346,083.73
	ABC	cube	74	8,000.00	593,286.40
	Ring Main Unit (Oil) 33kV	Nos.	2	1,815,600.00	3,631,200.00
a	TOTAL MATERIAL				25,486,524.14
b	Excavation+Cable handling+Backfilling+ Cable laying				3,201,630.00
c	TRANSPORT				70,000.00
d	LABOUR for Jointing & termination	Hrs	900	345.00	310,500.00
f	OVERHEAD for Jointing & termination	Hrs	900	185.00	166,500.00
g	Authority payment for excavtion	m	1000	5787.17	5,787,171.12
i	OTHER COST				-
Construction Cost - 240sqmm, 3C,XLPE,33kV UG cable					35,022,325.26
Cost Summary					
	• <i>Material Cost</i>				<i>25,486,520.00</i>
	• <i>Labor cost</i>				<i>3,678,630.00</i>
	• <i>Transport cost</i>				<i>70,000.00</i>
	• <i>Authority</i>				<i>5,787,170.00</i>
	Total Cost				35,022,320.00

				<i>Annex VII</i>
<u>Cost to be paid for excavation, Cable handling, Laying and backfilling to lay MV UG cable 1km</u>				
Cost category as per Approved rates in CC 2019/2020		Qty	Rate (LKR)	Sub total (LKR)
A	Excavation (Carpet) - per m ³	500	3,996.00	1,998,000.00
B	Cable Handling - per m (Group 5)	1000	500.00	500,000.00
C	Backfilling - per m ³	500	930.00	465,000.00
D	Excess Earth removing - per m ³	50	1,492.00	74,600.00
E	Other related work - per m	0	146.00	-
F	Wash the road - per m	1000	88.00	88,000.00
G	CRS 1 Coating - perm	0	98.00	-
H	Forklift (8000/= per 4hr and additional hr 3000/=)			-
Hiring	Rammer machine hiring charges	7	7,290.00	51,030.00
Equipmen	Demolishing machine breaker	5	5,000.00	25,000.00
Excavation+Cable handling+Backfilling+ Cable laying				<u>3,201,630.00</u>
<u>Authority payment for excavtion - Average cost per meter has been paid on 2018 to RDA for laying MV UG cable from Ratmalana GSS to Angulana PSS - 1.93km</u>				
	Authority	Length (m)	Cost (LKR)	Cost Per m (LKR)
	Road Development Authority (RDA)	116	610,283.50	5,261.06
	After 10% allowance to adjust 2020 - LKR/m			<u>5,787.17</u>
Reference				
1. Ceylon Electricity Board, "Approved rates in Colombo City Branch 2019/2020", Colombo, Sri Lanka, 2019.				

Maintenance Cost of 33kV 240mm² /Cu/XLPE/SWA Line per year per km				Annex VIII	
RMU maintenance cost(A)					
	Maintenance Cost for RMU	48,186.00	per RMU		
	Maintenance cycle of RMU	4.00	years		
	Maintenance cost for RMU	12,050.00	per RMU per annum		
	No of SS per km	2.00	Nos.		
	Maintenance cost per year per km (A)	24,100.00	/km /year		
Breakdown maintenance cost of 33kV, 240sqmm, 3C UG cable (B)					
PL code	Item Description	Unit	Qty	Quantity	Sub Total
M 14 36	33kV/240mm ² /3C/CU/XLPE/SWA/UG Cable	m	10	16,870.00	168,700.00
V 12 10	HT Cable Tiles	Nos.	30	296.00	8,880.00
NPL	Warning Tapes	m	10	21.00	210.00
N 11 12	Straight Through Joint HS- 33kV/240mm ² /3C/CU/XLPE/SWA	Nos.	2	111,110.00	222,220.00
G 02 10	Surge Arrestors 33kV - 10 kA	Nos.	0		-
	Sand	cube	2	18,000.00	36,000.00
	Quarry dust	cube	1	8,000.00	8,000.00
	ABC	cube	1	8,000.00	8,000.00
a	TOTAL MATERIAL				452,010.00
b	Excavation+Cable handling+Backfilling+ Cable laying				37,666.00
c	TRANSPORT				30,000.00
d	LABOUR for Jointing & termination	Hrs	144	477.00	68,688.00
f	OVERHEAD for Jointing & termination	Hrs	144	346.00	49,824.00
g	Authority payment for excavtion	m	10	5787.17	57,871.70
i	OTHER COST				-
	Breakdown maintenace cost per breakdown- 240sqmm, 3C,XLPE,33kV UG cable (B)				696,060.00
Annual cost of maintenace 1 breakdown per 10 years (A+B/10) - per km per year					93,710.00

Maintenance Cost of 11kV 240mm² /Cu/XLPE/SWA Line per year per km				Annex IX	
RMU maintenance cost(A)					
	Maintenance Cost for RMU	48,186.00	per RMU		
	Maintenance cycle of RMU	4.00	years		
			per RMU per annum		
	Maintenance cost for RMU	12,050.00			
	No of SS per km	2.00	Nos.		
	Maintenance cost per year per km (A)	24,100.00	/km /year		
Breakdown maintenance cost of 33kV, 240sqmm, 3C UG cable (B)					
PL code	Item Description	Unit	Qty	Quantity	Sub Total
M 12 35	11kV/240mm2 /3C/CU/XLPE/SWA/UG Cable	m	10	14,230.00	142,300.00
V 12 10	HT Cable Tiles	Nos.	30	296.00	8,880.00
NPL	Warning Tapes	m	10	21.00	210.00
N 11 04	Straight Through Joint HS- 11kV/240mm2 /3C/CU/XLPE/SWA	Nos.	2	27,700.00	55,400.00
G 02 10	Surge Arrestors 11kV - 10 kA	Nos.	0		-
	Sand	cube	2	18,000.00	33,372.36
	Quarry dust	cube	1	8,000.00	5,191.26
	ABC	cube	1	8,000.00	8,899.30
Summary of cost					
a	Total Material				254,252.91
b	Excavation+Cable handling+Backfilling+ Cable laying				37,666.00
c	TRANSPORT				30,000.00
d	LABOUR for Jointing & termination	Hrs	144	477.00	68,688.00
f	OVERHEAD for Jointing & termination	Hrs	144	346.00	49,824.00
g	Authority payment for excavtion	m	10	5787.17	57,871.70
i	OTHER COST				-
	Breakdown maintenace cost per breakdown- 240sqmm, 3C,XLPE,11kV UG cable (B)				498,300.00
Annual cost of maintenace 1 breakdown per 10 years (A+B/10) - per km per year					73,930.00

Calculation failure rate improvement of MVUGC			Annex X	
<i>1. Dehiwala PSS feeder 01 (Underground Cable)</i>				
Month	# Interruptions			
Oct-18	0			
Nov-18	0			
Dec-18	0			
Jan-19	0			
Feb-19	0			
Mar-19	0			
Apr-19	1			
May-19	1			
Jun-19	0			
Jul-19	1			
Aug-19	0			
Sep-19	0			
Length	3.2	km		
Total interruptions	3	Nos		
FR _{UG}	0.94	#/km/year		
<i>2. Dehiwala PSS feeder 05 (Bare Overhead Line)</i>				
Month	# Interruptions			
Oct-18	0			
Nov-18	2			
Dec-18	0			
Jan-19	0			
Feb-19	1			
Mar-19	0			
Apr-19	2			
May-19	1			
Jun-19	4			
Jul-19	3			
Aug-19	0			
Sep-19	1			
Length	2.9	km		
Total interruptions	14	Nos		
FR _{BOH}	4.83	#/km/year		
Improvement of failure rate compared with MVBOH	$(FR_{BOH} - FR_{UGC}) / FR_{BOH} \%$			
	81%			

