TECHNO ECONOMIC ANALYSIS ON THE USE OF FULLY INSULATED CABLE FOR 33KV OVERHEAD POWER DISTRIBUTION SYSTEM IN SRI LANKA

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DECLARATION

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ABSTRACT

Electricity Supply has become a fundamental commodity of present society. Hence, the availability and the reliability of the electricity distribution system have gained an utmost concern. Currently, Sri Lankan electricity distribution system of all over the island other than Colombo and Kandy Cities are networked through the 33kV Bare Overhead (BOH) lines. Ceylon Electricity Board (CEB) is being rapidly expanded 33 kV distribution network to cater rural electrification demands and the urban development demands. 33kV network has been constructed with poles and towers, many 33 kV lines pass through jungles and thick vegetation and further expose to the sea and lightning prone areas.

Therefore, nowadays the utility has to face some critical issues along with existing distribution system, especially higher number of feeder tripping during the rainy seasons due to thick vegetation. Even with the new regulations and demands, lines are unable to maintain right-of-way with required safety clearance especially in urban areas. Thus, in my dissertation discussed the 33kV Aerial Bundled Cable (MVABC) system as a more economical alternative to Medium Voltage Bare Overhead (MVBOH) lines. Further, address how to mitigate certain operational, climatic and environmental issues with MVABC. It is presented a comparative economic analysis of MVABC with MVBOH and MVUG systems. The analysis takes into consideration the initial investment costs, net present value (NPV) of operational and maintenance costs and NPV of unserved energy of lines along with their specific lifetime period.

Further, an algorithm has been developed that can be used all over the country to make decision for MVABC adaptation on feeders. Finally, a Software Tool is developed to make easy to generate decision for the same and review each case by doing the Sensitivity Analysis.

The dissertation concludes with few recommendations, technical issues associated with MVABC can be mitigated by purchasing cables according to the finalized specification. Use of MVABC shall improve availability and the reliability of consumers' power supply wherever the decision generated by mathematical model is yes.

Keywords: Electricity Distribution System, Medium Voltage, Bare Overhead System, Aerial Bundled Cable

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LIST OF ABBREVIATIONS

Abbreviation	Description
MV	Medium Voltage
ABC	Aerial Bundle Cable
BOH	Bare Over Head
CC	Covered Conductor
UG	Underground
CEB	Ceylon Electricity Board
LECO	Lanka Electricity Company
CMC	Colombo Municipal Council
GSS	Grid Substation
LKR	Sri Lankan Rupee
US$	United State Dollar
WPN	Western Province North
NWP	North Western Province
TNB	Tenaga Nasional Berhad
O&M	Operation & Maintenance
NPV	Net Present Value
kWh	kilo watt hour
XLPE	Cross Link Polyethylene
PVC	Polyvinyl Chloride
ROW	Right of Way
kV	kilo Volts

1 INTRODUCTION

1.1 Background

Utility supply of the Sri Lanka is governed by Ceylon Electricity Board (CEB) and 15% of total power distribution is maintained by Lanka Electricity Company (LECO). Electricity Supply has become a fundamental commodity of present society. Hence the reliability of distribution of electricity has gained utmost concern. The Distribution System consists of 33kV, 11kV and 0.4kV distribution networks. Normally, 11kV distribution can be considered as Underground System while 0.4kV Low Voltage System becomes downstream to 33kV Overhead network system. Reliability and the availability of consumers' power supply mainly depends on the 33kV medium voltage distribution system. Normally, 33kV Overhead distribution lines are constructed on poles and towers using bare conductors. However, distribution network is rapidly expanded to cater rural electrification demands and urban development demands. These 33kV lines pass through thick vegetation areas, coastal belt and urban areas where building density is higher.

As a results of that, nowadays, the 33kV Overhead Distribution lines are subjected to many system faults; mainly it is due to thick vegetation resulting transient and permanent faults. Fully Insulated 33kV overhead cable is an option for prevention of fault in the network and improves the reliability of power supply.

1.2 Motivation

As per the breakdown statistics of Distribution Division 02 of CEB, approximately, 50% of faults happened due to Wayleaves and Animals. Table 1-1 is illustrated the contribution of each breakdown categories in the year 2014.

Table 1-1: 33kV Breakdown Analysis of Distribution Division 02 in the Year 2014

Major Causes	Dec	Nov	Oct	Sep	Aug	Jul	Jun	May	Apr	Mar	Feb	Jan
Wayleaves related	126	133	140	125	129	116	149	93	96	92	81	77
Animal & Birds	47	55	85	91	89	77	57	50	28	47	28	34
Bad weather	182	110	99	93	79	103	119	46	56	69	23	23
Aging of fuses	136	204	245	266	271	237	224	203	215	127	135	164
*ACB tripping, fuses blown	380	454	469	354	324	379	453	300	328	312	225	211
Others	189	206	259	357	259	240	221	168	117	156	160	157
Total	1013	1107	1212	1195	1062	1075	1166	810	812	756	624	632

Further, following prevailing problems are existing with present system

Figure 1-1: Inadequate Safety Clearance

Figure 1-2: Non Standard Construction

Figure 1-3: O & M difficulties

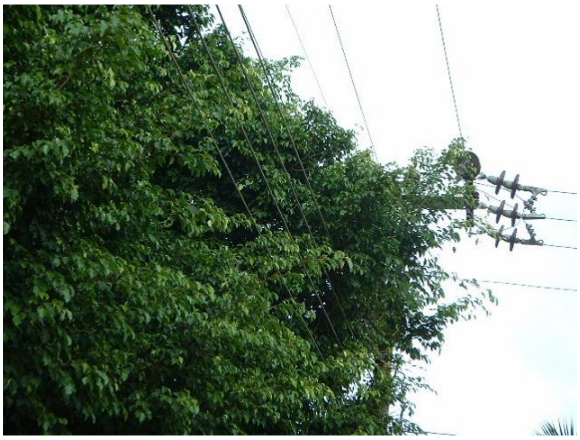


Figure 1-4: Vegetation Problems

It is clear that continuity of these issues may harm to system reliability and consumers' good will on CEB. On the other hand, CEB expends lots of money to maintain the existing 33kV BOH network system. For an example, Table 1-2 illustrate the cost that incurred yearly for the maintenance of North West Province of CEB.

Table 1-2: Annual Network Maintenance Cost of NWP, CEB

Item		**Cost/ LKR**
Maintenance Costs	Clearance of Vegetation / km	2,100
	Breakdown Maintenance / Nos.	8,944
	Preventive Maintenance / km	85,000
Maintenance Cost per Year	Clearance of Vegetation	197,000,000 (31,233 km)
	Breakdown Maintenance	526,000,000 (58,800 nos.)
	Preventive Maintenance	2,655,000,000
Total Maintenance Cost per year of NWP, CEB		**3,378,000,000**

1.3 Objectives of the study

The Objective of the study is to do Techno Economic Analysis on the use of Fully Insulated Cable for 33kV Overhead Power Distribution System in Sri Lanka.

- Verify the associated technical and economic issues.
- Finally, considering all the factors, prepare a model to generate decision for feeders which are more effective to convert from MV BOH to MV ABC or provide references to select methodology for new feeder development & implementation and develop software tool for the same.

1.4 Methodology

For the timely completion of the research, the work flow was arranged in the manner given below.

i. **Literature review**

Under the literature survey, literatures which discussed the existing problem and alternative solutions were referred. Most of the papers introduced Aerial Bundled Cables as a solution and discussed some technical & economic issues. The findings of the literature survey and other related information are discussed in Chapter 2.

ii. **Identify necessary data for compare feeders to make decision**

In making a decision using a model, it needs number of input data related to 33kV BOH Distribution System of Sri Lanka. The required input data relates to technical and economic parameters of the feeders. Specially, data relates to Initial Investment Cost, Operational & Maintenance Cost and Cost of Unserved Energy of each and every feeders. Hence, it is very much essential to scale down for a specific area and gather the data.

iii. **Analyses the General Capital Cost of MV ABC against MV BOH and MV UG.**

It is necessary to have a clear idea on basic capital cost comparison in between an available alternative solution for MV BOH. Basically, Initial Investment Cost analysis is carried out for 1km installation of MV ABC, MV BOH and MV UG.

iv. Develop an algorithm and equation model for Financial Feasibility Study.

In financial feasibility study, it is discussed Initial Investment Cost, Maintenance Cost and Unserved Energy Cost for feeders. Further, it is buildup a relationship each other and illustrate how to calculate each value for an application. Details on the financial feasibility study is given under Chapter 05

v. Validate the results

The results obtained in this research were validated by comparing them with case studies. Chapter 06 describes the validation procedure.

vi. Develop Software module for the same

As a result of the research, finally a software module was developed. The software helps for fast calculations, decision making and sensitivity analysis.

1.5 Contributions

Though, MV ABC is available in World Market and used as an alternative solution for MV BOH in some other part of the World, CEB does not have any installation of MV ABC in their 33kV Distribution System. It is high time to replace some of existing critical MV BOH lines from MV ABC. But the implementation shall not come across due to the cost factor, normally capital cost for MV ABC is 3 time greater than MV BOH. Therefore, the Research is discussed pros and cons of MV ABC, how to mitigate those technical issues and develop a financial model to evaluate each and every distribution feeder considering all aspects. Finally, it present a software module to the planners for their analysis works.

1.6 Organization

Rest of this dissertation is organized as follows.

- Chapter 2 summarizes the literature survey.
- Chapter 3, 4, and 5 explain the preparing of the model of the study
- Chapter 6 gives the results of the study
- Chapter 7 discusses about the software development and the sensitivity analysis
- Chapter 8 discusses on the conclusions of the research

2 LITERATURE REVIEW

A thorough literature review was done at the outset of this research to identify the solutions for the existing problems associated with MV BOH lines. Further, it is identified that MV ABC shall be a best solution with some technical issues to be verify. This section summarizes the information gathered through the literature review and the key findings of it.

2.1 General Information

As introduced in the motivation, approximately 50% of system faults can be reduced by converting Bare Overhead lines into Insulated Overhead lines. In 1990's TNB Malaysia was faced similar experience with their distribution system. As shown in Figure 2-1, failure of TNB Distribution Network causes followings [1].

Major Causes	2001/02	2002/03	2003/04	2004/05	2006/07
Transient	174	106	101	188	112
Lightning	114	96	98	151	79
Ageing	64	42	47	51	31
Trees	60	43	24	43	43
Animals	55	31	34	26	42
Poor Contact	28	22	16	40	21
Thunderstorm	18	13	6	14	14
Others	57	93	105	210	79

Figure 2-1: MV BOH Top Failure Causes

It is clear that more than 50% faults happened due to Trees, Animals and Lightning, and it could be totally mitigate by using Insulated Cables instead of BOH lines. Further, more than 50% of faults in Thunderstorm and Transient categories also can be minimized with the same approach.

2.2 Identified Alternative Solutions for MV BOH with their attributes

Partially Insulated Covered Cable, Fully Insulated Aerial Bundled Cable, and Underground Cable Systems are increasingly emerging as a popular alternative to Bare Overhead Distribution System, while improving both electricity supply reliability and personnel's safety [2].

a) Partially Insulated Covered Cable System

PVC Covered All Aluminum Allow Conductors without metal sheaths Cable is developed in order to improve the reliability of MV Network and prevent bush fire initiation [3].

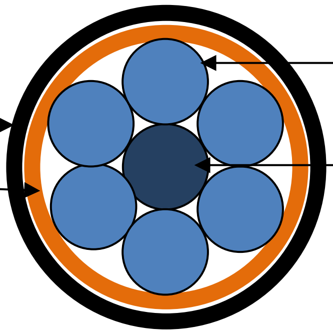


Figure 2-2: MV Covered Cable Cross Section Structure

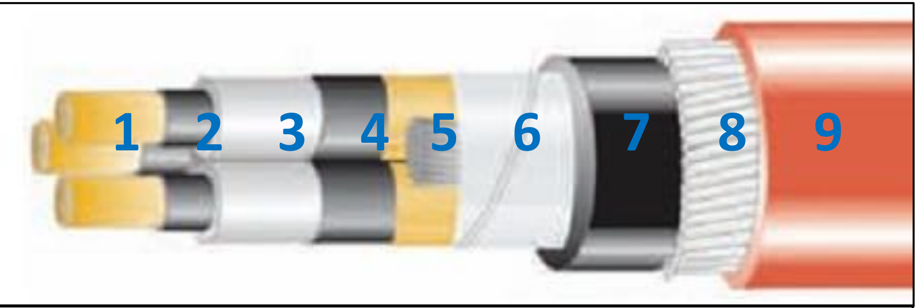
The Covered Cable System helps in minimizing frequent tripping on account of accidental contact of phase to phase or phase to earth through way leaves due to growth of vegetation. The covering of the cable does not provide rated insulation and therefore, these cables are not touch proof but it is narrow down the Right of Way (ROW) corridor. According to Sri Lanka Electricity Act, No. 20 of 2009, Covered Cable is considered as "**not surrounded by insulation**" [4]. Therefore, narrow downing the ROW is not possible in Sri Lanka with current Electricity Act.

However, the major problem of MV Covered Cable is the long term reliability with water ingress. This happens due to the use of Insulation Piercing Connector, Arcing Gaps and Spacers and etc. As the insulation damage at the supportive point due to electrical stress create any of above, water entry into PVC-covered non- compacted aluminum conductor caused rapid corrosion of the aluminum and develop many failures.

Figure 2-3: MV Covered Cable Damages at Supportive Points

b) Underground Cable System (UG)

The use of Underground Cables is the best solution from the point of view of the visual impact and also it is suitable for congested urban areas where overhead lines may be difficult or impossible to install [5].



1. CU conductor
2. Conductor Screen (semi-conducting)
3. XLPE Insulation
4. Insulation Screen (semi-conducting)
5. CU Tape Screen
6. Filling materials (Polymers)
7. PVC inner sheath
8. Galvanized Steel Amour
9. PVC outer sheath

Figure 2-4: MV Underground Cable Structure

Cross linked polyethylene (XLPE) is used as its insulation medium while all semi-conductive screen used to make uniform surface to each layer and support for electrical stress control. Copper Tape Screen is used as earth conductor which make closed path for faults currents. The Underground (UG) cables are most vulnerable to mechanical damage while having unauthorized excavation. Therefore, UG cable is mechanically strength by Galvanized Steel Amour.

However, the underground cable is the most attractive electrical distribution system in the point of City Planners of Municipal Council, the Environmentalist and most importantly electrical Consumers due to the visual impact and supply reliability. Further, from utility point of view following benefits are highlighted.

- Low maintenance due to fewer faults
- Not susceptible to shaking and shorting due to vibrations, wind, accidents, etc.
- Not easy to steal, make illegal connections or sabotage
- Poses no danger to wildlife or low flying aircraft.

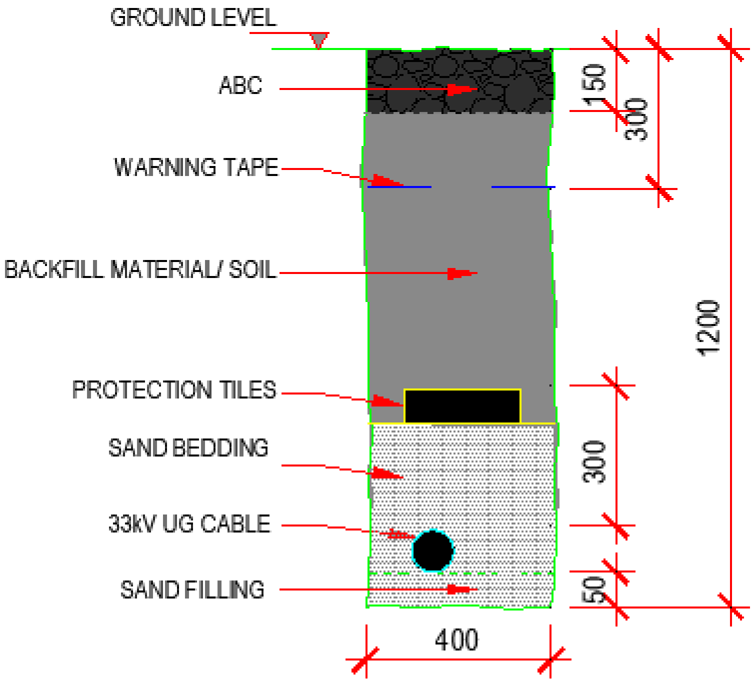


Figure 2-5: Direct Buried Cable Trench Layout

Figure 2-5 shows that how to install 33kV UG Cable in direct buried method which used in Colombo City, CEB. However, due to the following disadvantages of UG cable, electricity utility providers shall not planned to install UG Cable Distribution Systems if and only if it is very much critical,

- More expensive (10 time of BOH line cost)
- Third party approvals are mandatory
- Difficult in identifying and repairing broken cables
- Damage to cables or electrocution may occur to people digging the ground and if they are unaware of the cable's existence

c) Fully Insulated Aerial Bundled Cable System (ABC)

Medium Voltage Fully Insulated Aerial Bundled Cable consist of a copper metallic shield which create a designated path for charging current during normal operation and fault current during insulation failure, the semi-conductive screen layer makes the transition from the insulation to avoid different electrical potential over insulation surface and to drain the dielectric current on all circumference over the insulation, and the XLPE insulation is designed and tested to function at full operating voltage [2], [6]. Further, Messenger Conductor used to mount the cable on pole top.

