OPTIMUM DESIGN FOR MEDIUM VOLTAGE POWER DISTRIBUTION IN PLANNED CITY UNDER CONSTARAINTS

A CASE STUDY: COLOMBO PORT CITY

YKBS Ranaweera

128783H

Degree of Master of Science

Department of Electrical Engineering

University of Moratuwa
Sri Lanka

June 2017

OPTIMUM DESIGN FOR MEDIUM VOLTAGE POWER DISTRIBUTION IN PLANNED CITY UNDER CONSTARAINTS

A CASE STUDY: COLOMBO PORT CITY

YKBS Ranaweera

128783H

Thesis/Dissertation submitted in partial fulfilment of the requirements for the degree
Master of Science

Department of Electrical Engineering

University of Moratuwa
Sri Lanka

June 2017

DECLARATION

"I declare that this is my own work and this thesis / dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my thesis/dissertation, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

....

Signature: Date:

(YKBS Ranaweera)

The above candidate has carried out research for the Masters' Thesis/ Dissertation under my supervision.

....

Signature of the supervisor: Date

(Dr. W D Asanka S Rodrigo)

ABSTRACT

Rapid population growth, resource scarcity, rural-urban migration, severe poverty, socioeconomic inequality etc. can be recognized as the foremost challenges, faced by the most of the countries in the world including Sri Lanka. Almost all the major cities are now rapidly becoming urban, which leads to emergence of massive problems related to infrastructure, portable water & sanitation, electricity, housing development etc. As a result, planned cities have been introduced while giving solutions for complex processes of urban planning.

One of the critical challenges in urban planning is to provide sufficient medium voltage distribution, to cater the increasing demand associated with the development. Even though many numbers of researches has been conducted to introduce optimum solutions to address this matter in various places in the world, no literature was found to discuss the optimum value for medium voltage distribution and optimum locations for the complete distribution system. It was evident that common papers about optimal distribution design do not include practical examples of a true multi objective optimization of an actual complete system of significant dimensions as those papers were discussing on existing networks or extensions to existing networks as improvements.

This paper presents new criteria for medium voltage selection, optimum location selection and minimization of losses in the Medium Voltage network. Finally a general model was developed to assist city planners to arrange the medium voltage power distribution for the planned cities.

Due to easy access to information, Colombo port city was selected as the case study in this research study. There are four available locations (A, B, C & D) for GSS in port city conceptual master plan and it was found that “B” and “C” were optimum locations for GSS. The optimum value for the MV power distribution is 22kV. The significant gain of the discussed methodology is that, it provides a set of solutions that can be considered simultaneously. Accordingly, this guide will not only raise awareness and build capacities in this regard, but will also offer directions for upcoming initiatives in this regard.

Key Words - Mega cities, optimum solution, medium voltage (MV), Colombo port city, novel concept

DEDICATION

I dedicate this thesis, which I completed successfully as my first research work, to my mother Mrs. H A L Kulathunga and my father, late Mr. Y K D P Ranaweera, who were always there as my strong pillars and my source of inspiration, by supporting me to make my dreams come true. I also dedicate this to my wife, Mrs. Asha Ranaweera, to my children and to all other knowledge seekers, who attempt to develop a better future.

ACKNOWLEDGEMENT

First and foremost, I pay my sincere gratitude to my supervisor Dr. Asanka Rodrigo, who encouraged and guided me to conduct this investigation and to prepare the final dissertation; without his excellent guiding, there will not be a research like this.

I acknowledge the staff members of the Department of Electrical Engineering, University of Moratuwa and to all the coordinators, who arranged this Master's program in such a productive manner. I extend my gratitude to Prof. M.P. Dias, Head of the Department of Electrical Engineering and to the staff of the Department of Electrical Engineering for the support given to me, during my study period. Further, my gratitude offers to Prof. J. R. Lucas, Prof. N.K. Wickramarachchi, Prof. J.P. Karunadasa, Dr. S.S. Namasivayam, Dr. Thilak Siyambalapitiya, Dr. Upuli Jayathunga, Eng. Anura Wijayapala and others for the guidance given for studying various subjects of Electrical Installation during the master's degree programme.

