DESIGN OF COLOMBO CITY ELECTRICITY NETWORK FOR ANTICIPATED FUTURE DEMAND

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

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June 2015

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ABSTRACT

In "Colombo City Development Plan – 2020" published by Urban Development Authority in 2008, Colombo City is divided into 9 zones based on the major developments in each zone. The major projects proposed to be completed by 2020 are sited in concentrated development zone and port related activity zone. With the upcoming projects in each zone, the amount of electricity required in each zone will be increased and existing load centers will be shifted. Specially commercial and industrial zones will require higher amount of energy. With the zoning plan & upcoming projects most of the grid substations with two numbers of transformers & underground cables will be fully overloaded during peak hours in future. Therefore tripping of one transformer and/or underground cable will cause power interruptions to large number of industrial and domestic customers since rest of the network can't cater the demand. This is due to the capacity limitation of the present transformers, limitation of the number of transformers in each GSS, capacity limitations of underground cables and not having GSSs in required load centers. These are major setbacks in Colombo City system operation and reliability.

Presently Colombo city distribution network is operating at 11 kV voltage level. Due to this voltage level, with the future growing demand network loss will also grow drastically. In addition to the line losses, present transformer impedances also contribute to these losses.

This dissertation discusses on designing of an upgraded network for Colombo City in 2021 with minimum overloading of transformers and underground cables. Further, analysis is done to examine the best transmission voltage in 2021 according to the demand growth.

Load forecast was prepared up to 2021 based on past data obtained from system control center of Ceylon Electricity Board and spot load data obtained from UDA. Accordingly, the load centers are identified. Sri Lankan power system has been modeled using the PSS®E (Power System Simulator for Engineers) software. The Existing Colombo City Electricity Network was simulated using this model and its drawbacks were identified. Two effective networks i.e. 132 kV solution and 220 kV solution, were proposed for Colombo City in 2021and system improvements were tested with simulations. The observations and results obtained from the simulations include short circuit levels and transmission losses. Economic and financial analysis was carried out and finally comparing all the results the most effective network for Colombo City in 2021 was selected.

This newly proposed network for Colombo City in 2021 will improve the Power System reliability and have a definite positive effect on customers which in turn improve the welfare of the people and economy of the country.

Key words: Load Centers, Short Circuit Levels, Network Losses, Simulations, Network, Reliability.

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Abbreviations

Abbreviation	Meaning
GS	Grid Substation
GSs	Grid Substations
GIS	Gas Insulated Switchgear
SUB	Substation
UDA	Urban Development Authority
OHL	Overhead Line

1. INTRODUCTION

1.1 Background

In Sri Lanka electricity network, generation stations are not located close proximity to the load centers. Therefore generated electricity has to be transmitted using 220 kV and 132 kV high voltage transmission lines and distributed using 33 kV and 11 kV medium voltage lines to load centers. The transformation of high voltage levels to medium voltage level is done at GSs. There are number of 220/132/33 kV, 132/33 kV & 132/11 kV transformers with different capacities installed in the GSs for this purpose.

Colombo City electricity network differs from rest of the Sri Lankan network because Colombo City is the heart of the Sri Lanka, and it is the main load center of the electricity network as well as it consumes over 40% of the regional energy demand. Moreover the load curve of the province is different from the rest of the country as it shows a higher day peak demand whereas the whole Island shows a higher night peak demand. The day peak demand in the Colombo City occurs during the period 1100 h – 1130 h and the night peak demand of the province occurs between 1830 h to 1900 h.

The peak power demand of Colombo City exceeds 250 MW while its annual energy consumption is around 1200 GWh (around 11% of total energy sales in 2014) and the annual demand growth is around 3%. Its operating area is the City limits of Colombo which coincides exactly with that of the Colombo Municipal Council area, being only geography of 37 km^2 and having a population of over a million people. Electricity distribution network in the City is almost fully underground. There are five numbers of 132/11 kV GSs (SUB A, SUB C, SUB E, SUB F & SUB I) and two numbers of 132/33 kV GSs (Kolonnawa & Kelanitissa) in Colombo City electrical network. This Colombo City network connects to national grid via Kolonnawa, Kelanitissa & Dehiwala GSs.

Colombo City has 160,000 customer base, 10% of which is heavy supplies over 112 kVA, accounts for 20% of the country's electricity sales and 20% of the revenue earnings of CEB. Colombo City thus is essentially the flagship of CEB transmission and distribution sector.

Therefore, reliable electricity supply to the Colombo City is one of the prime importance in today's context.

1.2 Importance of the Study

According to the "Colombo City Development Plan – 2020" published by Urban Development Authority in 2008, it will be divided into 9 zones. They are namely as follows:

i. Special Primary Residential Zone
ii. Primary residential Zone
iii. Special Mixed Residential Zone
iv. Sea Front Zone
v. Mixed Development Zone
vi. Port Related Activity Zone
vii. Commercial Zone
viii. Concentrated Development Zone
ix. Public Open Spaces

The zones are categorized as residential, commercial and industrial. With the upcoming projects in each zone, the amount of electricity required in each zone will be increased. Specially commercial and industrial zones will require higher amount of energy. Further with the zoning plan, the existing load centers will be changed.

Therefore introducing reliable electricity network for Colombo City considering zoning plan is very essential.

1.3 Identification of the Problem

With the zoning plan and upcoming projects most of the GSs with two numbers of transformers will be fully overloaded during peak hours in future. Therefore tripping of one transformer will cause power interruptions to large number of industrial and domestic customers since other transformer/s can't cater the additional demand. This is due to the capacity limitation of the present transformers, limitation of the number of transformers in each GS and not having GSs in required load centers. This is one of the major setbacks in Colombo city electricity transmission system.

Presently Colombo City distribution network is operating in 11 kV voltage level. Due to this voltage level with the future growing demand network loss will grow drastically. In addition to the line losses, present transformer impedances also contribute to these losses. Therefore it is necessary to propose an effective transmission network for Colombo City in 2021.

1.4 Motivation

The outcome of this project will be to propose the most effective electricity transmission network for Colombo City in 2021 with minimum overloading of transformers and underground cables. New GSs will be proposed identifying new load centers according to the UDA zoning plan for 2020. Further, analysis is done to examine the best transmission voltage in 2021 according to the demand growth. Hence the analysis will be continued to examine the most appropriate distribution voltage level.

1.5 Objective of the Study

Objective of the study is to propose optimum transmission network for Colombo City in 2021 to comply with "UDA Colombo City Development Plan – year 2020" by considering most suitable transmission and distribution voltage levels.

1.6 Methodology

1. Collect existing GSs data, underground cable data.
2. Analyze existing Colombo City Network using PSS/E software to identify the drawbacks.
3. Collect present load data of Colombo City for last 20 years.
4. Identify spot loads of Colombo City.
5. Prepare the load forecast of Colombo city in year 2020 (considering UDA Plan).
6. Select number of transformers in existing GSs (Expansion requirement).

7. Identify the necessity of implementation of new GSs and their optimum transformer capacities.
8. Model the proposed Colombo city network in PSS/E software.
9. Select most suitable transmission voltage level with different network modifications.
10. Select most suitable distribution voltage level with different network modifications.
11. Select most suitable transformer impedances (reduce losses and maintain fault levels within equipment ratings).
12. Cost analysis to select economically viable solution in 2021.

This study will help to find a feasible solution for the problems mentioned in section 1.3 and the results obtained through this study could be used to develop Colombo City Electricity Network according to the demand growth.

2. EXISTING COLOMBO CITY TRANSMISSION NETWORK

2.1 Colombo City Network

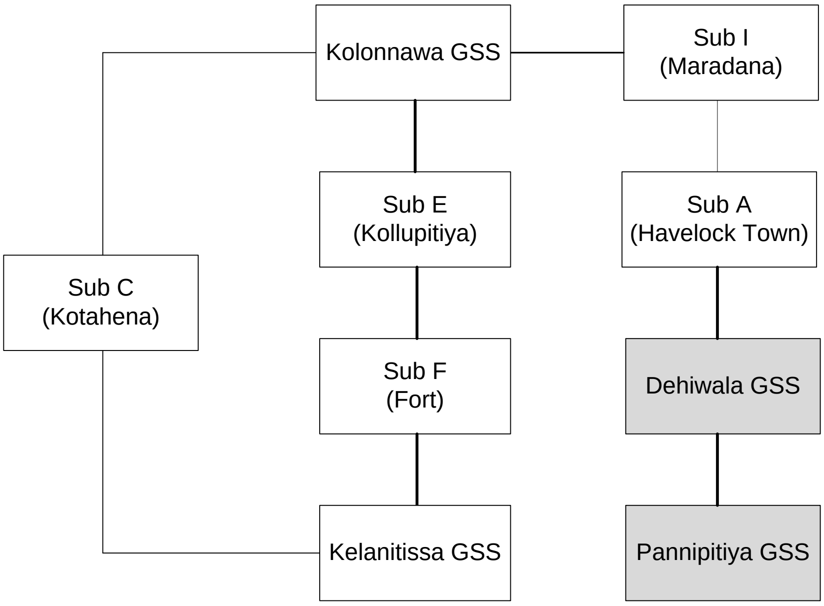

Figure 2.1– Existing Colombo City 132 kV Underground Transmission Network

As shown in Figures 2.1 and 2.2 there are five numbers of 132/11 kV indoor, GIS type GSs; SUB A (Havelock Town), SUB C (Kotahena), SUB E (Kollupitiya), SUB F (Fort) & SUB I (Maradana) and two numbers of 132/33 kV GSs; Kolonnawa & Kelanitissa belongs to Colombo City network. Three 132 kV underground cable sections mentioned below are used to feed Colombo load.

- Kelanitissa, SUB F, SUB E, Kolonnawa
- Kolonnawa, SUB I, SUB A, Dehiwala and Pannipitiya GSs
- Kolonnawa, SUB C, Kelanitissa

The Colombo city network connects to national grid via Kolonnawa GS (through Athurugiriya 1&2, Seethawaka, Kosgama, Kelaniya 1&2, Pannipitiya 1&2, Kelanitissa 1&2), Kelanitissa GS (through Kolonnawa 1&2, 220/132/33 kV 150 MVA transformer 1&2) & SUB A (through Dehiwala GS).

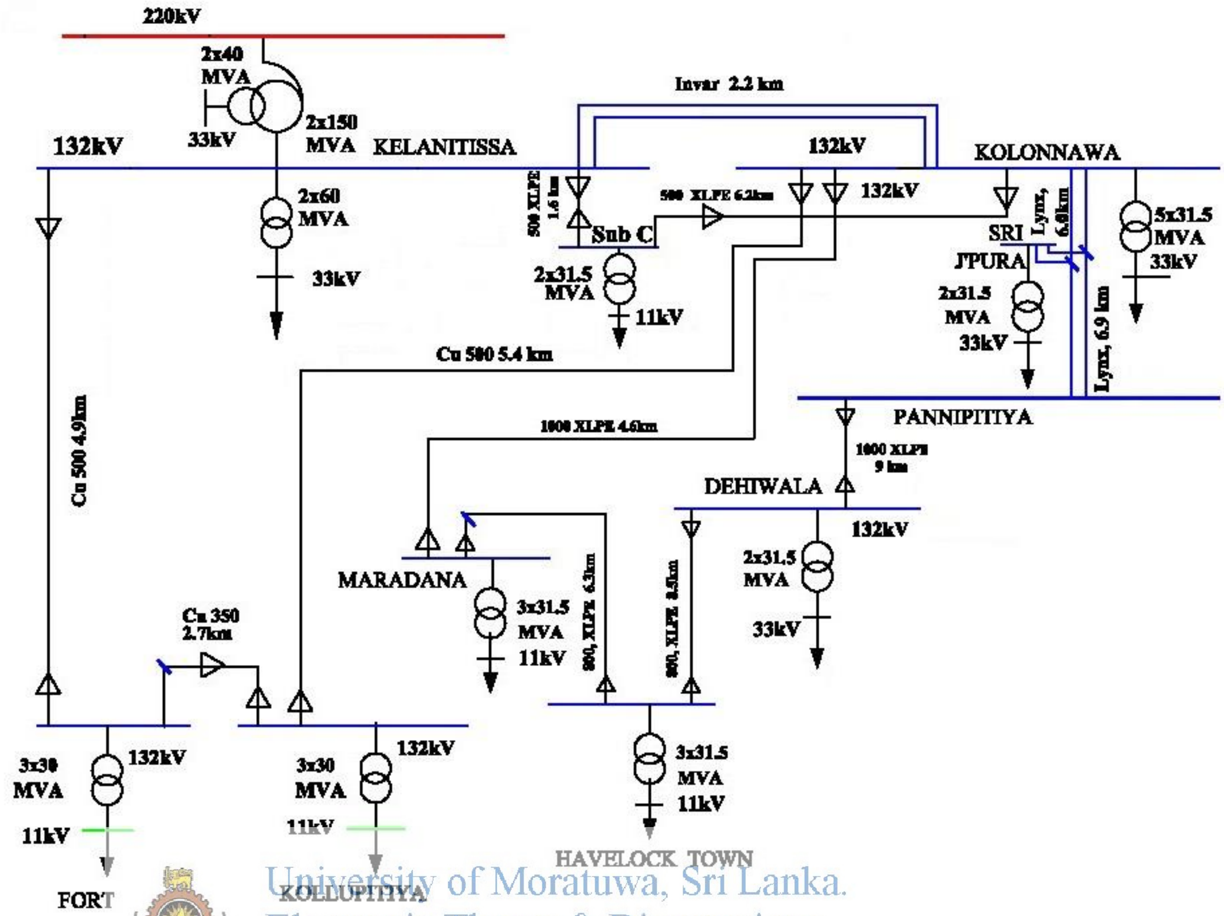

Figure 2.2– Single Line Diagram of Existing Colombo City 132 kV Network

2.2 Geographical Locations of Colombo City GSs

Figure 2.3 below shows geographical locations of each GSs. With the zoning plan, upcoming massive industries will shift the load centers. For example with the expansion of port related activities, SUB F will be unable to supply the demand. Therefore new GSs should be introduced to cater this demand. Then the transmission system have to be expanded to supply power to newly introduced GSs.

ATTACHED IN NEXT PAGE

Figure 2.3 – Existing Colombo City GSs Geographical Locations


City of Colombo
Scale 1:15,000
SEA
HARBOUR
KELANI GANGA
Hendala
Kadirana
Crow Island
Pasbetal
Wattala
Hunupitiya
Wanawasala
Telangapatha
Mattakkuliya
Modera
Dippitigoda
Peliyagoda
Bloemendhal
Grandpass
Sedawatta
Weragoda
Kotuwila
Kotahena
Orugodawatta
Kittanpahuwa
Gunasinghapura
Maligawatta
Wennawatta
Meetotamulla
Wellampitiya
Fort
Pettah
Hultsdorf
Dematagoda
Megoda Kolonnawa
Maligakanda
Kolonnawa
Gothatuwa
Kompannaveediya
Beira Lake
Borella
Rajagiriya
Madinnagoda
Kollupitiya
Cinnamon Gardens
Eladuwa
Etul Kotte
Narahenpita
Koswatta
Bambalapitiya
Timbirigasyaya
Havelock Town
Nawala
Pitakotte
Pagoda
Kirillapone
Poorvarama Colony
Mirihana
Wellawatta
Nugegoda
Kohuwala
Kalubowila
Dehiwala
Jambugasmulla
LEGEND
Main Road
Minor Road
Other Road
Railway / Station
City Limit
Park or Playground
Cemetery
Police Station
School
Post Office
Filling Station
Hospital
Hotel
Embassy
Cinema Hall
Important Building
Temple
Kovil
Mosque
Church
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2.3 Capacities of each GS

Table 2.1 shows the existing capacities of each GS. In SUB A, SUB C and SUB I have provision to install one transformer with capacity 31.5 MVA.

Table 2.1 – Grid Substation Capacities of Each GS

Grid Substation	Transformer Capacity (MVA)	Number of Transformers	Total Capacity (MVA)
SUB A – Havelock Town	31.5	2	63
SUB C - Kotahena	31.5	2	63
SUB E - Kollupitiya	30.0	3	90
SUB F – Fort	30.0	3	90
SUB I - Maradana	31.5	2	63
Kolonnawa	31.5	2	63
Kelanitissa	60.0	2	120

2.4 Technical Details of UG Cables

Table 2.2 – Underground Cable Data

Line Section	Voltage (kV)	Conductor	Length (km)	Cable Capacity (MVA)
Kelanitissa – Fort	132	500 mm^2 Cu/LEAD/PVC	4.90	150
Fort – Kollupitiya	132	350 mm^2 Cu/LEAD/PVC	2.70	75
Kollupitiya – Kolonnawa	132	500 mm^2 Cu/LEAD/PVC	5.40	150
Maradana – Havelock	132	800 mm^2 Cu/XLPE/PVC	6.30	183
Havelock – Dehiwala	132	800 mm^2 Cu/XLPE/PVC	8.50	183
Kolonnawa – Maradana	132	1000 mm^2 Cu/XLPE/PVC	4.60	202
Dehiwala - Pannipitiya	132	1000 mm^2 Cu/XLPE/PVC	9.00	202
Kolonnawa – Kotahena	132	500 mm^2 Cu/XLPE/PVC	6.00	144
Kotahena - Kelanitissa	132	500 mm^2 Cu/XLPE/PVC	2.00	144

2.5 Single Line Diagrams of Existing GS

2.5.1 SUB A – Havelock Town GS

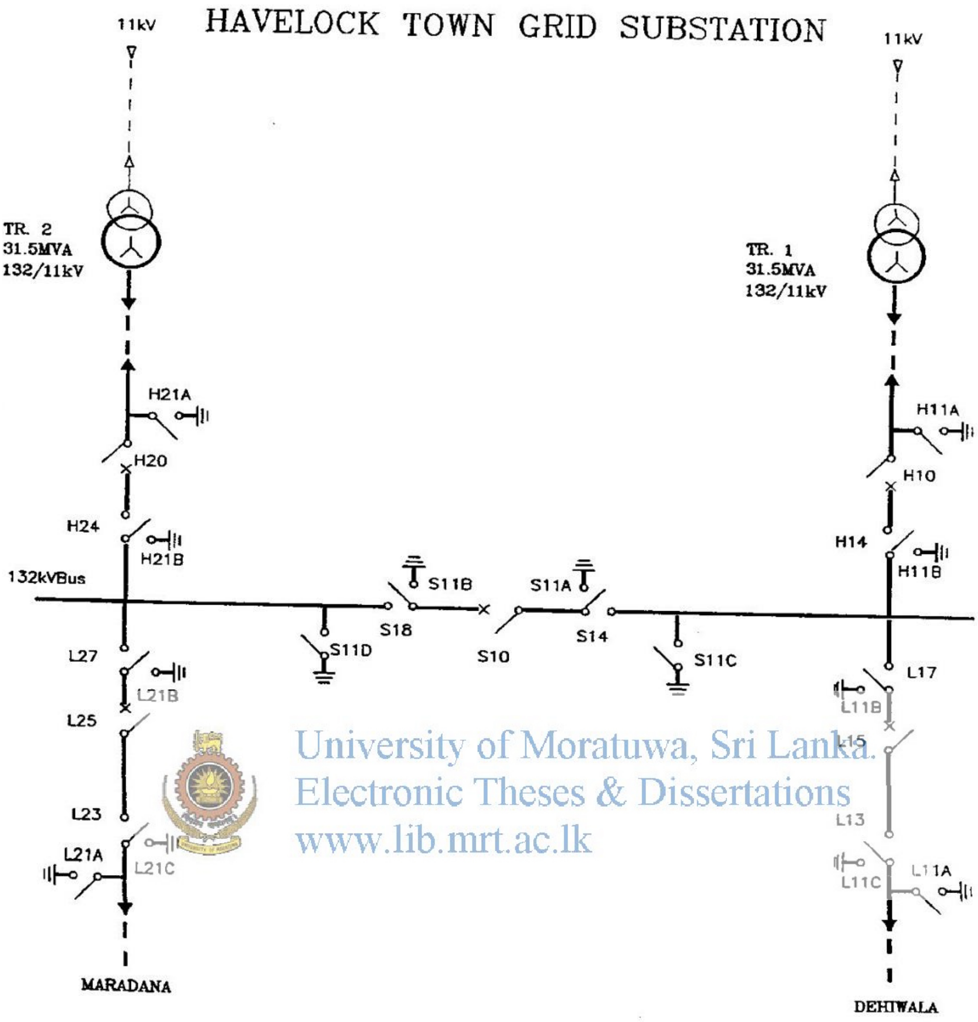

Figure 2.4 – Single Line Diagram of SUB A

As per the "Long Term Transmission Development Plan 2011-2020" one 31.5 MVA transformer will be installed at SUB A by 2017. [1]