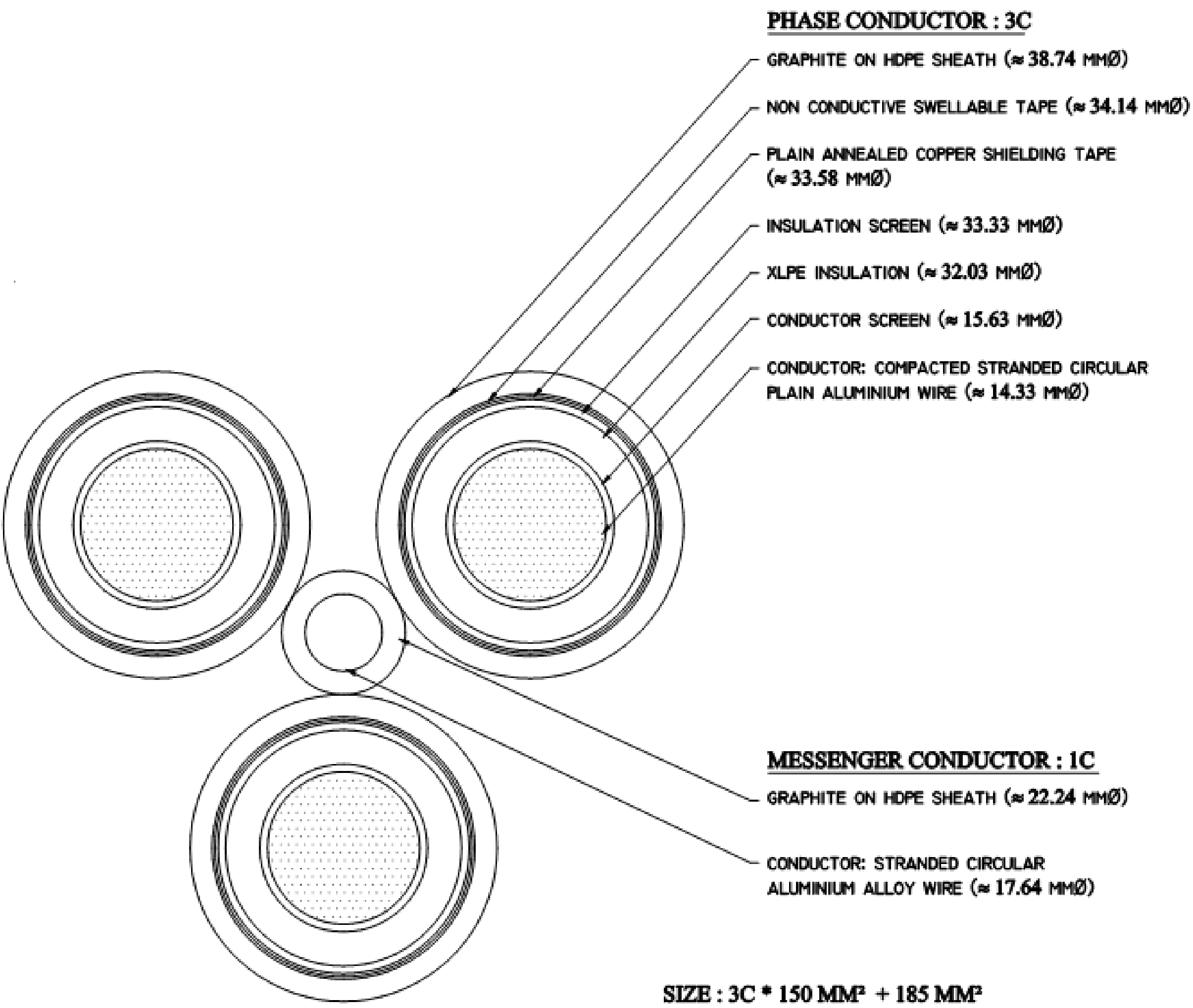


Figure 2-6: MV ABC Cross Section Structure

The advantages with the MV ABC design as compared to MV BOH are as follows,

- Overcoming right-of-way or acquisition issues with the convenience of having the MVABC system easily constructed by the roadside
- Conductor being bundled together, no phase to phase or phase to earth clearance required
- Mitigating supply interruptions due to transient faults caused by vegetation, animals or weather-related outages such as lightning and strong wind
- Requiring shorter poles with the use of spun concrete poles
- Providing cost-effective and faster construction and maintenance
- Touch safety for people and animal

Therefore, this system is identified as most techno- economic solution particularly where constraints on availability of way- leave clearance exist and also where bush fire risk with overhanging trees exist, in highly congested localities where obtaining live metal clearances is a bottleneck and where vulnerability to power thefts exist.

Figure 2-7: MV ABC Construction flexibility

However, MV ABC has been introduced into Australian Power System since 1984. Most of the Australian Utilities greatly underestimated the difficulties of MV ABC installation [3]. The traditional overhead distribution system does not require multi-skilled workforce such as linesman and jointers but MV ABC. Therefore, at the beginning the countries did not achieved what they expected from MV ABC but some system improvement. Further, Brazil, Malaysia and India were adopted MV ABC on trial basis and subsequently on regular basis. The summary of the literature review is shown in the Table 2-1.

Table 2-1: Summery of available solution

No	Features	MVUGC	MVCC	MVABC
1.	Capital Cost	Very High	Medium	High
2.	Third Party Approvals (Municipal Council & Police)	Mandatory	No	No
3.	Construction Time Period	High	Less	Less
4.	Access for the Maintenance	Difficult	Easy	Easy
5.	Reliability (Interruptions)	Very Good	Fair	Good
6.	Safety (Human access and Lightning strikes)	Good	Same as MVBOH	Very Good
7.	Environmental aspects	Excellent	Good	Very Good

Therefore, MV ABC is selected as the best alternative for MV BOH and considered further techno economic analysis.

3 VERIFY THE INITIAL PRACTICES AND ISSUES WITH MV ABC

So, it is clear that before adopt the MV ABC system, utility shall be verified in details the available technical and installation issues.

3.1 Factors to be considered during the preparation of Specification of MV ABC

The most common issues with MV ABC are as follows,

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

1. Stress Crack on the outer sheath of the cable

The Stress Crack found on the outer sheath of the MV ABC cable due to material characteristic of HDPE (High Density Polyethylene). HDPE is less ductile, poor weathering resistance, low strength, stiffness, hence as illustrated in Figure 3-1 stress crack is progressed.

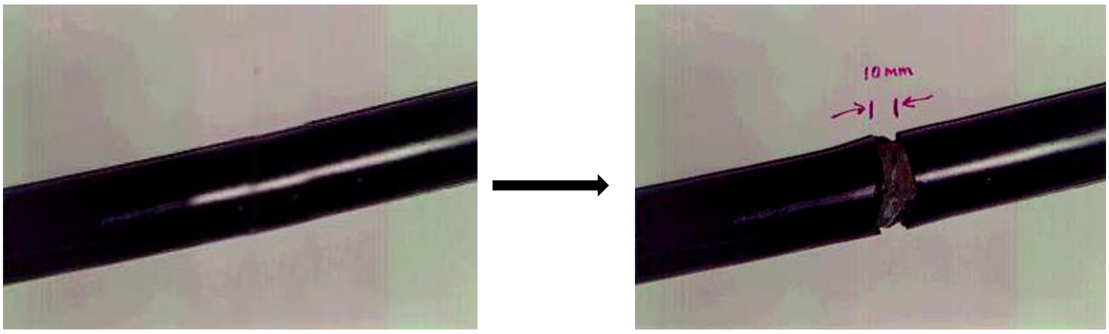


Figure 3-1: Stress Crack on HDPE Outer Sheath of MVABC

As a results of that water ingress to core and experienced premature failure. Therefore, issue was addresses by replacing the outer sheath material from HDPE to PVC Grade ST-2. Although the use of PVC Grade ST-2 as the outer sheath has mitigated the stress crack issues, care must be taken when pulling the MVABC cable onto the poles as PVC is softer than HDPE and improper pulling and laying of the PVC during construction can damage the outer sheath of the new MV ABC. Thus, it is better to go for two layer outer sheath, first PVC layer and then MDPE outer sheath.

2. Damaged Copper Screen

In the MV ABC, the design was only with one layer of copper screen. If the only layer of copper screen were to be damaged or cracked as shown in Figure 3-2, the MV ABC would be exposed to local overheating and further damage as mentioned above whenever fault occurred.

Figure 3-2: Damaged Copper Screen

In order to improve the reliability of the MV ABC copper screen, two layers of copper screen with a 15% overlapping between the layers are used. Such design not only ensures the robustness of the copper screen but also improves the sheath current carrying capacity of the MVABC. Thus, enhancing the life cycle of the insulation of the MV ABC.

3. Burnt Outer Sheath

With the copper screen damaged or cracked, the capability of the MVABC to carry fault current would be compromised as damaged or cracked copper screen would create a high resistance path.

Figure 3-3: Burnt Outer Sheath

If a fault occur on the MVABC feeder, the fault current would flow to the source through the damaged or cracked copper screen. Thus, with the copper screen becoming highly resistance, the fault current would overheat the XLPE and outer sheath and subsequently would damage the MVABC as illustrated in Figure 3-3 above. With the improved following cable structure design, mentioned issues can be rectified.

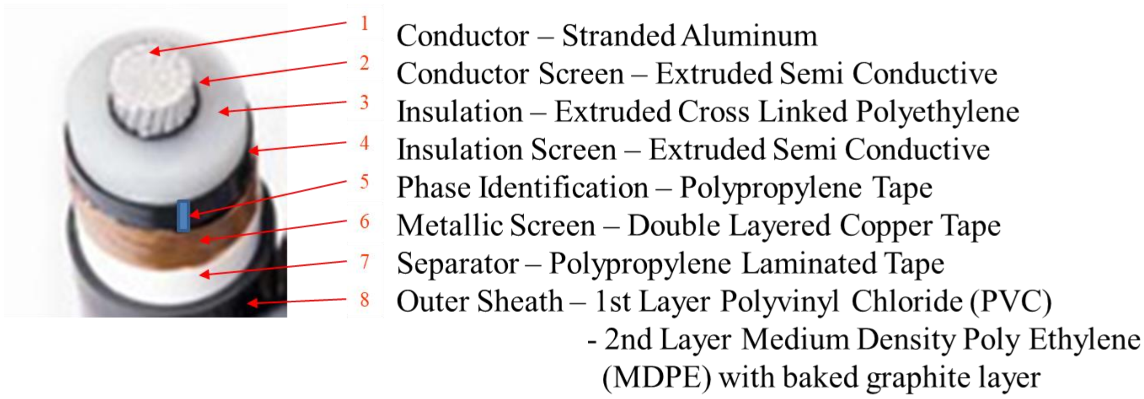


Figure 3-4: Improved Cable Structure

3.2 Factors to be considered in MV ABC Installation

1. <u>Performance against the Lightning and Surges</u>

Lightning over voltages are one of the most frequent causes of the medium voltage distribution systems outages. The induced over voltages caused by the indirect lightning strikes to the nearby objects or the direct strikes [3]. MV ABC is consisted with a copper screen which is kept at ground potential as it is bonded to earth. Thus, voltage rise induced by lightning strike shall be at a minimum. However, when the MVABC is connected to the following installations, surge arresters need to be installed:

- Where air-break type isolators or load break switches are installed;
- Where uninsulated switches or control gear, such as expulsion drop-out fuse assembly, are installed;
- Where a connection to the bare overhead line system is necessary.

Figure 3-5: Installation of SA where ACB placed in between ABC line

Therefore, MV ABC is a very good solution for the areas where lightning prone.

2. Presence of Induced Voltage on Metallic Screen of the Cable

As current flows through the conductor of a power cable, a voltage will be induced on the power cable metallic sheath. When the single core cable run is long and are only earthed at one end, will have a voltage appearing at the other end. The induced voltage will be a function of the following;

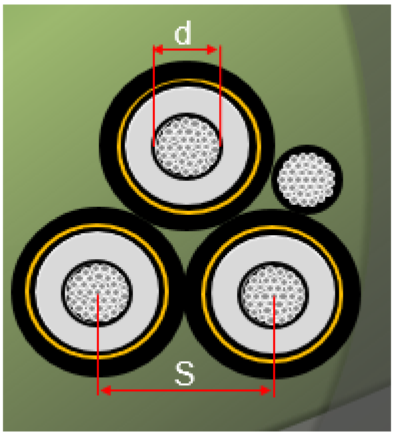
- the current in the cable conductor
- the frequency of the current (50Hz)
- the length of the cable
- the proximity of the other two cables
- the mutual inductance per phase

The Voltage (V), induced between the conductor and the sheath is given by; [7]

$$\mathbf{V = I\omega M} \text{ Volts/ m}$$

Where, I = current in the conductor, ω = 2πf (314 for 50Hz system), M = 0.2 ln [2S/d] μH / m
The total inductance of a cable in a circuit consisting parallel cables is given by:

$$\mathbf{M = 0.2 \ln (2\, S/d)}\ \mu\text{H / m}$$



Where;

S = axial spacing between conductors of a trefoil group of single-core cables (mm)
d = diameter of circular conductor (mm)

eg: Load Current in Conductor, I_L = 290 A (still air),
Induced Voltage, V_{Sh} = 15 V/km

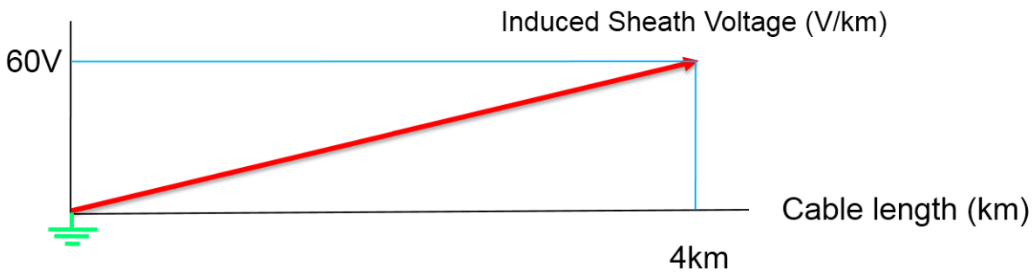


Figure 3-6: Induced voltage of single core cable earth at the end

When single core cable is earthed at both ends current will flow in the sheath as a result of the induced voltage.

The current is calculated as follows;

$$I_C = [V / Z]\ A$$

Where, I_C = circulating current

V = induced voltage

$Z = \sqrt{R^2 + (\omega M)^2}\ \Omega / m$ (impedance of the sheath)

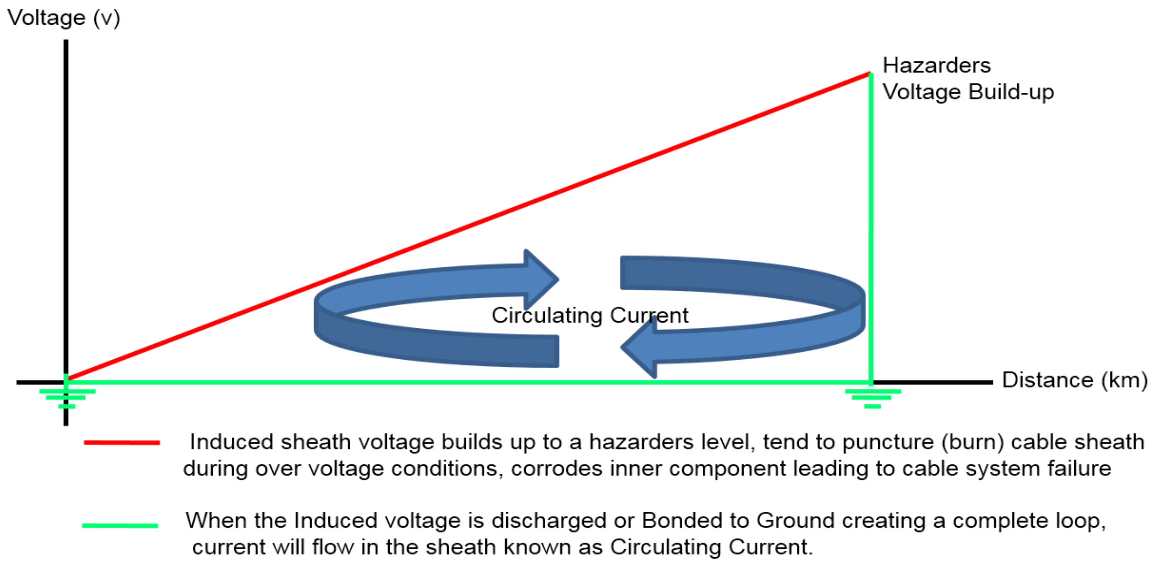


Figure 3-7: Induced voltage of single core cable earth at both end

Normally, MV ABC drum length is 500m. Therefore, a joint is appeared each and every kilometer. If the cable is grounded at every joint point as earth bonding to convert the induced voltage to circulating current of smaller magnitude creating a saw tooth voltage profile.