My special thanks go to Eng. A. J Edirisinghe, Eng. UGJK Gamlath and Eng. D.T. Dissanayake, who helped me for the investigation and finalization of the thesis work. Further, I would like to take this opportunity to extend my sincere thanks to Eng. Yasith Nupearachchi and all other office staff of the Colombo City Office of Ceylon Electricity Board and China Harbour Engineering Corporation (Port City Development office) who gave their co-operation to conduct my research work successfully.

It is a great pleasure to remember the kind co-operation and motivation provided by my friends and my family, especially my wife Asha, my son Seniru and my daughter Sanuki who helped me to continue the studies from the beginning to end.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ACSR	-	Aluminium –Conductor Steel- Reinforced
CBD	-	Central Business District of Colombo City
CEB	-	Ceylon Electricity Board
EMF	-	Electric and Magnetic Fields
GCTDLRP	-	Greater Colombo Transmission & Distribution Loss Reduction Project
GIS	-	Gas Insulated Switch Gear
GSS	-	Grid Substations
HDB	-	Housing Development Board
HDD	-	Horizontal direct drilling
HV	-	High Voltage
kV	-	Kilo Volt
kVA	-	Kilovolt - Ampere
LV	-	Low Voltage
MV	-	Medium Voltage
MVA	-	Megavolt –Ampere
NGO	-	Non-Government Organization
PPC	-	Preliminary Permission Clearance
PUCSL	-	Public Utilities Commission of Sri Lanka
R&D	-	Research & Development
SL	-	Sri Lanka
UG	-	Under Ground
XLPE	-	Cross Linked Polyethylene

CHAPTER 01: INTRODUCTION

1.1. Background

Rapid population growth, resource scarcity, rural-urban migration, severe poverty, socioeconomic inequality etc, can be mentioned as the foremost challenges, which are faced by most of the cities in Africa, Asia, the Middle East, Latin America, and the Caribbean. Since Sri Lanka is still identified as a developing country in Asia, the above mentioned challenges have impacted in a same terrible manner towards Sri Lankan economy during the last decade. Almost all the main cities are now rapidly becoming urban, which leads for arising several huge problems in following sectors,

- Infrastructure
- Potable water and sanitation
- Electricity
- Housing development etc.

Local government, Non-Government Organizations (NGOs), Public Institutions and Private Sector Entrepreneurs are more or less involving in to address these issues; while presenting valid opportunities to unleash massive economic potential, increase energy efficiency, reduce inequities and to create sustainable livelihoods for all in proper way. As a result, mega cities or planned cities have been introduced while giving solutions for complex process of urban planning. Urban planning considers social, technical and political demands with the use of land and designs the urban environment including all infrastructure facilities. This should be carefully planned from its commencement, in order to avoid misuse of lands and other resources. However, land utilization is a critical factor for Sri Lanka, since there are very limited availability of lands for development and residential activities, especially in urban areas. A new ministry has been formed in Sri Lankan, for the development of Mega Cities, in which Electrical Engineers also play a major role to carefully handle the critical challenge which was common for global electricity due to massive urbanization.

Urban planning is a vital concept, since it facilitates in achieving the sustainable development, through early scheduling and anticipating the future; which allows us to attain better living standards and comfortable future. Accordingly, planners always try to seek opportunities and manage risks from different aspects, by staying ahead of all the challenges. It will facilitate them to make connection between the long term vision and short term actions, in a way that urban life and their activities will be economically viable.

Development of Colombo port city complex is one such key activity under current development processes; and it is possible to address the identified constrains as it will be implemented from grass root stage. Accordingly, Colombo port city is considered as the case study for this research work, since it is an ongoing and significant model for this novel concept.