Calculation Mean Time to Repair of MVUGC		<i>Annex XI</i>
<i>Medium voltage failure report of Colombo city province of CEB</i>		
Month	Interruption duration (min)	No of interruptions
<i>Nov-18</i>	29,960	86
<i>Dec-18</i>	27,704	78
<i>Jan-19</i>	20,271	63
<i>Feb-19</i>	19,560	60
<i>Mar-19</i>	32,355	96
<i>Apr-19</i>	14,664	42
<i>May-19</i>	20,585	56
<i>Jun-19</i>	10,026	35
<i>Jul-19</i>	6,838	24
<i>Aug-19</i>	9,424	36
<i>Sep-19</i>	18,389	56
Total interruption duration	209,776	minutes
Total no of interruption	632	# interruptions
Mean Time to Repair(MTTR ug)	332	min/#interruption

Cost for constructing ABC 33kV 3 x 150 + 50 sqmm					Annex XII
Material					
PL code	Item Description	Unit	Qty	Unit Price	Sub Total
A 04 30	Poles Concrete Prestressed 11m/ 500kg	Nos.	34	39,300.00	1,336,200.00
A 04 30	Strut Poles Concrete Prestressed 11m/ 500kg	Nos.	1	39,300.00	39,300.00
B 02 50	Stay Clamps, G.I.	Nos.	5	202.00	1,010.00
B 08 15	Stay Wire - G.S. 7/4.00 mm - (Grade - 700)	kg	50	182.00	9,100.00
B 10 15	Thimbles - Galvanized 7/4.06 mm	Nos.	5	27.00	135.00
B 09 10	Stay Assembly Complete HT Galvanized 2.4 m x 20 mm	Nos.	5	4,630.00	23,150.00
B 02 55	Strut Bracket - G.I.	Nos.	1	666.00	666.00
B 07 75	Bolts & Nuts - G.I. 250 x 16 mm	Nos.	3	224.00	672.00
B 16 09	Suspension Assembly for ABC 33 kV (For 50 sqmm G.S. Messenger)	Nos.	22	6,170.00	135,740.00
B 16 19	Dead End Assembly for ABC 33 kV (For 50 sqmm G.S. Messenger)	Nos.	4	15,960.00	63,840.00
B 16 13	Large Angle Assembly for ABC 33 kV (For 50 sqmm G.S. Messenger)	Nos.	2	32,590.00	65,180.00
B 22 60	Composite Cable Joint tray C/W Galvanized Mounting Bracket for ABC 33 kV	Nos.	3	15,400.00	46,200.00
D 12 33	Straight Through Joints Insulated for ABC 33 kV 3 x 150 + 50 sqmm	Nos.	1	275,580.00	275,580.00
D 17 66	Earth Bond Messenger Earthing Kit for ABC 33 kV (50 sqmm G.S Messenger)	Nos.		8,590.00	-
D 15 65	Termination Kit for ABC 33 kV 3 x 150 + 50 sqmm	Nos.	4	67,630.00	270,520.00
G 03 10	Surge Arrestors 33kV - 10 kA	Nos.	6	9,650.00	57,900.00
L 08 65	Aerial Bundled Conductor Alu.(ABC) 33 kV 3 x 150 + 50 sqmm	m	1000	5,430.00	5,430,000.00
B 05 15	Danger Boards - 33kV	Nos.	15	513.00	7,695.00
D 12 88	T - Off Joints insulated for ABC 33kV 3 x 150 + 50 sqmm	Nos.	2	623,930.00	1,247,860.00
B 04 20	Cross Arm - Tension G.S. 33kV	Nos.	3	16,870.00	50,610.00
L 07 17	Cable Cu. PVC Insulated - single (for earthing) 50sqmm	m	24	735.00	17,640.00
	Earth cage	Nos.	2	1,500.00	3,000.00
	Sand	Cube	0.125	18,000.00	2,250.00
	Cement	Cube	5	950.00	4,750.00
	3/4" metal	Cube	0.25	6,500.00	1,625.00
J 03 03	Copper Bonded Steel Rod for Concrete Block	Nos.	2	2,530.00	5,060.00
J 03 04	Weld Metal Tube for Exothermic Earth Connection	Nos.	2	815.00	1,630.00
P 04 12	Socket Cable Crimp type Cu. 50sqmm	Nos.	10	79.00	790.00
Cost Summary					
A	MATERIAL TOTAL				9,098,103.00
B	WAYLEAVES TOTAL				-
C	TRANSPORT TOTAL				280,500.00
D	LABOUR	Hrs	900	477.00	429,300.00
E	SUBSISTANCE	Hrs	100	400.00	40,000.00
F	CONTINGENCIES (2%) - Min LKR 3500.00				181,962.06
G	OVERHEAD	Hrs	900	346.00	311,400.00
I	OTHER COST				-
Construction Cost -33kV Racoon Line					10,341,265.06
Cost Summary					
	• Material Cost		9,280,070.00		
	• Labor cost		780,700.00		
	• Transport cost		280,500.00		
	• Wayleaves		-		
	Total Cost		10,341,270.00		

Cost for constructing ABC 11kV 3 x 150 + 50 sqmm					Annex XIII
Material					
PL code	Item Description	Unit	Qty	Unit Price	Sub Total
A 04 30	Poles Concrete Prestressed 11m/ 500kg	Nos.	34	39,300.00	1,336,200.00
A 04 30	Strut Poles Concrete Prestressed 11m/ 500kg	Nos.	1	39,300.00	39,300.00
B 02 50	Stay Clamps, G.I.	Nos.	5	202.00	1,010.00
B 08 15	Stay Wire - G.S. 7/4.00 mm - (Grade - 700)	kg	50	182.00	9,100.00
B 10 15	Thimbles - Galvanized 7/4.06 mm	Nos.	5	27.00	135.00
B 09 10	Stay Assembly Complete HT Galvanized 2.4 m x 20 mm	Nos.	5	4,630.00	23,150.00
B 02 55	Strut Bracket - G.I.	Nos.	1	666.00	666.00
B 07 75	Bolts & Nuts - G.I. 250 x 16 mm	Nos.	3	224.00	672.00
B 16 08	Suspension Assembly for ABC 11 kV (For 50 sqmm G.S. Messenger)	Nos.	22	6,110.00	134,420.00
B 16 18	Dead End Assembly for ABC 11 kV (For 50 sqmm G.S. Messenger)	Nos.	4	15,300.00	61,200.00
B 16 12	Large Angle Assembly for ABC 11 kV (For 50 sqmm G.S. Messenger)	Nos.	2	30,700.00	61,400.00
B 22 55	Composite Cable Joint tray C/W Galvanized Mounting Bracket for ABC 11 kV	Nos.	3	15,400.00	46,200.00
D 12 31	Straight Through Joints Insulated for ABC 11 kV 3 x 150 + 50 sqmm	Nos.	1	252,770.00	252,770.00
D 18 66	Earth Bond Messenger Earthing Kit for ABC 11 kV (50 sqmm G.S Messenger)	Nos.		10,430.00	-
D 15 55	Termination Kit for ABC 11 kV 3 x 150 + 50 sqmm	Nos.	4	67,000.00	268,000.00
G 02 10	Surge Arrestors 11kV - 10 kA	Nos.	6	5,240.00	31,440.00
L 08 55	Aerial Bundled Conductor Alu.(ABC) 11 kV 3 x 150 + 50 sqmm	m	1000	4,060.00	4,060,000.00
B 05 10	Danger Boards - 11kV	Nos.	15	513.00	7,695.00
D 12 86	T - Off Joints insulated for ABC 11 kV 3 x 150 + 50 sqmm	Nos.	2.0	541,800.00	1,083,600.00
B 04 15	Cross Arm - Tension G.S. 11 kV	Nos.	3	6,550.00	19,650.00
L 07 17	Cable Cu. PVC Insulated - single (for earthing) 50sqmm	m	24	735.00	17,640.00
	Earth cage	Nos.	2	1,500.00	3,000.00
	Sand	Cube	0.125	18,000.00	2,250.00
	Cement	Cube	5	950.00	4,750.00
	3/4" metal	Cube	0.25	6,500.00	1,625.00
J 03 03	Copper Bonded Steel Rod for Concrete Block	Nos.	2	2,530.00	5,060.00
J 03 04	Weld Metal Tube for Exothermic Earth Connection	Nos.	2	815.00	1,630.00
P 04 12	Socket Cable Crimp type Cu. 50sqmm	Nos.	10	79.00	790.00
Cost Summary					
A	MATERIAL TOTAL				7,473,353.00
B	WAYLEAVES TOTAL				-
C	TRANSPORT TOTAL				280,500.00
D	LABOUR	Hrs	900	477.00	429,300.00
E	SUBSISTANCE	Hrs	100	400.00	40,000.00
F	CONTINGENCIES (2%) - Min LKR 3500.00				149,467.06
G	OVERHEAD	Hrs	900	346.00	311,400.00
I	OTHER COST				-
Construction Cost -33kV Racoon Line					8,684,020.06
Cost Summary					
	• Material Cost		7,622,820.00		
	• Labor cost		780,700.00		
	• Transport cost		280,500.00		
	• Wayleaves		-		
	Total Cost		8,684,020.00		