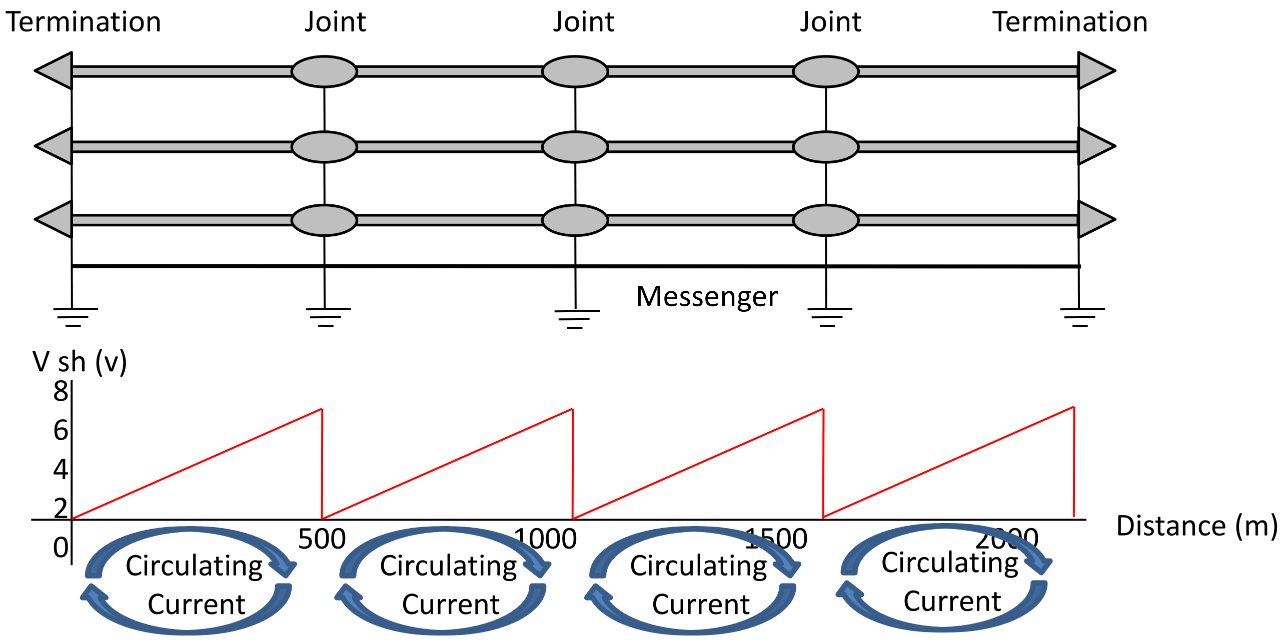


Figure 3-8: Induced Current mitigated by having Earth Bonding at all Joint

3. Limitation with MV ABC Feeder Length

Usually, overhead lines are bare conductors, but MV ABC is a fully insulated screen cable. Therefore, effect of the capacitance and the voltage drop is high compared to BOH lines. As an example;

Referring cable catalogue, MV ABC 3C x 120 mm^2 + 50mm^2 [8],

Rated Current Capacity = *311 A*

Rated Voltage = *33kV*

Maximum DC resistance of conductor at 20ºC = *0.253 Ω/km*

As per the Grid Code voltage variation = ± 6%

Then maximum feeder length can be calculated as follows,

$$l_{max} = \Delta V/(IR)$$

$$\approx 25 \text{ km}$$

Hence, it is not advisable to use MV ABC for long distance feeder lines. However, considering load currents, line length can be adjusted as much as possible.

4 GENERAL CAPITAL COST ANALYSIS OF MV ABC AGAINST MV BOH AND MV UG

It is need to evaluate system capital cost of Ariel Bundle Cable against traditional Bare Overhead System and Underground System and get comparative figure which make sense system planners. This analysis takes into consideration the supply and installation of one kilometer 33kV line. However, the conductor size selection for the comparison has done based on current rating as illustrated in table 4-1.

Table 4-1: Cable Size Selection for the comparison

Parameter	MV BOH- Racoon	MV ABC	MV UG
System Voltage, kV	33	33	33
Rated Current, A	307	311	305
Nominal size, mm^2	92.4	3 x 120	150/ 3C
Conductor	ACSR	Al	Cu
Insulation	N/A	XLPE	XLPE

4.1 Capital Cost Calculation for 33kV BOH line per km

Assume line is constructed using Racoon Conductor on 11m Pole.

a) <u>Material Cost of 33kV BOH per km</u>

Referring the Price List of CEB in year 2017 [9]. Following table has summarized the Bill of Quantity for 1km Racoon Line according to the CEB Distribution Construction Standard for Medium Voltage [10].

Table 4-2: Standard Material List for 1 km Racoon Conductor 33kV on 11m Pole

No	Item Description	Qty	Unit	Rate/ LKR	Total / LKR
1	Poles Concrete Prestressed 11m 350kg	8	Nos.	41,465.00	331,720.00
2	Poles Concrete Prestressed 11m 500kg	5	Nos.	45,155.00	225,775.00
3	Poles Concrete Prestressed 11m 850kg	4	Nos.	62,495.00	249,980.00

4	Poles Concrete Prestressed 11m 1200kg	1	Nos.	66,910.00	66,910.00
5	Cross Arm Pin 33kV	11	Nos.	7,505.00	82,555.00
6	Cross Arm Tension 33kV	4	Nos.	15,730.00	62,920.00
7	Board Danger 33kV	15	Nos.	480.00	7,200.00
8	Washers G 1 16mm	127	Nos.	17.50	2,222.50
9	Bolts & Nuts G 1 50mm * 16mm	49	Nos.	57.50	2,817.50
10	Bolts & Nuts G 1 200mm * 16mm	40	Nos.	127.50	5,100.00
11	Bolts & Nuts G 1 230mm * 16mm	20	Nos.	142.50	2,850.00
12	Bolts & Nuts G 1 250mm * 16mm	8	Nos.	145.00	1,160.00
13	Bolts & Nuts G 1 300mm * 16mm	8	Nos.	210.00	1,680.00
14	Bolts & Nuts G 1 360mm * 16mm	2	Nos.	267.50	535.00
15	Wire Stay 7/4.06mm	120	Kg	270.00	32,400.00
16	Stay Assembly 2400mm * 16mm	12	Nos.	5,730.00	68,760.00
17	Thimbles 7/4.06mm	12	Nos.	32.50	390.00
18	Stay Clamp G I	12	Nos.	145.00	1,740.00
19	Strust Bracket G I	3	Set.	290.00	870.00
20	Stainless Steel Strap for ABC	10	m.	165.00	1,650.00
21	Buckles Straps Stainless Steel For ABC	12	Nos.	45.00	540.00
22	Insulator Stav H T	12	Nos.	147.50	1,770.00
23	Insulator Pin 33kV	42	Nos.	3,525.00	148,050.00
24	Insulator Tension 33kV	18	Set.	7,145.00	128,610.00
25	Alu. A C S R 7/4.09mm(Racoon)	1005	Kg.	435.00	437,175.00
26	Wire Binding Alu.(No. 9)	10	Kg	790.00	7,900.00
27	Al/Al 7/4.09.7/4.09H Type Compression Line Tap	3	Nos.	370.00	1,110.00
28	Wire G S 5mm (No.6)	152	Kg.	275.00	41,800.00
29	Earth Rods Steel Copper Clam 1.2m	4	Nos.	675.00	2,700.00
30	Brass Sleeve 5.5mm * 50mm	4	Nos.	210.00	840.00
31	Joint Compression Midspan 7/4.09 Racoon	3	Nos.	1,830.00	5,490.00
32	Joint Compression Non Tention Sleeve 7/4.09 Racoon	9	Nos.	1,140.00	10,260.00
				Grand Total/ LKR	**1,935,480.00**

b) Labour Cost of 33kV BOH per km

Referring the Contractor Labour Rates of CEB in year 2017 [11]. Following table has summarized the Construction Cost for 1km Racoon Line.

Table 4-3: Standard Labour Rate for 1km Racoon Conductor 33kV on 11m Pole

No	Item Description	Qty.	Unit	Rate/ LKR	Total / LKR
1	Excavation Of Pole Pit 11m 350kg	8	Nos.	1,510.00	12,080.00
2	Excavation Of Pole Pit 11m 500kg	5	Nos.	2,260.00	11,300.00
3	Excavation Of Pole Pit 11m 850kg	4	Nos.	2,260.00	9,040.00
4	Excavation Of Pole Pit 11m 1200kg	1	Nos.	3,020.00	3,020.00
5	Excavation Of Pole Pit for Struts 11m 350kg	3	Nos.	750.00	2,250.00
6	Excavation Pit for Stays	12	Nos.	1,510.00	18,120.00
7	Erection of 11m 350kg PS Pole	8	Nos.	2,210.00	17,680.00
8	Erection of 11m 500kg PS Pole	5	Nos.	2,210.00	11,050.00
9	Erection of 11m 850kg PS Pole	4	Nos.	3,130.00	12,520.00
10	Erection of 11m 1200kg PS Pole	1	Nos.	3,130.00	3,130.00
11	Erection of 11m 350kg PS Struts	3	Nos.	2,450.00	7,350.00
12	Concreting of Pole pits	21	Nos.	1,300.00	27,300.00
13	Erection of Stays	12	Nos.	1,760.00	21,120.00
14	Dressing of Pin poles (Fixing of X-arms & Insulators)	8	Nos.	1,680.00	13,440.00
15	Dressing of Tension poles (Fixing of X-arms & Insulators)	8	Nos.	2,260.00	18,080.00
16	Dressing of Shackle poles (Fixing of X-arms & Insulators)	2	Nos.	3,390.00	6,780.00
17	Stringing of three conductors & Earth wire (including binding & Jumper Connections Clamping, Crimping of joint necessary)	1	Lot	79,200.00	79,200.00
18	Earthing	4	Nos.	500.00	2,000.00
				Grand Total/ LKR	**275,460.00**

Total Cost for the 1km Racoon Conductor 33kV on 11m Pole = Material + Labour

= 1,935,480 + 275,460

= **LKR 2,210,940.00**

4.2 Capital Cost Calculation for 33kV ABC per km

Even though CEB doesn't has the Standard Material List and Contractor Labour Rate for 33kV ABC, it is necessary to has both to generate cost comparative figure. Therefore, hypothetical 1km line design is very much essential to identify the standard materials and Figure 4-1 shows the way capital cost calculation is planned.

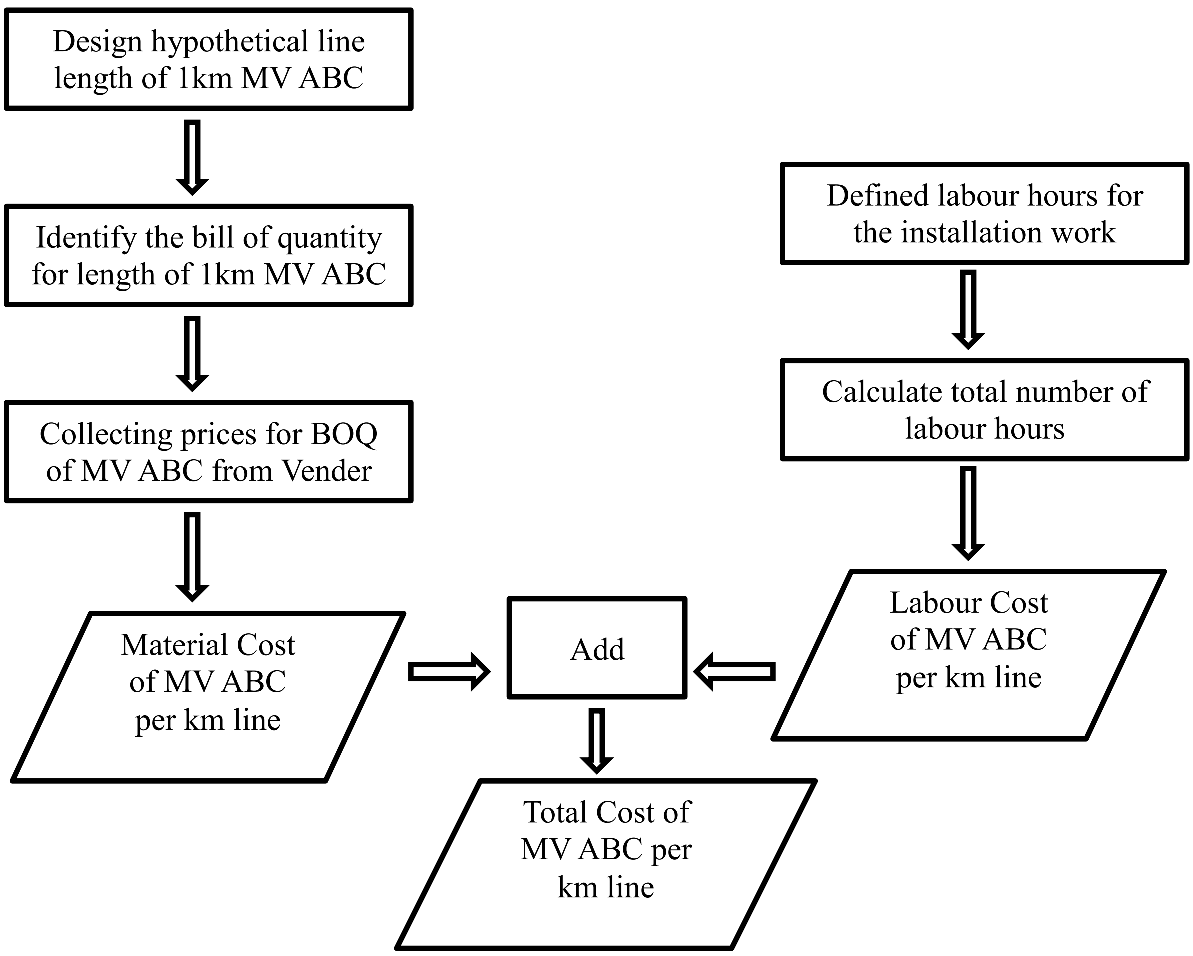


Figure 4-1: Capital Cost Calculation Flow Chart of MV ABC

a) Design 33kV ABC Hypothetical Line

- **Useful equations;** [12]

i. Wind Load = Wind pressure x Cable diameter
ii. Wind pressure = 1/2 x Density of air x Wind speed^2 x Drag coefficient
iii. Effective weight of cable = √(weight/m ^2 + wind load ^2)
iv. Weight of cable = mass of cable x gravity force
v. Line sag = (effective cable weight x span length ^2)/(8 x effective tension)
vi. Conductor length = Span length + [(8 x Line sag^2) / (3 x Span length)]
vii. Classic sag = not exceeding 5% of span length for span length of less than 300 m

- **System Data ;** [8],[10],[12]

Pre-Stressed 11m Pole Working Load	500 kg
Safety Factor	2.5
Cable Size of MV ABC (Al)	3 x 120 + 50 sqmm (GSW)
Overall mass of ABC	5.05 kg/m
Overall diameter of ABC	90.00 mm
Wind speed	34 m/s
Density of air	1.23 kg/m^3
Gravity force	9.81 m/s^2
GSW breaking Load	61400 N
Safety Factor of GSW	5
Drag coefficient (shape factor)	2/3 for cylinder

- **Span length and tension point calculation of Aerial bundled cable (cylinder) suspended in air by GSW messenger (single circuit)**

Using equation (ii),

Wind Pressure on the Cable $= 0.5 \times 1.23 \times 34^2 \times 2/3$

$= 474 \text{ N/m}^2$

Using equation (i),

Wind Load on the Cable $= 474 \times 0.09$

$= 42.7$ N/m

Using equation (iv),

Weight of the Cable per meter $= 5.05 \times 9.81$

= 49.5 N/m

Using equation (iii),

Effective weight of the Cable per meter = $\sqrt{49.5^2 \times 42.7^2}$

= 65.4 N/m

Effective Tension of messenger (GSW) = 61400 × 1/5

= 12280 N

Span length based on effective tension (T) of GSW $= \frac{\text{Effective Tension of messenger (GSW)}}{\text{Effective weight of the Cable per meter}}$

= 12280/ 65.4

= 188 m

That's meant that, L = 188m is the maximum length between tension points, in other word length between section pole to section pole = 188m

Span length based on pole strength (transverse) $= \frac{\text{Pole Strength in transverse}}{\text{Effective weight of the Cable per meter}}$

= [(500 × 9.81)/ 2.5]/ 65.4

= 30 m

No of spans between section poles $= \frac{\text{Length between section poles}}{\text{Span length}}$

= 188/ 30

= 6.3 ≈ 6

Using equation (v),

Line Sag $= \frac{65.4 \times 30^2}{8 \times 12280}$

= 0.6 m

Final Sag is maximum of 10% plus to the line sag = 0.6 × 110%

= 0.66 m

Therefore, the conductor length using equation (vi);

Effective Conductor length (*l*) $= 30 + \frac{8 \times 0.66^2}{3 \times 30}$

= 30.04 m

Final conductor length is maximum of (+10%) to (*l*) = 30.04 × 110%

= 33 m

Results:

Span length, pole to pole = 30m

No of Spans between section poles = 6 Nos.

Utilized cable length for the span = 33m

Following Figure 4-2, illustrate the general case for the above calculation,

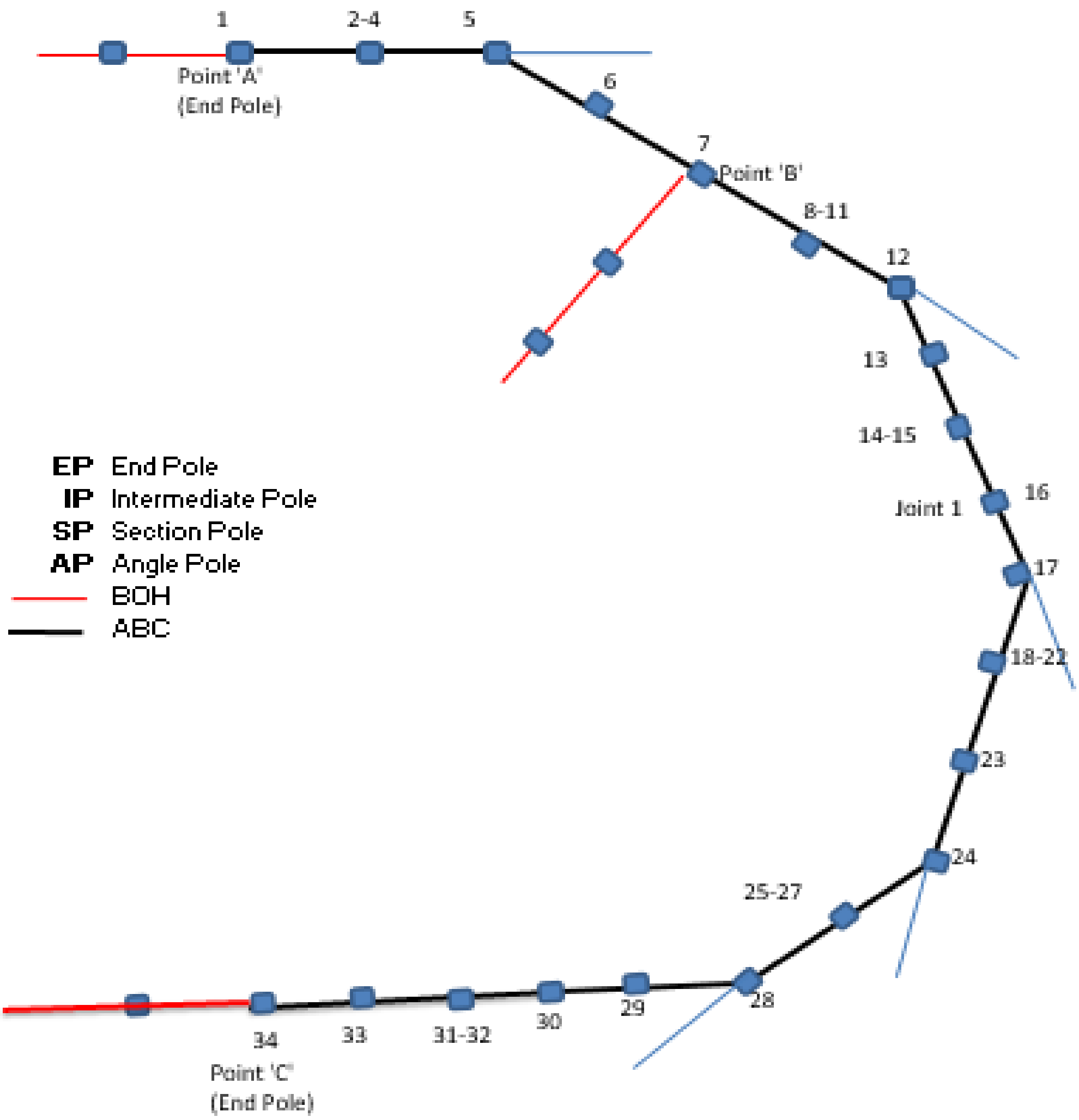


Figure 4-2: Designed Pegging line diagram of 1km length MV ABC

Let’s identified the ABC Support requirements according to pegging line diagram.