This research focuses on uncovering a new approach for addressing the above mentioned issues in relating to urban planning, by providing a solution for the attempts of local leaders, who are principally engaged in shaping the future growth of our cities. I believe that, this guide will not only raise awareness and build capacities in this regard, further it will offer directions for upcoming initiatives in this regard.

1.2. Planned Cities in the World

The development and widening of cities in the 20th century; especially in the late 90’s and early 00’ has been phenomenal. The statistics shows that, majority of the world population of 7 billion people around the world are currently living in urban areas / suburbs. The key factor that attracts more people towards the cities is the availability of facilities in one place. Thus, the urbanization has been a powerful tool for economic growth and poverty reduction. When all facilities and resources are arranged in a one place, in a well planned manner, it will facilitate more comfortable lifestyles for the people living in, by making cities an extremely productive place.

Accordingly, Singapore can be recognized as the highest rank from the developed planned cities in the world due to its excellent infrastructure, parks, gardens, public transport, leisure options, well laid out neighbourhoods, great clean public spaces etc. They have used a concept which contains special features including public housing for developing those planned cities. Public housing in Singapore is managed by the Housing and Development Board (HDB), where more than eighty percent of Singaporeans currently live in those HDB flats. These flats are located in housing estates, which consist of self-contained satellite towns with schools, supermarkets, clinics, hawker centres as well as sports and recreational facilities.

Correspondingly, there are some more outstanding planned cities in major cities of the world, which consist more or lesser facilities than HBD.

- Seoul
- Berlin
- Amsterdam
- Washington D.C
- Copenhagen
- Qatar
- New Mumbai
- New York
- Sapporo, Japan
- Manhattan
- Abu Dhabi
- Chicago

1.3. Planned Cities in Sri Lanka (Colombo Port City)

China Harbor Engineering Company got the opportunity to invest and operate with land preparation for Colombo Port City Development in Sri Lanka. The project is an extension through landfill of approximately 2.75 km^2, connected to the Fort district and Central Business District (CBD) in Central Colombo which is also close to the industrial harbor. According to the rough time schedules, whole land preparation including landfill and infrastructure construction will be completed in three or four years' time, and land lease as well as further construction will take approximately 10 years' time. The 2.75 km^2 city will additionally bring several opportunities to start from scratch, to innovate and design a new world-leading city development, based on best practices and international experience, which especially grasps the Sri Lankan perspective and climate. This exceptional opportunity will create a world-class community which fosters a living, working and learning environment while emphasizing the environmental and social quality.

The city will be developed under three main stages namely (I), (II) and (III) stages. The lands with highest commercial value in the country will be located in this complex and it will also be varied depending on the location and angle of the sea view to the land slot. Therefore, land usage for any utility activity becomes a considerable and costly activity for this kind of developments. The total power demand for the city is 400MW under the worst scenario, which is a novel case to Sri Lanka. Under the present capacity, the medium voltage network of Ceylon Electricity Board (CEB) in Colombo city is not adequate to cater the demand of Colombo Port City. Therefore, it is essential to implement a new grid substations and transmission lines to meet the demand.

1.4. Problem Identification

Accordingly, the implementation of a new grid substation/s to meet the demand, is considered for this research study. The location of substation/s, optimum value for medium voltage distribution, cost of cables, power losses, life cycle cost of cables, land usage shall be optimized subject to the following constrains,

- Optimum medium voltage for power distribution
- Extremely high land value
- Length of cable
- Voltage drop
- Availability of space is very limited
- Reliable supply shall be arranged
- Esthetic condition shall be maintained
- Power loss shall be minimized
- Possibility of providing new supplies/expansions

1.5. Motivation

The outcomes of this research will be used to develop a generalized model for medium voltage power distribution for a planned city under constrains and to set off guidelines for proper selection of optimum value for medium voltage power distribution.