Maintenance Cost of ABC 33kV 3 x 150 + 50 sqmm					Annex XIV.
<i>Breakdown Cost - Due to fall of tree(A)</i>					
PL code	Item Description	Unit	Qty	Unit Price	Sub Total
A 04 30	Poles Concrete Prestressed 11m/ 500kg	Nos.	1	39,300.00	39,300.00
B 16 19	Dead End Assembly for ABC 33kV (For 50 sqmm G.S. Messenger)	Nos.	2	15,960.00	31,920.00
B 22 60	Composite Cable Joint tray C/W Galvanized Mounting Bracket for ABC 33 kV	Nos.	2	15,400.00	30,800.00
D 12 33	Straight Through Joints Insulated for ABC 33kV 3 x 150 + 50 sqmm	Nos.	2	275,580.00	551,160.00
L 08 65	Aerial Bundled Conductor Alu.(ABC) 33kV 3 x 150 + 50 sqmm	m	30	5,430.00	162,900.00
B 05 15	Danger Boards - 11kV	Nos.	1	513.00	513.00
A	MATERIAL TOTAL				816,593.00
B	WAYLEAVES TOTAL				-
	TRANSPORT TOTAL				44,100.00
D	LABOUR	Hrs	180	477.00	85,860.00
E	SUBSISTANCE	Hrs	20	400.00	8,000.00
F	CONTINGENCIES (2%) - Min LKR 3500.00				16,331.86
G	OVERHEAD	Hrs	180	346.00	62,280.00
I	OTHER COST				-
	Breakdown Cost - Due to fall of tree(A)				1,016,830.00
	<i>Way leaves cost (B) - 1 cycle per year - LKR per km annum</i>				3480.00
	Annual cost of maintenace 1 breakdown per 10 years (A+B/10) - LKR per km per year				<u>105,160.00</u>

Maintenance Cost of MVABC 11kV 3 x 150 + 50 sqmm					Annex XV
<i>Breakdown Cost - Due to fall of tree(A)</i>					
PL code	Item Description	Unit	Qty	Unit Price	Sub Total
A 04 30	Poles Concrete Prestressed 11m/ 500kg	Nos.	1	39,300.00	39,300.00
B 16 18	Dead End Assembly for ABC 11 kV (For 50 sqmm G.S. Messenger)	Nos.	2	15,300.00	30,600.00
B 22 55	Composite Cable Joint tray C/W Galvanized Mounting Bracket for ABC 11 kV	Nos.	2	15,400.00	30,800.00
D 12 31	Straight Through Joints Insulated for ABC 11 kV 3 x 150 + 50 sqmm	Nos.	2	252,770.00	505,540.00
L 08 55	Aerial Bundled Conductor Alu.(ABC) 11 kV 3 x 150 + 50 sqmm	m	30	4,060.00	121,800.00
B 05 10	Danger Boards - 11kV	Nos.	1	513.00	513.00
A	MATERIAL TOTAL				728,553.00
B	WAYLEAVES TOTAL				0
	TRANSPORT TOTAL				44,100.00
D	LABOUR	Hrs	180	477.00	85,860.00
E	SUBSISTANCE	Hrs	20	400.00	8,000.00
F	CONTINGENCIES (2%) - Min LKR 3500.00				14,571.06
G	OVERHEAD	Hrs	180	346.00	62,280.00
I	OTHER COST				-
	Breakdown Cost - Due to fall of tree(A)				928,790.00
	<i>Way leaves cost (B) - 1 cycle per year- LKR per km annum</i>				3480.00
	Annual cost of maintenace cost by assumij1 breakdown per 10 years (A+B/10) - LKR per km per year				96,360.00

Calculation failure rate improvement of		<i>Annex XVI</i>
<i>Failure details of Wind power plant located at Puttalam (MVABC)</i>		
Month	No of interruptions	Interruption duration (min)
<i>Dec-17</i>	1	12
<i>Jan-18</i>	0	0
<i>Feb-18</i>	0	0
<i>Mar-18</i>	0	0
<i>Apr-18</i>	0	0
<i>May-18</i>	0	0
<i>Jun-18</i>	0	0
<i>Jul-18</i>	0	0
<i>Aug-18</i>	0	0
<i>Sep-18</i>	0	0
<i>Oct-18</i>	1	12
<i>Nov-18</i>	0	0
<i>Dec-18</i>	0	0
<i>Jan-19</i>	1	24
<i>Feb-19</i>	2	48
<i>Mar-19</i>	1	12
<i>Apr-19</i>	1	24
<i>May-19</i>	1	14
Length	22	km
Total interruptions	8	Nos
FR _{UG}	0.24	#/km/year
<i>Failure details of Puttalam GSS feeder 3 (MVBOH)</i>		
Month	No of interruptions	
Oct-18	5	
Nov-18	8	
Dec-18	1	
Jan-19	0	
Feb-19	4	
Mar-19	1	
Apr-19	1	
May-19	7	
Jun-19	2	
Jul-19	1	
Aug-19	9	
Sep-19	17	
Length	64.5	km
Total interruptions	56	Nos
FR _{BOH}	0.87	#/km/year
Improvement of failure rate compared with MVBOH	$(FR_{BOH} - FR_{ABC}) / FR_{BOH} \%$	
	72%	
Calculation Mean Time to Repair of MVABC		
Total interruption duration	146	hr
Total no of interruption	8	# interruptions
Mean Time to Repair(MTTR _{ABC})	1095	min/#interruption