DA Dead End Bracket c/w Anchor Unit
TS Triangular Bracket c/w Suspension Clamp
TO Non Thermal Termination (Out Door)
JE Premoulded Straight Through Joint (Earth Bond) c/w Composite Joint Tray
ES Earthing Set (Earth Bonding kit)
LA Lighning Arrestors

Table 4-4: ABC Support requirements according to pegging line diagram

Pole No.	Type	DA	TS	JE	TO	ES	LA
1	EP	1	0	0	1	1	1
2 to 4	IP	0	3	0	0	0	0
5	AP	2	0	0	0	0	0
6	IP	0	1	0	0	0	0
7	SP	2	0	0	2	2	1
8 to 11	IP	0	4	0	0	0	0
12	AP	2	0	0	0	0	0
13	SP	2	0	0	0	0	0
14 to 15	IP	0	2	0	0	0	0
16	SP	2	0	1	0	1	0
17	AP	2	0	0	0	0	0
18 to 22	IP	0	5	0	0	0	0
24	AP	2	0	0	0	0	0
25 to 27	IP	0	3	0	0	0	0
28	AP	2	0	0	0	0	0
29	SP	2	0	0	0	0	0
30 to 33	IP	0	4	0	0	0	0
34	EP	1	0	0	1	1	1
	Total	**20**	**22**	**1**	**4**	**5**	**3**

b) <u>Material Cost of 33kV ABC per km</u>

Referring the material quantities abstract from hypothetical MV ABC line designed and budgetary values were given by M/s. Olex (Pvt.) in year 2015 for the Nexus Cable accessories & Malaysian Pole accessories. Following table has summarized the Bill of Quantity for 1km ABC line.

Table 4-5: Estimated Material List for 1 km ABC 33kV on 11m Pole

No	Item Description	Qty.	Unit	Rate/ LKR	Total /LKR
1	Poles Concrete Prestressed 11m/ 500kg	34	Nos.	45,155	1,535,270
2	Strut Poles Concrete Prestressed 11m/ 350kg	1	Nos.	41,465	41,465
3	Stay Assembly c/w all other accessories	5	Nos.	8,700	43,500
4	Galvanized Triangular Bracket with Insulated Suspension Clamp and U bolt	22	Nos.	9,282	204,204
5	Galvanized Single Dead End Bracket with U – Shackle and Insulated Dead End Clamp c/w Al. Alloy Parallel Clamp	20	Nos.	16,380	327,600
6	Composite Cable Joint Tray c/w Galvanized Mounting Bracket	1	Nos.	23,615	23,615
7	Cold Shrink Straight Through Joint for 33kV 3 x 1Core 120mm2 XLPE ABC Alu Cable c/w Alu. Ferrule	1	kits	58,286	58,286
8	Earth Bond & Messenger Earthing Kit	5	sets	9,146	45,728
9	Messenger Continuity Kit	12	sets	1,300	15,600
10	Cold Shrink OUTDOOR End Termination Kit for 33kV 3 x 1Core 120mm2 XLPE ABC Alu Cable c/w Bi-Metal Lugs	4	kits	58,286	233,142
11	Surge Arrestor 33kV, 10kA	3	Sets	26,160	78,480
12	33kV ABC 3x120mm2 XLPE/SCT/PVC/HDPE/AL	1000	m	3,930	3,930,000
13	33kV Danger Board	15	Nos.	480	7,200
Grand Total/ LKR					**6,544,089**

c) Labour Cost of 33kV ABC per km

Referring the report for the Contractor Labour Rates for MV ABC of CEB for the year 2016 [13] was drafted by Committees for Preparation of Construction Rates. Following table has summarized the Construction Cost for 1km MV ABC Line.

Table 4-6: Drafted Standard Labour Rate for 1km ABC 33kV on 11m Pole

No	Item Description	Qty.	Unit	Rate/ LKR	Total / LKR
1	Excavation Of Pole Pit 11m /500kg	34	Nos.	2,260	76,840
2	Excavation Of Pits For Strut 11m /350kg	1	Nos.	1,510	1,510
3	Excavation Of Pits For Stays	5	Nos.	1,510	7,550
4	Erection Of 11m /500kg Concrete Pole	34	Nos.	2,210	75,140
5	Erection Of 11m /350kg Strut Pole	1	Nos.	2,210	2,210
6	Concreting of Pole pits	4	Nos.	1,300	5,200
7	Erection Of Stay	5	Nos.	1,760	8,800
8	Fixing Triangular suspension Assembly	22	Nos.	229.50	5,049
10	Fixing Dead end Assembly	20	Nos.	229.50	4,590
11	Pulling pilot wire	1	Lot	3,825	3,825
12	Fixing of running blocks	34	Nos.	153	5,202
13	Pulling cable	1	Lot	22,950	22,950
14	Tensioning of cable	1	Lot	3,060	3,060
15	Connecting suspension clamp	22	Nos.	138.13	3,039
16	Cable joints	1	Nos.	5,100	5,100
17	End Termination joint	2	Nos.	3,825	7,650
18	Tee-off joint	1	Nos.	5,100	5,100
19	Earthing	2	Nos.	4,080	8,160
20	Connection of lightning arrestor	1	Nos.	1,530	1,530
				Grand Total/ LKR	**252,505**

Total Cost for the 1km ABC 33kV on 11m Pole = Material + Labour

= 6,544,089 + 252,505

= LKR 6,796,594

4.3 Capital Cost Calculation for 33kV UG per km

Assuming Underground Cable is laying direct buried method along the carpet road and both end is terminated on pole top. Cable drum length is 250m. Though, 150mm^2 /3C/CU/XLPE/UG cable is matched with Racoon Conductor with respect to current carry capacity, currently, CEB does not used 150mm^2 /3C/CU/XLPE/UG cable for the installation. Therefore, it has to consider 185mm^2 /3C/CU/XLPE/UG cable as next suitable for the comparison work.

Referring the Price List of CEB in year 2017 [9], the Contractor Labour Rates of CEB in year 2017 [11], Underground Cable laying Contractor Rates of CEB for the year 2016/2017 [15], and Standard Road Restatement Rate of Colombo Municipal Council [16], following table has summarized the Bill of Quantity with Labour for 1km 185mm^2 /3C/CU/XLPE/UG.

Table 4-7: Standard Rate for 1km UG 33kV Cable laying in direct buried method

No	Item Description	Qty	Unit	Rate/ LKR	Total / LKR
Materials					
1	33kV/185mm^2 /3C/CU/XLPE/SWA/UG Cable	1,000	m	44,260	44,260,000
2	HT Cable Tiles	3,000	Nos.	440	1,320,000
3	Warning Tapes	1,000	m.	63	63,000
4	End Termination Kit HS Outdoor- 33kV/185mm^2 /3C/CU/XLPE/SWA	2	Nos.	39,985	79,970
5	Straight Through Joint HS-33kV/185mm^2 /3C/CU/XLPE/SWA	3	Nos.	76,500	229,500
6	ABC	447	Nos.	1,250	558,750
7	Quarry Dust	894	Nos.	1,250	1,117,500
				Total Cost for the Materials	**47,628,720**
Labour					
8	Cable Laying	7,506	Nos.	442	3,317,652
9	Cable Jointing & Termination	180	Nos.	598	107,640
				Total Cost for the Labour	**3,425,292**
10	**CMC Restatement Cost**	**1,000**	**m**	**3850**	**3,850,000**
				Grand Total/ LKR	**54,904,012**

Table 4-8: Summery of Capital Cost Values

Item	33kV Racoon BOH System	33kV ABC System	33kV UG Cable System
Material cost per km in LKR	1,935,480	6,544,089	47,628,720
Labour cost per in LKR	275,460	252,505	3,425,292
CMC Restatement Cost in LKR	N/A	N/A	3,850,000
Total Cost per km in LKR	2,210,840	6,796,594	54,904,012
Cost factor with respect to BOH System	**1.00**	**3.07**	**24.8**

5 MV ABC ECONOMIC FEASIBILITY STUDY FOR DIFFERENT FEEDERS

According to the analysis done in chapter 04, MV Underground Systems' Cost factor over the MV BOH is about 25 times. Then, it is clearly indicated that MV UG system is suitable for the application where MV BOH and MV ABC are not appropriated in the sense of technical and practical.

Therefore, only MV ABC is considered for the economic feasibility study based on initial investment, annual operational & maintenance cost and cost of unserved energy and etc. as illustrate in Figure 5-1.

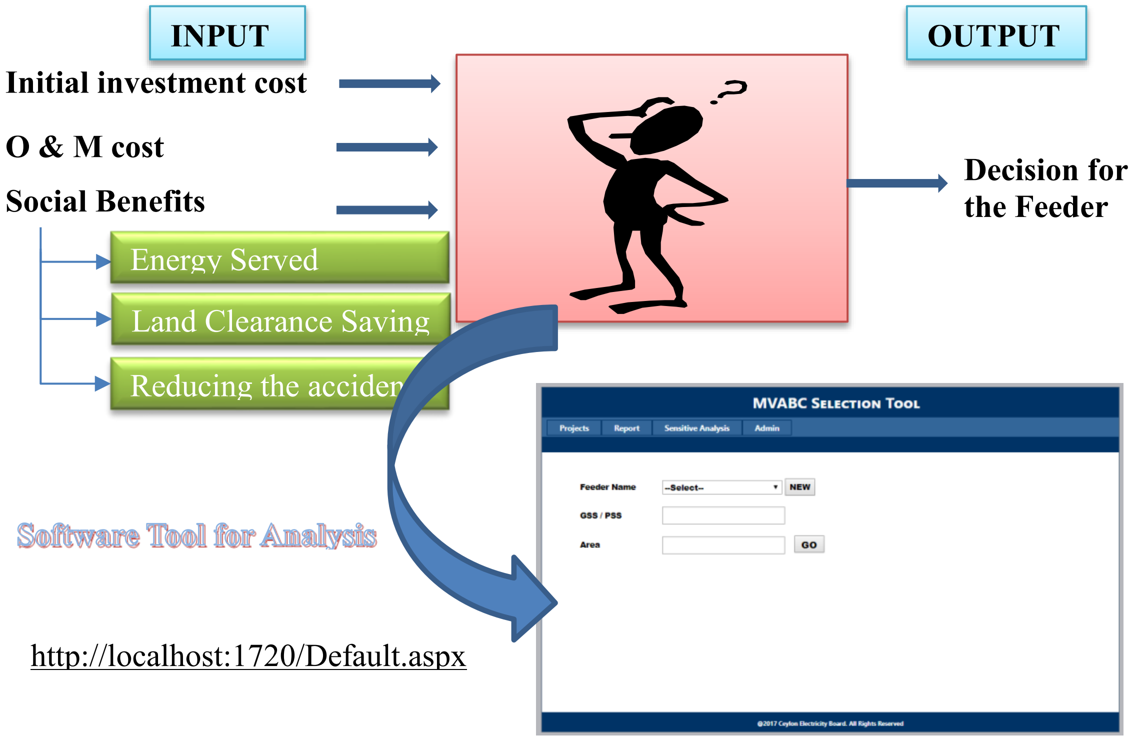


Figure 5-1: Inputs for the economic feasibility

i. Initial Investment Cost/ Capital Cost (C_C)

The cost of initial investment is the summation of the material and the cost of labour.

$$C_C = l.\,(C_M + C_L) \quad \text{………………………………………………………} \quad (1)$$

l – *Length of the feeder in km*

C_M – *Standard Material Cost in rupees per km*

C_L – *Standard Labour Cost in rupees per km*

ii. Annual Operational and Maintenance Costs (C_{OM})

The cost of annual operational & maintenance is the sum of preventive maintenance cost, vegetation clearance cost and breakdown maintenance cost.

$$C_{OM} = l.\ (nC_V + C_{PM}) + b.\ C_B \quad \text{………………………………………..…….} \quad (2)$$

C_V – *Standard Vegetation Clearance Cost in rupees per km*

C_{PM} – *Average Preventive Maintenance Cost in rupees per km*

C_B – *Average Breakdown Cost in rupees per Breakdown*

b – *Number of Breakdown happened in the feeder*

L – *Line length in km*

n – *Number of Vegetation Clearance turns per year*

Preventive Maintenance

33kV distribution lines are drawn across the country covering vast geographical territories. Generally, whole or a position of these lines pass through dense forests, high mountains, rivers, etc. Most of times, neglecting the maintenance of electrical equipment over a long period of time will inevitably lead to costly emergency repairs and equipment failures in addition to elevated safety and property risks. Therefore, it is essential to undertake preventive maintenance activities. In CEB, following preventive maintenance are carried out for the distribution lines.

- Check line supports and associated structures.
- Check tightness of stay wires and soundness of stay insulators. Replace cracked, broken line insulators.
- Maintain ground, structure and building clearance of line conductors and other live parts.
- Clean bird nests and chemicals from cross arms and insulators
- Clean creepers growing along stays and supports
- Check earth resistance and etc.

However, in this report, wayleaves is not considered under preventive maintenance, it is addressed separately as Vegetation Clearance Cost.

➢ **Selecting Values for MV BOH Lines**

According to the total cost incurred for the preventive maintenance of MV BOH in Western Province North (WPN) of CEB for the year 2016, average preventive maintenance cost of MV BOH is about Rs. 230,000.00 per kilometer. Further, this value is considered for the all calculation which is processed here onwards.

➢ **Selecting Values MV ABC Lines**

In Sri Lankan contest, it is impossible to find out average preventive cost for MV ABC due to none of experience. Hence, in this research, Brazilian Distribution System experience after converting BOH to ABC has adopted to get fair result as shown in table 5-1[14].

Table 5-1: Average Operational Cost of Brazilian Distribution System in US$/ pole

Maintenance	MV BOH	MV ABC
Preventive	461	34
Breakdown	67	13

According to table 5-1, the preventive cost has reduced to 7.4% that of MV BOH.

<u>Breakdown Maintenance</u>

Normally, this type of maintenance is processed after breakdown happened. Followings are illustrated some of them in briefly,

- Insulator flashover
- Line to line or line to earth short circuits in permanently
- Structural line failure and etc.

For the calculation, followings assumptions are made here onwards;

- If, line breakdown is happened to rectify that, it will takes equal or more than half hour (≥ ½ hrs).

➢ **Selecting Values for MV BOH Lines**

- According to the total cost incurred for the breakdown maintenance in Western Province North (WPN) of CEB for the year 2016, average breakdown maintenance cost is Rs. 25,000.00 per breakdown.

- **Selecting Values for MV ABC Lines**

  As mentioned in preventive maintenance clause, in Sri Lankan contest, it is very difficult to find out average breakdown cost for MV ABC due to lack of experience. Hence, in this research, Brazilian Distribution System experience after converting BOH to ABC has adopted [14] to get fair result as shown in table 5-1.

  According to table 5-1, the breakdown cost has reduced to 19.4% that of MV BOH.

iii. Unserved Energy Cost (C_{USE})

The economic losses due to planned and unplanned power interruptions can also be expressed in other forms. One of the commonly used is the economic loss (in US$) per unit of supply loss (kWh); identified as the cost of unserved energy. The cost of unserved energy for the Sri Lanka system [17];

Table 5-2: The cost of unserved energy for the Sri Lanka system

Interruption Types	Cost of Unserved Energy
Planned Interruption	US$ 0.66
Unplanned Interruption	US$ 1.06

Then, cost of total unserved energy in US$ can be illustrate as equation 03.

$$\boldsymbol{C_{TUSE}} = (\mathbf{0.66\,X + 1.06Y}) \quad \ldots\ldots\ldots\ldots\ldots\ldots \textbf{\textit{(3)}}$$

$$\boldsymbol{X} - \textit{Number of loss supply units due to planned interruption}$$

$$\boldsymbol{Y} - \textit{Number of loss supply units due to unplanned interruption}$$

According to the equation 03, it is essential to know X & Y for that particular feeder to calculate the cost of total unserved energy. As summarized in the chapter 01, Data gathering has converged for a specific area and carried out the analysis. The required input data relates to X and Y are identified from the Daily HT Feeder Failure Report 2016 of WPN, Ceylon Electricity Board [18].