2.5.2 SUB C – Kotahena GS

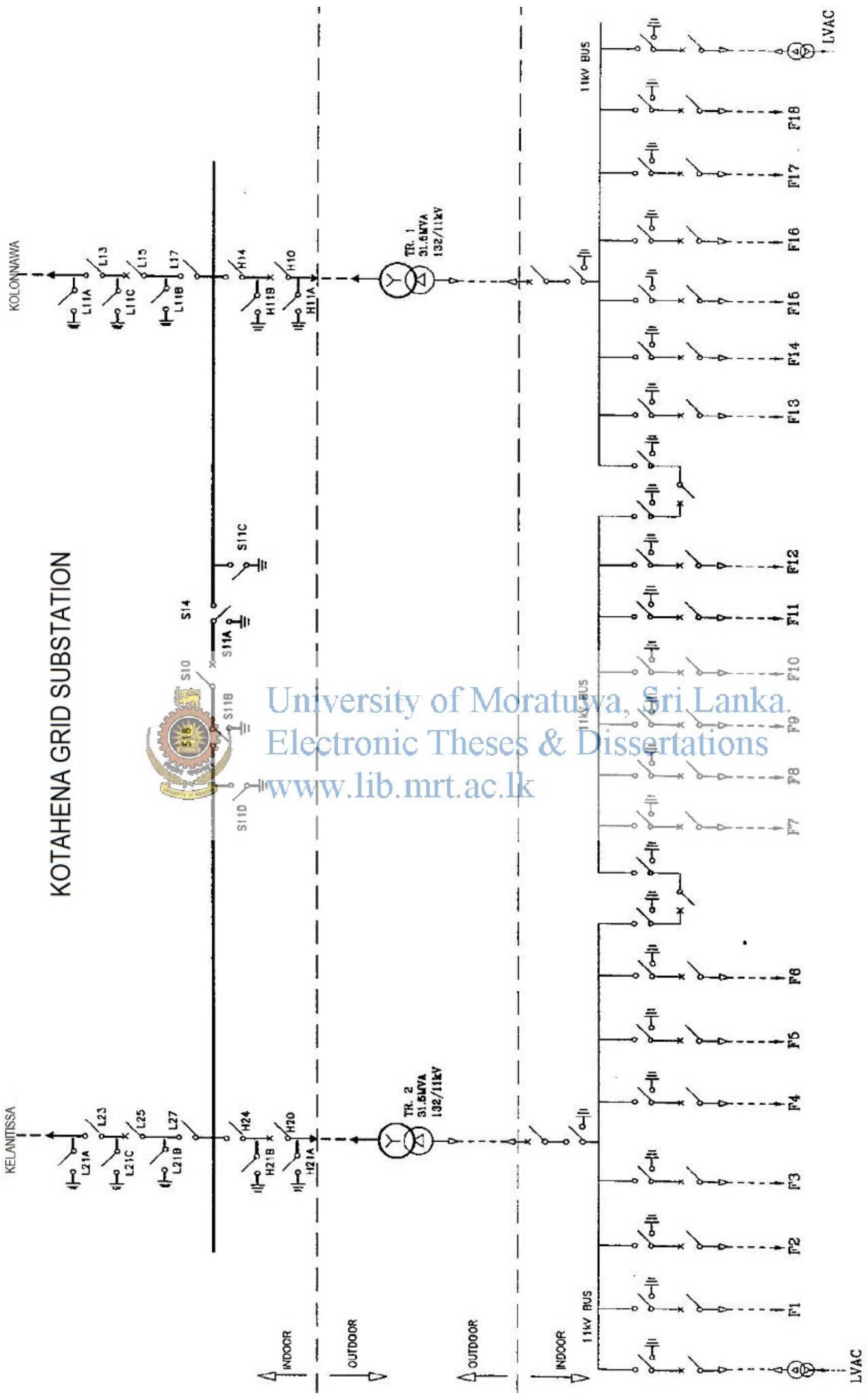

Figure 2.5 – Single Line Diagram of SUB C

2.5.3 SUB E – Kollupitiya GS

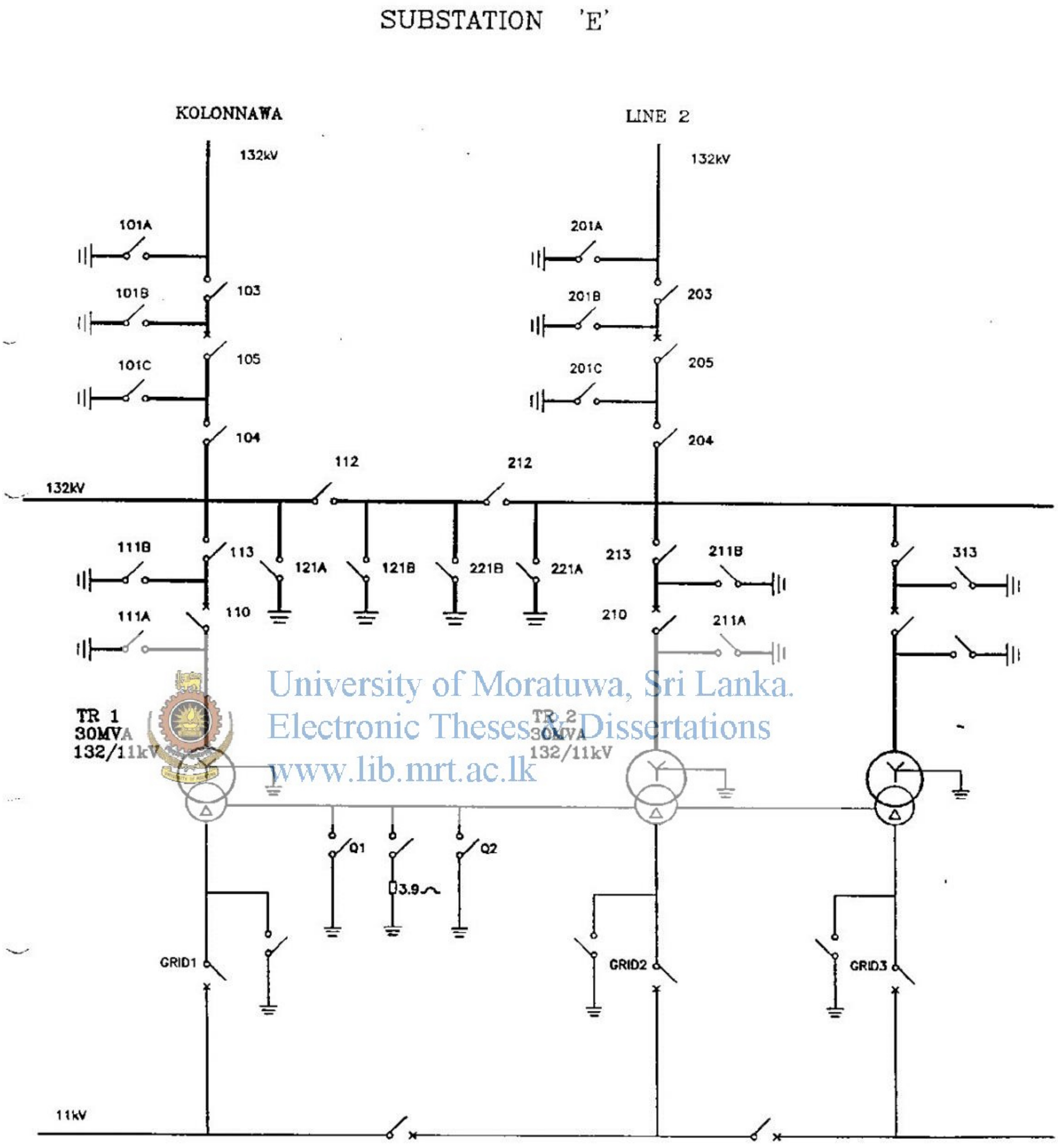

Figure 2.6 – Single Line Diagram of SUB E

2.5.4 SUB F – Fort GS

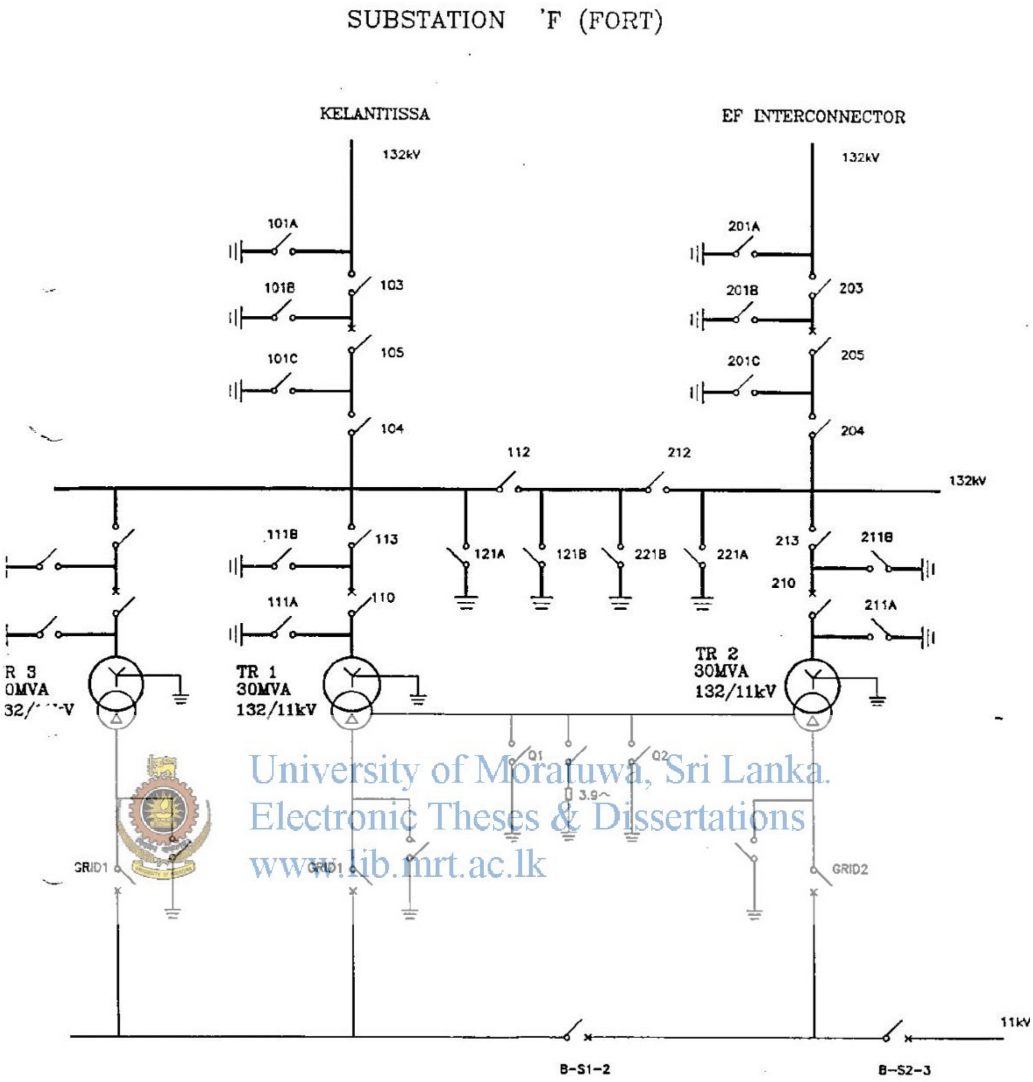

Figure 2.7 – Single Line Diagram of SUB F

2.5.5 SUB I – Maradana GS

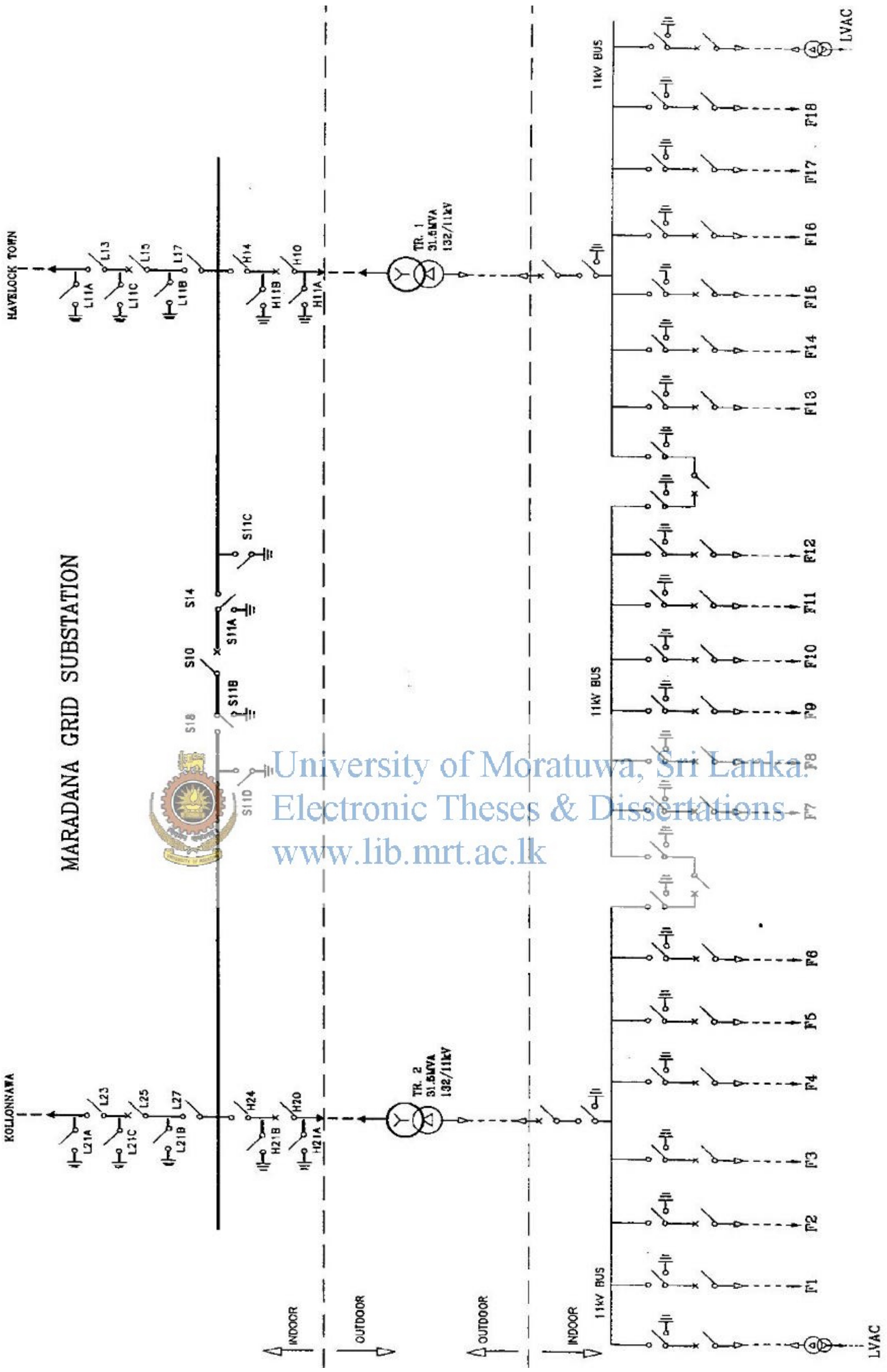

Figure 2.8 – Single Line Diagram of SUB I

As per the "Long Term Transmission Development Plan 2011-2020" one 31.5 MVA transformer will be installed at SUB I. [1]

2.5.6 Kelanitissa GS

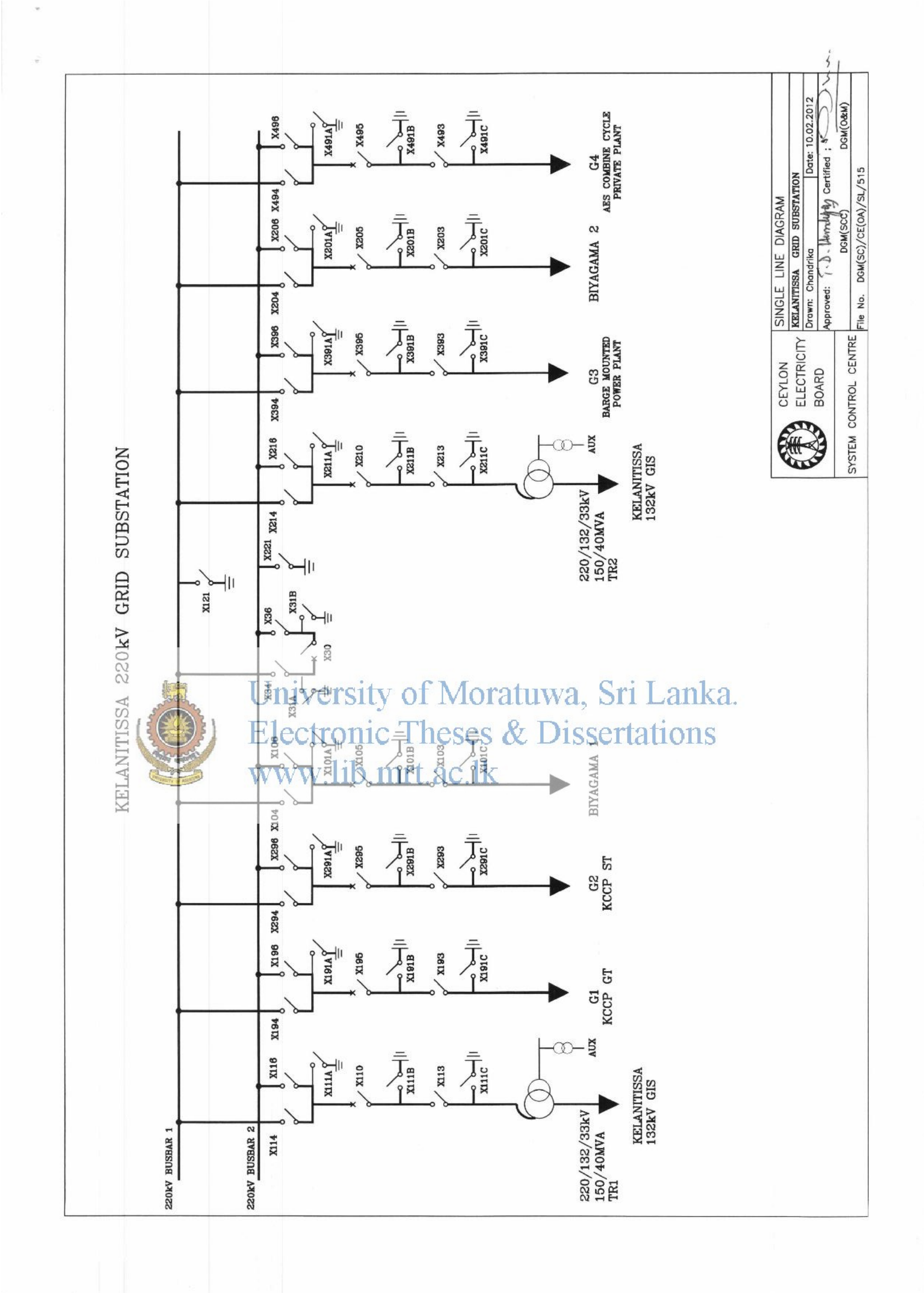

Figure 2.9 – Single Line Diagram of Kelanitissa 220 kV GS

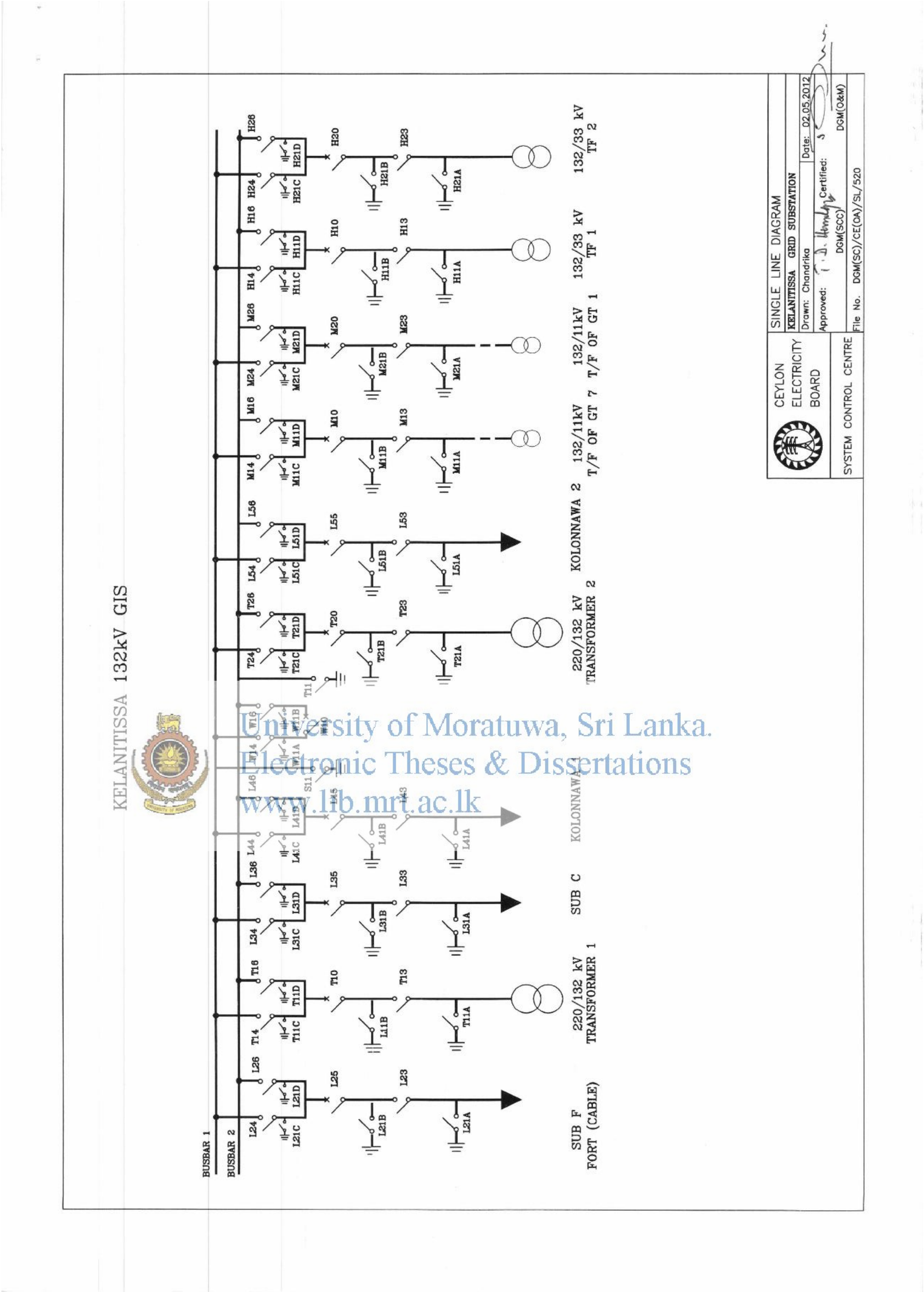

Figure 2.10 – Single Line Diagram of Kelanitissa 132 kV GS

2.5.7 Kolonnawa GS

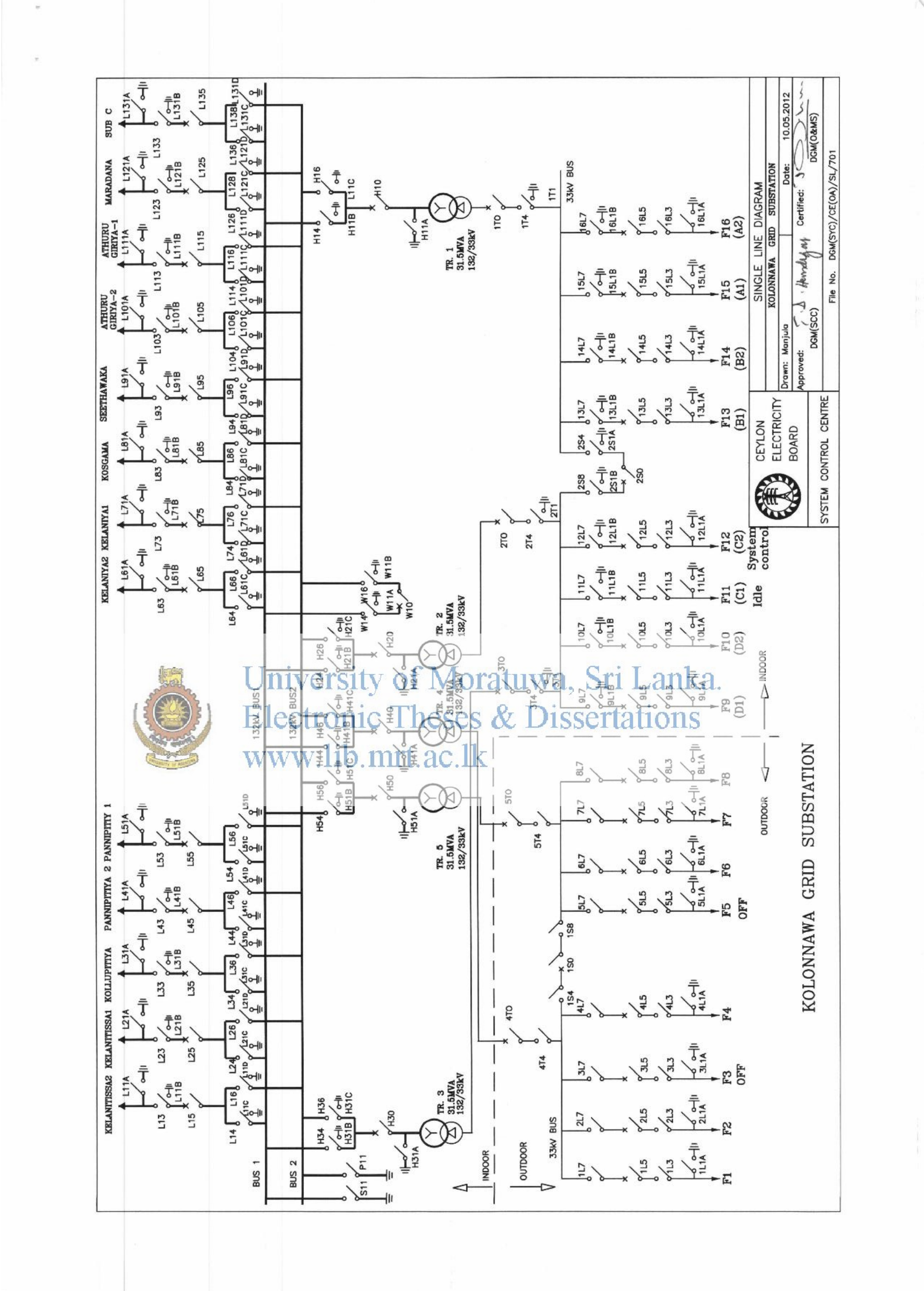

Figure 2.11 – Single Line Diagram of Kolonnawa GS

3. DEMAND GROWTH CONSIDERING MAJOR PROJECTS

Colombo City is divided into 9 zones as mentioned earlier in Chapter 1. The permitted developments and uses of each zone will be different thus the Electricity requirement of each zone will be different. The Geographical Area of each zone is shown in Figure 3.1.

3.1 Allowable Constructions at Each Zone

The specific features and uses of each zone are summarized as follows to get an idea about the electricity requirement and its capacity.

3.1.1 Special Primary Residential Zone

This zone is mainly for residential development and it will have housing units ranging from a single floor to a maximum of 3 floors including the ground floor. The following uses may be permitted in the Special Primary Residential zone:

i. Dwellings and flats up to a maximum of 3 stories (Gr. + 2 floors) In addition a basement floor is permitted.

ii. Dormitories and hostels, children homes/orphanages, home for the aged.

iii. Diplomatic Embassies and Consulates.

iv. Hotels and Lodges not exceeding 10 rooms and with a gross floor area not exceeding 150 m^2 with a site extent exceeding 1000 m^2 or more.

v. Restaurants with a maximum gross floor area of 150 m^2 with a site extent exceeding 1000 m^2 or more.

vi. Public Offices, Institutions, Bank offices with a site extent exceeding 1000 $m^{2.}$

vii. Professional offices not exceeding a floor area of 500 m^2. Professional uses include professional practice of those who are professionally employed as Lawyers, Engineers Architects Town Planners, and Doctors etc.

viii. Educational Institutions including pre-schools and primary schools each within sites of extent exceeding 1000 m^2 and 0.5 ha.

ix. Consumer oriented services such as barber shops, beauty parlours, studios, fitness centres not exceeding 100 m^2 etc.

x. Retails shops each having net floor area not exceeding 50 m^2.

xi. Places of religious worship each within sites of extent exceeding 500 m^2.