						<i>Annex XVII</i>
Cost for constructing 33kV MVCC Al Alloy XLPE (CC) – 95mm2 by replacing MVBOH						
Material						
PL code	Item Description	Unit	Qty	Unit Price	Sub Total	
B 04 10	Cross Arm - Pin G.S. 33 kV	Nos.	7	8,660.00	60,620.00	
B 04 20	Cross Arm - Tension G.S. 33 kV	Nos.	7	16,870.00	118,090.00	
B 04 21	Cross Arm - Tension G.S. 33 kV	Nos.	1	16,870.00	16,870.00	
SDI84.1M2	Composite Line Post insulator	Nos.	42	21,307.10	894,898.20	
SDI95.1	Composite Tension insulator	Nos.	45	13,901.77	625,579.65	
SO256	Tension Clamp	Nos.	45	12,570.00	565,650.00	
CO70	Hericle Tie	Nos.	42	375.00	15,750.00	
SLW26	IPC CC - CC	Nos.	6	2,802.25	16,813.50	
SEW20.72	IPC CC - BOH	Nos.	3	2,802.25	8,406.75	
SDI27.1	PAD	Nos.	42	8,038.50	337,617.00	
SEW20.1	APD	Nos.	6	4,140.16	24,840.96	
SD146	CLD	Nos.	6	48,875.00	293,250.00	
	MVCC conductor SAX-C 95mm2	m	3000	395.00	1,185,000.00	
L 07 17	Cu Cable - 50mm2	m	40	735.00	29,400.00	
J 03 03	Cu Rod	Nos.	2	2,530.00	5,060.00	
J 03 04	Weld metal tube	Nos.	2	815.00	1,630.00	
SLW26	IPC CC- CC(For tapping the line for ss =2)	Nos.	6	2,802.25	16,813.50	
Cost Summary						
A	MATERIAL TOTAL					4,216,289.56
B	WAYLEAVES TOTAL					50,000.00
C	TRANSPORT TOTAL					105,000.00
D	LABOUR	Hrs	540	477.00	257,580.00	
E	SUBSISTANCE	Hrs	60	400.00	24,000.00	
F	CONTINGENCIES (2%) - Min LKR 3500.00					84,325.79
G	OVERHEAD	Hrs	540	346.00	186,840.00	
I	OTHER COST					-
	Construction Cost - Al Alloy XLPE (CC) – 95sqmm by replacing MVBOH					4,924,035.35
Cost Summary						
	• Material Cost				4,300,620.00	
	• Labor cost				468,420.00	
	• Transport cost				105,000.00	
	• Wayleaves				50,000.00	
	Total Cost				4,924,040.00	

Cost for constructing 11kV MVCC Al Alloy XLPE (CC) – 95sqmm by replacing MVBOH

Material					
PL code	Item Description	Unit	Qty	Unit Price	Sub Total
B 04 05	Cross Arm - Pin G.S. 11 kV	Nos.	7	4,270.00	29,890.00
B 04 15	Cross Arm - Tension G.S. 11 kV	Nos.	7	6,550.00	45,850.00
B 04 15	Cross Arm - Tension G.S. 11 kV	Nos.	1	6,550.00	6,550.00
	Composite Line Post insulator	Nos.	42	14,914.97	626,428.74
SDI90.150	Composite Tension insulator 12 - 24kV	Nos.	45	9,731.24	437,905.76
SO256	Tension Clamp (95 -157mm2)	Nos.	45	12,570.00	565,650.00
CO70	Herical Tie (70-95mm2)	Nos.	42	375.00	15,750.00
SLW26	IPC CC - CC (50 -157mm2)	Nos.	6	2,802.25	16,813.50
SEW20.72	IPC CC - BOH (35-157 mm2)	Nos.	3	2,802.25	8,406.75
SDI27.1	PAD (12kV - 36kV)	Nos.	42	8,038.50	337,617.00
SEW20.1	APD PAS/BLL-T 50-157mm ² AlMgSi	Nos.	6	4,140.16	24,840.96
SDI46.7	CLD (20 kV)	Nos.	6	34,212.50	205,275.00
	MVCC conductor SAX-C 95mm2	m	3000	355.50	1,066,500.00
L 07 17	Cu Cable - 50mm2	m	40	735.00	29,400.00
J 03 03	Cu Rod	Nos.	2	2,530.00	5,060.00
J 03 04	Weld metal tube	Nos.	2	815.00	1,630.00
SLW26	IPC CC- CC(For tapping the line for ss =2)	Nos.	6	2,802.25	16,813.50
Cost Summary					
A	MATERIAL TOTAL				3,440,381.21
B	WAYLEAVES TOTAL				50,000.00
C	TRANSPORT TOTAL				105,000.00
D	LABOUR	Hrs	540	477.00	257,580.00
E	SUBSISTANCE	Hrs	60	400.00	24,000.00
F	CONTINGENCIES (2%) - Min LKR 3500.00				68,807.62
G	OVERHEAD	Hrs	540	346.00	186,840.00
I	OTHER COST				-
	Construction Cost - Al Alloy XLPE (CC) – 95mm2 by replacing MVBOH				4,132,608.83
Cost Summary					
	• Material Cost				3,509,190.00
	• Labor cost				468,420.00
	• Transport cost				105,000.00
	• Wayleaves				50,000.00
	Total Cost				4,132,610.00

Maintenance Cost of 33kV Raccoon Line per year per km				Annex XIX
<i>MVCC line Maintenance Cost - 33kV</i>				
<i>J B Wareing, "Covered Conductor Systems for Distribution", Report No: 5925 Project No: 70580, December 2005.</i>				
<i>Experience in Scandinavian & UK, Maintenance Cost is same as MVBOH.</i>				
No	Job description	km	Job No	Cost
1	Maintenance of 33kV line at Gangalanga S/S to Puwakdola S/S - Reh 2km	2	5652	1,924,001.82
2	33kV line at KB06D3 DDLO to Bandanagoda Sub (KB100)	3.5	5735	1,037,345.64
3	Maintenance of 33kV line at Diganna DDLO to Harabakanada	6	5833	1,746,153.24
4	Maintenance of 33kV line at Kapugedara DDLO	4	5918	319,503.00
5	Maintenance of 33kV line at Jinaloka Mawatha S/S to Kuda Ambegoda	1.9	5919	182,464.00
6	Maintenance of 33kV line at Ilukpotha DDLO(KA024D3N) to Ilukpotha S/S(KA092)	2	5920	298,123.00
7	Maintenance of 33kV line at Naravila DDLO to Bopitiya S/S (KM011)	1.4	5949	694,864.84
8	Maintenance of KM049D3N DDLO to KM064 S/S	3.5	6027	2,818,319.12
9	Maintenance of 33kV line at KM034D3N DDLO to KM037 Makalamdawa S/S	1.3	6089	588,332.00
10	Maintenance of 33kV line at KM050D3N DDLO to KM063 S/S	2.2	6121	328,293.00
11	Maintenance of 33kV line at KM046D3N DDLO to Hallindola S/S(KM093)	3.5	6159	418,018.00
12	Maintenance of 33kV line at Main line to Deegalla LBS	3.2	6160	347,175.00
13	Maintenance of 33kV line at KMN006D3N DDLO to Deegalla LBS	2.7	6161	656,555.24
14	Maintenance of 33kV line at KA010D3N DDLO to KA044 S/S	5.5	6163	623,112.08
15	Maintenance of 33kV line at Thundola LBS to KM028 S/S	2.5	6234	1,673,912.56
16	Maintenance of 33kV line at KM052D3N to KM101 S/S	1.8	6235	174,509.00
17	Maintenance of 33kV line at KM051D3N to KM116 S/S	1.8	6237	173,476.00
18	Maintenance of 33kV line at KM067D3N to KM122 S/S	1.5	6238	112,857.00
		50.3		14,117,014.54
Maintenance cost per km				280,660.00
Annual Maintenance cost of 33kV MVCC line 1km [A] - 1 cycle per 4 year				70,165.00 LKR/km/year