Table 5-3: Sample format of Daily HT Feeder Failure Report 2016 of WPN, Ceylon Electricity Board.

G:S:S: Name	Feeder	Time		Duration	Load /A	Auto / Request	Reason For Failure	Remarks (Failure/Intr ruption,etc..)	Date
		From	To	Min					
Biyagama				0					1-Jan-2016
Bolawatta				0					1-Jan-2016
Veyangoda	F10	7:12	7:13	1	10	Auto	E/F		1-Jan-2016
Thulhiriya				0					1-Jan-2016
Kotugoda				0					1-Jan-2016
Sapugaskanda				0					1-Jan-2016
Kelaniya				0					1-Jan-2016
Kosgama	F1	8:10	8:10	0	80	Auto	E/F		1-Jan-2016
Kosgama	F7	9:18	9:18	0	112	Auto	E/F		1-Jan-2016
Kosgama	F7	15:14	15:14	0	105	Auto	E/F		1-Jan-2016
Aniyakanda	F7	8:36	8:37	1	145	Auto	O/C & E/F		1-Jan-2016
Pannala	F6	13:57	13:57	0	120	Auto	O/C & E/F		1-Jan-2016
Katunayake				0					1-Jan-2016
Biyagama	F7	4:37	4:38	1	10	On Request	E/S Wattala	request by system control for (ABS close) at Peliyagoda	2-Jan-2016
Biyagama	F7	8:52	8:53	1	310	Auto	E/F		2-Jan-2016
Biyagama	F7	12:18	12:19	1	245	On Request	E/S Wattala	(ABS open) at Peliyagoda	2-Jan-2016
Bolawatta				0					2-Jan-2016
Veyangoda	F4	9:35	9:36	1	165	On Request	E/S Veyang oda	supply interruption	2-Jan-2016
Thulhiriya	F6	19:30	19:31	1	100	Auto	O/C & E/F		2-Jan-2016
…………	……..	…….	…….	….	…..	……..	…….	**…………**	……

Reference to the Table 5-2, it can be identified planned and unplanned interruption separately. Further, it has indicated the load currents of each feeder when interrupted and how long interruption is held. Therefore, using following equation, number of interrupted unit of supply loss (kWh) can be calculated.

$$\boldsymbol{kWh = \sqrt{3}V\cos\emptyset \sum_{k=1}^{n} I_k t_k} \quad \text{(4)}$$

V – Line Voltage in kV

I – Plase Current in A

$\cos\emptyset$ – Power factor , As 0.9

t – time in hours

Then, using equation 04 the cost of total unserved energy in US$ can be illustrate as equation 05.

$$\boldsymbol{C_{TUSE}} = \sqrt{3}\boldsymbol{Vcos}\emptyset[\ \mathbf{0.66}(\textstyle\sum_{i=1}^{n} \boldsymbol{I_i t_i}) + \mathbf{1.06}\big(\textstyle\sum_{j=1}^{m} \boldsymbol{I_j t_j}\big)\ ]\text{.......................... (5)}$$

$\mathbf{0.66}$ $-$ US$ $per\ kWh\ unserved\ energy\ for\ planned\ interruption$

$\mathbf{1.06}$ $-$ US$ $per\ kWh\ unserved\ energy\ for\ unplanned\ interruption$

$$\sum_{i=1}^{n} \boldsymbol{I_i t_i} \quad - Planned\ Interruption\ Ampere\ Hour\ duration$$

$$\sum_{j=1}^{m} \boldsymbol{I_j t_j} \quad - Unplanned\ Interruption\ Ampere\ Hour\ duration$$

Middle Exchange Rate of US$ on 09th November 2017 of Central Bank of Sri Lanka, US$ = LKR 153.24 [19].

Therefore, using equation 03, the cost of total unserved energy in LKR can be express as follows;

$$\boldsymbol{C_{TUSE}} = (\mathbf{153.24}).\sqrt{3}\boldsymbol{Vcos}\emptyset[\ \mathbf{0.66}(\textstyle\sum_{i=1}^{n} \boldsymbol{I_i t_i}) + \mathbf{1.06}\big(\textstyle\sum_{j=1}^{m} \boldsymbol{I_j t_j}\big)\ ]\text{..................... (6)}$$

Planned Interruptions

Sometimes it has to interrupt electricity to carryout essential maintenance and to enable workers to work safely on system equipment. However, this type of interruption is taken with the coordination of Utility Control Centre after giving prior notice to the respective customers. In generally, planned interruptions cover following;

- Routing maintenance
- Preventive maintenance
- Wayleaves clearing
- Load shading
- Repairing due to breakdown and etc.

In this unserved energy calculation, planned interruption durations which are not make change though system convert BOH to ABC have not considered to get more impartial decision.

- **Selecting Values for MV BOH Lines**

  The required input data such as preventive maintenance, wayleaves clearing and breakdown maintenance interruptions can be identified from the Daily HT Feeder Failure Report 2016 of WPN, Ceylon Electricity Board [18].

- **Selecting Values for MV ABC Lines**

  Due to none of experience, following assumptions are made for the study.

  - As per the table 5-1, the preventive maintenance and the breakdown maintenance costs of MV ABC have reduced respectively to 7.4% and 19.4% that of MV BOH. Therefore, in this research, assume that the preventive maintenance and the breakdown maintenance interruptions are reduced to same percentages (**assumption 01**)
  - Normally, CEB plan three (3) wayleaves clearing cycle per year for MV BOH system. However, MV ABC systems are not vulnerable to tree, animal or phase to phase touching. Hence, lots of transient faults are minimized. Then, assume that only one wayleaves clearing cycle per year is enough for MV ABC system to protect cables from permanent damages (**assumption 02**).

Unplanned Interruptions

Most of times, electricity interrupt without informing to the respective customer due to following reasons;

- Earth faults: wayleaves touching due to bad weather and etc.
- Over Current faults: some short circuit incidents
- Under frequency situations
- Breakdowns and etc.

Here also, for the unserved energy calculation, unplanned interruption durations which are not make sense though system convert BOH to ABC have not considered to get more impartial decision.

- **Selecting Values for MV BOH Lines**

  The required input data such as earth faults and overcurrent faults interruptions can be identified from the Daily HT Feeder Failure Report 2016 of WPN, Ceylon Electricity Board [18].

- **Selecting Values for MV ABC Lines**

  Usually, earth faults and overcurrent faults are happened due to bare conductors. The BOH lines are most vulnerable to tree, animal or phase to phase touching. Hence, in this research none of unplanned interruption is considered other than breakdown interruptions. Assume that, the unplanned breakdown interruptions are reduced to 19.4% that of BOH system as per the table 5-1 (**assumption 03**).

Further, planned and unplanned Ampere Hour duration have calculated using the load current of the feeder and the interrupted time duration of the same feeder. Usually, distribution feeder is subjected to technical and non-technical losses. The distribution loss (DL) is about 8.7% as per the Annual Report of CEB at the year 2014. Therefore, it is not fair to consider feeder unserved energy as the customer end point unserved energy. Considering distribution loss, Unserved Energy can be express as follows.

$$\boldsymbol{C_{TUSE}} = (\mathbf{153.24}).\sqrt{\mathbf{3}}\,\boldsymbol{Vcos\emptyset}\left[\,\mathbf{0.66}\left(\textstyle\sum_{i=1}^{n}\boldsymbol{I_i t_i}\right) + \mathbf{1.06}\left(\textstyle\sum_{j=1}^{m}\boldsymbol{I_j t_j}\right)\right].\left[\mathbf{1} - \boldsymbol{DL}\%\right]$$

Here, ***DL = 8.7%*** thus $[\mathbf{1} - \boldsymbol{DL}\%]$ = ***0.913***

$$\boldsymbol{C_{TUSE}} = (\mathbf{0.913}).(\mathbf{153.24}).\sqrt{\mathbf{3}}\,\boldsymbol{Vcos\emptyset}\left[\,\mathbf{0.66}\left(\textstyle\sum_{i=1}^{n}\boldsymbol{I_i t_i}\right) + \mathbf{1.06}\left(\textstyle\sum_{j=1}^{m}\boldsymbol{I_j t_j}\right)\right] \ldots\ldots\ldots \ (7)$$

This chapter performs economic analysis with NPV (Net Present Value) analysis. The NPV analysis method can express the present monetary value for all calculated costs.

<u>Let's see how to calculate NPV and express "Feeder Comparative Cost/ Profit".</u>

However, aim is to do the economic feasibility study for each feeder and find out the advantages or the profit over capital investment. A 15 year net present value (NPV) analysis of the economic feasibility was conducted to compare the cost of the two types of distribution line.

$$\boldsymbol{F.C.\ C\ or\ Profit} = \Delta \boldsymbol{C_{C(BOH-ABC)}} + \boldsymbol{NPV}.\Delta\boldsymbol{C_{OM(BOH-ABC)}} + \boldsymbol{NPV}.\Delta\boldsymbol{C_{TUSE(BOH-ABC)}} \ldots\ldots\ldots \ (8)$$

$\Delta \boldsymbol{CC_{BOH-ABC}}$ $= Capital\ Cost\ difference\ in\ between\ BOH\ \&\ ABC\ in\ rupees$

$\boldsymbol{NPV}.\Delta\boldsymbol{C_{OM(BOH-ABC)}}$ $= Net\ Present\ Value\ of\ O\ \&\ M\ Cost\ difference\ inbetween\ BOH\ \&\ ABC\ in\ rupees$

$$\boldsymbol{NPV}.\Delta\boldsymbol{C_{OM(BOH-ABC)}} = \sum_{\boldsymbol{x=1}}^{\mathbf{15}} \frac{\Delta\boldsymbol{C_{OM(BOH-ABC)}}}{(\mathbf{1}+\boldsymbol{r})^{\boldsymbol{x}}}\ ; \quad \boldsymbol{r} = interest\ rate$$

$\boldsymbol{NPV}.\Delta\boldsymbol{C_{TUSE(BOH-ABC)}}$ $= Net\ Present\ Value\ \ for\ the\ difference\ of\ Unserved\ Energy\ by\ the\ BOH\ \&\ ABC\ feeder$

$$\boldsymbol{NPV}.\Delta\boldsymbol{C_{TUSE(BOH-ABC)}} = \sum_{\boldsymbol{x=1}}^{\mathbf{15}} \frac{\Delta\boldsymbol{C_{TUSE(BOH-ABC)}}}{(\mathbf{1}+\boldsymbol{r})^{\boldsymbol{x}}}$$

6 CASE STUDIES FOR MODEL VALIDATION

To validate the model it is essential to compare the results of the model with the results of a reference study. However, since there is not any 33kV ABC installation with historical data in Sri Lankan Distribution System, there is a lack of reference studies to be compared with the results of this study.

As an alternative way of validation, the results of the model are compared against two different case studies which can be simply decided at a glance, feeder conversion is profitable or not. Further, it is discussed an algorithm for decision making.

6.1 Case Study 01: Kotugoda GSS Feeder No.11

Let’s consider 33kV BOH Outgoing Feeder Line No.11 starting from Kotugoda Grid Substation (GSS). As shown in Figure 6-1, Feeder -11 is distributed across village area where thick vegetation is prone. Therefore, number of feeder tripping shall be definitely higher in this zone. Feeder length of the line is nearly 21km and the average and maximum load current are respectively about 155A and 304A [18]. Thus, it is clear that converting MV BOH to MV ABC is profitable.

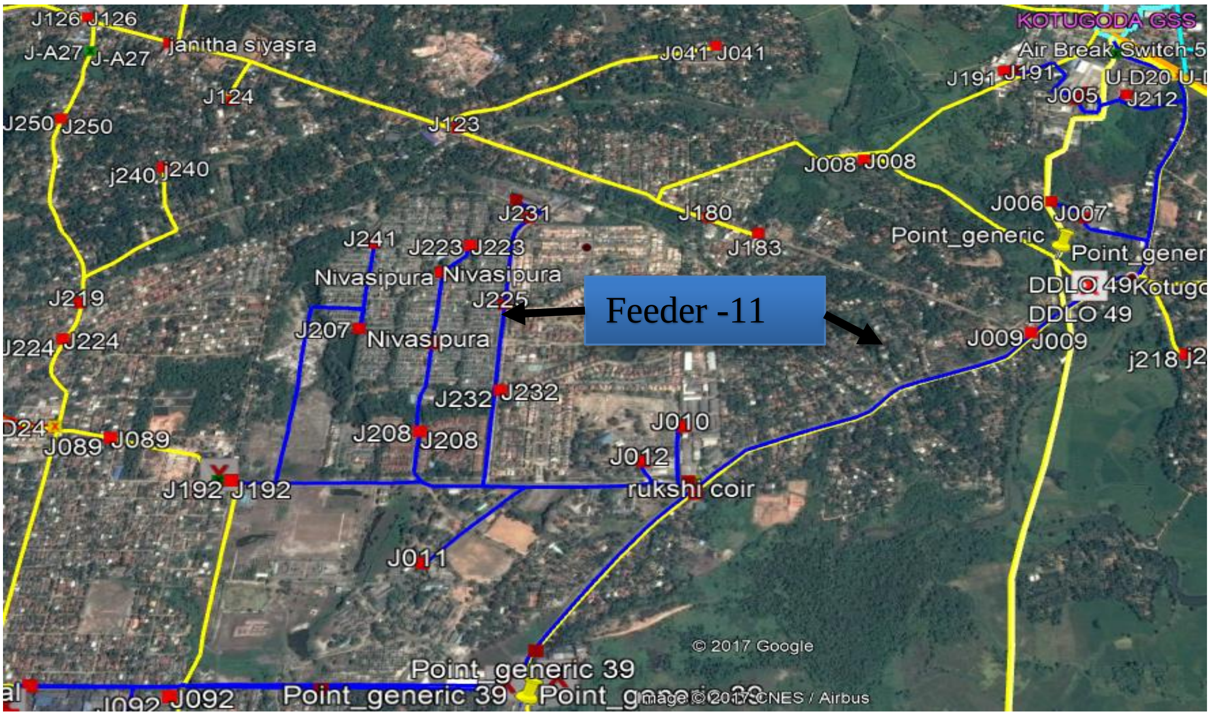


Figure 6-1: 33kV Kotugoda GSS Feeder No.11 in Geographical map

System Data

- Feeder Length = 21 km
- Standard Material Cost for BOH per km = Rs. 1,935,480
- Standard Labour Cost for BOH per km = Rs. 275,460
- Expected Material Cost for ABC per km = Rs. 6,544,089
- Expected Labour Cost for ABC per km = Rs. 252,505
- Standard Wayleaves Clearance Cost per km = Rs. 2,100
- No of Wayleaves Clearance Cycles per year = 3
- Average Breakdown Cost c/w labour = Rs. 25,000
- No of Feeder Breakdown in 2016 = 6
- Average Maintenance Cost c/w labour per km = Rs. 230,000
- **Table 6-1: Feeder 11, HT Interruption details for MV BOH in the year 2016 [18]**

Interruptions	No of Interruptions	Ampere Hour Duration/ A.hr	
		For Breakdown	For Preventive Maintenance (including wayleaves clearing)
Planned	12	295	6,646
Unplanned	57	1,939	

- **Table 6-2: Based on the assumptions calculated values for MV ABC Feeder 11**

Interruptions	No of Interruptions	Ampere Hour Duration/ A.hr	
		For Breakdown Maintenance	For Preventive Maintenance(including wayleaves clearing)
Planned	3	57	963
Unplanned	11	175	

Assumed calculations can be elaborated as follows,

As per the assumption 01;

No. of Planned Interruptions = Breakdown + Preventive

= (12 x 19.4%) + 1 = 3.3

≈ 3 Nos.

Thus,

A.hr for breakdown maintenance = 295 x 19.4%

= 57.23

≈ 57 A.hr

As per the assumption 02;

A.hr for preventive maintenance = [(746.2 + 1395 + 747) / 3] x 1

= 962.7

≈ 963 A.hr

As per the assumption 03;

No. of Unplanned Interruptions = (57 x 19.4%)

= 11 Nos.

A.hr for maintenance = (308 + 70.7 + 256.8 + 51 + 217) x 19.4%

= 175.3

≈ 175 A.hr

Financial Calculation

- Using eq. 01,

Capital Cost for BOH = Rs. 46,429,740

Capital Cost for ABC = Rs. 142,728,474

$\Delta \boldsymbol{C}_{\boldsymbol{C}(\boldsymbol{BOH}-\boldsymbol{ABC})}$ = Rs. (96,298,734)

- Using eq. 02,

O & M Cost for BOH = Rs. 5,112,300

O & M Cost for ABC = Rs. 430,620

$\Delta \boldsymbol{C}_{\boldsymbol{OM}(\boldsymbol{BOH}-\boldsymbol{ABC})}$ = Rs. 4,681,680

Assume, Feeder Life = 15 years

Normally in distribution planning projects, the standard rate for the interest is 10 %

Therefore, Interest rate = 10%

$\boldsymbol{NPV}\Delta \boldsymbol{C}_{\boldsymbol{OM}(\boldsymbol{BOH}-\boldsymbol{ABC})}$ = Rs. 35,609,230

- Using eq. 06,

  Cost of total unserved energy for BOH= Rs. 47,763,105

  Cost of total unserved energy for ABC= Rs. 6,180,185

  $NPV.\Delta C_{TUSE(BOH-ABC)}$ = Rs. 316,282,998

- Using eq. 07,

  Feeder Comparative cost/ Profit = Rs. 255,593,496

  Decision = **Yes** (due to value > 0)

6.2 Case Study 02: Katunayake GSS Feeder No.06

Let's consider 33kV BOH Outgoing Feeder Line No.06 starting from Katunayake Grid Substation (GSS). As shown in Figure 6-2, Feeder -06 is distributed across industrial area where vegetation is less. Hence, number of feeder tripping shall be definitely lesser in this zone. Feeder length of the line is nearly 04km and the average and maximum load current are respectively about 114A and 175A [18]. Therefore, it is clear that converting MV BOH to MV ABC is not profitable.