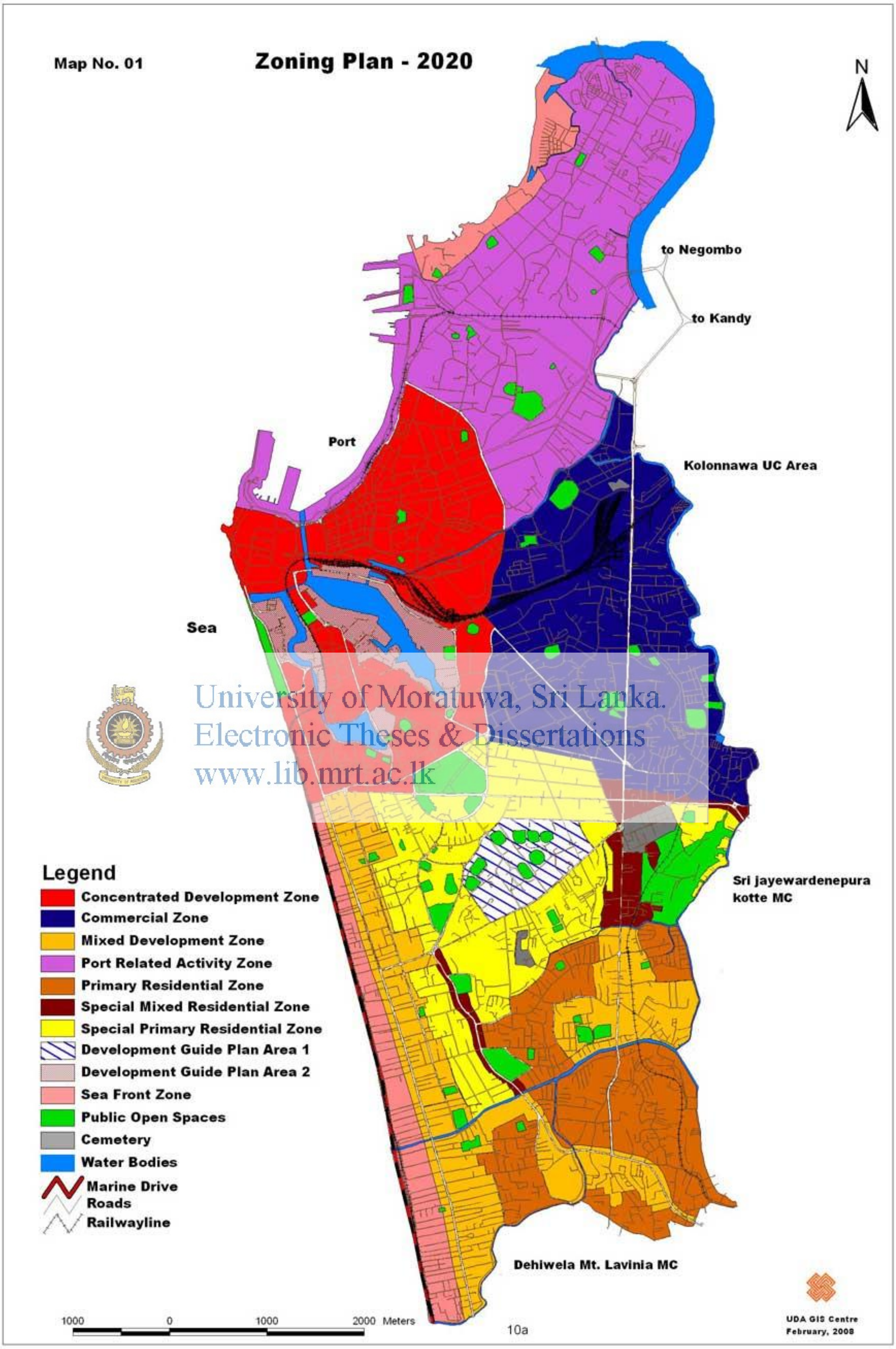

Figure 3.1 – Proposed UDA Zoning Plan in 2020

Any of the existing uses could be continued in this zone until such time they are relocated to a suitable place such as Petrol filling Stations, Groceries not exceeding 50 m^2 and Places of Public Worship.

3.1.2 Primary residential Zone

The following uses may be permitted in the Primary Residential Zone.

a. All uses permitted in Special Primary Residential will be permitted in this zone.

b. Multi storey housing complexes (maximum of 10 storey)

c. Hotels and lodges of 30 rooms and restaurants of 300 m^2 of floor area.

d. Retail shops and markets, Open air trading areas not exceeding floor area of 100 m^2.

e. Banking and insurance establishments, commercial offices each of net floor area not exceeding 200 m^2 each within sites of extent exceeding 500 m^2.

f. The professional and personal (consumer) service establishments (barber shops, beauty salons, health and fitness centers and allied activities each having net floor area not exceeding 200 m^2 each within sites of extent exceeding 500 m^2 will be allowed in this zone.

g. Indoor - amusement and entertainment establishments,

h. Places of public worship each within site extent of 500 m^2.

i. Socio - cultural institutions

j. Multi - storied car parks.

k. Filling stations

l. Educational institutions including pre-schools and primary schools each within sites of extent exceeding 500 m^2 and 0.5 ha

m. If the plot size is less than 10 perches in extent, the uses and heights of buildings permitted in a special primary residential zone area will only be permitted.

3.1.3 Special Mixed Residential Zone

The following uses may be permitted in the Special Mixed Residential Zone.

a. Dwelling houses/ units, apartment buildings

b. Restaurants in a site extent exceeding 1000 m^2.

c. Offices and institutions each in a site extent exceeding 500 m^2.

3.1.4 Sea Front Zone

The following uses may be permitted in the Sea Front Zone.

a. Dwelling houses/ units, apartment buildings

b. Banks and offices

c. Hotels and restaurants

d. Open air trading places

e. Customer care services – barber salons and allied activities

f. Indoor amusement and entertainment establishments

g. Places of worship each within sites of extent exceeding 500 m^2

h. Socio cultural institutions

i. Public outdoor recreational spaces

j. Educational institutions - pre-schools and primary schools each within sites of extent exceeding 500 m^2 and 0.5 ha

k. Vehicle parks

l. Filling stations

3.1.5 Mixed Development Zone

In a Mixed Development Zone, it is intended to serve as a transitional area between the Primary Residential and Commercial zones. The following uses may be permitted in the Mixed Development Zone:

a. All the activities allowed in a Primary Residential Development Zone.

b. Banks & commercial offices.

c. Hotels, lodges and restaurants.

d. Residential units could be converted in to professional and personal (consumer) service establishments with the approval of the authority, without a service charge.

e. Departmental stores and super markets.

f. Open air trading areas in identified areas.

g. Multi-storied housing complexes.

h. Laundries and dry cleaning establishments.

i. Repair shops excluding automobile repairs.

j. Health institutions.

k. Places of public assemblies.

l. Educational institutions.

3.1.6 Port Related Activity Zone

This activity zone was established specially to accommodate the activities of the Colombo Port which is to be improved to a very high standard. In this zone individual residential units are discouraged. However the land owners will be allowed to construct a residential building on their wishes. All the Port related activities such as warehouses, container yards, value added industries, non-polluting light industries, installation of power generating machines etc. are permitted.

a. Sub-division of lands into lots less than 25 perches will not be permitted for port related activities. However existing lot sizes could be continued to use provided they adhere to other planning and building regulations.

b. The road width has to be 40 ft.

c. A buffer zone has to be maintained around the site.

d. A clearance letter has to be obtained from the Ports Authority.

e. Parking on the road is strictly prohibited.

f. Multi-storied housing complexes.

The Authority may permit within the Zone any use provided it is satisfied that such use will not:

- Restrict use of the area for toxic industries.
- Hinder traffic movement and create traffic hazards.

The extent of the site should be adequate for the use and sufficient arrangements should be made for parking, loading and unloading of goods, water supply, effluent and waste disposal and safety from fire and other hazards.

In permitting any use in the area, the Authority may impose restrictions and conditions so as to eliminate or reduce water, air and environmental pollution, vibration and glare and to ensure safety from fire and other hazards.

3.1.7 Commercial Zone

In this zone Environment friendly nonpolluting light industries such as assembling of electronic components, garment industries etc. are permitted. This zone is specifically set aside for non -polluting industries, commercial activities engaged in high technology, high value added Industries and knowledge intensive activities.

The following categories will be permitted in the Commercial Zone:

a. In this zone all the activities permitted in other zones are allowed except activities in port related activity zone.
b. Service stations of vehicles.
c. Wholesale stores.
d. Warehouses up to 500 m^2.
e. Bakeries
f. Service industries - automobile repair, printing presses etc.

3.1.8 Concentrated Development Zone

In this zone high density development (high rise buildings) is permitted subject to individual merits of each site. Minimum number of floors should not be less than ten stories. All activities in other zones are permitted except the activities permitted in the Port related zone.

3.1.9 Public Open Spaces

The following will be permitted in this zone:

a. Residential, apartments, commercial offices, banks, restaurants, hotels & departmental shops as specified by the Development Guide Plan.
b. Water sports, bowling alley, Promenades, formal pedestrian mall/ walkway, plaza, linear park connectors, golf courses, fair and exhibition grounds, recreation clubs, gymnasiums and swimming pools, aquariums, recreation related commercial activities, cemeteries, restaurants.

In the Recreational Zone the following uses shall not be permitted.

- Industries and industrial buildings
- Dangerous and offensives trades

This zoning criterion is not considered in CEB Long Term Transmission Development Plan 2011-2020. Further, a separate load forecasting and analysis for Colombo City is needed to propose the most effective network solution in 2021.

3.2 Major Projects Planned to be completed in 2020

The identified major development projects are listed below.

1. Urban Development Project – Concentrated Development Zone
    a. Re-development of underserved settlement projects
    b. Slave Island I
    c. Slave Island II
2. Lotus Tower - Concentrated Development Zone
3. Port Expansion Project – Port Related Activity Zone
4. Triopoli Market Square Development Project - Concentrated Development Zone

5. Development of Beira Lake along D.R. Wijewardene Mawatha - Concentrated Development Zone
6. Mixed Development Projects at Jhon Keels Holdings Premises - Concentrated Development Zone
7. Gold Centre Development - Concentrated Development Zone
8. Hotel Development Project (Hotel Shangrilla, Cathie etc.) - Concentrated Development Zone
9. Panchikawatta Triangle Development Project - Concentrated Development Zone
10. Mixed Development at Colombo Commericial Land - Concentrated Development Zone
11. Mixed Development at Charmers Granaries - Concentrated Development Zone
12. Multi-storied Car Park - Concentrated Development Zone

ATTACHED IN NEXT PAGE

Figure 3.2 – Geographical Locations of Major Projects to be completed in 2020 and New Load Centers

3.3 Load Forecasting

3.3.1 Data Used

The data for past 11 years was obtained from system control center for each GS. The daily load data was sorted to get maximum loading of respective transformer of each month. Then from those daily data, the monthly maximum loading was obtained. From those monthly data annual data represented below was gathered. The peak power consumption occurs in day time in Colombo City. Therefore all data below shows are day peak readings.

Table 3.1 Yearly Day Peak Data

GS	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
A-MW					25.00	25.50	45.40	43.50	46.50	55.70	57.20
A-Mvar					15.50	11.50	13.70	16.40	18.50	19.90	20.90
C-MW										18.50	40.10
C-Mvar										11.00	27.40
E-MW	46.55	53.40	50.00	50.71	42.30	53.00	57.40	55.50	60.30	52.50	51.70
E-Mvar	34.10	28.60	31.91	32.32	26.20	36.70	39.20	33.30	34.00	32.30	36.00
F-MW	29.60	30.10	36.43	39.36	43.60	43.20	43.50	45.00	55.50	52.20	51.80
F-Mvar	18.70	16.50	21.87	23.80	27.00	26.10	26.00	42.00	37.50	34.50	30.30
I-MW					30.00	18.50	40.90	29.10	39.50	37.60	38.00
I-Mvar					18.60	8.20	18.90	12.20	17.20	15.90	16.60
KE-MW	27.70	29.50	30.90	32.20	38.60	37.10	40.12	43.38	25.47	27.63	30.11
KE-Mvar	17.15	16.60	17.20	19.30	23.90	22.00	23.86	25.87	14.74	16.04	17.60
KO-MW	51.75	64.40	49.71	47.30	46.40	44.30	48.64	52.95	35.64	38.60	43.45
KO-Mvar	32.05	40.30	30.06	28.40	28.80	21.57	23.77	26.03	14.51	15.98	18.76

3.3.2 Initial Load Forecast

The initial load forecast was prepared based on above GSs load variation.

Table 3.2 Initial Load Forecast Considering Day Peak Data

GS	2013	2014	2015	2016	2017	2018	2019	2020	2021
A-MW	60.02	62.85	65.67	68.49	71.32	72.73	74.14	75.55	76.96
A-Mvar	21.58	22.25	22.93	23.60	24.28	24.61	24.95	25.29	25.63
PF	0.94	0.94	0.94	0.95	0.95	0.95	0.95	0.95	0.95
C-MW	42.80	45.50	48.20	50.90	53.60	54.95	56.30	57.65	59.00
C-Mvar	29.45	31.50	33.55	35.60	37.65	38.68	39.70	40.73	41.75
PF	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82
E-MW	52.05	52.41	52.76	53.11	53.47	53.64	53.82	54.00	54.17
E-Mvar	36.21	36.42	36.64	36.85	37.06	37.17	37.27	37.38	37.48
PF	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82
F-MW	53.02	54.23	55.45	56.67	57.89	58.49	59.10	59.71	60.32
F-Mvar	31.26	32.23	33.19	34.16	35.12	35.61	36.09	36.57	37.05
PF	0.86	0.86	0.86	0.86	0.85	0.85	0.85	0.85	0.85
I-MW	39.09	40.17	41.26	42.34	43.43	43.97	44.51	45.06	45.60
I-Mvar	16.74	16.88	17.01	17.15	17.29	17.36	17.43	17.49	17.56
PF	0.92	0.92	0.92	0.93	0.93	0.93	0.93	0.93	0.93
KE-MW	32.58	35.06	37.53	40.01	42.48	44.96	47.44	49.91	52.39
KE-Mvar	19.16	20.72	22.27	23.83	25.39	26.95	28.50	30.06	31.62
KO-MW	48.29	53.13	57.98	62.82	67.67	72.51	77.35	82.20	87.04
KO-Mvar	21.53	24.31	27.08	29.86	32.64	35.41	38.19	40.96	43.74

3.3.3 Spot Loads

Spot Loads calculated for projects mentioned in 3.2 and other bulk supply customers obtained from Colombo City Planning Branch are shown in appendix A. Assuming 1/3 of the spot loads are contributed to the load forecasting, 2/3 of the spot loads are considered.

Table 3.3 Spot Loads

Year	A PF – 0.95			C PF – 0.82			E PF – 0.82			F PF – 0.85			I PF – 0.93		
	MVA	MW	Mvar	MVA	MW	Mvar	MVA	MW	Mvar	MVA	MW	Mvar	MVA	MW	Mvar
2013	0.50	0.32	0.10	1.00	0.55	0.38	0.00	0.00	0.00	24.00	13.60	8.43	1.40	0.87	0.34
2014	4.40	2.79	0.92	2.00	1.09	0.76	12.00	6.56	4.58	24.00	13.60	8.43	7.80	4.84	1.91
2015	4.50	4.28	1.41	4.00	3.28	2.29	13.00	10.66	7.44	46.67	39.67	24.58	11.20	10.42	4.12
2016	9.17	8.71	2.86	18.67	15.31	10.68	20.13	16.51	11.52	125.00	106.25	65.85	41.20	38.32	15.14
2017	9.17	8.71	2.86	21.33	17.49	12.21	25.47	20.88	14.58	149.67	127.22	78.84	41.20	38.32	15.14
2018	9.53	9.06	2.98	34.67	28.43	19.84	26.13	21.43	14.96	201.33	171.13	106.06	47.87	44.52	17.59
2019	9.53	9.06	2.98	34.67	28.43	19.84	27.13	22.25	15.53	201.33	171.13	106.06	47.87	44.52	17.59
2020	9.53	9.06	2.98	34.67	28.43	19.84	27.47	22.52	15.72	248.00	210.80	130.64	47.87	44.52	17.59
2021	9.53	9.06	2.98	34.67	28.43	19.84	27.47	22.52	15.72	248.33	211.08	130.82	47.87	44.52	17.59

3.3.4 Final Load Forecast

The final load forecast was obtained by adding the spot loads calculated in table 3.3 to initial load forecast shown in table 3.2 for each GS.

Table 3.4 Final Load Forecast Considering Day Peak Data

GS	2013	2014	2015	2016	2017	2018	2019	2020	2021
A-MW	60.34	65.63	69.94	77.20	80.02	81.78	83.20	84.61	86.02
A-Mvar	21.68	23.17	24.33	26.46	27.14	27.59	27.93	28.26	28.60
A-MVA	64.12	69.60	74.06	81.61	84.50	86.31	87.76	89.20	90.65
C-MW	43.35	46.59	51.48	66.21	71.09	83.38	84.73	86.08	87.43
C-Mvar	29.83	32.26	35.84	46.28	49.86	58.52	59.54	60.57	61.59
C-MVA	52.62	56.67	62.73	80.78	86.84	101.86	103.56	105.25	106.94
E-MW	52.05	58.97	63.42	69.62	74.35	75.07	76.07	76.52	76.70
E-Mvar	36.21	41.00	44.08	48.37	51.64	52.12	52.80	53.10	53.20
E-MVA	63.41	71.82	77.23	84.78	90.52	91.39	92.60	93.14	93.34
F-MW	66.62	67.83	95.12	162.92	185.10	229.63	230.24	270.51	271.40
F-Mvar	39.69	40.66	57.78	100.01	113.97	141.67	142.15	167.21	167.87
F-MVA	77.55	79.09	111.29	191.16	217.37	269.81	270.58	318.02	319.13
I-MW	39.95	45.01	51.67	80.66	81.74	88.49	89.03	89.57	90.12
I-Mvar	17.08	18.79	21.13	32.29	32.43	34.95	35.02	35.09	35.16
I-MVA	43.45	48.77	55.83	86.88	87.94	95.14	95.67	96.20	96.73
KE-MW	32.58	35.06	37.53	40.01	42.48	44.96	47.44	49.91	52.39
KE-Mvar	19.16	20.72	22.27	23.83	25.39	26.95	28.50	30.06	31.62
KE-MVA	37.80	40.72	43.64	46.57	49.49	52.42	55.34	58.27	61.19
KO-MW	48.29	53.13	57.98	62.82	67.67	72.51	77.35	82.20	87.04
KO-Mvar	21.53	24.31	27.08	29.86	32.64	35.41	38.19	40.96	43.74
KO-MVA	52.87	58.43	63.99	69.56	75.13	80.70	86.27	91.84	97.41

If we consider 20% overloading of transformers in emergency situation, below shows the maximum load one GS able to withstand.

Table 3.5 Overloading of GSs in 2021

GS	Installed Capacity (MVA)	Full Capacity with Expansion (MVA)	Available Maximum Capacity (MVA)	Required Capacity in 2021 (MVA)	Overloading in 2021 (MVA)
Colombo-A (Havelock)	63.00	94.50	75.60	90.65	15.05
Colombo - C (Kotahena)	63.00	94.50	75.60	106.94	31.34
Colombo E (Kolpitiya)	90.00	90.00	72.00	93.34	21.34
Colombo-F (Fort)	90.00	90.00	72.00	319.13	247.13
Colombo-I (Maradana)	63.00	94.50	75.60	96.73	21.13
Kelanitissa	120.00	120.00	72.00	61.19	-10.81
Kolonnawa -Colombo	63.00	94.50	75.60	97.41	21.81
Total	**552.00**	**678.00**	**518.40**	**865.40**	**347.00**

As per table 3.5 all grid substations get overloaded except for Kelanitissa GS. Therefore new Grid Substations have to be constructed and/or need to go for higher transmission voltage level.

4. PROBLEMS ENCOUNTERED IN MEETING THE DEMAND

4.1 Problems Encountered in Modifying Existing Network

4.1.1 Interbus Transformers at Kelanitissa and Pannipitiya

Available maximum capacity of existing Colombo City network is 518.40 MVA (449.82 MW) considering n-1 criteria. According to the Final Load Forecast shown in Table 3.4 and Demand Growth shown in Table 4.1existing network will not be able to cater the demand of 691.79 MVA (602.46 MW) in 2017. The interbus transformers at Kelanitissa and Pannipitiya will also get overloaded. Therefore, requirement of new feeding point to feed Colombo City will be a must. Kerawalapitiya to SUB L connection is required to supply the Colombo City load beyond 2017 by feeding Kerawalapitiya generation to Colombo City. The percentage capacity increase in 2017 is 79.94% as shown in Table 4.1. Therefore simulation will be done to see what happens in 2017 and 2021 with different network modifications. As per the "Long Term Transmission Development Plan 2013-2022" prepared by CEB, SUB L of capacity 180 MVA and Kerawalapitiya - SUB L UG cable construction will be finished by 2017.

Table 4.1 Demand Growth Considering Day Peak Demands

Year	2013	2014	2015	2016	2017	2018	2019	2020	2021
Total Demand (MW)	343.18	372.23	427.15	559.44	**602.46**	675.82	688.05	739.40	**751.09**
Total Capacity (MVA)	391.81	425.10	488.77	641.34	**691.79**	777.63	791.77	851.92	**865.40**
Percentage Increase	45.20	49.12	56.48	74.11	**79.94**	89.86	91.49	98.44	**100.00**

4.1.2 Capacity Limitations of Existing UG Cables

Figure 2.1 shows the existing Colombo City 132 kV Underground Transmission Network. The UG cable used in Kolonnawa-SUB E-SUB F-Kelanitissa ring is Cu 500 oil filled cable with current carrying capacity of 600 A at 90 ^{0}C. If feeding from Kelenitissa Power Station goes off or the cable between Kelanitissa-SUB F fails, 144 MVA of cable capacity needed between Kolonnawa-SUB E to operate without any interruptions. The cable has the capacity of 137 MVA and 10% overloading of cable is acceptable as per CEB standards. Then the above mentioned cable can be loaded up to 150.7 MVA. Then there is enough capacity to operate SUB E and SUB F without interruptions and there is no provision to connect another GS to Kolonnawa-SUB E-SUB F-Kelanitissa ring.

The UG cables used in Kolonnawa-SUB I-SUB A-Dehiwala-Pannipitiya ring are shown in Table 2.2. 800 mm^2 XLPE cable with current carrying capacity of 1009 A at 90 ^{0}C is used between SUB I-SUB A and SUB A-Dehiwala. 1000 mm^2 XLPE cable with current carrying capacity of 1115 A at 90 ^{0}C is used between Kolonnawa-SUB I and Dehiwala-Pannipitiya. For example if we assume cable between Kolonnawa-SUB I fails, cable between Pannipitiya-Dehiwala need to have capacity of 223.2 MVA. The respective cable has 253 MVA and it is enough to operate without interruptions. But there is no provision to connect another GS to the above ring.

The UG cable used in Kolonnawa-SUB C-Kelanitissa ring is 500 mm^2 XLPE cable with current carrying capacity of 825 A at 90 ^{0}C. The capacity of the above cable is 189 MVA. Therefore the provision is there to connect one 132/11 kV 94.5 MVA GS to above ring. But with this addition also existing system cannot cater the required demand of 559.44 MW in 2016.

4.1.3 The Lifespan of GSs

SUB E and SUB F are almost 30 years old. The cables installed in Kolonnawa-SUB E-SUB F-Kelanitissa ring also 30 years in operation. Therefore we need to analyze augmenting SUB E and SUB F is cost effective or not.

4.2 Problems Encountered with Zoning Criteria

In the Colombo City development plan, developments in “Concentrated Development Zone” and “Port Related Activity Zone” will be carried out up to 2020. As shown in annexure 1 most of the spot loads considered are also situated in the above two zones. Then SUB A, SUB C, SUB E, SUB F and SUB I will be overloaded.

5. SOLUTIONS

Considering problems discussed in Chapter 4, this study proposes 2 network development solutions. First one is developing existing 132 kV network with new 220 kV feeding point from Kerawalapitiya. Secondly developing new 220 kV ring to accommodate the demand in 2021.