B	Way leave clearance cost per km - 1 cycle per year			3,480.00	LKR/km
C	Breakdown Cost - Natural due to fall of tree branch				
Material	Description	Unit	Quantity	Unit Price	Sub Total
B 04 10	Cross Arm - Pin G.S. 33 kV	Nos	1	8,660.00	8,660.00
SDI84.1M					
24	Composite Line Post insulator	Nos.	1	21,307.10	21,307.10
CO70	Hericle Tie	Nos	3	375.00	1,125.00
	MVCC conductor SAX-C 95mm2	m	10	395.00	3,950.00
	Cable joint	Nos	2	24,000.00	48,000.00
A 04 25	PS pole 11m/350kg	Nos	1	33,380.00	33,380.00
a	MATERIAL TOTAL				116,422.10
b	WAYLEAVES TOTAL				
C	VAN/D CAB	LKR/KM		40.00	-
	CREW CAB/SMALL LORRY	LKR/KM	50	60.00	3,000.00
	LARGE LORRY	LKR/KM		70.00	-
	CRANE/AUGOR/BUCKET LORRY	LKR/KM	50	90.00	4,500.00
	CRANE/BUCKET LORRY (LIFTING)	Hrs	4	1,500.00	6,000.00
	AUGOR (WORKING)	Hrs	4	2,000.00	8,000.00
	HIRED VEHICLE 1	LKR/KM		60.00	-
	HIRED VEHICLE 2	LKR/KM			
		LKR/KM			
c	TRANSPORT TOTAL				21,500.00
d	LABOUR	Hrs	72	477.00	34,344.00
e	SUBSISTANCE	Hrs	8	400.00	3,200.00
f	CONTINGENCIES (2%) - Min LKR 3500.00				3,500.00
g	OVERHEAD	Hrs	72	346.00	24,912.00
i	OTHER COST				-
	Breakdown Cost - Natural due to fall of tree branch [C]				203,880.00
D	Breakdown Cost - Flash over of insulator				
Material	Description	Unit	Quantity	Unit Price	Sub Total
SDI84.1					
M24	Composite Line Post insulator	Nos	1	21,307.10	21,307.10
CO70	Hericle Tie	kg	1	375.00	375.00
a	MATERIAL TOTAL				21,682.10
b	WAYLEAVES TOTAL				-
c	TRANSPORT TOTAL				7,200.00
d	LABOUR	Hrs	12	477.00	5,724.00
e	SUBSISTANCE	Hrs	1	400.00	200.00
f	CONTINGENCIES (2%) - Min LKR 3500.00				3,500.00
g	OVERHEAD	Hrs	12	346.00	4,152.00
i	OTHER COST				-
	Breakdown Maintenece Cost due to flash over of insulatos (D)				42,460.00
Breakdown cost by assuming 1 fallen of tree per 10 years and insulator flashover per 5 year.					
(A+B+C/10+D/5) - LKR/km/year					102,530.00

Maintenance Cost of 11kV Raccoon Line per year per km				Annex XX	
<i>MV line Routine Maintenance Cost - 11kV</i>					
J B Wareing, "Covered Conductor Systems for Distribution" , Report No: 5925 Project No: 70580, December 2005. Experience in Scandinavian & UK, Maintenance Cost is same as MVBOH.					
No	Job description	km	Job No	Cost	
1	Kalubowila PSS to Wikies LBS	7.6	5748/2018D	886,170.00	
			5707/2018D	1,275,773.00	
2	Saranankara Police LBS to Pamankada SF6 LBS	3.75	5945/2018D	152,632.00	
3	Pamankada SF6 LBS to Mudali Mawatha SF6 LBS	3.1	5749/2018D	619,775.00	
4	Peters Lane LBS to Highlevel Road	3.2	5462/2018D	507,376.00	
5	Kalubowila PSS to Nelus ABS	11.6	5845/2018D	902,357.40	
6	Alubogahawaththa LBS to Kohuwala Gantry LBS	5.3		386,484.40	
7	Galvihara Road Junction to Munciple Council	4.7	5942/2018D	407,522.00	
8	AGA Office LBS to Wikies LBS	5.75	5866/2018D	857,665.00	
9	Karagampitiya Junction LBS to Galvihara Road Junction LBS	4.2	5960/2018D	227,186.00	
10	Station Road LBS to AGA Office LBS	3.95	5855/2018D	555,954.00	
11	Dehiwala PSS to Station Road LBS	2.15	5848/2018D	453,121.00	
12	Nadimala Gantry to Galle Road	4.8	5900/2018D	578,031.00	
13	Dehiwala PSS to Aurban's place LBS	1.3	5867/2018D	185,150.00	
14	Keselkotuwa DDLO to Galle Road	2.1	5844/2018D	223,193.00	
15	Dehiwala PSS to Telecom Gantry	2.55	6030/2019D	206,425.00	
16	Dehiwala PSS to Kaudana Broudway LBS	1.55	6076/2019D	147,766.40	
17	Flam Beach Hotel LBS to Telecom LBS	1.8	6014/2019D	193,434.40	
18	Suntel LBS to Hotel Road LBS	1.85	5984/2019D	249,346.40	
19	RM- Lavima Station Road LBS to Flam Beach Hotel LBS	0			
20	Attidiya PSS to Watarappala Road LBS and Kawdana Broadway LBS	5.3	5985/2019D	386,484.40	
21	Templers Road Junction to Suntel LBS	2.3	6074/2019D	260,546.00	
22	Templers Road Junction to Katukurunduwatta Junction LBS	2.55	5938/2018D	270,665.00	
23	Attidiya PSS to KALAPURA LBS & Katukurunduwatta LBS	2.7	6075/2019D	179,794.00	
24	Lake road LBS to Nadimala Gantry LBS & Alubogahawatta LBS	4.45	5946/2018D	274,787.00	
		3.3	5944/2018D	287,647.00	
25	Kalubowila PSS to Nadimala Gantry & Galwihara road LBS ,Dehiwala GSS to Balapokuna line End Dehiwala 1,3 (Combine 33kV and 11kV)	2.6	6197/2019D	714,806.80	
26	Athtidiya PSS to Nedimala Gantry 11kV F6 & Dehiwala 33kV F06 & F 08 From Dehiwala GSS to Attidiya PSS	5	6079/2019D	297,065.00	
27	Attidiya PSS to Katukurunduwatta LBS	1.4	RM/426D	249,346.40	
28	Attidiya PSS to Dehiwala PSS	1.3	6077/2019D	243,629.00	
		102.1		12,180,132.60	
Maintenance cost per km				119,300.00	LKR/km
Annual Maintenance cost of 11kV MVCC line 1km [A] - 1 cycle per 4 year				29,830.00	LKR/km/Year