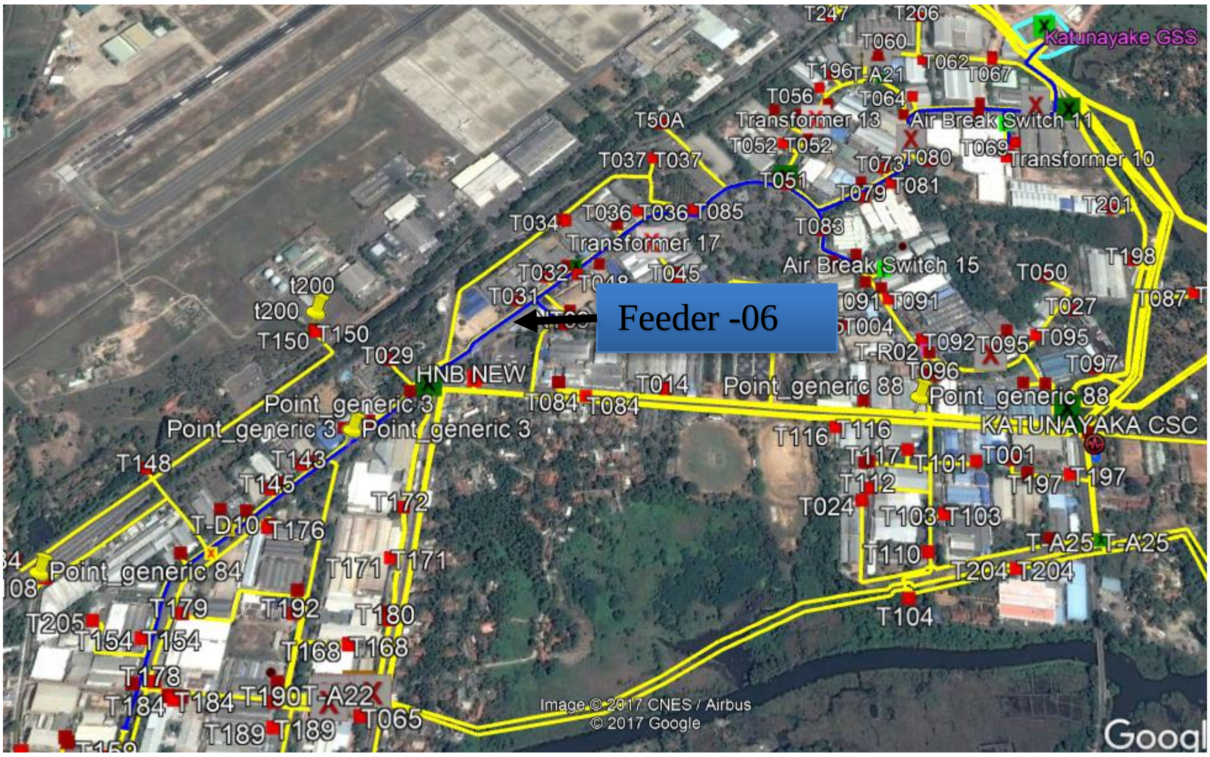


Figure 6-2: 33kV Katunayake GSS Feeder No.06 in Geographical map

System Data

- Feeder Length = 4 km
- Standard Material Cost for BOH per km = Rs. 1,935,480
- Standard Labour Cost for BOH per km = Rs. 275,460
- Expected Material Cost for ABC per km = Rs. 6,544,089
- Expected Labour Cost for ABC per km = Rs. 252,505
- Standard Wayleaves Clearance Cost per km = Rs. 2,100
- No of Wayleaves Clearance Cycles per year = 3
- Average Breakdown Cost c/w labour = Rs. 25,000
- No of Feeder Breakdown in 2016 = 1
- Average Maintenance Cost c/w labour per km = Rs. 230,000
- **Table 6-3: Feeder 06, HT Interruption details in the year 2016 [18]**

Interruptions	No of Interruptions	Ampere Hour Duration/ A.hr	
		For Breakdown	For Preventive Maintenance(including wayleaves clearing)
Planned	02	279	
Unplanned	11	103	

- **Table 6-4: Based on the assumptions calculated values for MV ABC Feeder 06**

Interruptions	No of Interruptions	Ampere Hour Duration/ A.hr	
		For Breakdown Maintenance	For Preventive Maintenance(including wayleaves clearing)
Planned	01	279	
Unplanned	02	15	

Assumed calculations can be elaborated as follows,

As per the assumption 01;

No. of Planned Interruptions = Breakdown + Preventive

= (2 x 19.4%) + 1 = 1.4

≈ 1 Nos.

As per the assumption 02;

A.hr for preventive maintenance = 279 x 1

= 279 A.hr

As per the assumption 03;

No. of Unplanned Interruptions = 11 x 19.4%

= 2 Nos.

A.hr for maintenance = 76 x 19.4%

= 14.7 ≈ 15 A.hr

Financial Calculation

- Using eq. 01,

  Capital Cost for BOH = Rs. 8,843,760

  Capital Cost for ABC = Rs. 27,186,376

  $\Delta \boldsymbol{C}_{\boldsymbol{C}(\boldsymbol{BOH-ABC})}$ = Rs. (18,342,616)

- Using eq. 02,

  O & M Cost for BOH = Rs. 953,400

  O & M Cost for ABC = Rs. 76,480

  $\Delta \boldsymbol{C}_{\boldsymbol{OM}(\boldsymbol{BOH-ABC})}$ **=** Rs. 876,920

  Assume, Feeder Life = 15 years

  Interest rate = 10%

  $\boldsymbol{NPV}\Delta \boldsymbol{C}_{\boldsymbol{OM}(\boldsymbol{BOH-ABC})}$ = Rs. 6,669,923

- Using eq. 03,

  Cost of Unserved energy of BOH = Rs. 2,111,065

  Cost of Unserved energy of ABC = Rs. 1,439,716

  $\boldsymbol{NPV}.\Delta \boldsymbol{C}_{\boldsymbol{USE}(\boldsymbol{BOH-ABC})}$ = Rs. 5,106,336

- Using eq. 04,

  Feeder Comparative cost/ Profit = Rs. (6,566,356)

  Decision **= No** (due to value < 0)

The results of the model are verified the real scenario of each case studies. Then, it is clear that module validation is successfully completed. However, it is not advisable to compile data of each and every cases and see the results at the end. Therefore, before compiling data to the model, it is advisable to go through following algorithm and find out the appropriate solution at the glance.

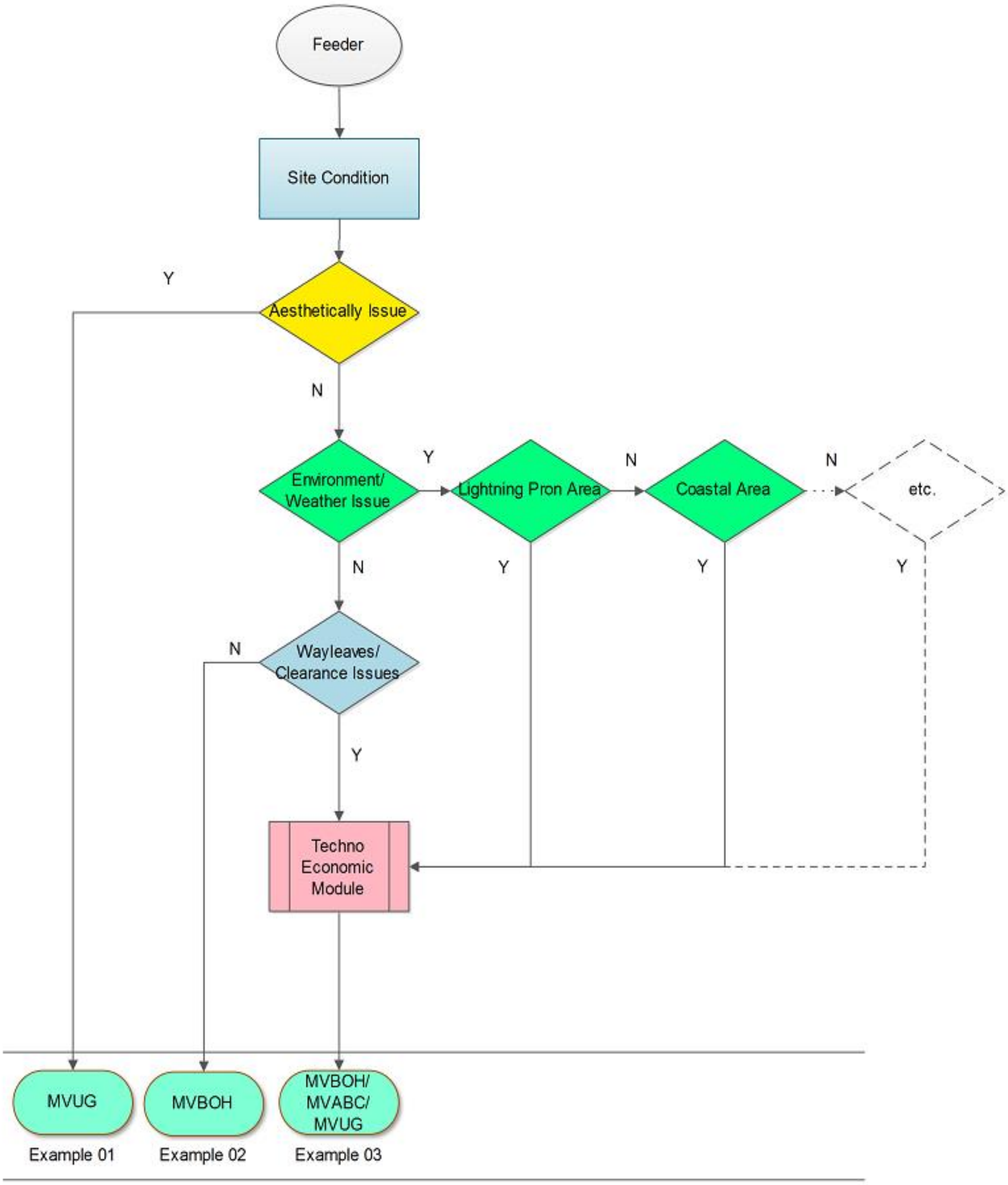


Figure 6-3: The algorithm to select correct installation methodology for the electrical distribution system

The use of the algorithm can be elaborated while discussing the electrical distribution system of following areas,

Example 01: Colombo City

The building density of Colombo City is very high especially high rise building. Further, being the commercial capital city of Sri Lanka, its' land value is very high. Therefore, CMC is not permitted to install overhead electrical distribution system by considering mentioned facts, aesthetic view and etc. Hence, as per the algorithm, installation methodology shall be underground system.

Example 02: Rural Area where thick vegetation is less

The Right of Way can be accommodated easily. Hence, as per the algorithm, installation methodology shall be overhead system.

Example 03: Semi-urban Area where thick vegetation is prone

Though, it does not has any aesthetic view issue or specific weather/environmental issues, the Right of Way cannot be accommodated due to thick vegetation. Hence, as per the algorithm, installation methodology shall be decided after Techno- Economic Analysis.

7 SOFTWARE DEVELOPMENT FOR MV ABC ANALYSIS

In this chapter, it is going to discuss a software tool that develop to assist planners by automating all tasks performed during chapter 06.

7.1 Overview of MV ABC Selection Tool

MV ABC Selection Tool is a software tool that is used to analyze data and preview existing MV BOH distribution line and forecast new MV ABC line to select correct installation methodology for the existing or new power lines. The purpose of this tool is to assist distribution planners and management to get decision on the selection of proper installation methodology for the overhead power lines. This tool has developed using VB programming language and incorporate with Microsoft SQL data base.

7.2 Functions of MV ABC Selection Tool

This section provides a general walkthrough of the system from initiation through final. MV ABC Selection Tool is basically provided four function tabs as shown in the figure 7-1.

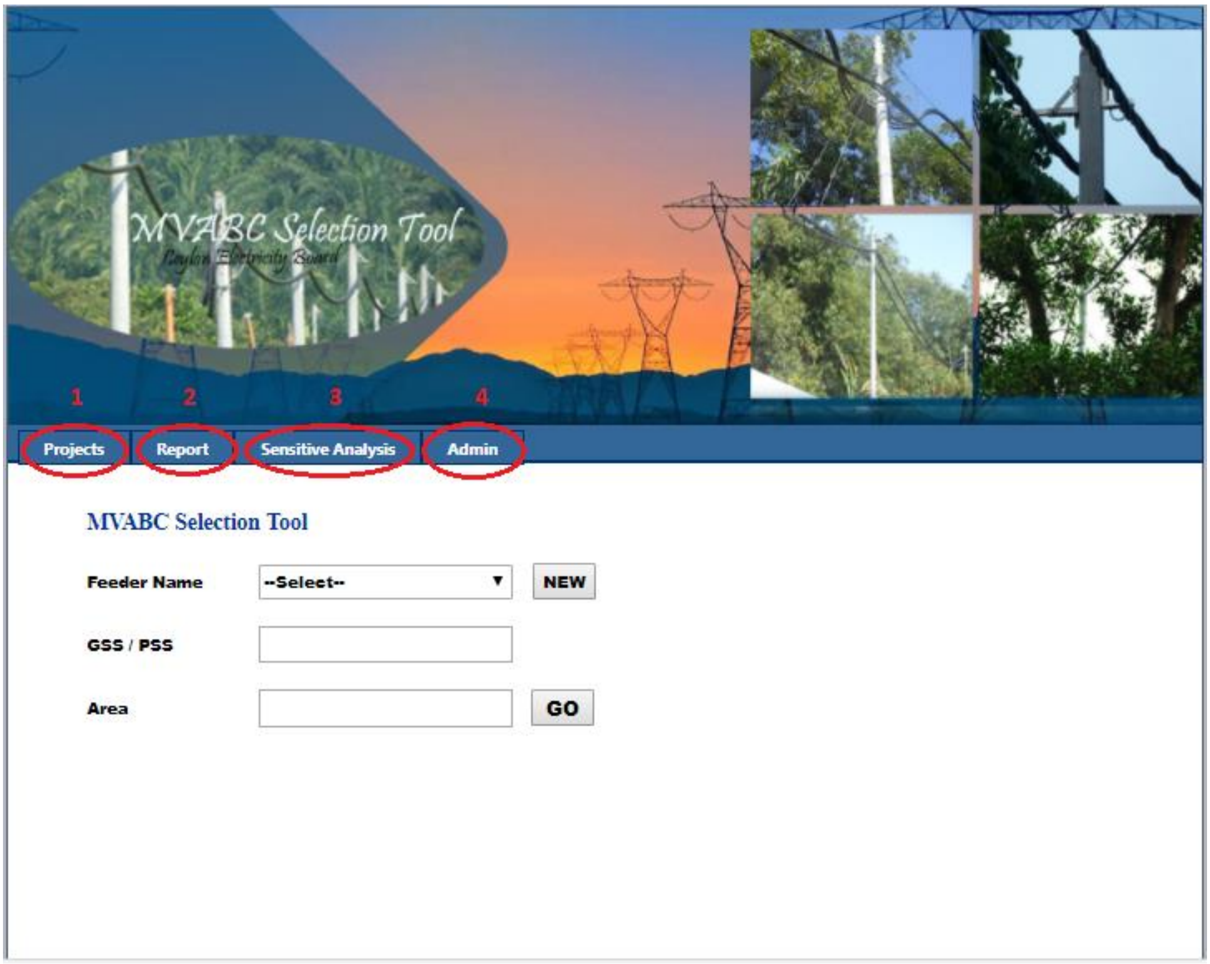


Figure 7-1: User Interface of MV ABC Selection Tool

1. **Projects Tab :**

   Main tasks have organized under this tab such as data entering and data processing of a project.

Figure 7-2: Starting User Interface of MV ABC Selection Tool

The project tab (Figure 7-2) consists of 3 input fields containing basic information about the distribution feeder such as Feeder Name, Grid Substation, and Feeder Area. Then, just open feeder data entering user interface and process the calculation as follows,

1. Click the “Go” button to open, data insert user interface.
2. Data insert user interface consist with 6 tabs (Figure 7-3).
3. Click the “Material” button to find out material cost for the feeder (Figure 7-4).