Sri Lankan Network is drawn in PSSE simulator and two networks will be analyzed further. A detailed power system analysis consisting of cable capacity, load flow, transmission losses and short circuit studies are conducted to verify any planning criteria violations.

5.1 Proposed 132 kV Solution in 2021

Maximum demand in Colombo City in 2021 will be 751.09 MW (Capacity 865.40 MVA). Figure 5.1 shows the proposed 132 kV solution in 2021. When we simulate Existing network and the corresponding loads in 2021, Kelanitissa and Pannitipitiya Interbus Transformers get overloaded. Therefore, introduce new 220 kV feeding point. i.e. SUB L – Port. SUB B, SUB N, SUB M and SUB O are introduced to cater the increased demand.

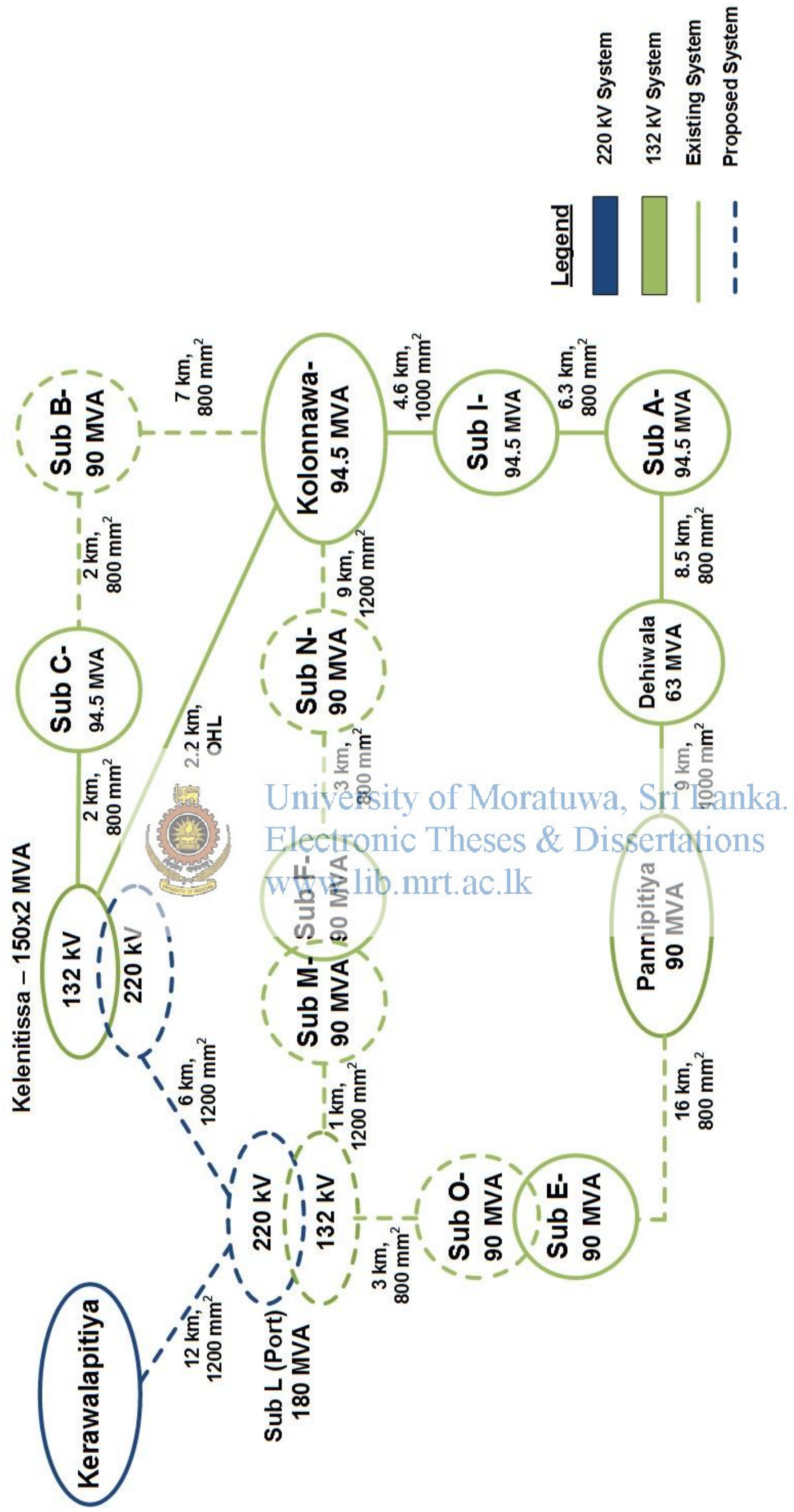

Figure 5.1 - Proposed 132 kV Colombo City Transmission Network

5.1.1 Underground Cable Capacity Analysis

Following assumptions and criteria were used in cable rating calculation:

1. Cable network is rated by considering all the grid substations and capacities shown in figure 5.1.
2. Colombo city grid substations are loaded up to their full capacity.
3. Cable ratings are selected such that there will be no overloading of cables even in the case of single cable outage condition subjected to transformer loading as assumed in 2 above.
4. In determining current rating of cables, the following assumptions were made.
    - Cable type: XLPE insulated, single core, copper conductor, 132kV /220kV cables
    - Type of lying: Flat spaced, ducted with 1.2m cable lying depth and 380mm axial spacing.

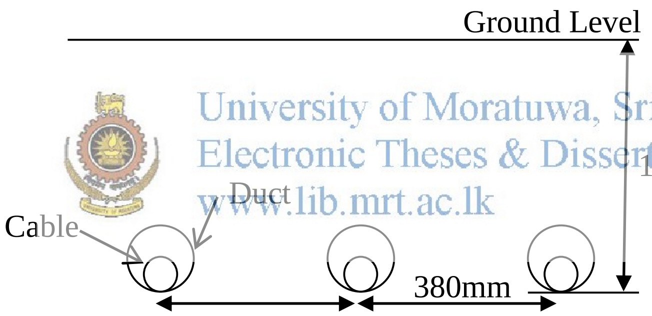

Figure 5.2 – Underground Cable Arrangement

- Bonding of metallic screens : Cross –bonding
- Maximum continuous conductor temperature is 90^0C
- Ground temperature is 30^0C
- Thermal resistivity of soil is 1K.m/W

5. Following correction factors were applied when calculating cable current carrying capacities: The correction factors are taken from ABB XLPE Land Cable Systems User's Guide – Rev 5 [5]. (The current carrying capacity calculation and datasheet are attached in appendix E & appendix F respectively)
    - 0.88 For ground temperature correction
    - 0.98 For lying depth correction

- 1.08 For axial spacing correction
- 0.9 For ducted cable correction

6. Cable lengths, sizes, capacities and electrical parameters used for load flow analysis is shown in table 5.1.

Table 5.1 UG Cable Details of Proposed 132 kV Solution in 2021

Line	Length (Km)	Voltage (kV)	Size (mm^2)	R (p.u. on 100MVA	X(p.u. on 100MVA base)	B(p.u. on 100MVA base)	Capacity (MVA)
Kerawalapitiya-SUB L	12.0	220	1200	0.000498	0.004050	0.383174	400
Kelenitissa-SUB L	6.0	220	1200	0.000249	0.002025	0.191587	400
SUB L-SUB E/ SUB O	3.0	132	800	0.000561	0.002922	0.037333	183
SUB E-Pannipitiya	16.0	132	800	0.002992	0.015584	0.201440	183
SUB L-SUB F/ SUB M	1.0	132	1200	0.000115	0.000902	0.015874	237
SUB F-SUB N	3.0	132	800	0.000561	0.002922	0.037333	183
SUB N-Kolonnawa	9.0	132	1200	0.001683	0.008766	0.11331	237
Kelanitissa – SUB C	2.0	132	800	0.000374	0.001947	0.025180	183
SUB C – SUB B	2.0	132	800	0.000374	0.001947	0.025180	183
SUB B - Kolonnawa	7.0	132	800	0.001310	0.006815	0.088130	183

5.1.2 Load Flow Studies

The main objective of the load flow study is to determine the steady state performance of the network. The potential problems such as unacceptable voltage conditions and overloading of transmission network elements are identified from load flow studies. Load flow studies were performed for year 2017 and 2020 systems, by considering day peak, loading conditions and by considering number of critical generation scenarios. 132/11kV, 31.5MVA and 45 MVA transformers were used for this proposal with 30% transformer impedance. 220/132/33kV, 250MVA transformers were used at Colombo L grid substation. Load flow studies were performed under following conditions:

- Kolonnawa- Sri J'Pura- Pannipitiya 132kV ring is opened from Kolonnawa end.
- Keleniya-Kolonnawa 132kV lines are opened
- All Colombo City cable rings are closed.

No any planning criteria violations were identified.

5.1.3 Transmission Losses

Transmission losses were calculated for both options in year 2017 and 2021 systems and shown in Table 5.2.

Table 5.2 Transmission Losses for Proposed 132 kV Solution in2021

Year	Loading Scenario	Losses(MW)	Constant Load (MW)
2017	Day Peak	39.06	
2021	Day Peak	76.56	3208.5

5.1.4 Short Circuit Analysis

The short circuit studies were done to calculate fault currents at each GS. Allowable three phase short circuit levels as per Ceylon Electricity Board standards are as follows.

- 220 and 132 kV - 40 kA
- 33 kV - 25 kA
- 11 kV - 25 kA

Maximum three phase short circuit levels at Colombo City grid substations in year 2017 and 2020 were calculated and shown in table 5.3 with proposed developments. The maximum three phase short circuit levels were obtained by assuming all 132kV underground cables and 132kV transmission connections between Kolonnawa - Pannipitiya and Kolonnawa-Keleniya are in service.

Following assumptions were made during the short circuit analysis:

- All bus voltages are set to one per unit at zero phase angles.
- Constant power, current, and admittance loads are set to zero.
- Generator power outputs are set to zero.

- Transformer phase shift angles are set to zero. Any transformer impedance, which is a function of phase shift angle is set to its nominal value.
- All transformer turns ratios are set to one. This includes generator step-up transformers, which are modeled as part of the machine representation (i.e., the GENTAP). Any transformer impedance, which is a function of turns ratio, is set to its nominal value.
- Line charging is set to zero
- Shunt elements, including magnetizing admittances of transformers, are set to zero; switched shunts are zeroed.

Table 5.3 Maximum Three Phase Short Circuit Levels for Proposed 132 kV Solution

Grid Substation	Maximum Three Phase Short Circuit Current (kA)
Colombo L -220kV	18.5
132kV	19.7
11kV	15.1
Colombo A-132kV	16.5
11kV	15.0
Colombo C-132kV	18.8
11kV	15.2
Colombo E-132kV	18.5
11kV	15.2
Colombo F-132kV	19.6
11kV	15.1
Colombo I-132kV	18.1
11kV	16.5
Colombo B-132kV	18.5
11kV	15.1
Colombo N-132kV	19.7
11kV	15.1
Colombo M-132kV	19.7
11kV	15.1
Colombo O-132kV	19.7
11kV	15.1
Pannipitiya-220kV	17.7
Kelanitissa-220kV	19.1
Kerawalapitiya-220kV	18.4

5.2 Proposed 220 kV Solution in 2021

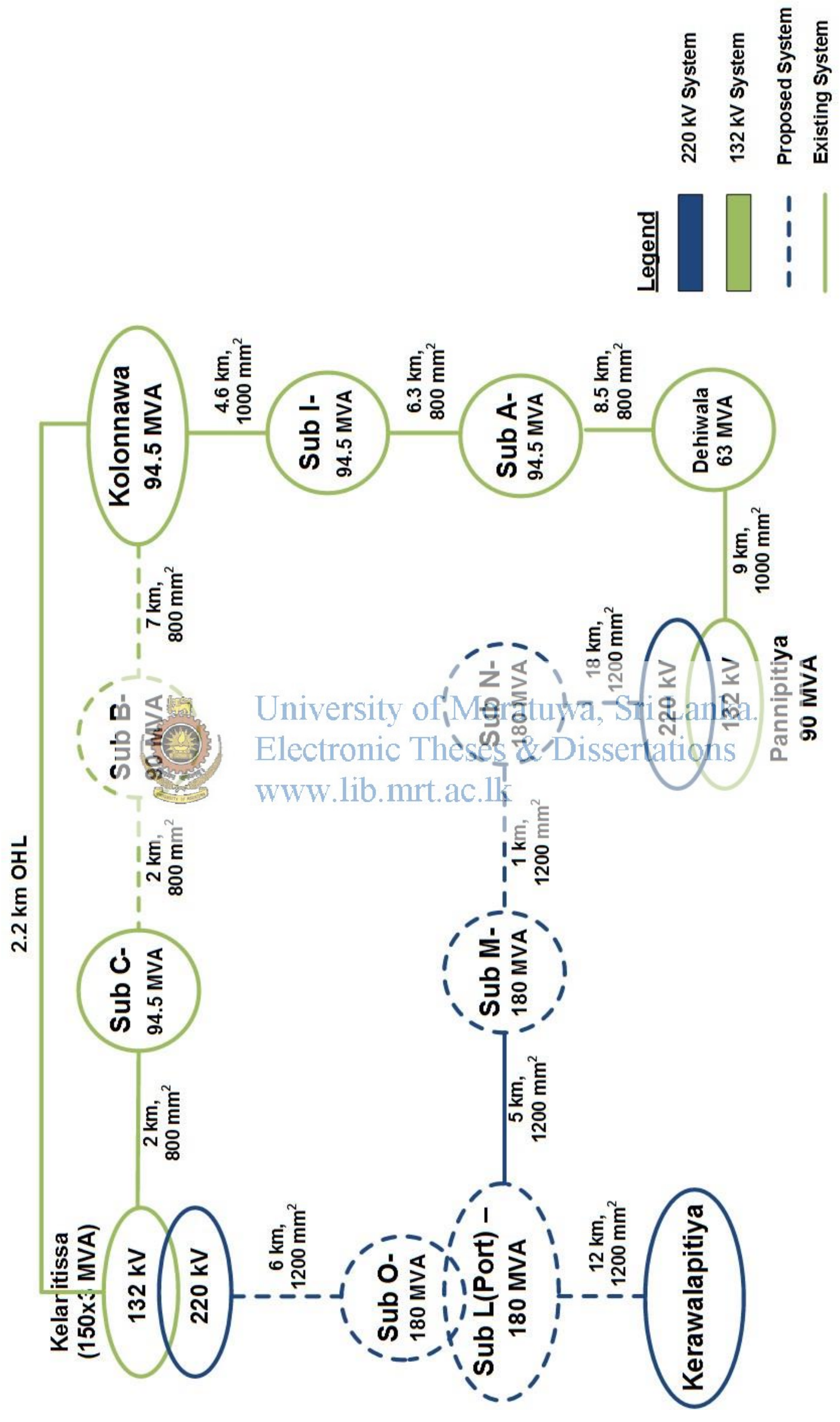

Figure 5.3 - Proposed 220 kV Colombo City Transmission Network

In Figure 5.2 shows the proposed 220 kV solution in 2021. New two 220 kV rings were proposed as follows.

- Kerawalapitiya GS-SUB L-SUB M-SUB N-Pannipitiya GS.
- Kelanitissa GS-SUB O-SUB L

One 220/132 kV, 150 MVA interbus transformer is introduced at Kelanitissa GS. SUB B is introduced to 132 kV existing network. Cable Capacities, fault levels and losses are analyzed for above solution.

5.2.1 Underground Cable Capacity Analysis

Following assumptions and criteria were used in cable rating calculation:

1. Cable network is rated by considering all the grid substations and capacities shown in figure 5.2.
2. Colombo city grid substations are loaded up to their full capacity.
3. Cable ratings are selected such that there will be no overloading of cables even in the case of single cable outage conditions subjected to transformer loading as depicted in 2 above.
4. In determining current rating of cables, the following assumptions were made.
    - Cable type: XLPE insulated, single core, copper conductor, 132kV /220kV cables
    - Type of lying: Flat spaced, ducted with 1.2m cable lying depth and 380mm axial spacing.
    - Bonding of metallic screens : Cross –bonding
    - Maximum continuous conductor temperature is 90^0C
    - Ground temperature is 30^0C
    - Thermal resistivity of soil is 1K.m/W
5. Following correction factors were applied when calculating cable current carrying capacities: (The current carrying capacity calculation and datasheet are attached in appendix E & appendix F respectively) [5]
    - 0.88 For ground temperature correction
    - 0.98 For lying depth correction
    - 1.09 For axial spacing correction

- 0.9 For ducted cable correction

6. Cable lengths, sizes, capacities and electrical parameters used for load flow analysis is shown in table 5.4.

Table 5.4 UG Cable Capacities for Proposed 220 kV Solution in 2021

Line	Length (km)	Voltage (kV)	Size (mm^2)	R (p.u. on 100MVA base)	X(p.u. on 100MVA base)	B(p.u. on 100MVA base)	Capacity (MVA)
Kerawalapitiya-SUB L	12	220	1200	0.000498	0.004050	0.383174	400
SUB L-SUB M	5	220	1200	0.000207	0.001687	0.159656	400
SUB M-SUB N	1	220	1200	0.000042	0.000338	0.287380	400
SUB N-Pannipitiya	18	220	1200	0.000747	0.006075	0.574761	400
Kelanitissa-SUB L /SUB O	6	220	1200	0.002492	0.002025	0.191587	400

5.2.2 Load Flow Studies

Load flow studies were performed for year 2017 and 2020 systems, by considering day peak loading conditions and by considering number of critical generation scenarios. 132/11kV, 31.5MVA and 220/22 kV 45 MVA transformers were used for this proposal with 30% transformer impedance. 220/132/33kV, 250MVA transformers were used at Colombo L grid substation.

Load flow studies were performed under following conditions:

- Kolonnawa- Sri J'Pura- Pannipitiya 132kV ring is opened from Kolonnawa end.
- Keleniya-Kolonnawa 132kV lines are opened
- All Colombo City cable rings are closed.

5.2.3 Transmission Losses

Transmission losses were calculated for both options in year 2017 and 2021 systems and shown in Table 5.5.

Table 5.5 UG Transmission Losses for Proposed 220 kV Solution in2021

Year	**Loading Scenario**	**Losses(MW)**	**Constant Load (MW)**
2017	Day Peak	39.06	
2021	Day Peak	76.25	3211

5.2.4 Short Circuit Analysis

Maximum three phase short circuit levels at Colombo City grid substations in year 2017 and 2020 were calculated and depicted in Table 5.6 with proposed developments. The maximum three phase short circuit levels were obtained by assuming all 220 kV & 132kV underground cables and 132kV transmission connections between Kolonnawa - Pannipitiya and Kolonnawa- Keleniya are in service.

Following assumptions were made during the short circuit analysis:

- All bus voltages are set to one per unit at zero phase angles.
- Constant power, current, and admittance loads are set to zero.
- Generator power outputs are set to zero.
- Transformer phase shift angles are set to zero. Any transformer impedance, which is a function of phase shift angle is set to its nominal value.
- All transformer turns ratios are set to one. This includes generator step-up transformers, which are modeled as part of the machine representation (i.e., the GENTAP). Any transformer impedance, which is a function of turns ratio, is set to its nominal value.
- Line charging is set to zero
- Shunt elements, including magnetizing admittances of transformers, are set to zero; switched shunts are zeroed.

Table 5.6 Maximum Three Phase Short Circuit Levels for Proposed 220 kV Solution

Grid Substation	Maximum Three Phase Short Circuit Current (kA)
Colombo L-220 kV	19.2
22 kV	15.3
Colombo M-220 kV	18.4
22 kV	22.8
Colombo N-220 kV	15.1
22 kV	22.5
Colombo O-220 kV	19.2
22 kV	22.8
Colombo A-11 kV	14.9
Colombo I-11 kV	15.0
Colombo C-11 kV	15.1
Colombo B-11 kV	15.0
Kerawalapitiya-220 kV	18.6
Kelanitissa-220 kV	19.4
Pannipitiya-220 kV	18.3

5.3 Comparison of Proposed Two Solutions

Table 5.7 Comparison of 132 kV and 220 kV Solutions

Item	132 kV Solution (Option 1)	220 kV Solution (Option 2)
1	Losses are high.	Losses are lower than 132 kV solution.
2	SUB E and F are almost 25 years in operation and if we decide to develop the 132 kV solution, we have to rehabilitate two SUBs. Cost involved.	If we decide to develop 220 kV solution, we have to shift 11 kV distribution voltage level to 22 kV. Therefore have to consider existing cable capacities and distribution network development cost.
3	Land scarcity problem due to many number of 132/11 kV GSs.	Can cater the increasing demand with lesser number of 220/22 kV SUBs. Solution for land scarcity.

6. COST BENEFIT ANALYSIS

6.1. Cost Analysis

Cost estimate for the two solutions mentioned in section 5.1 and 5.2 are given in table 6.1 and 6.2. The cost is based on year 2013 Transmission Planning Cost Database and conversion rate is 1USD= LKR 110. The cable costs that are not listed in the Transmission Planning Cost Database were taken from cable manufactures and apply civil and installation cost approximations.