It is a rare and worthy experience to obtain the chance to study about the optimum value for medium voltage distribution since utility was bonded only with traditional voltages. This would enable planners and other interested groups to gain an idea on how to arrange the medium voltage power distribution and its cost involvement under different scenarios before practically implementing them. According to my perception, the unplanned nature of inter related activities in Colombo city create bad experiences for many professionals in the field as well as to general public. Therefore, this research study was conducted to explain those difficult situations and further as self-satisfaction, while attempting to see others' perspectives as well.

Colombo Port City was selected as the case study due to the easy access to information. This study provided opportunities to design the power distribution in a modern city with the public, to promote a broader understanding of the value of lands and importance of the value of medium voltage power distribution system without limiting to traditional voltages. Further, this study founded the opportunities for me to utilize the experience and expertise as a utility engineer in order to address the difficulties that will be faced by the general public who will be living in urban areas.

1.6. Objectives of the Research

The main objective of this thesis is to introduce the optimal design for medium voltage power distribution in a planned city under constrains. It is to develop a suitable methodology to assist planners to build the correct in the right place with the optimum features.

The study was conducted by considering the following mentioned factors as major constrains to formulate a model for a planned city.

- Medium Voltage Distribution value
- Land Usage
- Power Loss
- Total Cost per KVA
- Optimum Location

This will be very important to design / estimate the possible arrangements of MV distribution. This information will be very much beneficial for the rapid development process of the country, since main purpose of this research is to introduce a methodology to assist engineers who are working with city planning activities.

1.7. Research Methodology

This study was conducted under descriptive research methodology, which is tabulated as follows,

- Familiarization of the development plan of a planned city
- Data collection of proposed city
- Demand calculation of proposed city
- Possible arrangements of Grid Sub Stations (GSS)
- Optimum voltage selection criteria
- Total cost for GSS arrangements
- Calculation of Losses
- Optimum location for GSS
- Applicability to Colombo port city
- Find out the optimum values for Colombo port city

Accordingly, this study discusses the methods of arranging the MV power distribution in a planned city under constrains in Sri Lanka. The outcomes of the thesis are diverse to the traditional MV distribution arrangement but it is in par with applicable standards.

The study begins with a brief discussion about existing MV values and arrangements, including a general overview of Sri Lankan power system. The second chapter discusses previous literature in relation to MV distribution values of other countries, environmental conditions, suitability of underground cables, overhead distribution for planned cities, cable selection, laying, testing & commissioning arrangements and reliability. The fourth section describes the optimum voltage selection criteria with a particular focus on the total demand of the selected area to be developed, MV values including cost involvements and total cost variation of GSS against the MVA rate. The optimum location selection criteria with a particular focus on the typical arrangement of planned city, minimization of losses and variation of land cost are discussed in the fifth section. The outcome of the research is discussed under the sixth chapter as the case study of Colombo Port City, which will demonstrate a set of solutions (optimal or closer) that can be considered simultaneously to finalize the design.

CHAPTER 02: LITERATURE REVIEW

2.1. Overview of Sri Lankan Power System

Power Systems operates for converting energy from some other forms to electricity and for distributing it to the consumers while maintaining its applicable standards. Traditional Power Systems consist with three main elements, i.e. Power Generation, Power Transmission and Power Distribution. Power Transmission system consists of a network of overhead lines or underground cables, especially in urban or densly populated areas. These lines are designed to transmit large amount of power from one point of generation to main grid sub stations (GSS). Medium voltage (MV) power distribution network is initiated from GSS to load centers. Power Distribution system consists of a network overhead lines and underground cables by which the power is distributed to the ultimate users and these users of electricity is called as the system load. These activities are carried out under various system voltages as shown in table 2.1.

Table 2.1: Accepted voltages for Power Generation, Transmission & Distribution

Activity	**Voltage Range (kV)**
Power Generation	*10 ~ 36*
Power Transmission	*115 ~ 400*
Power Distribution (MV)	*3.3 ~ 36*
Power Distribution (LV)	*0.4 ~ 0.11*

The power distribution is carried out under MV range; which is comparatively the largest network within the transmission network. There are few values to be experinced in MV power distribution activities, which are covered by the respecitve IEC standards, i.e. IEC 60071-1 and IEC 62271-1. The respective utilities are responsible for generating electrical power, transmitting the power and then distributing it to customers at appropriate voltage levels, while maintaining the reliability and power quality that are compiled to applicable standards as per the guidelines of Public Utilities Commission of Sri Lanka (PUCSL) [1].