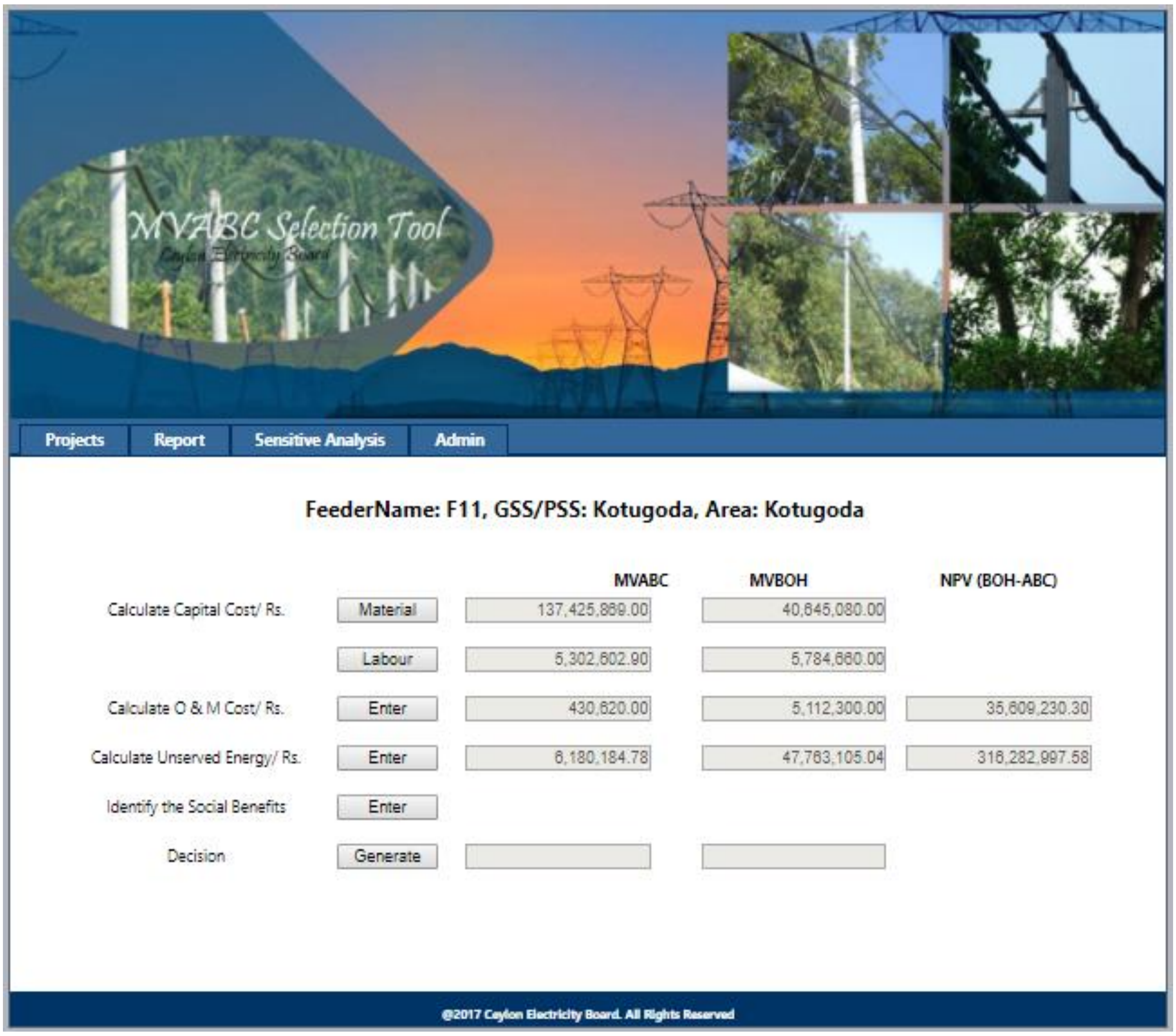


Figure 7-3: User Interface of the Feeder Cost Calculation

The Material Tab consists of 3 input fields such as estimated material list, estimated material cost per km and feeder length in km. Then, it is calculated the total material cost of the respective feeder. The default estimated material list has in built with editable facility.

4. Click the "Save" button to save inserted data in the data base.
5. Click the "Labour" button to open, data insert user interface (Figure 7-5).

Here also, the Labour Tab consists of 3 input fields such as estimated labour items, estimated labour cost per km and feeder length in km. Then, it is calculated the total labour cost of the respective feeder. The default estimated labour items has in built with editable facility.

6. Click the "Save" button to save inserted data in the data base.

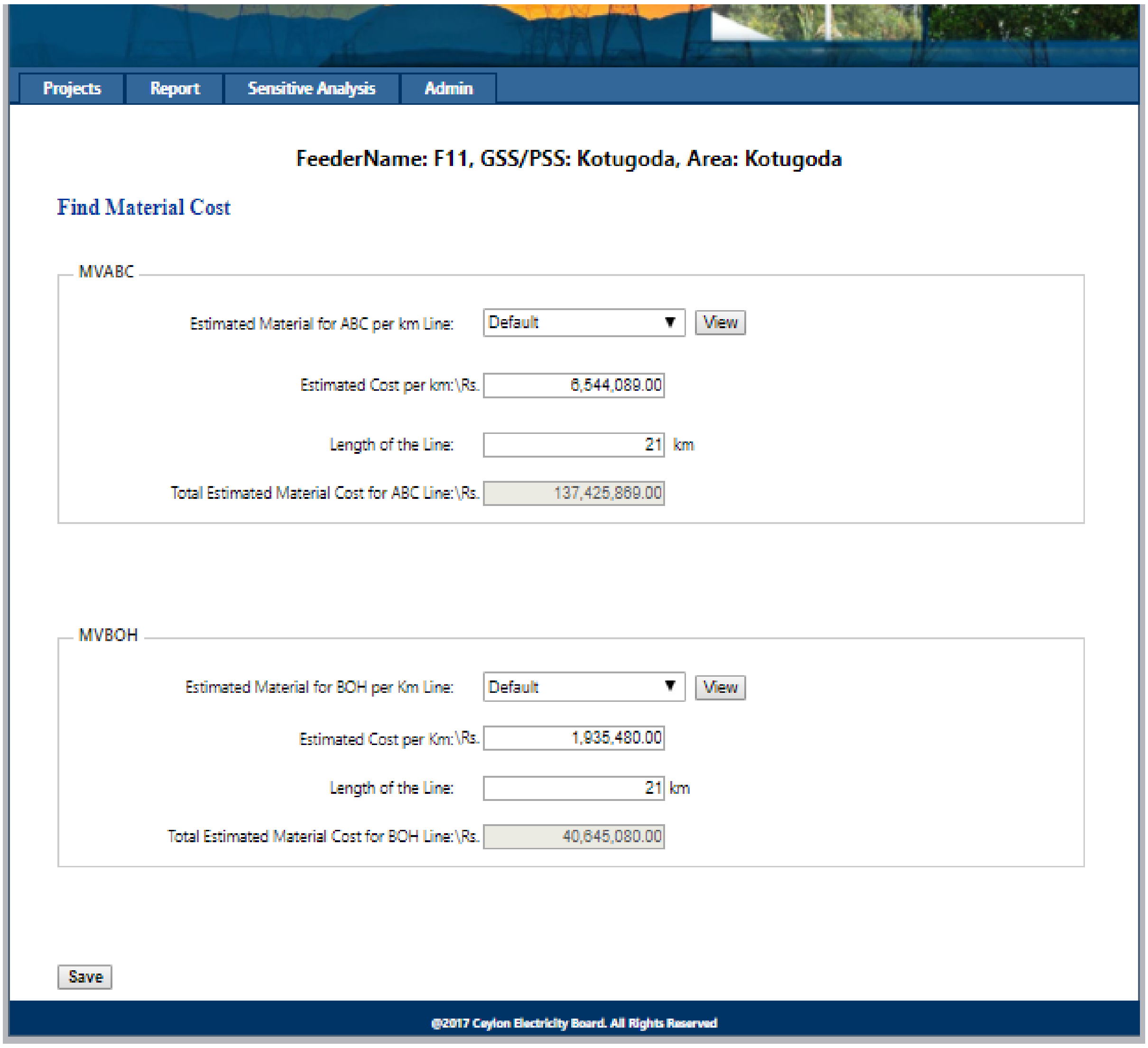


Figure 7-4: User Interface of Material Cost Calculation

7. Click the “O & M Cost Enter” button to open, data insert user interface (Figure 7-6).

The data insert user interface consists of 3 input tabs to enter costs of Vegetation Clearance, HT Breakdown and Preventive Maintenance separately. Then, it is calculated the total O & M cost of the respective feeder. Further, Net Present Value of the O & M Cost difference between BOH and ABC is calculated assuming feeder life and interest rate respectively 15 years and 10%.

8. Click the “Save” button to save inserted data in the data base.

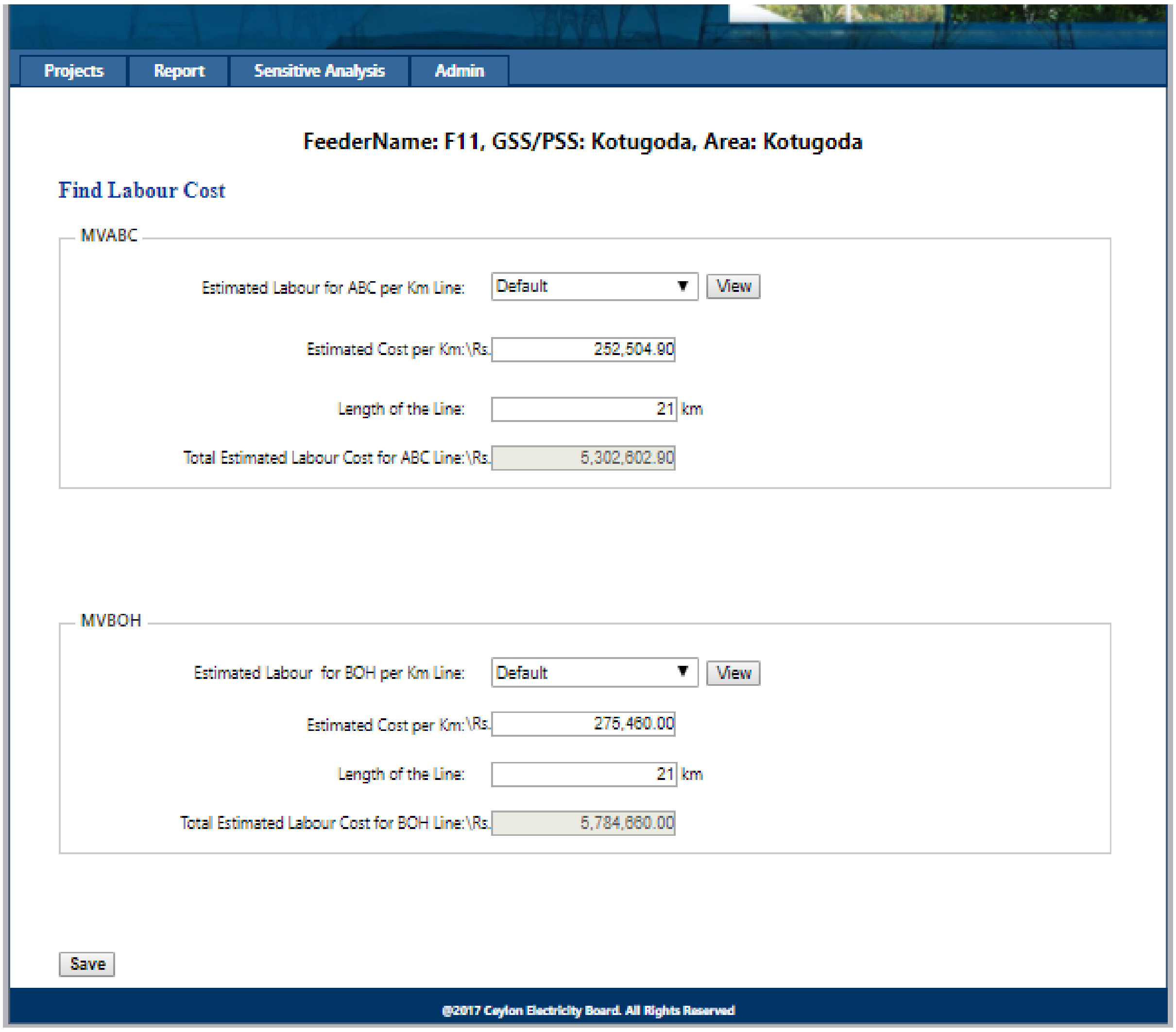


Figure 7-5: User Interface of Labour Cost Calculation

9. Click the "Unserved Energy Enter" button to open, data insert user interface (Figure 7-7).

The Unserved Energy data insert user interface consists of 4 input tabs to enter planned and unplanned ampere hour interruption durations, distribution loss factor and US $ rate separately. Then, it is calculated the total unserved energy cost of the respective feeder. Further, Net Present Value of the Unserved Energy Cost difference between BOH and ABC is calculated assuming feeder life and interest rate respectively 15 years and 10%.

10. Click the "Save" button to save inserted data in the data base.

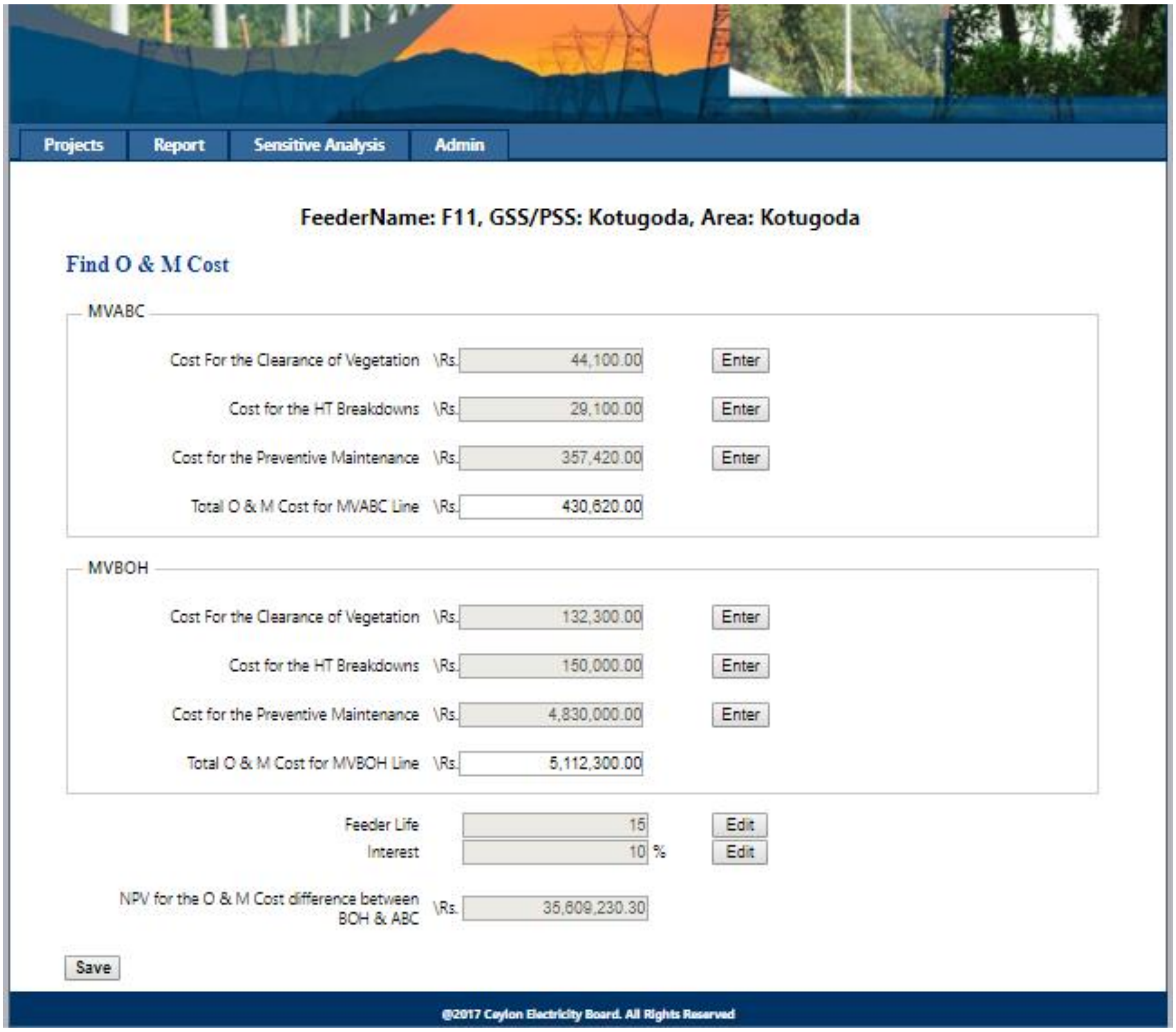


Figure 7-6: User Interface of O & M Cost Calculation

11. Click the “Social Benefits Enter” button to open, data insert user interface (Figure 7-8).

The social benefits due to the conversion of distribution system BOH to ABC can be enter here.