6.1.1. Cost Breakdown for Proposed 132 kV Solution in 2021

Table 6.1 Cost Breakdown for 132 kV Solution in 2021

Item No.	Scope of Works	Cost in Million LKR
1	**Construction of Colombo N GS 132/11kV GS**(2x45MVA, 132/11kV indoor transformers,2x132kV indoor single busbar transformer bays, 2x11kV indoor single busbar transformer bays, 16x 11kV indoor cable bays ,2x 132kV single busbar indoor cable bays,1x 132kV indoor bus section bay with single busbar arrangement and 1X11kV indoor bus section bays with single busbar arrangement).	1077
2	**Construction of Colombo B GS 132/11kV GS**(2x45MVA, 132/11kV indoor transformers,2x132kV indoor single busbar transformer bays, 2x11kV indoor single busbar transformer bays, 16x 11kV indoor cable bays ,2x 132kV single busbar indoor cable bays,1x 132kV indoor bus section bay with single busbar arrangement and 1X11kV indoor bus section bays with single busbar arrangement).	1077
3	**Construction of Port 220/132/33kV GS** (2x250MVA, 220/132/33kV transformer, 2x220kV double busbar transformer bay,2x220kV indoor double busbar cable bay,1x220kV bus section bay 2x132kV indoor double busbar cable bay, 2x132kV double busbar transformer bay,1x132kV bus coupler bay, 2x33kV transformer bay and 1x33kV indoor bus section bay with single busbar arrangement)	1785
4	**Construction of Colombo M GS 132/11kV GS** (2x45MVA, 132/11kV indoor transformers,2x132kV indoor single busbar transformer bays, 2x11kV indoor single busbar transformer bays, 16x 11kV indoor cable bays ,2x 132kV single busbar indoor cable bays,1x 132kV indoor bus section bay with single busbar arrangement and 1X11kV indoor bus section bays with single busbar arrangement).	1077

5	**Construction of Colombo O GS 132/11kV GS**(2x45MVA, 132/11kV indoor transformers,2x132kV indoor single busbar transformer bays, 2x11kV indoor single busbar transformer bays, 16x 11kV indoor cable bays ,2x 132kV single busbar indoor cable bays,1x 132kV indoor bus section bay with single busbar arrangement and 1X11kV indoor bus section bays with single busbar arrangement).	1077
6	Construction of 220kV, Cu (XLPE) 1200mm^2, 6km cable between Kelenitissa and Port GS.	1200
7	Construction of 220kV, Cu (XLPE) 1200mm^2, 12km cable between Kerawalapitiya and Port GS.	2400
8	Construction of 132kV, Cu (XLPE) 1200 mm^2, 1km cable between Colombo F and Port GS.	200
9	Construction of 132kV, Cu (XLPE) 800mm^2, 3km cable between Colombo E and Port GS.	450
10	Construction of 132kV, Cu (XLPE) 800mm^2, 2 km cable between Colombo B and Colombo C GS	300
11	Construction of 132kV, Cu (XLPE) 800mm^2, 3km cable between Colombo F and Colombo N GS.	450
12	Construction of 132kV, Cu (XLPE) 800mm^2, 9km cable between Colombo N and Kolonnawa GS.	1350
13	Construction of 132kV, Cu (XLPE) 800mm^2,12 km cable between Colombo B and Kolonnawa GS	1800
14	Construction of 132kV, Cu (XLPE) 800mm^2, 16km cable between Colombo E and Pannipitiya GS.	2400
	Grid Augmentations	
15	Installation of 31.5MVA Transformer with 6 feeder bays at Kolonnawa GS	280
16	Installation of 31.5MVA Transformer with 6 feeder bays at Colombo A GS	280
17	Installation of 31.5MVA Transformer with 6 feeder bays at Colombo C GS	280
18	Installation of 31.5MVA Transformer with 6 feeder bays at Colombo I GS	280
19	Enhancement cost for E and F SUBs	2582
	Total Cost	**20345**

6.1.2. Cost Breakdown for Proposed 220 kV Solution in 2021

Table 6.2 Cost Breakdown for 220 kV Solution in 2021

Item No.	Scope of Works	Cost in Million LKR
1	**Construction of Port 220/22kV GS** (2x250MVA, 220/22kV transformer, 2x220kV double busbar transformer bay,2x220kV indoor double busbar cable bay,1x220kV bus section bay 2x22kV transformer bay and 1x22kV indoor bus section bay with single busbar arrangement).	1460
2	**Construction of Colombo N GS 220/22kV GS**(2x90MVA, 220/22kV indoor transformers,2x220kV indoor single busbar transformer bays, 2x22kV indoor single busbar transformer bays, 12x 22kV indoor cable bays ,2x 220kV single busbar indoor cable bays,1x 220kV indoor bus section bay with single busbar arrangement and 1X22kV indoor bus section bays with single busbar arrangement).	1382
3	**Construction of Colombo M GS 220/22kV GS**(2x90MVA, 220/22kV indoor transformers,2x220kV indoor single busbar transformer bays, 2x22kV indoor single busbar transformer bays, 12x 22kV indoor cable bays ,2x 220kV single busbar indoor cable bays,1x 220kV indoor bus section bay with single busbar arrangement and 1X22kV indoor bus section bays with single busbar arrangement).	1382
4	**Construction of Colombo B GS 132/11kV GS**(2x45MVA, 132/11kV indoor transformers,2x132kV indoor single busbar transformer bays, 2x11kV indoor single busbar transformer bays, 16x 11kV indoor cable bays ,2x 132kV single busbar indoor cable bays,1x 132kV indoor bus section bay with single busbar arrangement and 1X11kV indoor bus section bays with single busbar arrangement).	1077
5	**Construction of Colombo O GS 220/22kV GS**(2x90MVA, 220/22kV indoor transformers,2x220kV indoor single busbar transformer bays, 2x22kV indoor single busbar transformer bays, 12x 22kV indoor cable bays ,2x 220kV single busbar indoor cable bays,1x 220kV indoor bus section bay with single busbar arrangement and 1X22kV indoor bus section bays with single busbar arrangement).	1077
6	Construction of 220kV, Cu (XLPE) 1200mm^2, 12km cable between Kerawalapitiya and Port GS.	2400
7	Construction of 220kV, Cu (XLPE) 1200 mm^2, 5 km cable between Port and Colombo M GS	1000
8	Construction of 220kV, Cu (XLPE) 1200 mm^2, 1 km cable between Colombo M and Colombo N GS	200
9	Construction of 220kV, Cu (XLPE) 1200mm^2, 18km cable between Colombo N and Pannipitiya GS.	3600

10	Construction of 132kV, Cu (XLPE) 800mm^2, 2 km cable between Colombo B and Colombo C GS	2700
11	Construction of 132kV, Cu (XLPE) 800mm^2,12 km cable between Colombo B and Kolonnawa GS	1800
	Grid Augmentations	
12	Installation of 31.5MVA Transformer with 6 feeder bays at Kolonnawa GS	280
13	Installation of 31.5MVA Transformer with 6 feeder bays at Colombo A GS	280
14	Installation of 31.5MVA Transformer with 6 feeder bays at Colombo C GS	280
15	Installation of 31.5MVA Transformer with 6 feeder bays at Colombo I GS	280
16	Kelenitissa 132/33 150 MVA Interbus Transformer	145
	Total Cost	**19343**

The total base cost for 132 kV solution = 20,345 Million LKR

The total base cost for 220 kV solution = 19,343 Million LKR

Benefit of implementing 220 kV solution = 1002 Million LKR

6.2. Economic Analysis

Economic Analysis was done to evaluate the loss savings by implementing 220 kV solution.

Benefit from Loss saving of 220 kV solution for 15 years = 105 Million LKR

The Discount Rate is taken as 10%. Detailed analysis is shown in appendix D.

7. CONCLUSION & RECOMMENDATION

Colombo City is currently fed through five numbers of 132/11 kV GIS type GSs. According to the UDA Colombo City Development Plan 2020, Colombo City is divided into 9 zones based on its uses as discussed in Chapter 3. When we analyze the development plan, the developments in "Concentrated Development Zone" and "Port Related Activity Zone" are the priority up to 2020. Most of the major projects that were discussed in section 3.2 and most of the spot loads shown in Appendix A are constructed in above two zones. The existing Colombo City Transmission Network cannot cater to the demand increase due to above projects. Therefore this dissertation discusses about optimum, economically viable and cost effective Transmission Network Solution for Colombo City in 2021.

In Chapter 5, whole Sri Lankan power system has been modeled using the PSS®E software and Existing Network was simulated using this model. As per the simulation existing SUB A, SUB C, SUB E, SUB F, SUB I and Kolonnawa get overloaded. Therefore existing 132 kV network was developed as option 1 and new 220/22 kV ring was developed as option 2 to overcome above problem in 2021. Finally in Chapter 5 and Chapter 6 the proposed two options were analyzed.

In 132 kV solution (Option 1) 132/11 kV 45 MVA transformers were used where in 220 kV solution (Option 2) 220/22 kV 90 MVA transformers were used. To keep the distribution side fault level below 25 kA need to use 220/22 kV transformers. Therefore, in developing option 2, the distribution network has to be developed in 22 kV. The optimum distribution voltage level that can be used is 22 kV but the study is open to propose most economical and cost effective distribution voltage level because 33 kV is the commonly used distribution voltage level.

Cost saving of 1102 Million LKR can be achieved by developing the 220 kV solution i.e. option 2 as per the cost analysis done in section 6.1. 105 Million LKR loss saving for 15 years can also be obtained.

The developments in other seven zones will be started beyond 2020 and 220 kV solution can be developed to cater that demand increase with lesser number of substations than the132 kV solution.

Finally it is recommended to develop 220 kV transmission network to cater to the demand increase in 2020 and beyond. Further the proposed 220 kV solution has to be revised according to the UDA Colombo City Development Plan beyond 2020.

Reference list

[1] Ceylon Electricity Board, "Long Term Transmission Development Plan 2011-2020", July 2011, pp 5-7.

[2] Siemens Energy Inc., "PSS®E 32.0 Program Operation Manual", Siemens Power Technologies International, New York, USA, 2009.

[3] Ceylon Electricity Board, "Statistical Digest 2013".

[4] Urban Development Authority "City of Colombo Development Plan 2020".

[5] ABB Ltd., "XLPE Land Cable Systems User's Guide – Rev 5", pp 11-12.

Appendix A: Spot Loads Considered to Develop Final Load Forecast

	project / Developer	Location	Zone	GS	Required Capacity (MVA)	2013	2014	2015	2016	2017	2018	2019	2020	2021
1	Colombo South Harbour/Sri Lanka Ports Authority	Chathiya Road, Colombo 01	Col - 01	F	40				20	20	20	20	40	40
2	Colombo International container Terminals Ltd./ Sri Lanka Ports	Chathiya Road, Colombo 01	Col - 01	F	43	12	12	12	30	30	30	30	30	30
				F		12	12	12	13	13	13	13	13	13
3	Shangrila	Galle face Green Project	Col - 01	F	19			12	14	19	19	19	19	19
4	GF 2nd Development	Galle face Green Project	Col - 01	F	12				3	7	12	12	12	12
	GF 3nd Development	Galle face Green Project	Col - 01	F	9				3	4	9	9	9	9
5	John Keells Holdings	Glennie Street	Col - 02	F	32				20.5	20.5	20.5	20.5	20.5	20.5
6	reagal Theatre Premises/UDA	Sir Chittampalam A Gardined Mw.	Col - 02	F	2.5			2.5	2.5	2.5	2.5	2.5	2.5	2.5
7	Nawaloka Hospital/UDA Colombo Residential	Plot 1 Colombo Commercial Land	Col - 02	F	4.5			2	3	4.5	4.5	4.5	4.5	4.5
		Plot 2Colombo Commercial Land		F	7.5			7.5	7.5	7.5	7.5	7.5	7.5	7.5
8	TATA Development	Colombo 02	Col - 02	F	10				10	10	10	10	10	10
	Ceyexxe Limited/UDA	Kew Road	Col - 02	F	4.5			2	3	4.5	4.5	4.5	4.5	4.5
9	Sri Lanka Tourism Development	Sir Chittampalam A Gardined Mw.	Col - 02	F	4				4	4	4	4	4	4
10	Cargills (Ceylon)Ltd/UDA	York Street	Col - 01	F	2				2	2	2	2	2	2
	Indocean Developers (Pvt)/UDA	No.127, Sir James Peris Mawatha	Col - 02	F	8				3	5	7.5	7.5	7.5	8
11	PAC Australia Pvt. Ltd.	Colombo 02	Col - 02	F	15			4	8	15	15	15	15	15

	project / Developer	Location	Zone	GS	Required Capacity (MVA)	2013	2014	2015	2016	2017	2018	2019	2020	2021
12	Mixed Development/UDA	Pettah	Col - 11	F	10			10	10	10	10	10	10	10
	Imperial Builders	Colombo 02	Col -02	F	10				10	10	10	10	10	10
13	Krrish Development	Chatham Street		F	45				15	30	45	45	45	45
14	Port City	Fort		F	200						50	50	100	100
	CWE Co-operative & Internal Trade	Colombo 12	Col - 12	F	4			4	4	4	4	4	4	4
15	South East Asia Construction	Chatham Street		F	2			2	2	2	2	2	2	2
					484	**24**	**24**	**70**	**187.5**	**224.5**	**302**	**302**	**372**	**372.5**
16	Softlogic Holding Ltd,/UDA	Dharmapala MW	Col - 02	E	3		3	3	3	3	3	3	3	3
17	Ready Wear Industries	Morgan Rd.,	Col - 03	E	2			2	2	2	2	2	2	2
18	Star City Hotel	Ananda Kumaraswamy Mw	Col - 03	E	1.5				1.5	1.5	1.5	1.5	1.5	1.5
19	Sri Lanka Tourism Development	213,215 Galle Road, Kollupitiya	Col - 03	E	1.5			1.5	1.5	1.5	1.5	1.5	1.5	1.5
20	Premier Pacific	Kollupitiya	Col - 03	E	2		2	2	2	2	2	2	2	2
21	Access Realities Tower 02	Vauxhall Street	Col - 02	E	2.5		2	2	2.5	2.5	2.5	2.5	2.5	2.5
22	John Keells Holdings	Union Place	Col - 02	E	3.7		2.5	3	3.7	3.7	3.7	3.7	3.7	3.7
23	Hygett Regency	Kollupitiya	Col - 03	E	4		2.5	3	3.5	4	4	4	4	4
24	Damro Industries	Kollupitiya	Col - 04	E	3			3	3	3	3	3	3	3
25	Abans Investments	Colombo 02	Col -02	E	10				7.5	10	10	10	10	10
26	Liberty Towers	Kollupitiya	Col - 03	E	8					5	6	7.5	8	8
					41.2	**0**	**12**	**19.5**	**30.2**	**38.2**	**39.2**	**40.7**	**41.2**	**41.2**
27	Orion City	Dr. Danister De silva Mw.	Col - 09	C	9	1	2	3	5	9	9	9	9	9

	project / Developer	Location	Zone	GS	Required Capacity (MVA)	2013	2014	2015	2016	2017	2018	2019	2020	2021
28	Urban Development Authority	Panchikawatta Triangle Development Project	Col - 10	C	40				20	20	40	40	40	40
29	Gold Centre	Abdul Cadher Mawatha		C	3			3	3	3	3	3	3	3
					52	**1**	**2**	**6**	**28**	**32**	**52**	**52**	**52**	**52**
30	Mireka Capital Land/UDA	Havelock City Project	Col - 06	A	6				6	6	6	6	6	6
31	UDA	DS office, Narahenpita	Col - 05	A	1.8	0.5	0.5	1.25	1.25	1.25	1.8	1.8	1.8	1.8
32	Army Hospital	Narahenpita	Col - 08	A	1.5		1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
33	Russian Embassy	Borella	Col - 03	A	1.5		1.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5
34	Asiri Surgical	Narahenpita	Col - 05	A	1.5		1	1.5	1.5	1.5	1.5	1.5	1.5	1.5
35	Hotel @ Charlemont Road	Wellawatta	Col - 06	A	2			1	2	2	2	2	2	2
					14.3	**0.5**	**4.4**	**6.75**	**13.75**	**13.75**	**14.3**	**14.3**	**14.3**	**14.3**
36	Telecommunications Regulatory (Lotus Tower)	DR Wijewardana Mawatha	Col - 10	I	3		1	2	3	3	3	3	3	3
37	Epilepsy Hospital & Health	Hospital Square	Col - 10	I	2		2	2	2	2	2	2	2	2
38	Tripoli Market Square De. Project	DR Wijewardana Mawatha	Col - 10	I	8			8	8	8	8	8	8	8
39	Urban Development Authority	Railway Land	Col - 10	I	10						10	10	10	10
40	Urban Development Authority	Railway Land	Col - 10	I	12				12	12	12	12	12	12
41	Urban Development Authority	Govt, Stores Land Developments	Col - 10	I	25				25	25	25	25	25	25
42	Urban Development Authority	UDA Office Premises Development	Col - 10	I	7				7	7	7	7	7	7
43	House of Fashions	House of Fashions	Col-08	I	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4

	project / Developer	Location	Zone	GS	Required Capacity (MVA)	2013	2014	2015	2016	2017	2018	2019	2020	2021
44	Lakeside Property Developers	Darley Road	Col - 10	I	1.4		1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
45	Dialog	Colombo 09	Col - 09	I	2		2	2	2	2	2	2	2	2
					71.8	**1.4**	**7.8**	**16.8**	**61.8**	**61.8**	**71.8**	**71.8**	**71.8**	**71.8**
	TOTAL				**663.3**	**26.9**	**50.2**	**119.05**	**321.25**	**370.25**	**479.3**	**480.8**	**551.3**	**551.8**

Appendix B: Proposed 132 kV Solution in 2021 (Option 1)

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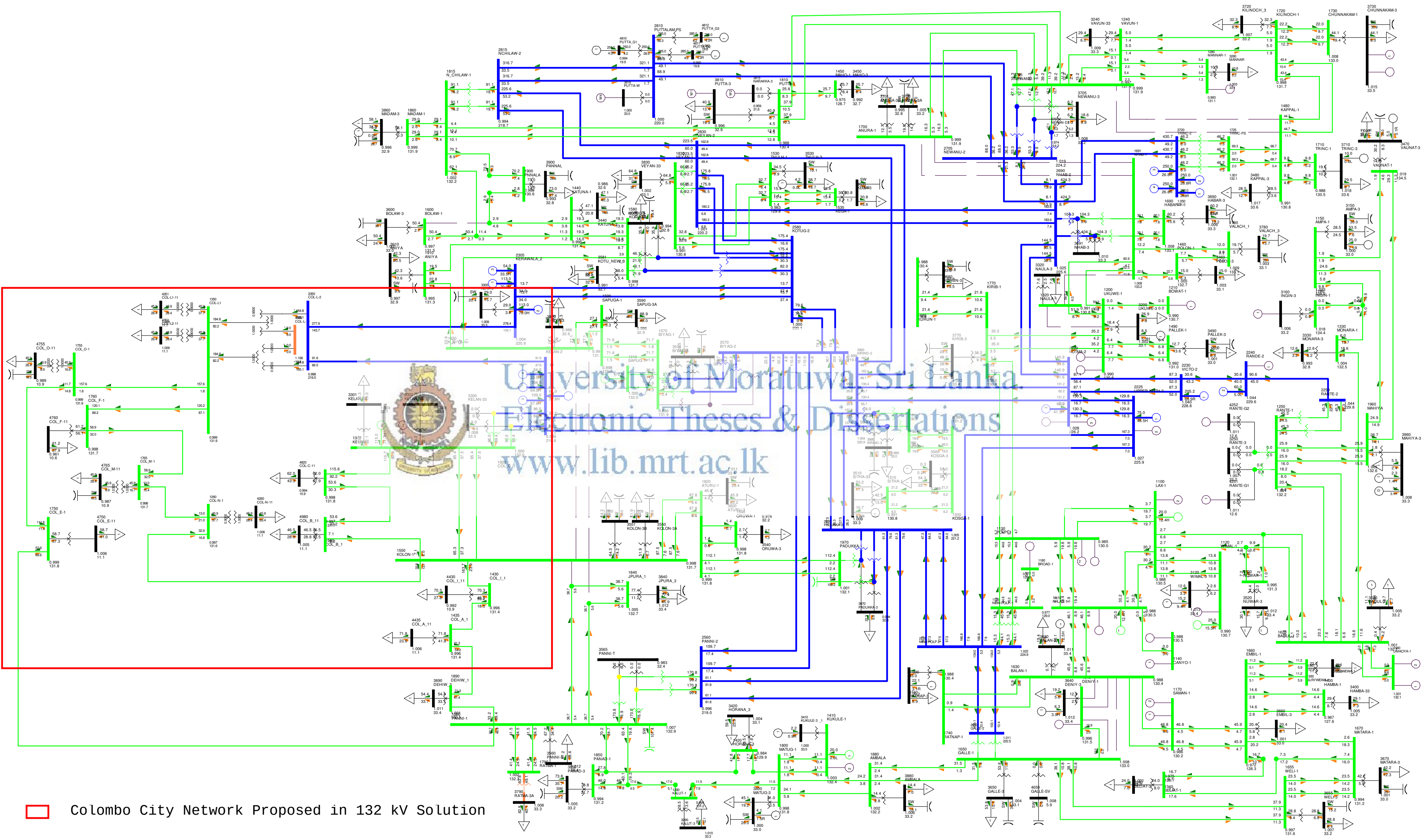

Colombo City Network Proposed in 132 kV Solution

Annex C-15: Year 2020 Sri Lanka Transmission Network - Minimum Loading Condition

Appendix C: Proposed 220 kV Solution in 2021 (Option 2)

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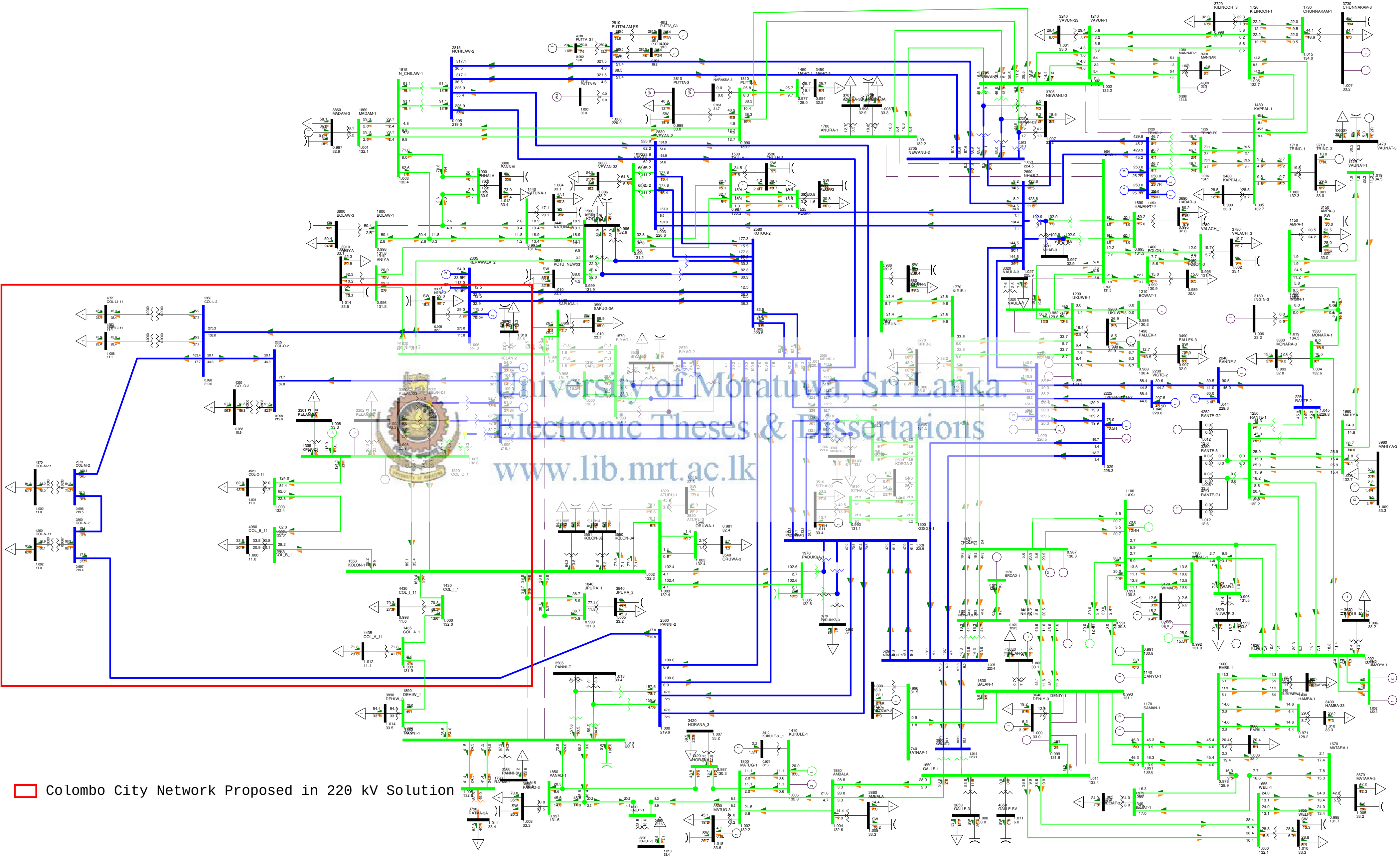

Annex C-15: Year 2020 Sri Lanka Transmission Network - Minimum Loading Condition

Appendix D: Loss Saving Calculation

Day Peak Saving	=	0.31 MW
Loss Load Factor	=	0.432
Cost Difference in two options	=	1002 Million LKR
Assume,		
Generation Cost	=	13 LKR/kWh
Energy Saving	=	(Day Peak Saving)×LLF×24×365×1000
	=	1,173,139.2 kWh
Discount Rate	=	10%
Cost Saving	=	15.3 Million LKR

All costs are in Million LKR

Year	Cost	Benefit	Cost-Benefit	PV cost	PV Benefit
0			0.00	0	
1		15.3	15.25		13.86
2		15.3	15.25		12.60
3		15.3	15.25		11.46
4		15.3	15.25		10.42
5		15.3	15.25		9.47
6		15.3	15.25		8.61
7		15.3	15.25		7.83
8		15.3	15.25		7.11
9		15.3	15.25		6.47
10		15.3	15.25		5.88
11		15.3	15.25		5.35
12		15.3	15.25		4.86
13		15.3	15.25		4.42
14		15.3	15.25		4.02
15		15.3	15.25		3.65
				Total	**116.00**

Net Present Value (NPV) = 105 Million LKR

Appendix E: Current Carrying Capacity Calculation of XLPE UG Cables

Sample Calculation

One group of 245 kV 1200 mm^2 XLPE cable with copper conductors in the ground in flat formation. Metal screens are cross bonded 90 ^{0}C conductor temperature and ducted.

		Table	Rating Factor
Current Rating at 65 ^{0}C	1115 A	4	
Laying Depth	1.2 m	7	0.98
Ground Temperature	30 ^{0}C	8	0.88
Ground Thermal Resistivity	1.0 km/W	9	1.00
Phase Spacing	380 mm	10	1.09
Ducted Cables in ground		12	0.9

Adjusted Current Rating = 1115×0.98×0.88×1.00×1.09×0.9

= 943 A

Adjusted Current Carrying Capacity = sqrt(3)×245×943.31

= 400 MVA

Description		Unit	Used XLPE UG Cable Types						
Maximum Operating Voltage		kV	245			145			
Cross Section Area of Conductor		mm^2	1200	1000	800	1200	1000	800	500
Current Rating at 65 ^{0}C		A	1115	960	870	1115	960	870	685
Correction Factors	Laying Depth		0.98	0.98	0.98	0.98	0.98	0.98	0.98
	Ground Temperature		0.88	0.88	0.88	0.88	0.88	0.88	0.88
	Ground Thermal Resistivity		1	1	1	1	1	1	1
	Phase Spacing		1.09	1.09	1.09	1.09	1.08	1.08	1.08
	Ducted Cables in Ground		0.9	0.9	0.9	0.9	0.9	0.9	0.9
Adjusted Current Rating		A	943.31	812.17	736.03	943.31	804.72	729.28	574.20
Adjusted Current Carrying Capacity		**MVA**	**400.29**	**344.65**	**312.34**	**236.91**	**202.10**	**183.16**	**144.21**

Appendix F: UG XLPE Cable Datasheet

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XLPE Land Cable Systems
User´s Guide

Rev 5

Power and productivity
for a better world™

ABB

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To make sure you have the latest version of this brochure, have a look at www.abb.com/cables

INTRODUCTION

Interfaces you can trust
ABB manufactures land and submarine power cables up to the highest voltages available.