B	Way leave clearance cost per km - 1 cycle per year			3,480.00	LKR/km
C	Breakdown Cost - Accident and pole damage				
Material	Description	Unit	Quantity	Unit Price	Sub Total
SDI84.1M2	Composite Line Post insulator	Nos.	1	14,914.97	14,914.97
CO70	Hericle Tie	Nos	3	375.00	1,125.00
A 04 25	PS pole 11m/350kg	Nos	1	33,380.00	33,380.00
A	MATERIAL TOTAL				49,419.97
B	WAYLEAVES TOTAL				
C	VAN/D CAB	LKR/KM		40.00	-
	CREW CAB/SMALL LORRY	LKR/KM	50	60.00	3,000.00
	LARGE LORRY	LKR/KM		70.00	-
	CRANE/AUGOR/BUCKET LORRY	LKR/KM	50	90.00	4,500.00
	CRANE/BUCKET LORRY (LIFTING)	Hrs	4	1,500.00	6,000.00
	AUGOR (WORKING)	Hrs	4	2,000.00	8,000.00
	HIRED VEHICLE 1	LKR/KM		60.00	-
	HIRED VEHICLE 2	LKR/KM			
		LKR/KM			
C	TRANSPORT TOTAL				21,500.00
D	LABOUR	Hrs	72	477.00	34,344.00
E	SUBSISTANCE	Hrs	8	400.00	3,200.00
F	CONTINGENCIES (2%) - Min LKR 3500.00				3,500.00
G	OVERHEAD	Hrs	72	346.00	24,912.00
I	OTHER COST				-
	Breakdown Maintenace Cost due to accident (C)				136,880.00
D	Breakdown Cost - Flash over of insulator				
Material	Description	Unit	Quantity	Unit Price	Sub Total
SDI84.1M2	Composite Line Post insulator	Nos	1	14,914.97	14,914.97
CO70	Hericle Tie	kg	1	375.00	375.00
A	MATERIAL TOTAL				15,289.97
B	WAYLEAVES TOTAL				
C	TRANSPORT TOTAL				7,200.00
D	LABOUR	Hrs	12	477.00	5,724.00
E	SUBSISTANCE	Hrs	0.5	400.00	200.00
F	CONTINGENCIES (2%) - Min LKR 3500.00				3,500.00
G	OVERHEAD	Hrs	12	346.00	4,152.00
I	OTHER COST				-
	Breakdown Maintenace Cost due to flash over of insulatos (D)				36,070.00
Breakdown cost by assuming 1 vehicle accident per 10 years and insulator flashover per 2 year. (A+B+C/10+D/5) - LKR/km/year					54,210.00

Calculation failure rate improvement of MVCC			Annex XXI
<i>Failure details of part of Beliatta GSS F1 which converted MVCC</i>			
Month	No of interruptions	Interruption duration (min)	
19-Jan	0	0	
19-Feb	0	0	
19-Mar	0	0	
19-Apr	0	0	
19-May	0	0	
19-Jun	0	0	
19-Jul	0	0	
19-Aug	0	0	
19-Sep	0	0	
19-Oct	0	0	
19-Nov	1	25	
19-Dec	0	0	
Length	0.63	km	
Total interruptions	1	Nos	
FR _{UG}	1.59	#/km/year	
<i>Failure details of Ratmalana GSS Feeder 09 (MVBOH)</i>			
Month	No of interruptions		
19-Jan	2		
19-Feb	2		
19-Mar	1		
19-Apr	2		
19-May	3		
19-Jun	2		
19-Jul	4		
19-Aug	3		
19-Sep	2		
19-Oct	3		
19-Nov	3		
19-Dec	1		
Length	7.5	km	
Total interruptions	28	Nos	
FR _{BOH}	3.73	#/km/year	
Improvement of failure rate compared with MVBOH	$(FR_{BOH} - FR_{CC}) / FR_{BOH} \%$		
	57%		
Calculation Mean Time to Repair of MVCC			
Total interruption duration		25 minutes	
Total no of interruption		1 # interruptions	
Mean Time to Repair(MTTR _{ABC})		25 min/#interruption	

Cost for convert RTV coated insulators - 33kV line					<i>Annex XXII</i>
(a) Material cost					
PL Code	Material	Unit	Qty	Unit Cost	Sub total
	Coat 33kV pin insulator	Nos	45	3,893.43	175,204.35
	Coat 33kV tension insulator	Nos	54	1,946.72	105,122.88
D 06 05	Aluminium Binding Wire (No. 9) 3.6mm	kg	8.1	707.00	5,726.70
Cost Summary					
A	TOTAL MATERIAL				286,053.93
B	WAYLEAVES				-
C	TOTAL TRANSPORT				6,000.00
D	LABOUR	Hrs	90	477.00	42,930.00
E	SUBSISTANCE	Hrs	10	400.00	4,000.00
F	CONTINGENCIES (2%) - Min LKR 3500.00				5,721.08
G	OVERHEAD	Hrs	90	346.00	31,140.00
I	OTHER COST				-
Cost for convert RTV coated insulators - 33kV line					375,845.01
Reference					
1. Actual cost spent in Southern Province					
Maintenance Cost of 33kV RTV Coated Raccoon Line per year per km					
A	Maintenance cost of BOH 33kV line per cycle			280,660.00	
	Annual Maintenance cost for 33kV line 1km [A] - 1 cycle per 4 year			70,170.00	LKR/km/year
B	Way leave clearance cost per km			3,480.00	LKR/km
	Annual Way leave clearance cost - 2 cycle per year			6,960.00	LKR/km
C	Breakdown Cost - Natural due to fall of tree branch				
Material	Description	Unit	Quantity	Unit Price	Sub Total
B 04 10	Cross Arm - Pin G.S. 33 kV	Nos	1	8,660.00	8,660.00
C 01 35	Insulator - Pin 33kV	Nos	1	3,930.00	3,930.00
	Coat 33kV pin insulator	Nos	1	3,893.43	3,893.43
D 06 05	Wire binding	kg	0.5	707.00	353.50
W 05 30	Repair Sleeve Tension for ACSR 7/4.09mm	Nos	1	514.00	514.00
A 04 25	PS pole 11m/350kg	Nos	1	33,380.00	33,380.00
a	TOTAL MATERIAL				50,730.93
b	WAYLEAVES				-
c	TOTAL TRANSPORT				21,500.00
d	LABOUR	Hrs	72	477.00	34,344.00
e	SUBSISTANCE	Hrs	8	400.00	3,200.00
f	CONTINGENCIES (2%) - Min LKR 3500.00				3,500.00
g	OVERHEAD	Hrs	72	346.00	24,912.00
i	OTHER COST				-
Breakdown Cost - Natural due to fall of tree branch [C]					138,190.00
D	Breakdown Cost - Flash over of insulator				
Material	Description	Unit	Quantity	Unit Price	Sub Total
C 01 35	Insulator - Pin 33kV	Nos	1	3,930.00	3,930.00
	Coat 33kV pin insulator	Nos	1	3,893.43	3,893.43
D 06 05	Wire binding	kg	0.5	707.00	353.50
a	TOTAL MATERIAL				8,176.93
b	WAYLEAVES				-
C	VAN/D CAB	LKR/KM		40.00	-
c	TOTAL TRANSPORT				7,200.00
d	LABOUR	Hrs	12	477.00	5,724.00
e	SUBSISTANCE	Hrs	1	400.00	200.00
f	CONTINGENCIES (2%) - Min LKR 3500.00				3,500.00
g	OVERHEAD	Hrs	12	346.00	4,152.00
i	OTHER COST				-
Breakdown Maintenance Cost due to flash over of insulators (D)					28,950.00
Breakdown cost by assuming 1 fallen of tree per 10 years and insulator flashover per 4 year.					98,190.00

Cost for convert RTV coated insulators - 11kV line					<i>Annex XXIII</i>
(a) Material cost					
PL Code	Material	Unit	Qty	Unit Cost	Sub total
	Coat 11kV pin insulator	Nos	45	1,946.72	87,602.18
	Coat 11kV tension insulator	Nos	36	1946.70	70,081.20
D 06 05	Aluminium Binding Wire (No. 9) 3.6mm	kg	8.1	707.00	5,726.70
Cost Summary					
A	TOTAL MATERIAL				163,410.08
B	WAYLEAVES				-
C	TOTAL TRANSPORT				6,000.00
D	LABOUR	Hrs	90	477.00	42,930.00
E	SUBSISTANCE	Hrs	10	400.00	4,000.00
F	CONTINGENCIES (2%) - Min LKR 3500.00				3,500.00
G	OVERHEAD	Hrs	90	346.00	31,140.00
I	OTHER COST				-
	Cost for con				250,980.08
Reference					
1. Actual cost spent in Southern Province					
Maintenance Cost of 11kV Raccoon Line per year per km					
A	Maintenance cost of BOH 11kV line per cycle			119,300.00	
	Line Maintenance cost (A) - 1 cycle per 4 year			29,830.00	LKR/km/Year
B	Way leave clearance cost per km			3,480.00	LKR/km
	Annual Way leave clearance cost - 2 cycle per year			6,960.00	LKR/km
C	Breakdown Cost - Accident and pole damage				
Material	Description	Unit	Quantity	Unit Price	Sub Total
A 04 25	PS pole 11m/350kg	Nos	1	33,380.00	33,380.00
C 01 25	Insulator 11kV pin	Nos	1	1,800.00	1,800.00
	Coat 11kV pin insulator	Nos	1	1,946.72	1,946.72
D 06 05	Wire binding	kg	0.5	707.00	353.50