12. Click the “Save” button to save inserted data in the data base.

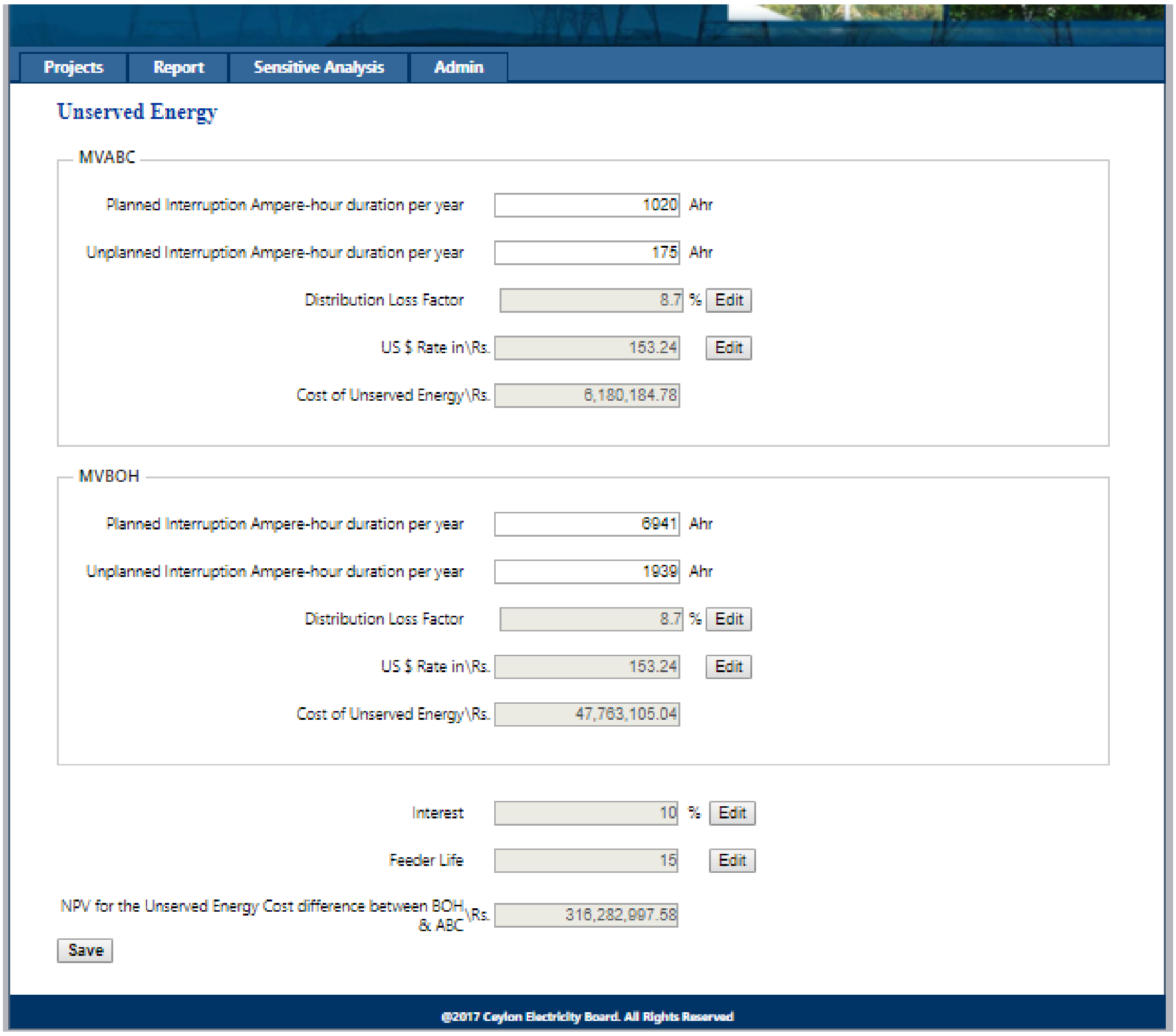


Figure 7-7: User Interface of Unserved Energy Cost Calculation

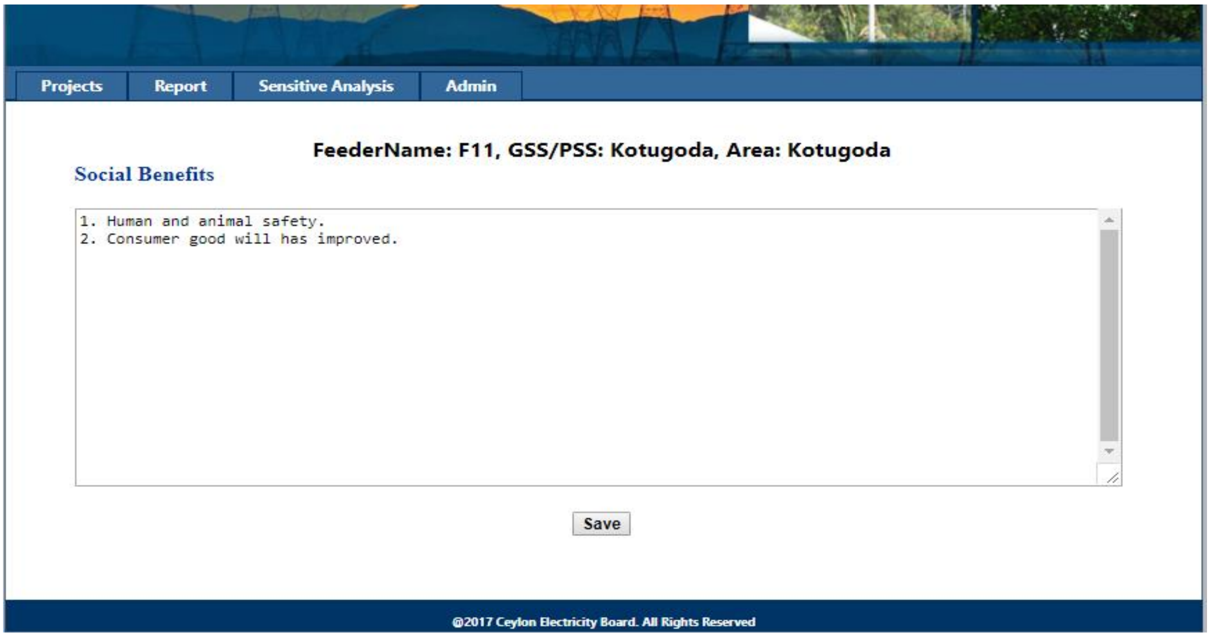


Figure 7-8: User Interface of Social Benefits

2. **Report Tab :**

Under this tab user can produced financial comparison report with summery and also user can save document as PDF version.

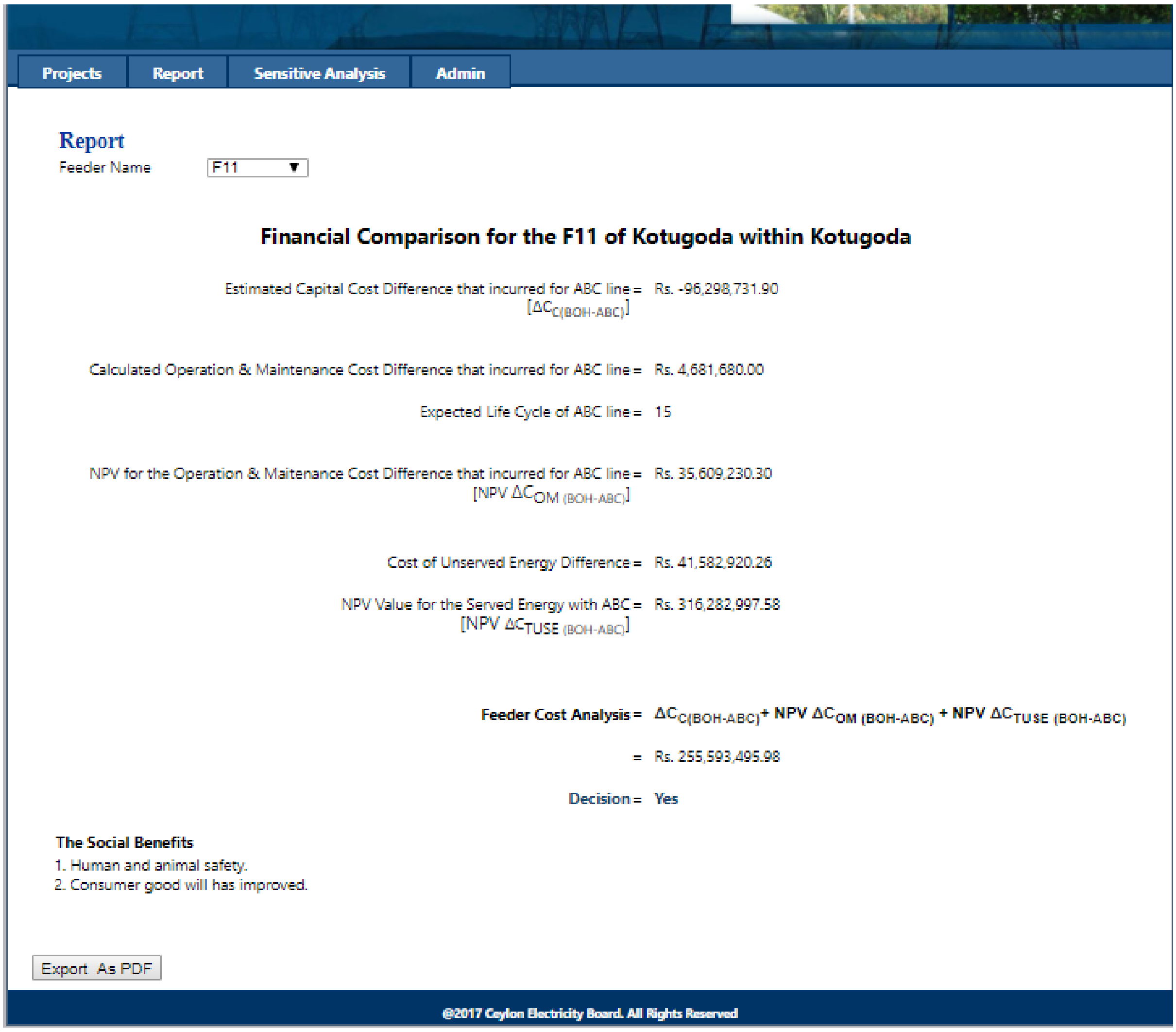


Figure 7-9: User Interface of Report Summery

3. Sensitive Analysis Tab :

Sensitivity analysis was done to examine the changes in the output of the base case under different scenarios. Under sensitive analysis tab, all the input data previously entered can be changed and see the output accordingly as shown in Figure 7-10 and Figure 7-11. However, it is clear that mainly drastic change could occurred when unserved energy figure is changed.

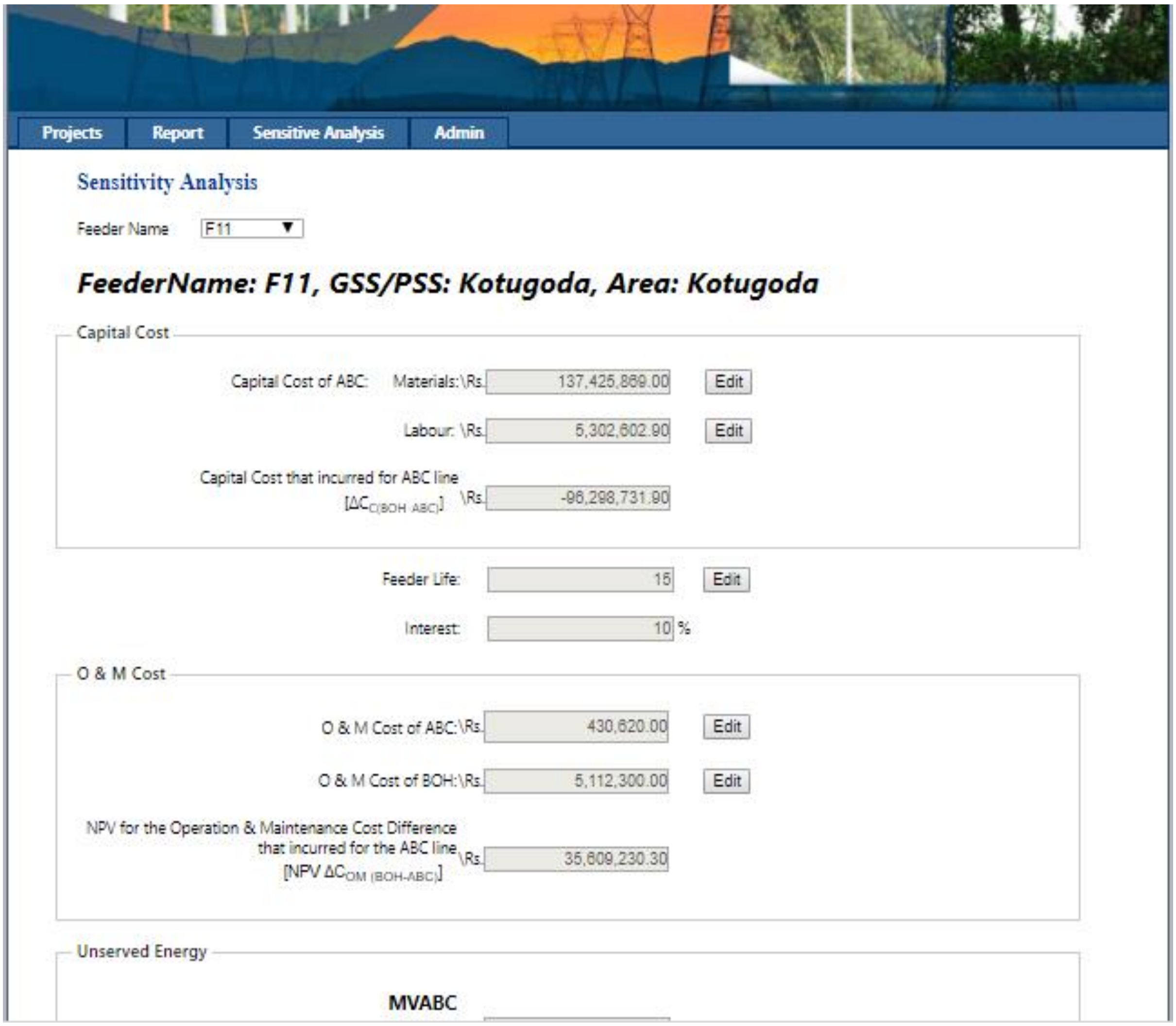


Figure 7-10: User Interface of Sensitive Analysis_ Part 1

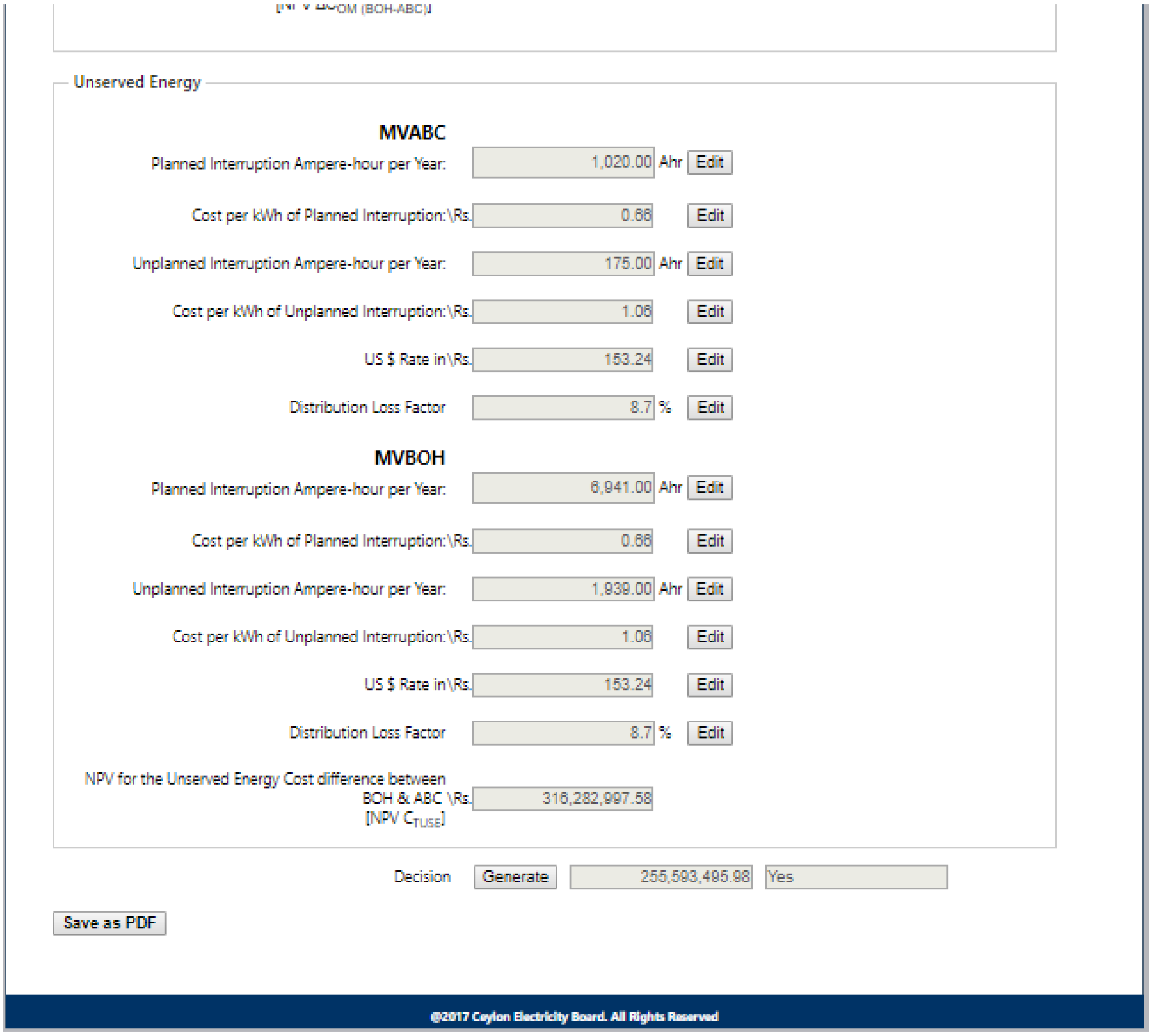


Figure 7-11: User Interface of Sensitive Analysis_ Part 2

4. Admin Tab :

1. Click the “Edit” button under the “Admin” user interface to edit name of feeder, GSS or area.
2. Click the “Delete” button under the “Admin” user interface to project.
3. Click the “Save” button to save inserted data in the data base.

8 DISCUSSION AND CONCLUSIONS

It is high time, and it would be the biggest step forward in the Sri Lankan Power Distribution System to introduce MV ABC systems instead of conventional BOH system. MV ABC offers technical and economic advantages, and solutions to the problems of reliability and public safety now faced by utility, CEB. However, proper design and quality of the system as well as all accessories should be done to take care screen insulated cable system to provide sound insulation. Therefore, it is essential to procure all accessories with correct specification especially for the cable and the cable joints as discussed in literature review.

Further, it is not advisable to install MV ABC system everywhere due to high cost factor. Therefore, developed an algorithm that can be used all over the country for making decision for MVABC adaptation. The final product, MV ABC Software Tool can be used to generate decision for the same and for the Sensitivity Analysis. Additionally,

- **Urban Areas**

  Normally, load current is high. Therefore, few interruptions may costly higher unserved energy. As per the sensitivity analysis, unserved energy can make big impact on the decision. Further, urban areas consist higher building density. Hence, it is very difficult to maintain minimum clearance. Thus, it has higher probability to fatal accident and though if it is feasible to maintain minimum clearance, the land value of Right of Way (ROW) is very much high. Then, where MV UG is not essential or practical to install, the best installation method is MV ABC.

- **Sub-Urban and Rural Areas**

  All parameters mentioned above such as load current and the land value of Right of Way (ROW) are in medium or low scale compare to urban area. Hence, it is recommended to apply an algorithm that can be used for making decision for MVABC adaptation. However, it is recommended to go for MV ABC where MV ABC is sort listed as the best solution for environmental issue.

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