Furthermore, we produce associated joints, terminations and other accessories for all types of cables. The products are designed to work together as a cable system.

Experience you can rely on
We have extensive experience of cable projects all over the world, encompassing every aspect from planning to commissioning, including engineering, route surveys, cable-laying, installation and final testing. Very few manufacturers can point to such a long tradition in the high voltage field as ABB. We delivered our first electrical cable in 1883 and introduced triple-extruded XLPE cables around 1970. In the early 1970s we started to supply cables for over 100 kV and our first 245 kV XLPE cable was put into service in 1978. ABB has since then supplied more than 8,800 km of XLPE cables above 100 kV. Experience you can rely on.

Research and development
ABB has always been a pioneer in the high voltage field and we have many world's first and world records among our references. But there are no shortcuts to success. Maintaining our position calls for innovative research and development, backed up by the wealth of know-how we have accumulated over the years. One of the driving forces for our R&D is to meet the new and constantly increasing requirements from the power industry and a deregulated market. Today we aim to develop the solutions our customers will need tomorrow.

State-of-the-art manufacturing lines
Experience and state-of-the-art expertise go hand in hand for us. We have been manufacturing cables for over 125 years and have since the beginning been one of the leading producers. Our manufacturing plants are among the most modern in the world and our advanced quality system leaves nothing to chance. Every cubic millimeter of the cable has to be perfect. We design and produce cables in accordance with international and national standards or/and according to our customers' specifications.

This guide presents XLPE cables and systems for land applications mainly.

DESIGN, INSTALLATION AND TESTING

XLPE cables

XLPE cables consist of the following components:
- Conductor
  - Copper (Cu) or Aluminium (Al) stranded compacted conductor or
  - Cu segmental conductor or
  - Cu or Al conductor with key-stone shaped profiles
  - Longitudinal water sealing of conductor
- Triple extruded and dry cured XLPE insulation system
- Metallic screen
  - Copper wire screen
  - Copper tape screen
  - Radial water sealing
    - Metallic laminate solidly bonded to outer polyethylene sheath or
    - Lead sheath
  - Longitudinal water sealing of metallic screen
- Non-metallic outer sheath
  - PE
  - PVC
  - Halogen free flame retardant
  - Co-extruded conductive layer over the sheath for special sheath testing

Cable accessories

ABB's line-up of cable accessories for ABB XLPE cable systems includes:

- Straight joints and joints with integrated screen separation for cross bonding
- Transition joints for connection of XLPE to fluid-filled cables
- Outdoor terminations with porcelain or composite insulators
- Screened separable connectors for switchgears and transformers
- Cable terminations for transformers and Gas Insulated Switchgears (GIS)
- Link boxes for earthing and cross-bonding
- Distributed Temperature Sensing (DTS) Systems with integrated optical fibre in metallic tube (FIMT)

More information about our accessories is available on www.abb.com

DESIGN, INSTALLATION AND TESTING

Installation of XLPE cable systems

Installation of cable systems includes trenching, cable pulling, clamping of cable, cable splicing as well as mounting of accessories. High quality installation work performed by ABB certified field personnel is essential for achieving the low failure rates and reliability performance that is expected from modern underground transmission and distribution circuits.

ABB has long and extensive experience from different types of cable installations including direct burial, duct, shaft, trough, tunnel and submarine installations, but also trenchless technologies like directional drilling, pipe jacking and others.

Testing of XLPE cable systems

Standard routine tests, sample tests, type tests and after laying tests are normally performed according to IEC-standards. Other international or national standards may be followed upon agreement between contractor and purchaser.

Routine tests of XLPE cables and accessories
- PD measurement test
- High-voltage test of main insulation
- Electrical test of oversheath
- Visual inspection

Sample tests
Sample tests are carried out with a frequency according to applicable IEC standards.

- Conductor examination
- Electrical resistance of conductor
- Check of dimensions
- Capacitance test
- Hot set test
- Electrical tests

After laying tests
- DC voltage test of oversheath
- AC voltage test of main insulation

XLPE CABLE AND CABLE SYSTEM STANDARDS

ABB´s XLPE cable systems are designed to meet requirements in international and/or national standards. Some of these are listed below.

IEC

XLPE cable systems specified according to IEC (International Electrotechnical Commission) are among many other standards accepted. IEC standards are considered to express an international consensus of opinion.

Some frequently used standards are:

IEC 60228
Conductors of insulated cables.

IEC 60287
Electric cables - Calculation of the current rating.

IEC 60332
Tests on electric cables under fire conditions.

IEC 60502
Power cables with extruded insulation and their accessories for rated voltage from 1 kV (Um=1,2 kV) up to 30 kV (Um=36 kV).

IEC 60840
Power cables with extruded insulation and their accessories for rated voltage above 30 kV (Um=36 kV) up to 150 kV (Um=170 kV). Test methods and requirements.

IEC 60853
Calculation of the cyclic and emergency current rating of cables.

IEC 61443
Short-circuit temperature limits of electric cables with rated voltages above 30 kV (Um=36 kV).

IEC 62067
Power cables with extruded insulation and their accessories for rated voltage above 150 kV (Um=170 kV) up to 500 kV (Um=550 kV). Test methods and requirements.

CENELEC

In Europe, cable standards are issued by CENELEC. (European Committee for Electrotechnical Standardization.) They are as a rule implementations of the IEC specifications. Special features in design may occur depending on national conditions.

HD 620
Distribution cables with extruded insulation for rated voltages from 3.6/6 (7.2) kV up to and including 20.8/36 (42) kV.

HD 632
Power cables with extruded insulation and their accessories for rated voltage above 36 kV (Um=42 kV) up to 150 kV (Um=170 kV). Part 1- General test requirements.
Part 1 is based on IEC 60840, and follows that standard closely.
HD 632 is completed with a number of parts and subsections for different cables intended to be used under special conditions which can vary nationally in Europe.

ICEA

For North America cables are often specified according to ICEA (Insulated Cable Engineers Association, Inc.).

S-97-682
Standard for utility shielded power cables rated 5-46 kV.

S-108-720
Standard for extruded insulated power cables rated above 46 through 345 kV.

ISO Standards

ABB has well-developed systems for quality and environmental management which put the needs and wishes of the customer first. Our systems comply with the requirements of ISO 9001 and ISO 14001 and are certified by Bureau Veritas Quality International.

ISO 14001 and ISO 9001
Certificate of Approval

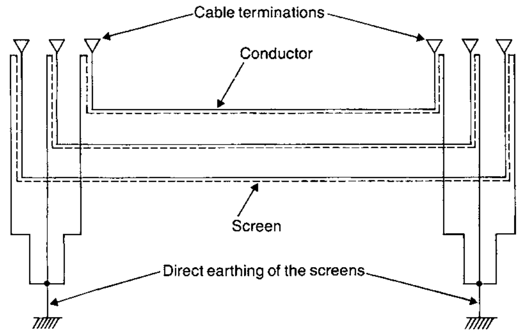
XLPE LAND CABLE SYSTEM CONFIGURATIONS

Trefoil and flat formation

The three cables in a 3-phase circuit can be placed in different formations. Typical formations include trefoil (triangular) and flat formations. The choice depends on several factors like screen bonding method, conductor area and available space for installation.

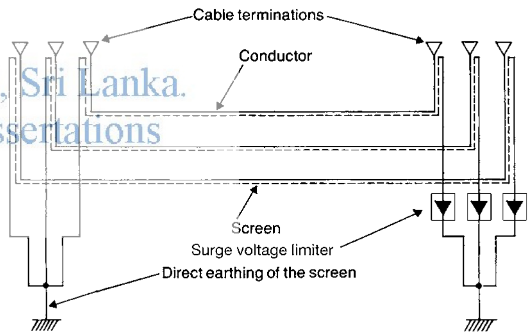
Bonding of the metallic screens

The electric power losses in a cable circuit are dependent on the currents flowing in the metallic sheaths of the cables. Therefore, by reducing or eliminating the metallic sheath currents through different methods of bonding, it is possible to incresase the load current carrying capacity (ampacity) of the cable circuit. The usual bonding methods are described below:



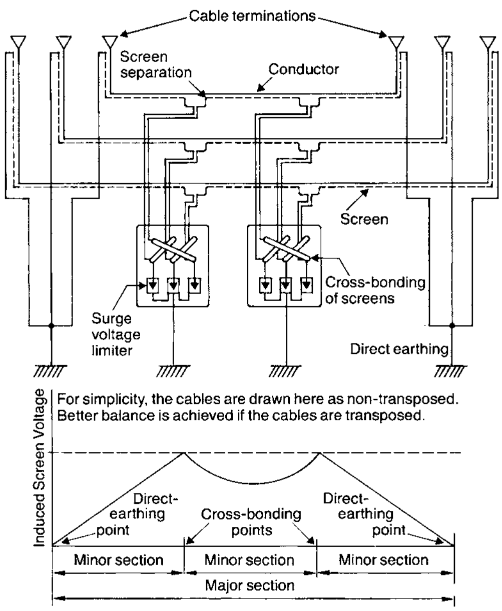
Both-ends bonding

A system is both ends bonded if the arrangements are such that the cable sheaths provide path for circulating currents at normal conditions. This will cause losses in the screen, which reduce the cable current carrying capacity. These losses are smaller for cables in trefoil formation than in flat formation with separation.



Single-point bonding

A system is single point bonded if the arrangements are such that the cable sheaths provide no path for the flow of circulating currents or external fault currents. In such case, a voltage will be induced between screens of adjacent phases of the cable circuit and between screen and earth, but no current will flow. This induced voltage is proportional to the cable length and current. Single-point bonding can only be used for limited route lengths, but in general the accepted screen voltage potential limits the length.



Cross-bonding

A system is cross-bonded if the arrangements are such that the circuit provides electrically continuous sheath runs from earthed termination to earthed termination but with the sheaths so sectionalized and cross-connected in order to eliminate the sheath circulating currents. In such case, a voltage will be induced between screen and earth, but no significant current will flow. The maximum induced voltage will appear at the link boxes for cross-bonding. This method permits a cable current-carrying capacity as high as with single-point bonding but longer route lengths than the latter. It requires screen separation and additional link boxes.

CURRENT RATING FOR XLPE LAND CABLE SYSTEMS

The XLPE cable should at least have a conductor cross section area adequate to meet the system requirements for power transmission capacity. The cost of energy losses can be reduced by using larger conductor.

Load losses in XLPE cables are primarily due to the ohmic losses in the conductor and the metallic screen. XLPE cables can be loaded continuously to a conductor temperature of 90°C.

The dielectric losses in the XLPE insulation system are present also at no load current and depend primarily on the magnitude of the operating voltage.

Dielectric losses in XLPE cables are lower than for EPR and fluid-filled cables.

Continuous current ratings for single-core cables are given in tables 1-4. The continuous current ratings are calculated according to IEC 60287 series of standards and with the following conditions:

- One three-phase group of single-core cables
- Ground temperature 20°C
- Ambient air temperature 35°C
- Laying depth L 1.0 m
- Distance “s” between cable axes laid in flat formation 70 mm + D_e
- Ground thermal resistivity 1.0 Km/W

Rating factors for single-core cables are given in Tables 5-13.

CURRENT RATING FOR XLPE LAND CABLE SYSTEMS

Current rating for single-core cables, ampères

Table 1

Rated voltage 45-66 kV, aluminium conductor – 35 mm² screen																
Cross section con-ductor	Cables in Ground								Cables in Air							
	Flat formation ●●●				Trefoil formation				Flat formation ●●●				Trefoil formation			
	Cross bonded		Both ends		Cross bonded		Both ends		Cross bonded		Both ends		Cross bonded		Both ends	
mm²	65°C	90°C	65°C	90°C	65°C	90°C	65°C	90°C	65°C	90°C	65°C	90°C	65°C	90°C	65°C	90°C
95	220	265	215	260	210	250	210	250	230	310	225	305	200	270	200	270
120	250	300	245	295	235	285	240	285	265	355	260	350	230	310	230	315
150	280	335	270	325	265	320	265	320	305	410	290	395	260	355	260	355
185	320	380	300	365	300	360	300	360	350	470	330	445	300	405	300	405
240	370	445	345	420	350	420	350	420	410	555	380	520	355	480	350	480
300	420	500	385	465	395	475	390	470	475	640	430	590	405	550	400	550
400	480	575	430	520	455	545	445	540	555	745	490	675	470	645	465	635
500	550	660	480	585	520	620	505	610	645	870	555	765	550	750	540	735
630	630	755	530	650	590	710	570	690	750	1020	630	870	635	870	620	850
800	710	855	580	710	665	805	640	775	870	1180	700	975	730	1005	705	975
1000	795	960	625	775	740	895	700	855	995	1350	770	1080	830	1140	795	1100
1200	860	1040	660	815	795	965	750	915	1095	1490	820	1155	905	1245	855	1190
1400	920	1115	685	855	845	1030	790	965	1190	1620	870	1225	975	1345	915	1275
1600	970	1175	710	885	890	1080	820	1005	1265	1730	905	1285	1030	1425	965	1350
2000	1060	1285	745	930	960	1170	875	1075	1410	1930	965	1380	1135	1575	1050	1470

Table 2

Rated voltage 45-66 kV, copper conductor – 35 mm² screen									Segmental conductor for 1200 mm² or higher							
Cross section con-ductor	Cables in Ground								Cables in Air							
	Flat formation ●●●				Trefoil formation				Flat formation ●●●				Trefoil formation			
	Cross bonded		Both ends		Cross bonded		Both ends		Cross bonded		Both ends		Cross bonded		Both ends	
mm²	65°C	90°C	65°C	90°C	65°C	90°C	65°C	90°C	65°C	90°C	65°C	90°C	65°C	90°C	65°C	90°C
95	285	340	275	330	270	320	270	325	295	400	285	390	255	350	255	350
120	325	380	310	370	305	365	305	365	340	460	325	440	295	400	295	400
150	360	435	340	410	345	410	340	410	390	525	360	495	335	455	335	455
185	410	490	375	455	385	465	385	460	445	600	405	555	385	520	380	520
240	475	570	425	515	450	540	440	530	525	710	465	640	450	615	445	610
300	535	645	465	570	505	610	495	600	605	820	520	720	515	705	505	695
400	610	735	515	630	575	690	560	675	705	955	585	815	595	815	580	800
500	695	835	565	695	650	785	625	760	815	1105	655	910	690	945	665	915
630	790	950	615	760	735	885	695	845	945	1285	725	1015	790	1085	755	1045
800	885	1070	660	820	815	990	765	930	1080	1470	795	1120	895	1230	845	1175
1000	975	1180	700	870	890	1080	820	1005	1215	1660	855	1215	995	1375	930	1295
1200	1130	1365	755	945	1060	1280	930	1145	1450	1965	955	1360	1215	1670	1090	1520
1400	1220	1475	785	985	1140	1380	980	1210	1590	2160	1010	1440	1325	1825	1170	1640
1600	1300	1570	810	1015	1205	1465	1025	1265	1720	2340	1055	1510	1420	1960	1240	1740
2000	1425	1730	840	1060	1315	1600	1085	1345	1915	2620	1110	1595	1570	2175	1335	1885

CURRENT RATING FOR XLPE LAND CABLE SYSTEMS

Table 3

Rated voltage 110-500 kV, aluminium conductor – 95 mm² screen																
Cross section con-ductor	Cables in Ground								Cables in Air							
	Flat formation ●●●				Trefoil formation				Flat formation ●●●				Trefoil formation			
	Cross bonded		Both ends		Cross bonded		Both ends		Cross bonded		Both ends		Cross bonded		Both ends	
mm²	65°C	90°C	65°C	90°C	65°C	90°C	65°C	90°C	65°C	90°C	65°C	90°C	65°C	90°C	65°C	90°C
300	415	495	365	445	395	475	385	460	465	625	415	565	410	550	400	540
400	470	565	410	500	450	540	435	525	535	715	470	640	475	640	460	625
500	540	645	455	555	515	620	490	595	620	835	530	725	550	745	530	720
630	620	740	500	610	590	710	550	670	730	975	595	820	640	865	605	830
800	700	845	540	665	670	805	610	745	840	1130	660	910	735	995	685	940
1000	785	950	585	720	745	900	670	820	960	1295	720	1005	830	1135	765	1055
1200	850	1025	610	755	805	970	710	870	1055	1420	765	1070	905	1235	825	1140
1400	910	1100	635	785	855	1040	745	915	1140	1545	805	1125	975	1335	880	1220
1600	960	1165	655	815	900	1095	775	955	1220	1650	835	1170	1035	1420	925	1285
2000	1050	1275	685	855	975	1190	820	1015	1355	1840	885	1250	1140	1570	1000	1395

Table 4

Rated voltage 110-500 kV, copper conductor – 95 mm² screen. Segmental conductor for 1200 mm² or higher																
Cross section con-ductor	Cables in Ground								Cables in Air							
	Flat formation ●●●				Trefoil formation				Flat formation ●●●				Trefoil formation			
	Cross bonded		Both ends		Cross bonded		Both ends		Cross bonded		Both ends		Cross bonded		Both ends	
mm²	65°C	90°C	65°C	90°C	65°C	90°C	65°C	90°C	65°C	90°C	65°C	90°C	65°C	90°C	65°C	90°C
300	530	640	440	535	505	610	480	580	600	805	500	685	525	710	500	685
400	600	720	485	595	575	690	540	650	680	915	565	775	605	820	575	785
500	685	825	530	650	655	785	600	730	790	1060	625	860	695	945	650	895
630	780	940	570	705	740	890	660	810	915	1235	685	950	800	1085	735	1010
800	870	1055	610	755	825	995	720	885	1045	1415	745	1040	905	1235	815	1130
1000	960	1165	645	800	900	1095	770	950	1175	1590	800	1125	1005	1380	895	1245
1200	1115	1345	690	860	1060	1280	855	1055	1395	1880	880	1240	1210	1650	1025	1425
1400	1205	1455	715	890	1145	1385	895	1110	1530	2065	920	1300	1320	1800	1090	1525
1600	1280	1550	735	920	1215	1470	930	1155	1655	2235	960	1355	1420	1940	1150	1615
2000	1410	1705	765	955	1320	1605	980	1220	1845	2500	1000	1425	1565	2145	1230	1740
2500	1540	1875	795	1000	1445	1755	1025	1285	2095	2845	1065	1515	1750	2410	1330	1890

CURRENT RATING FOR XLPE LAND CABLE SYSTEMS

Rating factors

Rating factors for cross section area of the metal screen of single core cables.

The rating factor is applicable to single-core cables in flat and trefoil formation with the screens bonded at both ends.

The rating factor does not apply to single-point bonding or cross-bonded systems.

Table 5 **45-66 kV 35 mm² screen**

Rating factor for tables 1 and 2							
Conductor mm²							
Al	Cu	35	50	95	150	240	300
300		1	0.99	0.98	0.97	0.96	0.95
500	300	1	0.99	0.97	0.95	0.93	0.93
800	500	1	0.99	0.96	0.93	0.90	0.90
1200	630	1	0.99	0.95	0.92	0.89	0.88
2000	800	1	0.98	0.94	0.91	0.87	0.86
	1200	1	0.97	0.91	0.85	0.81	0.80
	2000	1	0.96	0.88	0.82	0.77	0.76

Table 6 **110-500 kV 95 mm² screen**

Rating factor for tables 3 and 4						
Conductor mm²						
Al	Cu	50	95	150	240	300
300		1.01	1	0.99	0.98	0.97
500	300	1.02	1	0.98	0.96	0.96
800	500	1.03	1	0.97	0.94	0.94
1200	630	1.04	1	0.97	0.93	0.92
2000	800	1.04	1	0.96	0.92	0.91
	1200	1.07	1	0.94	0.89	0.88
	2000	1.09	1	0.93	0.87	0.86

1 mm² copper screen is equivalent to:
1.66 mm² aluminium sheath
12.40 mm² lead sheath

Rating factor for ground temperature

Table 7

Rating factor for laying depth	
Laying depth, m	Rating factor
0.50	1.10
0.70	1.05
0.90	1.01
1.00	1.00
1.20	0.98
1.50	0.95

Table 8

Rating factor for ground temperature								
Conductor temperature, °C	Ground temperature, °C							
	10	15	20	25	30	35	40	45
90	1.07	1.04	1	0.96	0.93	0.89	0.84	0.80
65	1.11	1.05	1	0.94	0.88	0.82	0.74	0.66

Table 9

Rating factor for ground thermal resistivity							
Thermal resistivity, Km/W	0.7	1.0	1.2	1.5	2.0	2.5	3.0
Rating factor	1.14	1.00	0.93	0.84	0.74	0.67	0.61

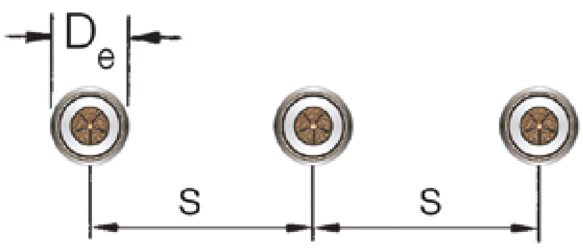


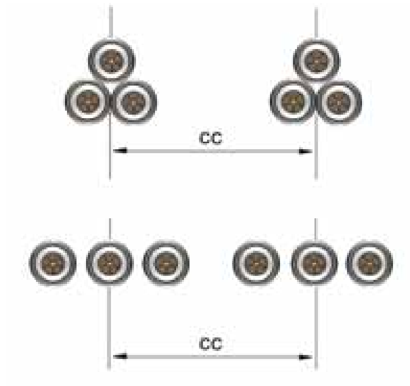
Table 10

Rating factor for phase spacing One group in flat formation with cross-bonded or single-bonded screens						
Spacing s, mm	D_e	D_e+70	250	300	350	400
Cable diam, mm	Rating factor					
<80	0.93	1.00	1.05	1.07	1.08	1.09
81-110	0.93	1.00	1.04	1.06	1.08	1.09
111-140	0.93	1.00	1.03	1.06	1.09	1.11

CURRENT RATING FOR XLPE LAND CABLE SYSTEMS

Table 11

Rating factor for groups of cables in the ground									
Distance cc between groups, mm	Number of groups								
	1	2	3	4	5	6	7	8	9
100	1	0.78	0.66	0.60	0.55	0.52	0.49	0.47	0.45
200	1	0.81	0.70	0.65	0.61	0.58	0.55	0.54	0.52
400	1	0.86	0.76	0.72	0.68	0.66	0.64	0.63	0.61
600	1	0.89	0.80	0.77	0.74	0.72	0.70	0.69	0.69
800	1	0.91	0.83	0.81	0.78	0.77	0.75	0.75	0.74
2000	1	0.96	0.93	0.92	0.91	0.91	0.90	0.90	0.90



Rating factor for cables installed in pipes in the ground

The rating factor given for single-core cables partially installed in separate pipes, applies only when a cable section between screen earthing points must be partially laid in pipes, under the following conditions:

- the cables are laid in trefoil formation over the major portion of the section
- the pipes are laid in flat formation
- the piped length is less than 10% of the section between earthing points
- one cable per pipe
- the pipe diameter is two times the cable diameter.

Table 12

Rating factor for cables in pipes in ground			
Single-core cables partially in-stalled in separate pipes ●●●	Single-core cables in separate pipes ●●●	Single-core cables in a common pipe	Three-core cable in a pipe
0.94	0.90	0.90	0.90

Rating factor for cables installed in air

Table 13

Rating factor for ambient air temperature											
Air temperature, °C	5	10	15	20	25	30	35	40	45	50	55
Rating factor	1.28	1.24	1.19	1.15	1.10	1.05	1.0	0.95	0.89	0.83	0.77

Example of the use of rating factors

2 groups of 66 kV XLPE cables with aluminium conductors 1 x 500/150 mm² in the ground in trefoil formation. Metal screens bonded at both ends, 90°C conductor temperature. Table 1 gives current rating 610 A, unadjusted value.