A	TOTAL MATERIAL				37,480.22
B	WAYLEAVES				
C	VAN/D CAB	LKR/KM		40.00	-
	CREW CAB/SMALL LORRY	LKR/KM	50	60.00	3,000.00
	LARGE LORRY	LKR/KM		70.00	-
	CRANE/AUGOR/BUCKET LORRY	LKR/KM	50	90.00	4,500.00
	CRANE/BUCKET LORRY (LIFTING)	Hrs	4	1,500.00	6,000.00
	AUGOR (WORKING)	Hrs	4	2,000.00	8,000.00
	HIRED VEHICLE 1	LKR/KM		60.00	-
	HIRED VEHICLE 2	LKR/KM			
		LKR/KM			
C	TOTAL TRANSPORT				21,500.00
D	LABOUR	Hrs	72	477.00	34,344.00
E	SUBSISTANCE	Hrs	8	400.00	3,200.00
F	CONTINGENCIES (2%) - Min LKR 3500.00				3,500.00
G	OVERHEAD	Hrs	72	346.00	24,912.00
I	OTHER COST				-
	Breakdown Maintenace Cost due to accident (C)				124,940.00
D	Breakdown Cost - Flash over of insulator				
Material	Description	Unit	Quantity	Unit Price	Sub Total
C 01 25	Insulator 11kV pin	Nos	1	1,800.00	1,800.00
	Coat 11kV pin insulator	Nos	1	1,946.72	1,946.72
D 06 05	Wire binding	kg	0.5	707.00	353.50
A	TOTAL MATERIAL				4,100.22
B	WAYLEAVES				
C	VAN/D CAB	LKR/KM		40.00	-
	CREW CAB/SMALL LORRY	LKR/KM	20	60.00	1,200.00
	LARGE LORRY	LKR/KM		70.00	-
	CRANE/AUGOR/BUCKET LORRY	LKR/KM	0	90.00	-
	CRANE/BUCKET LORRY (LIFTING)	Hrs	4	1,500.00	6,000.00
	AUGOR (WORKING)	Hrs	0	2,000.00	-
	HIRED VEHICLE 1	LKR/KM		60.00	-
	HIRED VEHICLE 2	LKR/KM			
		LKR/KM			
C	TOTAL TRANSPORT				7,200.00
D	LABOUR	Hrs	12	477.00	5,724.00
E	SUBSISTANCE	Hrs	0.5	400.00	200.00
F	CONTINGENCIES (2%) - Min LKR 3500.00				3,500.00
G	OVERHEAD	Hrs	12	346.00	4,152.00
I	OTHER COST				-
	Breakdown Maintenace Cost due to flash over of insulatos (D)				24,880.00
	Breakdown cost by assuming 1 vehicle accident per 10 years and insulator flashover per 2 year.				
	(A+B+C/10+D/2) - LKR/km/year				55,500.00

Cost for installation Interruption Pulse Closer - 33kV					<i>Annex XXIV</i>
(a) Material cost as per PL price 2019 of CEB					
PL Code	Material	Unit	Qty	Unit Cost	Sub total
A 04 30	Poles - Concrete Pre-Stressed 11.0 m 500kg	Nos	1	39,300.00	39,300.00
B 03 70	Stainless Steel Straps, for Bundled Cable	Nos	5	148.00	740.00
B 04 10	Cross Arm - Pin G.S. 33 kV	Nos	1	8,660.00	8,660.00
B 04 20	Cross Arm - Tension G.S. 33 kV	Nos	2	16,870.00	33,740.00
B 07 10	Washer GI 16mm	Nos	10	29.00	290.00
B 07 35	Bolts & Nuts - G.I. 40 x 16 mm	Nos	16	70.00	1,120.00
B 07 55	Bolts & Nuts - G.I. 200 x 16 mm	Nos	10	152.00	1,520.00
B 07 75	Bolts & Nuts - G.I. 250 x 16 mm	Nos	7	224.00	1,568.00
B 07 85	Bolts & Nuts - G.I. 300 x 16 mm	Nos	4	285.00	1,140.00
B 07 90	Bolts & Nuts - G.I. 350 x 16 mm	Nos	4	340.00	1,360.00
B 07 92	Bolts & Nuts - G.I. 400 x 16 mm	Nos	4	396.00	1,584.00
B 17 05	Buckles, Straps Stainless Steel for ABC 230/400 V	Nos	5	26.00	130.00
B 21 05	Ties - Nylon for ABC 230/400 V	Nos	25	17.00	425.00
C 01 40	Insulator Tension Set 36 kV with Hardware (Racoon)	Nos	6	6,850.00	41,100.00
D 02 10	A.C.S.R. (Racoon) - 7/4.09 mm	kg	10	443.00	4,430.00
D 04 15	Copper Conductor (No. 4) - 6mm	kg	5	1,920.00	9,600.00
D 07 45	Compression Clamps AL/AL 7/4.09(Racoon) - 7/4.09(Racoon) H Type	Nos	2	189.00	378.00
	Interruption Pulse closer	Nos	1	7,427,188.89	7,427,188.89
F 04 11	Transformer - Outdoor 1 Phase 33 kV/LT - 5 kVA	Nos	1	231,010.00	231,010.00
G 03 10	Surge Arrestors 33kV - 10 kA	Nos	8	9,650.00	77,200.00
J 03 03	Copper Bonded Steel Rod for Concrete Block	Nos	2	2,530.00	5,060.00
J 03 04	Weld Metal Tube for Exothermic Earth Connection	Nos	2	815.00	1,630.00
L 07 17	Cable Cu. PVC Insulated - single (for earthing) 50sqmm	m	20	735.00	14,700.00
P 02 25	Socket Cable Crimp Type Bi metallic	Nos	8	238.00	1,904.00
P 04 12	Socket Cable Crimp type C	Nos	25	79.00	1,975.00
W 07 30	Non Tension Sleeves (Racoon) 7/4.09mm	Nos	6	696.00	4,176.00

Cost Summary				
A	TOTAL MATERIAL			7,911,928.89
B	WAYLEAVES			-
C	VAN/D CAB	LKR/KM		40.00
	CREW CAB/SMALL LORRY	LKR/KM	100	60.00
	LARGE LORRY	LKR/KM		70.00
	CRANE/AUGOR/BUCKET LORRY	LKR/KM	100	90.00
	CRANE/BUCKET LORRY (LIFTING)	Hrs	4	1,500.00
	AUGOR (WORKING)	Hrs	4	2,000.00
	HIRED VEHICLE 1	LKR/KM		60.00
	HIRED VEHICLE 2	LKR/KM		
		LKR/KM		
C	TOTAL TRANSPORT			29,000.00
D	LABOUR	Hrs	180	477.00
E	SUBSISTANCE	Hrs	20	400.00
F	CONTINGENCIES (2%) - Min LKR 3500.00			158,238.58
G	OVERHEAD	Hrs	180	346.00
I	OTHER COST			-
	Insatallation Cost - IPC			8,255,307.47
	Cost Summary			
	• <i>Material Cost (IPC 33kV)</i>			<i>7,427,190.00</i>
	• <i>Material Cost (Other material)</i>			<i>642,980.00</i>
	• <i>Labor cost</i>			<i>156,140.00</i>
	• <i>Transport cost</i>			<i>29,000.00</i>
	• <i>Wayleaves</i>			<i>-</i>
	Total Cost			8,255,310.00