		Table	Rating factor
Current rating	610 A	1	-
Screen area	150 mm²	5	0.95
Laying depth	1.5 m	7	0.95
Ground temperature	30ºC	8	0.93
Ground thermal resistivity	1.5 Km/W	9	0.84
Distance between groups	400 mm	11	0.85 (2 groups)

Adjusted current rating per group;

610 x 0.95 x 0.95 x 0.93 x 0.84 x 0.85 = 365 A

Please note that use of rating factors gives good general indication during planning future circuits.
Once a circuit layout is defined, an accurate calculation should be performed to confirm the assumptions.

Overload capacity

An XLPE cable may be overloaded up to 105°C. Singular emergency events are not expected to have any significant impact on the service life of the cable. The number of and the duration of overloads should be kept low, though. Cyclic and emergency ratings can be calculated according to IEC publication 60853.

Short-circuit currents

During short circuit events the maximum allowable temperature in conductor or screen/metallic sheath is determined by the adjoining insulation and sheath materials. This is specified in IEC 61443 “Short circuit temperature limits of electric cables with rated voltage above 30 kV (Um=36 kV). The dynamic forces between the conductors must be taken into account for cable installations.

CURRENT RATING FOR XLPE LAND CABLE SYSTEMS

Maximum short circuit currents due to thermal restrictions
The thermal energy developed during a short-circuit is determined by the short-circuit magnitude and duration. For design purposes, an equivalent short-circuit current with a duration of 1 sec is used according to formula below. This formula is valid for a short-circuit duration of 0.2 to 5.0 sec.

$$I_{sh} = \frac{I_1}{\sqrt{t_{sh}}} \quad [kA]$$

I_{sh}= short-circuit current [kA] during time t_{sh}

I_1 = short-circuit current rating during 1 second. See the 1 second value in Table 14 for the conductor and in Table 15 for the metal screen.

t_{sh}= short-circuit duration (sec)

For XLPE insulated conductors the maximum allowable short circuit temperature is 250°C.

Table 14

Max. short-circuit current on the conductor during 1 s, kA				
	Conductor temperature before the short-circuit			
Cross section	Aluminium conductor		Copper conductor	
mm²	65°C	90°C	65°C	90°C
35	3.6	3.3	5.5	5.0
50	5.2	4.7	7.8	7.2
70	7.2	6.6	11.0	10.0
95	9.8	9.0	14.9	13.6
120	12.4	11.3	18.8	17.2
150	15.5	14.2	23.5	21.5
185	19.2	17.5	29.0	26.5
240	24.8	22.7	37.6	34.5
300	31.1	28.3	47.0	42.9
400	41.4	37.8	62.7	57.2
500	51.8	47.2	78.4	71.5
630	65.2	59.5	98.7	90.1
800	82.8	75.6	125	114
1000	104	94.5	157	143
1200	124	113	188	172
1400	145	132	219	200
1600	166	151	251	229
2000	207	189	313	286
per mm²	0.104	0.0945	0.157	0.143

Copper screens may reach a temperature of 250°C without damaging adjacent insulating material. With an initial temperature of 50°C this corresponds to a current density of 165 A/mm² during 1s (both higher and lower current densities may be allowed if other conditions apply).

Lead sheath temperatures of up to 210°C are permitted in connection with short circuit events. With an initial temperature of 50°C this corresponds to a current density of 28 A/mm² during 1 s.

Table 15

Max. short-circuit current on the screen during 1 s, kA			
Metallic screen cross section, mm²		Metallic screen temperature before the short-circuit	
Copper screen	Lead sheath	50°C	70°C
35	206	5.8	5.4
50	295	8.3	7.7
95	560	16	15
150	884	25	23
300	1763	50	46
per mm² Cu		0.165	0.153
	per mm² Pb	0.028	0.026

Dynamic forces during short circuit events

In addition to the thermal stresses, the dynamic forces in the cables and accessories during a short circuit event must also be considered.

The dynamic effect of parallel conductors carrying current is responsible for the dynamic force.

The dynamic force between two conductors, can be calculated as:

$$F = \frac{0.2}{S} \cdot I_{peak}^2 \quad [N/m]$$

Where; I_{peak} = 2.5 I_{sh} [kA]

I_{sh} = Short-circuit current [kA] RMS

S = Centre to centre spacing between conductors [m]

F = Maximum force [N/m]

CABLE DRUMS - TESTING - CABLE HANDLING

Selection of cable drum

Wooden drums/reels are standardized. For certain purposes steel drums/reels are applicable. Both wooden and steel-drums can be obtained for special purposes with other dimensions than stated below.

Table 16

Cable lenghts in meters on standard wooden drums and steel drums																			
Dia.	Wooden drum										Steel drum								
mm	K16	K18	K20	K22	K24	K26	K28	K30	K321-20	K321-22	St 30	St 32	St 34	St 35	St 36	St 37	St 38	St 39	St 40
36	762	856	1158	1560	2091														
38	638	826	1124	1353	1858	2576													
40	614	690	948	1158	1636	2300	3288												
42	501	662	877	1071	1516	2166	3277	4119											
44	480	539	721	1031	1315	1910	2816	3764	4468										
46	457	514	692	861	1265	1856	2521	3584	4302	3419									
48	360	488	662	824	1079	1616	2460	3246	3754	3277									
50	363	409	557	709	1089	1564	2179	2921	3690	2848	2897								
52	344	386	531	677	915	1342	1837	2752	3179	2718	2780	3522							
54	323	363	505	643	871	1292	1855	2450	3116	2660	2661	3376	4136						
56	261	366	478	610	827	1090	1796	2382	2645	2205	2274	2956	3683	4064					
58	244	275	389	511	722	1044	1553	2098	2584	2152	2166	2819	3517	3883	3789				
60	246	277	366	482	682	1052	1496	2120	2523	2097	2118	2760	3446	3806	3710	3581			
62	229	257	368	485	687	869	1274	1849	2169	1751	1771	2379	3031	3374	3266	3126	3233		
64		259	346	456	548	827	1284	1785	2112	1703	1728	2323	2963	3300	3191	3052	3156	3259	
66		239	348	370	552	833	1230	1536	2054	1653	1684	2266	2575	2894	3115	2977	3077	3178	3278
68		240	324	345	516	789	1028	1550	1733	1604	1639	1918	2511	2824	2705	2559	2647	2735	2822
70		185	251	347	519	674	1036	1489	1680	1301	1594	1867	2446	2752	2634	2490	2575	2660	2744
72		169	233	322	482	636	986	1261	1627	1258	1294	1814	2380	2380	2562	2419	2501	2583	2665
74			234	323	402	640	993	1271	1636	1263	1255	1761	2031	2313	2190	2043	2427	2184	2254
76			235	325	404	601	811	1213	1348	1219	1215	1456	1971	2244	2123	1979	2047	2115	2183
78			216	299	373	605	816	1223	1300	1175	1220	1463	1982	2259	2135	1988	2056	2124	2192
80			217	231	375	503	771	1015	1307	1180	1180	1416	1920	1920	2067	1924	1989	2054	2120
82			218	232	377	470	776	1022	1258	921	1140	1368	1607	1857	1733	1858	1921	1984	2047
84			199	212	276	473	660	969	1209	884	926	1374	1615	1868	1741	1594	1649	1704	1759
86			143	213	277	438	619	976	1215	887	892	1326	1559	1804	1680	1537	1589	1642	1695
88				214	279	441	623	844	969	849	895	1108	1567	1567	1688	1543	1596	1649	1701
90				214	280	443	627	796	973	852	861	1066	1510	1510	1625	1485	1535	1586	1636
92				194	253	356	585	801	931	814	826	1024	1232	1452	1329	1426	1474	1523	1571
94				194	254	328	589	753	935	817	829	1028	1238	1459	1335	1432	1480	1528	1577
96						330	485	757	892	778	794	985	1187	1400	1280	1144	1183	1223	1263
98						331	452	641	895	605	797	989	1193	1193	1285	1148	1187	1227	1267
100						333	455	645	899	606	617	994	1198	1198	1291	1152	1191	1231	1271
102						304	457	602	688	576	590	764	1147	1147	1235	1101	1139	1176	1214
104						305	421	606	690	578	592	767	954	1152	1029	1105	1142	1180	1218
106						306	423	609	654	547	564	731	910	1099	981	1053	1089	1125	1161
108									657	548					985	1057	1093	1128	1164
110										550					989	1060	1096	1132	1168
112										519					940	813	841	870	898
114										520					944	816	844	872	900
116										522					895	773	799	826	853
118																775	801	828	855
120																777	804	830	857
122																779	806	833	859
124																736	761	786	811
126																738	763	788	813
128																	765	790	815
130																	719	743	766
132																	721	745	768
134																		576	595
136																		577	596
138																			558
140																			559
142																			560

CABLE DRUMS - TESTING - CABLE HANDLING

Sizes and weights of wooden drums and steel drums

Table 17

		Wooden drums - drum type									
		K16	K18	K20	K22	K24	K26	K28	K30	K321-20	K321-22
Shipping volume	m³	2.86	3.58	5.12	6.15	7.36	10.56	13.88	17.15	23.55	23.55
Drumweight incl. battens	kg	275	320	485	565	625	1145	1460	1820	2000	2000
a Diameter incl. battens	mm	1675	1875	2075	2275	2475	2676	2876	3076	3276	3276
b Flange diameter	mm	1600	1800	2000	2200	2400	2600	2800	3000	3200	3200
c Barrel diameter	mm	950	1100	1300	1400	1400	1500	1500	1500	2000	2200
d Total width	mm	1018	1075	1188	1188	1200	1448	1650	1800	2300	2300
e Spindle hole diameter	mm	106	131	131	131	131	132	132	132	132	132
Max. load	kg	2500	3000	3500	4500	5000	10000	12000	13000	13000	13000

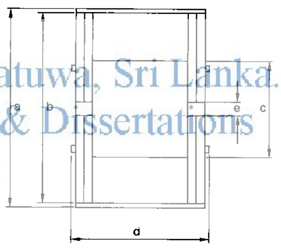
		Steel drums - drum type								
		St 30	St 32	St 34	St 35	St 36	St 37	St 38	St 39	St 40
Shipping volume	m³	23.5	26.6	28.9	31.6	33.4	35.2	37	38.9	40.9
Drumweight incl. battens	kg	1700	2200	2600	2700	2800	3000	3100	3300	3500
a Diameter incl. battens	mm	3130	3330	3530	3630	3730	3830	3930	4030	4130
b Flange diameter	mm	3000	3200	3400	3500	3600	3700	3800	3900	4000
c Barrel diameter*	mm	2000	2000	2000	2000	2200	2400	2500	2600	2700
d Total width	mm	2400	2400	2400	2400	2400	2400	2400	2400	2400
e Spindle hole diameter	mm	150	150	150	150	150	150	150	150	150
Max. load	kg	24000	24000	24000	24000	24000	24000	24000	24000	24000

* May vary depending on cable design

Large and special drums

Steel drums with larger outer diameters are available, but transport restrictions have to be considered. Special low-loading trailers and permits from traffic authorities might be needed depending on local regulations and conditions.

Special wooden drums with larger barrel diameter or larger width are also available.



a Diameter incl. battens
b Flange diameter
c Barrel diameter
d Total width
e Spindle hole diameter

Testing of XLPE cables

Table 18

Rated voltage and corresponding test voltages according to IEC				
	Type test	Routine tests		
Nominal voltage	Impulse voltage	AC voltage test		Partial discharge test at
kV	kV	kV	Duration minutes	kV
45	250	65	30	39
66	325	90	30	54
110	550	160	30	96
132	650	190	30	114
150	750	218	30	131
220	1050	318	30	190
275	1050	400	30	240
330	1175	420	60	285
400	1425	440	60	330
500	1550	580	60	435

Tests according to other standards can be carried out upon agreement.

Cable handling

Minimum bending radius

Table 19

Minimum bending radius for single core cables		
	Std cable design*	Special cable design**
At laying	15 D_e	18 D_e
When installed	10 D_e	12 D_e

D_e is the external diameter of the cable

* Cu-wire screen only
** Metallic laminated or lead sheathed cables or cables with integrated optic fibers

Maximum pulling forces

The following pulling forces should not be exceeded:

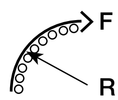
Aluminium conductors	40 N/mm² (4 kg/mm²)
Copper conductors	70 N/mm² (7 kg/mm²)

Maximum side wall pressure (SWP)

The following SWPs should not be exceeded:

Buried installation (rollers placed close)	500 kg /m*
Duct installation	750 kg/m*

$$SWP = \frac{F}{R} \; [kg/m]$$



* Depending on cable design and installation conditions higher values may be accepted.

Conductors

Table 20

IEC				
Cross section		Diameter approx.	Maximum d.c. resistance at 20°C, ohm/km	
mm²	kcmil	mm	aluminium	copper
95	187	11.2	0.320	0.193
120	237	12.8	0.253	0.153
150	296	14.2	0.206	0.124
185	365	15.9	0.164	0.0991
240	474	18.0	0.125	0.0754
300	592	20.5	0.100	0.0601
400	789	23.1	0.0778	0.0470
500	987	26.4	0.0605	0.0366
630	1243	30.2	0.0469	0.0283
800	1579	33.9	0.0367	0.0221
1000	1973	37.9	0.0291	0.0176
1200	2368	44*	0.0247	0.0151
1600	3158	52*	0.0186	0.0113
2000	3944	56*	0.0149	0.0090
2500	4931	66*	0.0120	0.0072

* Segmented Cu conductor including tapes

Table 21

ICEA					
Cross section			Diameter approx.	Nominal d.c. resistance at 20°C, ohm/km **	
AWG	kcmil	mm²	mm	aluminium	copper
3/0		85	10.7	0.383	0.206
4/0		107	12.1	0.269	0.164
	250	127	13.2	0.228	0.139
	300	152	14.5	0.190	0.116
	350	177	15.6	0.162	0.0990
	500	253	18.7	0.114	0.0695
	750	380	23.0	0.0759	0.0462
	1000	507	26.9	0.0563	0.0347
	1250	633	30.2	0.0454	0.0278
	1500	760	33.5	0.0380	0.0231
	1750	887	36.2	0.0325	0.0198
	2000	1013	38.0	0.0285	0.0173
	2500	1267	45*	0.0230	0.0140
	3000	1520	48*	0.0189	0.0117
	3500	1773	52.5*	0.0164	0.0100
	4000	2027	55*	0.0143	0.0087

1 ohm/100 ft = 3.28 ohm/km

* Segmented Cu conductor including tapes
** The maximum value can be 2% higher

Standards – IEC and ICEA
Conductors are manufactured according to the following standards:

IEC (International Electrotechnical Commission) Standard Publication 60228, Class 2: Stranded circular or shaped conductors of copper or aluminium.

ICEA, Standard Publication No. S-97-682, further specified in ASTM B 400-18 for aluminium, ASTM B 496-81 for copper.

Conductor water sealing
If required, the conductor can be water sealed by:

– Swelling material between the conductor strands. This material turns into jelly when in contact with water.
– Filling compound between the conductor strands.

XLPE CABLE DESIGN

Insulation

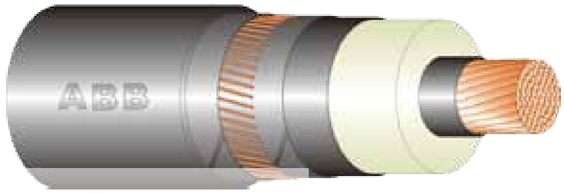
Conductor screen
The conductor screen consists of an extruded layer firmly bonded to the XLPE insulation. A very smooth material is used to obtain good electrical performance.

XLPE insulation
The XLPE insulation is extruded simultaneously with the conductor screen and the insulation screen, e.g. triple extrusion. The interface surfaces between insulation and conductive screens are not exposed at any stage of the manufacturing. High quality material-handling systems, triple extrusion, dry curing and super-clean XLPE materials guarantee high quality products. The insulation thickness is determined by the design electrical stresses for AC or impulse. The actual thickness for different voltage levels and conductor sizes is given in Tables 22 to 32.

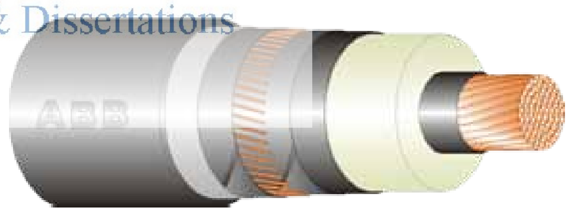
Insulation screen
This screen consists of an extruded layer firmly bonded to the XLPE insulation. The material is a high quality conductive compound. The interface between the screen and the insulation is smooth.

Metallic screen

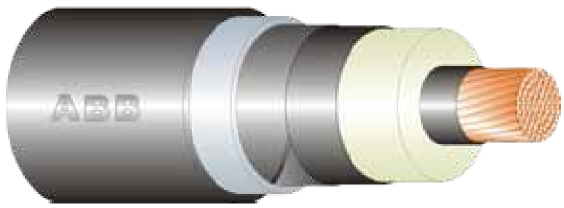
Copper wire screen, standard design
A polymeric sheath covers the copper wire screen.



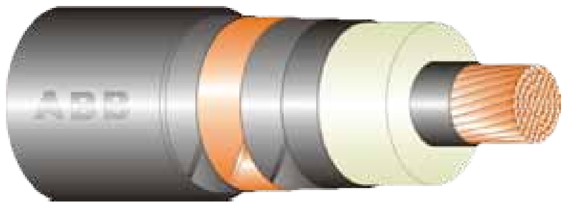
Copper wire screen, water tight design
Radial water sealing is achieved by using a metal-PE laminate. The metal is normally aluminium. Copper may also be used. The laminate is bonded to the polyethylene, which gives excellent mechanical properties. Longitudinal water sealing is achieved by using a water swelling material at the copper wires or swelling powder between the screen wires.



Lead sheath
Radial water sealing achieved by a corrosion resistant lead sheath. Longitudinal water sealing is achieved by using a water swelling material applied under the lead sheath.

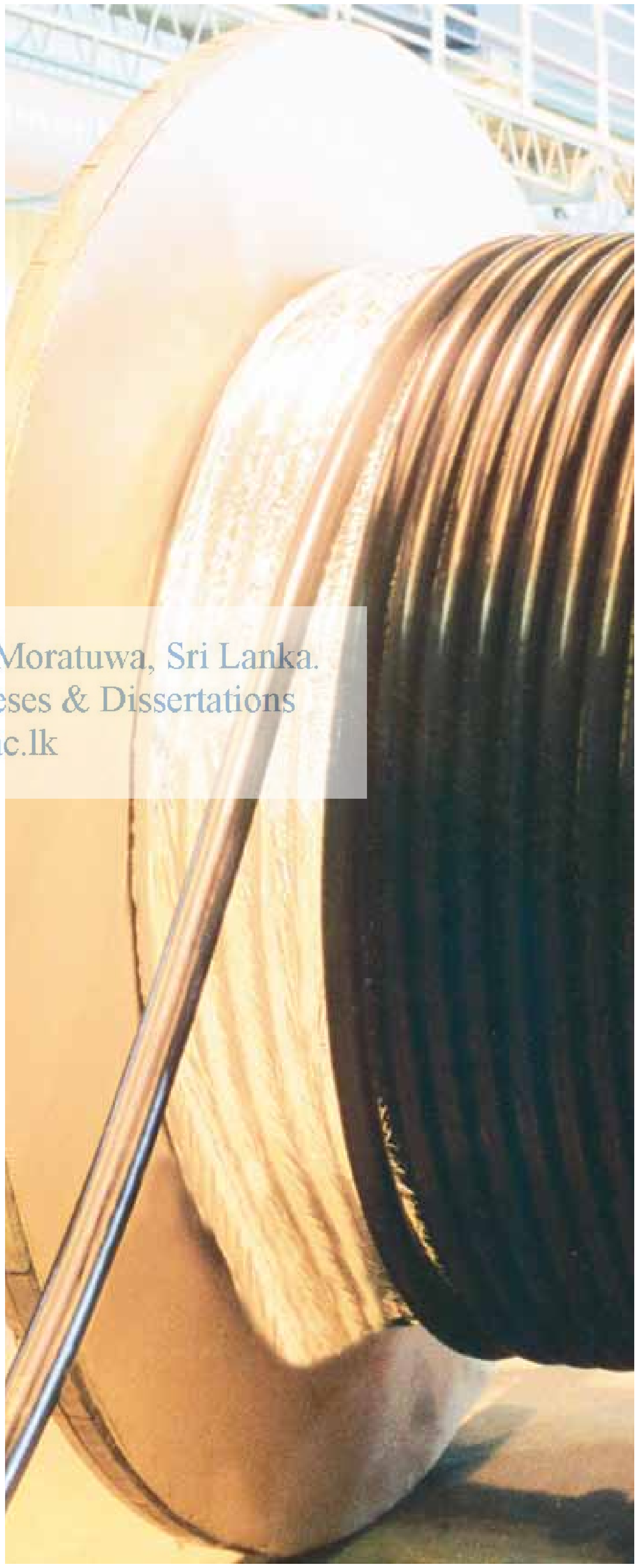


Copper tape screen
Cross section defined by the geometrical cross section of the copper tapes.



Non-metallic outer sheath

PE or PVC are normally used for the non-metallic outer sheath. IEC 60502 recommends a thickness of t = 0.035 x D + 1.0 mm, where D is the diameter under the sheath. For heavy installations a larger thickness is recommended. PE is the first choice for most applications. PVC is used when there are high requirements on fire retardation behaviour.



Conductive outer layer

A conductive outer layer facilitates testing of the non-metallic outer sheath. This testing is important to ensure the physical integrity of the cable from time to time, either in factory, after transportation, directly after laying, upon completion of the installation, or periodically thereafter.

A conductive outer layer obtained by simultaneous extrusion with the non-conductive outer sheath presents superior electrical and structural properties.

Flame retardant outer layer

For PE-sheathed cables a halogen free and flame retardant layer can be applied in order to limit the fire spread in buildings and tunnel installations.

Fire behavior

This relates to cables in buildings and tunnels.

Several serious fire accidents have focused attention on the fire behaviour of cables. Experience shows that cables seldom initiate fires. However, in some cases cable installations have influenced the extent of a fire, as a propagator of flames and/or as a source of intense aggressive smoke.

Cables having a PVC sheath are considered as flame retardant. However, once PVC is on fire, it generates hydrochloric acid fumes (HCl) acid. This gas is highly corrosive and irritating to inhale. Cables with a standard PE outer sheath do not generate any corrosive HCl but are not flame retardant. Special polyolefines with flame retardant properties but without chlorine or any other halogenes are optional for the outer sheath.

TECHNICAL DATA FOR XLPE LAND CABLE SYSTEMS

Table 22

Cross-section of conductor	Diameter of conductor	Insulation thickness	Diameter over insulation	Cross-section of screen	Outer diameter of cable	Cable weight (Al-conductor)	Cable weight (Cu-conductor)	Capacitance	Charging current per phase at 50 Hz	Inductance (trefoil)	Inductance (flat)	Surge impedance
mm²	mm	mm	mm	mm²	mm	kg/m	kg/m	μF/km	A/km	mH/km	mH/km	Ω
Single-core cables, nominal voltage 45 kV (U_m = 52 kV)												
95	11.2	8.0	29.6	25	40.0	1.4	2.0	0.18	1.5	0.44	0.69	35.6
120	12.6	8.0	31.0	25	41.6	1.5	2.3	0.19	1.6	0.43	0.67	33.2
150	14.2	8.0	32.6	35	44.0	1.8	2.7	0.21	1.7	0.41	0.65	31.0
185	15.8	8.0	34.2	35	45.6	1.9	3.1	0.22	1.8	0.40	0.63	28.9
240	18.1	8.0	36.5	35	48.1	2.2	3.7	0.24	2.0	0.38	0.61	26.4
300	20.4	8.0	38.8	35	50.6	2.5	4.3	0.26	2.1	0.37	0.59	24.4
400	23.2	8.0	41.6	35	53.6	2.9	5.3	0.29	2.3	0.36	0.57	22.3
500	26.2	8.0	45.0	35	57.2	3.3	6.4	0.32	2.6	0.34	0.55	20.4
630	29.8	8.0	48.6	35	61.0	3.8	7.7	0.35	2.8	0.33	0.53	18.5
800	33.7	8.0	52.5	35	65.7	4.5	9.5	0.38	3.1	0.32	0.51	17.0
1000	37.9	8.0	57.3	35	70.9	5.3	11.6	0.42	3.5	0.31	0.50	15.5
1200	42.8	8.0	63.8	35	77.8	6.3	13.8	0.48	3.9	0.31	0.48	14.2
1400	46.4	8.0	67.4	35	81.6	7.0	15.8	0.51	4.2	0.30	0.47	13.4
1600	49.8	8.0	70.8	35	85.2	7.8	17.7	0.54	4.4	0.30	0.46	12.6
2000	54.4	8.0	75.4	35	90.6	9.2	21.6	0.58	4.8	0.29	0.45	11.8

Table 23

Cross-section of conductor	Diameter of conductor	Insulation thickness	Diameter over insulation	Cross-section of screen	Outer diameter of cable	Cable weight (Al-conductor)	Cable weight (Cu-conductor)	Capacitance	Charging current per phase at 50 Hz	Inductance (trefoil)	Inductance (flat)	Surge impedance
mm²	mm	mm	mm	mm²	mm	kg/m	kg/m	μF/km	A/km	mH/km	mH/km	Ω
Single-core cables, nominal voltage 66 kV (U_m = 72.5 kV)												
95	11.2	9.0	31.6	25	42.2	1.5	2.1	0.16	2.0	0.45	0.70	38.0
120	12.6	9.0	33.0	25	43.8	1.7	2.4	0.18	2.1	0.44	0.68	35.5
150	14.2	9.0	34.6	35	46.0	1.9	2.8	0.19	2.3	0.42	0.65	33.1
185	15.8	9.0	36.2	35	47.8	2.1	3.2	0.20	2.4	0.41	0.64	31.0
240	18.1	9.0	38.5	35	50.3	2.3	3.8	0.22	2.6	0.39	0.61	28.4
300	20.4	9.0	40.8	35	52.8	2.6	4.5	0.24	2.9	0.38	0.59	26.2
400	23.2	9.0	43.6	35	55.8	3.0	5.5	0.26	3.1	0.36	0.57	24.0
500	26.2	9.0	47.0	35	59.4	3.5	6.6	0.29	3.4	0.35	0.55	22.0
630	29.8	9.0	50.6	35	63.2	4.0	7.9	0.32	3.8	0.34	0.53	20.0
800	33.7	9.0	54.5	35	67.9	4.7	9.7	0.35	4.1	0.33	0.52	18.4
1000	37.9	9.0	59.3	35	72.9	5.5	11.8	0.38	4.6	0.32	0.50	16.8
1200	42.8	9.0	65.8	35	79.8	6.5	14.0	0.43	5.2	0.31	0.49	15.4
1400	46.4	9.0	69.4	35	83.8	7.3	16.0	0.46	5.5	0.31	0.47	14.5
1600	49.8	9.0	72.8	35	87.4	8.0	18.0	0.49	5.9	0.30	0.47	13.7
2000	54.4	9.0	77.4	35	92.8	9.5	21.9	0.52	6.3	0.30	0.45	12.8

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Table 24

Cross-section of conductor	Diameter of conductor	Insulation thickness	Diameter over insulation	Cross-section of screen	Outer diameter of cable	Cable weight (Al-conductor)	Cable weight (Cu-conductor)	Capacitance	Charging current per phase at 50 Hz	Inductance ●●● (trefoil)	Inductance ●●● (flat)	Surge impedance
mm²	mm	mm	mm	mm²	mm	kg/m	kg/m	μF/km	A/km	mH/km	mH/km	Ω
Single-core cables, nominal voltage 70 kV (U_m=84 kV)												
150	14.2	10.0	36.6	35	48.2	2.0	3.0	0.18	2.2	0.43	0.66	35.2
185	15.8	10.0	38.2	35	50.0	2.2	3.4	0.19	2.4	0.42	0.64	33.0
240	18.1	10.0	40.5	35	52.3	2.5	4.0	0.20	2.6	0.40	0.62	30.2
300	20.4	10.0	42.8	35	54.8	2.8	4.6	0.22	2.8	0.39	0.60	28.0
400	23.2	10.0	45.6	35	57.8	3.2	5.7	0.24	3.1	0.37	0.58	25.6
500	26.2	10.0	49.0	35	61.4	3.6	6.7	0.26	3.4	0.36	0.56	23.5
630	29.8	10.0	52.6	35	65.4	4.2	8.1	0.29	3.7	0.35	0.54	21.4
800	33.7	10.0	56.5	35	69.9	4.9	9.9	0.32	4.0	0.33	0.52	19.7
1000	37.9	10.0	61.3	35	75.1	5.8	12.0	0.35	4.5	0.33	0.50	18.0
1200	42.8	10.0	67.8	35	82.0	6.8	14.3	0.40	5.0	0.32	0.49	16.5
1400	46.4	10.0	71.4	35	85.8	7.5	16.3	0.42	5.4	0.31	0.48	15.5
1600	49.8	10.0	74.8	35	90.0	8.4	18.3	0.45	5.7	0.31	0.47	14.8
2000	54.4	10.0	79.4	35	94.8	9.7	22.2	0.48	6.1	0.30	0.46	13.8

Table 25

Cross-section of conductor	Diameter of conductor	Insulation thickness	Diameter over insulation	Cross-section of screen	Outer diameter of cable	Cable weight (Al-conductor)	Cable weight (Cu-conductor)	Capacitance	Charging current per phase at 50 Hz	Inductance ●●● (trefoil)	Inductance ●●● (flat)	Surge impedance
mm²	mm	mm	mm	mm²	mm	kg/m	kg/m	μF/km	A/km	mH/km	mH/km	Ω
Single-core cables, nominal voltage 110 kV (U_m = 123 kV)												
185	15.8	16.0	50.2	95	63.3	3.7	4.9	0.14	2.7	0.47	0.66	43.0
240	18.1	15.0	50.5	95	63.6	3.9	5.4	0.15	3.1	0.44	0.63	38.4
300	20.4	14.0	50.8	95	63.9	4.0	5.9	0.17	3.5	0.42	0.61	34.3
400	23.2	13.0	51.6	95	64.9	4.3	6.8	0.20	4.0	0.39	0.59	30.2
500	26.2	13.0	55.0	95	68.5	4.8	7.9	0.22	4.3	0.38	0.57	27.8
630	29.8	13.0	58.6	95	72.3	5.3	9.3	0.24	4.7	0.37	0.55	25.5
800	33.7	13.0	62.5	95	76.8	6.1	11.1	0.26	5.2	0.35	0.53	23.5
1000	37.9	13.0	67.3	95	82.0	7.0	13.2	0.28	5.7	0.34	0.51	21.6
1200	42.8	13.0	73.8	95	89.5	8.2	15.6	0.32	6.4	0.34	0.50	19.8
1400	46.4	13.0	77.4	95	93.3	9.0	17.7	0.34	6.8	0.33	0.49	18.7
1600	49.8	13.0	80.8	95	96.9	9.7	19.7	0.36	7.1	0.32	0.48	17.7
2000	54.4	13.0	85.4	95	101.9	11.2	23.6	0.38	7.6	0.31	0.46	16.6
2500	62.0	13.0	93.0	95	109.9	13.1	28.7	0.42	8.5	0.30	0.45	14.9

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Cross-section of conductor	Diameter of conductor	Insulation thickness	Diameter over insulation	Cross-section of screen	Outer diameter of cable	Cable weight (Al-conductor)	Cable weight (Cu-conductor)	Capacitance	Charging current per phase at 50 Hz	Inductance ∴	Inductance ●●●	Surge impedance
mm²	mm	mm	mm	mm²	mm	kg/m	kg/m	μF/km	A/km	mH/km	mH/km	Ω

Table 26

Single-core cables, nominal voltage 132 kV (U_m = 145 kV)												
185	15.8	18.0	54.2	95	67.5	4.1	5.3	0.13	3.0	0.48	0.67	45.8
240	18.1	17.0	54.5	95	68.0	4.3	5.8	0.14	3.4	0.45	0.64	41.1
300	20.4	16.0	54.8	95	68.3	4.4	6.3	0.16	3.8	0.43	0.62	37.1
400	23.2	15.0	55.6	95	69.1	4.6	7.1	0.18	4.3	0.41	0.59	33.0
500	26.2	15.0	59.0	95	72.7	5.2	8.3	0.20	4.7	0.39	0.57	30.4
630	29.8	15.0	62.6	95	76.5	5.8	9.7	0.21	5.1	0.38	0.55	27.9
800	33.7	15.0	66.5	95	81.2	6.6	11.5	0.23	5.5	0.36	0.54	25.8
1000	37.9	15.0	71.3	95	86.4	7.5	13.7	0.25	6.1	0.35	0.52	23.7
1200	42.8	15.0	77.8	95	93.7	8.7	16.2	0.29	6.8	0.35	0.50	21.8
1400	46.4	15.0	81.4	95	97.5	9.5	18.2	0.30	7.2	0.34	0.49	20.6
1600	49.8	15.0	84.8	95	101.1	10.3	20.3	0.32	7.6	0.33	0.48	19.5
2000	54.4	15.0	89.4	95	106.1	11.8	24.2	0.34	8.1	0.32	0.47	18.3
2500	62.0	15.0	97.0	95	114.3	13.8	29.3	0.38	9.0	0.31	0.45	16.5

Table 27

Single-core cables, nominal voltage 150 kV (U_m = 170 kV)												
240	18.1	21.0	62.5	95	76.4	5.1	6.6	0.12	3.4	0.48	0.65	46.2
300	20.4	20.0	62.8	95	76.7	5.2	7.1	0.14	3.7	0.45	0.63	42.0
400	23.2	19.0	63.6	95	77.7	5.5	8.0	0.15	4.2	0.43	0.61	37.9
500	26.2	18.0	65.0	95	79.1	5.8	8.9	0.17	4.7	0.41	0.58	34.0
630	29.8	17.0	66.6	95	80.9	6.2	10.2	0.19	5.3	0.39	0.56	30.2
800	33.7	17.0	70.5	95	85.4	7.0	12.0	0.21	5.7	0.37	0.54	27.9
1000	37.9	17.0	75.3	95	91.0	8.1	14.3	0.23	6.3	0.36	0.52	25.8
1200	42.8	17.0	81.8	95	97.9	9.3	16.7	0.26	7.0	0.35	0.51	23.7
1400	46.4	17.0	85.4	95	101.9	10.1	18.8	0.27	7.4	0.35	0.50	22.4
1600	49.8	17.0	88.8	95	105.5	11.0	20.9	0.29	7.8	0.34	0.49	21.2
2000	54.4	17.0	93.4	95	110.3	12.4	24.9	0.31	8.3	0.33	0.47	19.9
2500	62.0	17.0	101.0	95	118.5	14.5	30.0	0.34	9.2	0.32	0.46	18.0

Table 28

Single-core cables, nominal voltage 220 kV (U_m = 245 kV)												
500	26.2	24.0	77.6	185	94.0	8.3	11.4	0.14	5.8	0.44	0.60	40.2
630	29.8	23.0	79.2	185	95.8	8.8	12.7	0.16	6.4	0.42	0.58	36.4
800	33.7	23.0	83.1	185	100.3	9.7	14.7	0.17	6.9	0.41	0.56	33.8
1000	37.9	23.0	87.3	185	104.9	10.7	16.9	0.19	7.4	0.39	0.54	31.3
1200	42.8	23.0	93.8	185	111.8	12.0	19.4	0.21	8.2	0.38	0.52	28.8
1400	46.4	23.0	97.4	185	115.6	12.9	21.6	0.22	8.7	0.37	0.51	27.3
1600	49.8	23.0	100.8	185	119.2	13.8	23.7	0.23	9.1	0.36	0.50	26.0
2000	54.4	23.0	105.4	185	124.2	15.4	27.8	0.24	9.7	0.35	0.49	24.5
2500	62.0	23.0	113.0	185	132.4	17.6	33.1	0.27	10.6	0.34	0.47	22.3

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Table 29

Cross-section of conductor	Diameter of conductor	Insulation thickness	Diameter over insulation	Cross-section of screen	Outer diameter of cable	Cable weight (Al-conductor)	Cable weight (Cu-conductor)	Capacitance	Charging current per phase at 50 Hz	Inductance (trefoil)	Inductance (flat)	Surge impedance
mm^2	mm	mm	mm	mm^2	mm	kg/m	kg/m	μF/km	A/km	mH/km	mH/km	Ω
Single-core cables, nominal voltage 275 kV (U_m = 300 kV)												
500	26.2	26.0	81.6	185	98.2	8.9	12.0	0.14	6.8	0.45	0.61	42.1
630	29.8	24.0	81.2	185	97.8	9.0	13.0	0.16	7.7	0.43	0.58	37.3
800	33.7	24.0	85.1	185	102.5	10.0	15.0	0.17	8.3	0.41	0.56	34.7
1000	37.9	24.0	89.3	185	106.9	11.0	17.2	0.18	9.0	0.40	0.54	32.2
1200	42.8	24.0	95.8	185	114.0	12.3	19.8	0.20	10.0	0.38	0.53	29.6
1400	46.4	24.0	99.4	185	117.8	13.2	22.0	0.21	10.5	0.37	0.51	28.1
1600	49.8	24.0	102.8	185	121.4	14.2	24.1	0.22	11.0	0.37	0.50	26.8
2000	54.4	24.0	107.4	185	126.4	15.8	28.2	0.23	11.7	0.36	0.49	25.2
2500	62.0	24.0	115.0	185	134.4	17.9	33.5	0.26	12.8	0.34	0.47	22.9

Table 30

Cross-section of conductor	Diameter of conductor	Insulation thickness	Diameter over insulation	Cross-section of screen	Outer diameter of cable	Cable weight (Al-conductor)	Cable weight (Cu-conductor)	Capacitance	Charging current per phase at 50 Hz	Inductance (trefoil)	Inductance (flat)	Surge impedance
mm^2	mm	mm	mm	mm^2	mm	kg/m	kg/m	μF/km	A/km	mH/km	mH/km	Ω
Single-core cables, nominal voltage 330 kV (U_m = 362 kV)												
630	29.8	28.0	89.2	185	106.4	10.3	14.2	0.14	8.4	0.44	0.59	40.8
800	33.7	27.0	91.1	185	108.9	10.9	15.9	0.15	9.3	0.42	0.57	37.2
1000	37.9	26.0	93.3	185	111.3	11.6	17.8	0.17	10.2	0.40	0.55	33.8
1200	42.8	25.0	97.8	185	116.0	12.6	20.1	0.19	11.6	0.39	0.53	30.4
1400	46.4	25.0	101.4	185	120.0	13.6	22.3	0.20	12.2	0.38	0.52	28.8
1600	49.8	25.0	104.8	185	123.6	14.5	24.5	0.21	12.8	0.37	0.51	27.5
2000	54.4	25.0	109.4	185	128.4	16.1	28.6	0.23	13.6	0.36	0.49	25.9
2500	62.0	25.0	117.0	185	136.6	18.4	33.9	0.25	14.9	0.35	0.48	23.6

Table 31

Cross-section of conductor	Diameter of conductor	Insulation thickness	Diameter over insulation	Cross-section of screen	Outer diameter of cable	Cable weight (Al-conductor)	Cable weight (Cu-conductor)	Capacitance	Charging current per phase at 50 Hz	Inductance (trefoil)	Inductance (flat)	Surge impedance
mm^2	mm	mm	mm	mm^2	mm	kg/m	kg/m	μF/km	A/km	mH/km	mH/km	Ω
Single-core cables, nominal voltage 400 kV (U_m = 420 kV)												
630	29.8	32.0	98.2	185	116.0	11.7	15.7	0.13	9.6	0.46	0.60	43.7
800	33.7	30.0	98.1	185	116.3	12.1	17.1	0.15	10.7	0.44	0.58	39.4
1000	37.9	29.0	100.3	185	118.7	12.8	19.0	0.16	11.7	0.42	0.56	36.0
1200	42.8	27.0	101.8	185	120.4	13.4	20.8	0.18	13.3	0.40	0.53	31.9
1400	46.4	27.0	105.4	185	124.2	14.3	23.0	0.19	14.0	0.39	0.52	30.2
1600	49.8	27.0	108.8	185	127.8	15.3	25.2	0.20	14.7	0.38	0.51	28.9
2000	54.4	27.0	113.4	185	132.8	16.9	29.4	0.21	15.6	0.37	0.50	27.2
2500	62.0	27.0	121.0	185	140.8	19.2	34.7	0.23	17.0	0.35	0.48	24.8

Table 32

Cross-section of conductor	Diameter of conductor	Insulation thickness	Diameter over insulation	Cross-section of screen	Outer diameter of cable	Cable weight (Al-conductor)	Cable weight (Cu-conductor)	Capacitance	Charging current per phase at 50 Hz	Inductance (trefoil)	Inductance (flat)	Surge impedance
mm^2	mm	mm	mm	mm^2	mm	kg/m	kg/m	μF/km	A/km	mH/km	mH/km	Ω
Single-core cables, nominal voltage 500 kV (U_m = 550 kV)												
800	33.7	34.0	106.1	185	124.9	13.5	18.5	0.14	12.3	0.45	0.59	42.3
1000	37.9	32.0	106.3	185	125.1	13.9	20.1	0.15	13.7	0.43	0.56	38.1
1200	42.8	31.0	109.8	185	128.8	14.8	22.3	0.17	15.1	0.41	0.54	34.7
1400	46.4	31.0	113.4	185	132.8	15.9	24.6	0.18	15.9	0.40	0.53	33.0
1600	49.8	31.0	116.8	185	136.4	16.9	26.8	0.18	16.6	0.39	0.52	31.5
2000	54.4	31.0	121.4	185	141.4	18.6	31.0	0.19	17.6	0.38	0.51	29.7
2500	62.0	31.0	129.0	185	149.4	20.9	36.5	0.21	19.2	0.36	0.49	27.2

FORMULAE

Formula for capacitance

$$C = \frac{\varepsilon_r}{18 \cdot \ln\left(\frac{r_o}{r_i}\right)} \quad [\mu F/km]$$

Where ε = relative permittivity of the insulation
r_o = external radius of the insulation (mm)
r_i = radius of conductor, including screen (mm)
$\varepsilon_{r\ XLPE}$ = 2.5 (Value from IEC 60287)

Formula for dielectric losses

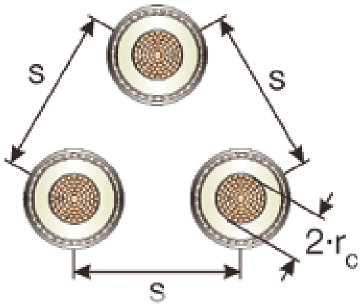
$$W = \frac{U^2}{3} 2\pi f \cdot C \cdot \tan(\delta) \quad [W/km]$$

Where U = rated voltage (kV)
f = frequency (Hz)
C = capacitance (μF/km)
tan δ = loss angle

Formula for inductance

$$L = 0.05 + 0.2 \cdot \ln\left(\frac{K \cdot s}{r_c}\right) \quad [mH/km]$$

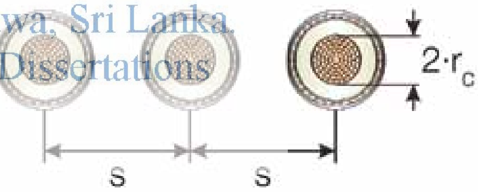
Where trefoil formation: K = 1
flat formation: K = 1.26
s = distance between conductor axes (mm)
r_C = conductor radius (mm)



Formula for inductive reactance

$$X = 2\pi f \cdot \frac{L}{1000} \quad [\Omega/km]$$

Where f = frequency (Hz)
L = inductance (mH/km)

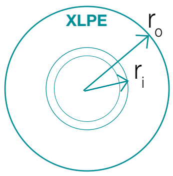


Formula for electric stress

Conductor screen: $E_{max} = \frac{U_o}{r_i \ln\left(\frac{r_o}{r_i}\right)}$ [kV/mm]

Insulation screen: $E_{min} = \frac{U_o}{r_o \ln\left(\frac{r_o}{r_i}\right)}$ [kV/mm]

r_i = radius of conductor screen
r_o = radius of XLPE insulation
U_o = voltage across insultaion



Formula for maximum short circuit currents

$$I_{sh} = \frac{I_1}{\sqrt{t_{sh}}} \quad [kA]$$

I_{sh} = short-circuit current during time t_{sh}
I_1 = short-circuit current rating during 1 second. See the 1 second value in tables 14 for the conductor and in Table 15 for the metallic screen.
t_{sh} = short-circuit duration (sec)

For XLPE insulated conductors the maximum allowable short circuit temperature is 250°C.

Formula for calculation of dynamic forces between two conductors

$$F = \frac{0.2}{S} \cdot I^2_{peak} \quad [N/m]$$

Where; I_{peak} = 2.5 I_{sh} [kA]
I_{sh} = short-circuit current [kA] RMS
S = centre to centre spacing between conductors [m]
F = maximum force [N/m]

SUPPORT

The transmission network in most countries is very large and complex. It may incorporate many different types of transmission circuits, including AC and DC over-head lines, fluid-filled cable systems and extruded cable systems, etc. Also, many modern networks contain extensive land and submarine cable systems for supply of major metropolitan areas and for interconnection with neighbouring countries.

ABB's experienced project managers, technical specialists and other staff will give their professional support in evaluating suitable solutions. We aim to offer the most optimal solution and we can supply the complete land or submarine cable system which can include:

- Power cables for land or submarine applications
- Cable accessories
- Control- and telecommunication cables
- System design for network optimization
- Project management
- Civil works
- Installation and supervision
- Testing and start-up operations
- Disassembly and recovery of old cables
- Fault localization and cable repair
- Maintenance of fluid-filled systems
- Leasing of installation equipment
- Training

NOTE: All data given in this brochure are non-binding and indicative only

CHECKLIST FOR CABLE INQUIRY

ABB is always prepared to work closely with our customers to develop optimized and cost effective cable system design solutions. In order for us to identify the best overall design solution for a specific application, we kindly request that the below data checklist is submitted with each inquiry (if some of the requested data is not available at the time of the inquiry or does not appear applicable, just insert N/A in the corresponding data cell).

Commercial information

* Required information

Name of project	*
Customer	*
Location of site for delivery	*
Inquiry for budget or purchase	*
Tender submission date	*
Do any special conditions apply	
How long should the tender be valid	*
Required delivery/completion time	*
Terms of delivery (FCA/CPT etc.)	*
Specific requirements on cable length per delivered drum	
Do any specific metal prices apply	
Installation: Turnkey by ABB Installation by ABB Supervision by ABB	*

Technical information

* Required information

Cable system input:		
Maximum System Voltage U_{max}	*	kV
Nominal System Operating Voltage U	*	kV
Continuous current capacity	*	A/MVA
Maximum symmetrical short-circuit current and duration	*	kA/s
Maximum earth-fault current and duration	*	kA/s
Route length	*	m
Conductor: copper/aluminum, cross-section		Cu/Al, mm
Longitudinal water protection	*	Yes/No
Radial water protection	*	Yes/No
Any special cable design requirements Customer specification		

Tests

Routine, sample and after installation test. IEC, other
Type test requirements. IEC, other
Other test requirements

Installation data

* Required information

Cable configuration: Flat/Trefoil		
Number of parallel circuits	*	
Distance between parallel circuits		mm
Heating from existing cables		Yes/No
If yes, distances to and losses of parallel cables		mm, W/m
Other heat sources, distance to and losses of sources		mm, W/m
Screen earthing (Both ends, Cross, Single)		

* Required information

Installed in air	*	Yes/No
Air temperature, maximum		°C
Installed in trough		Yes/No
If trough, inside dimension of trough (width • height)		mm • mm
If trough, filled or unfilled		
Exposed to solar radiation		Yes/No
Direct buried installation	*	Yes/No
Soil, ground temperature at laying depth		°C
Laying depth		mm
Thermal resistivity backfill		K•m/W
If drying out, thermal resistivity dry backfill close to cable		K•m/W
Backfill material: selected sand, CBS, etc		
Special requirements for trench		
Cables in ducts or pipes, buried ducts	*	Yes/No
Material: PVC, PE, Fibre, steel, etc		
Distance between ducts/pipes		mm
Outside duct/pipe diameter		mm
Inside duct/pipe diameter		mm
Ambient temperature at burial depth		°C
Thermal resistivity of ground		K•m/W
Thermal resistivity of backfill		K•m/W
If drying out, thermal resistivity dry backfill close to duct		K•m/W
Laying depth		mm
Backfill material: selected sand, CBS, etc		

Accessories

* Required information

Termination	
Type of termination and quantity. Indoor, outdoor, AIS, GIS, transformer, etc.	Type * Qty *
Special requirements - pollution level, rod gap, polymer insulator, etc.	
Joints	
Type of joint and quantity - premoulded, vulcanized, sectionalized, straight etc.	Type * Qty *
Special requirements	
Link boxes	
Type of link box	
Special requirements	
Other accessories	
Other relevant information	

NOTES

NOTES

Contact us

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Appendix G: Daily Load Curve