Cost for installation Interruption Pulse Closer - 11kV					<i>Annex XXV</i>
(a) Material cost as per PL price 2019 of CEB					
PL Code	Material	Unit	Qty	Unit Cost	Sub total
A 04 30	Poles - Concrete Pre-Stressed 11.0 m 500kg	Nos	1	39,300.00	39,300.00
B 03 70	Stainless Steel Straps, for Bundled Cable	Nos	5	148.00	740.00
B 04 05	Cross Arm - Pin G.S. 11 kV	Nos	1	4,270.00	4,270.00
B 04 15	Cross Arm - Tension G.S. 11 kV	Nos	2	6,550.00	13,100.00
B 07 10	Washer GI 12mm	Nos	10	29.00	290.00
B 07 35	Bolts & Nuts - G.I. 40 x 16 mm	Nos	16	70.00	1,120.00
B 07 55	Bolts & Nuts - G.I. 200 x 16 mm	Nos	10	152.00	1,520.00
B 07 75	Bolts & Nuts - G.I. 250 x 16 mm	Nos	7	224.00	1,568.00
B 07 85	Bolts & Nuts - G.I. 300 x 16 mm	Nos	4	285.00	1,140.00
B 07 90	Bolts & Nuts - G.I. 350 x 16 mm	Nos	4	340.00	1,360.00
B 07 92	Bolts & Nuts - G.I. 400 x 16 mm	Nos	4	396.00	1,584.00
B 17 05	Buckles, Straps Stainless Steel for ABC 230/400 V	Nos	5	26.00	130.00
B 21 05	Ties - Nylon for ABC 230/400 V	Nos	25	17.00	425.00
C 01 30	Insulator Tension Set 12 kV with Hardware (Racoon)	Nos	6	6,530.00	39,180.00
D 02 10	A.C.S.R. (Racoon) - 7/4.09 mm	kg	10	443.00	4,430.00
D 04 15	Copper Conductor (No. 4) - 6mm	kg	5	1,920.00	9,600.00
D 07 45	Compression Clamps AL/AL 7/4.09(Racoon) - 7/4.09(Racoon) H Type	Nos	2	189.00	378.00
	Interruption Pulse closer	Nos	1	6,253,141.45	6,253,141.45
F 02 36	Transformer - Outdoor 1 Phase 11 kV/LT - 5 kVA	Nos	1	222,330.00	222,330.00
G 02 10	Surge Arrestors 11kV - 10 kA	Nos	8	5,240.00	41,920.00
J 03 03	Copper Bonded Steel Rod for Concrete Block	Nos	2	2,530.00	5,060.00
J 03 04	Weld Metal Tube for Exothermic Earth Connection	Nos	2	815.00	1,630.00
L 07 17	Cable Cu. PVC Insulated - single (for earthing) 50sqmm	m	20	735.00	14,700.00
P 02 25	Socket Cable Crimp Type Bi metallic	Nos	8	238.00	1,904.00
P 04 12	Socket Cable Crimp type C	Nos	25	79.00	1,975.00
W 07 30	Non Tension Sleeves (Racoon) 7/4.09mm	Nos	6	696.00	4,176.00
Cost Summary					
A	TOTAL MATERIAL				6,666,971.45
B	WAYLEAVES				-
C	VAN/D CAB	LKR/KM		40.00	-
	CREW CAB/SMALL LORRY	LKR/KM	100	60.00	6,000.00
	LARGE LORRY	LKR/KM		70.00	-
	CRANE/AUGOR/BUCKET LORRY	LKR/KM	100	90.00	9,000.00
	CRANE/BUCKET LORRY (LIFTING)	Hrs	4	1,500.00	6,000.00
	AUGOR (WORKING)	Hrs	4	2,000.00	8,000.00
	HIRED VEHICLE 1	LKR/KM		60.00	-
	HIRED VEHICLE 2	LKR/KM			
		LKR/KM			
C	TOTAL TRANSPORT				29,000.00
D	LABOUR	Hrs	180	477.00	85,860.00
E	SUBSISTANCE	Hrs	20	400.00	8,000.00
F	CONTINGENCIES (2%) - Min LKR 3500.00				133,339.43
G	OVERHEAD	Hrs	180	346.00	62,280.00
I	OTHER COST				-
	Insatallation Cost - IPC				6,985,450.88
Cost Summary					
	• Material Cost (IPC 11kV)		6,253,140.00		
	• Material Cost (Other material)		547,170.00		
	• Labor cost		156,140.00		
	• Transport cost		29,000.00		
	• Wayleaves		-		
	Total Cost		6,985,450.00		

Cost of maintenance Intellirupter Pulse Closer 33kV				<i>Annex XXVI</i>
	<i>Condition of monitoring - 2 cycle per year</i>			
	<i>Routine maintenance of IPC per 2 year</i>			
	<i>Avg battery life time is 5 years</i>			
A	Condition Monitoring			
	Labour	6	477.00	2,862.00
	Overhead	6	346.00	2,076.00
	Subsistance	0.2	4,000.00	800.00
	Transport			2,000.00
	<i>Total for condition monitoring</i>			<i>7,740.00</i>
B	Routine Maintenance			
	Material - Surge Arrestors 33kV,10kA	1	9,650.00	9,650.00
	Labour	15	477.00	7,155.00
	Overhead	15	346.00	5,190.00
	Subsistance	0.5	4,000.00	2,000.00
	Transport			2,000.00
	<i>Total for RM of IPC</i>			<i>26,000.00</i>
C	Cost of battery - Need to bechanged every 5 years	<i>1</i>	<i>20,000.00</i>	<i>20,000.00</i>
D	Summary			
	Battery Inspection (A)			7,740.00
	Routine maintenance (B)			26,000.00
	Cost for battery (B)			20,000.00
	per 2 year & battery life time 5 years - A*2 + B/2 + C/5			32,480.00
Cost of maintenance Intellirupter Pulse Closer 11kV				
	<i>Every 2 year - Cleaning + testing + Normally replace 1 SA avg</i>			
	<i>2 services per day</i>			
	<i>Avg battery life time is 5 years</i>			
A	Condition Monitoring			
	Labour	6	477.00	2,862.00
	Overhead	6	346.00	2,076.00
	Subsistance	0.2	4,000.00	800.00
	Transport			2,000.00
	<i>Total for condition monitoring</i>			<i>7,740.00</i>
B	Routine Maintenance			
	Material- Surge Arrestors 11kV,10kA	1	5,240.00	5,240.00
	Labour	15	477.00	7,155.00
	Overhead	15	346.00	5,190.00
	Subsistance	0.5	4,000.00	2,000.00
	Transport			2,000.00
	<i>Total for RM of IPC</i>			<i>21,590.00</i>
C	Cost of battery - Need to bechanged every 5 years	<i>1</i>	<i>20,000.00</i>	<i>20,000.00</i>
	Battery Inspection (A)			7,740.00
	Routine maintenance (B)			21,590.00
	Cost for battery (B)			20,000.00
	Total Maintenance Cost - 2 inspection per year, 1 routine maintenace per 2 year & battery life time 5 years - A*2 + B/2 + C/5 - LKR/year			30,280.00