2.2. Literature Reviews for Research Papers and Publications

2.2.1. "Reliability & Cost Optimization for Distribution Networks Expansion Using an Evolutionary Algorithm"

This paper [2] presents a multi objective optimization methodology using evolutionary algorithm to optimize the distribution network reliability. The research was mainly focused to expand the existing system while improving the reliability and minimizing the system expansion costs. It introduced optimal sizing for existing feeders and required locations for future feeders as well. Evolutionary Algorithm (EA) was selected as the methodology for optimization the study. EA is based on the idea of biological evolution that consists of four main functions as Inheritance, Mutation, Selection and Cross over to find the survival of the fittest. The algorithm can determine the set of optimal non dominated solutions for the reference of the user. The required Parameters for this study were set of existing routes / proposed routes and set of existing nodes / proposed nodes, set of nodes to build substations, set of proposed substation sizes to be built, routes between nodes etc. for the complete network. A new operator called filter operator, has been applied in the EA in order to limit the investment for reserve feeders. Author was not concerned about the protection arrangement of the optimized feeders and reserve feeders.

2.2.2. "Genetic Algorithm for Open Loop Distribution System Design"

The method proposed in this paper [3] was to ensure a given level of reliability of energy supply. Accordingly, distribution networks should be configured in such a way that each load point may be supplied from alternative sources, but it needs to be designed with minimizing feeder length, energy losses and load imbalance between transformers subject to voltage drop and capacity constraints. This is an extra cost for the system, but the reliability could be increased since it is very important to maintain the uninterrupted power supply, which needs to be achieved by planning tie lines, connecting different feeders or substations. Two levels of serviceability of energy distribution are notable as feeder serviceability level and transformer serviceability level.

Each pair of connected feeders forms a loop which may be supplied from two different sources. Thus an outage of any single section of a feeder does not cause an interruption of power delivery. But it shall be noted that the voltage drop and total load during the outage condition must be within the specified limitations and the transformers and cables shall be chosen which are to supply simultaneously to all the consumers belonging to the loop. To defer the capital investment in the replacement of existing transformers and to prevent unexpected faults due to transformer over loads, the load imbalances of transformers were minimized. Genetic Algorithm was selected as the optimization methodology of this research. The algorithm suggested in this paper is aimed at obtaining the optimal set of compromise solutions and it provides a set of solutions that may be considered simultaneously. But it is not possible to find a solution that the length, power loss and load imbalances are minimized simultaneously. It needs additional cost for over capacity equipment and cables.

Connecting two different feeders for one single load is not practiced at CEB network as a policy. But this combination was suggested in this paper to improve the reliability.

2.2.3 "Techno – Economic Feasibility Study on HTS Power Cables"

This paper [4] discusses about possible network concepts with superconducting cables for power transmission and evaluated technically as well as economically. It compares the network model with conventional XLPE cables and HTS (High Temperature Superconducting) cables. It indicated the possibility to replace the conventional multiple cables with HTS cables in high current capacity. The total loss of HTS cable is 50% to 35% of conventional XLPE cables and Life expectancy of all underground cables are considered as 35years and operating cost is considered as 2% of the investment cost. It compared a traditional network arrangement with XLPE cables and equivalent HTS network arrangement. The annual cost (K) of cable is considered as follows for both cases,

$K = K_d + K_v + K_o$

K_d = Investment cost

K_v = Annual loss cost

K_o= Annual operating cost

In this paper, possible network concepts with superconducting cables for power distribution network are discussed and evaluated technically as well as economically. Annual cost method was used for the cost calculation and it was applied to XLPE cables as well. The application of HTS cables were limited to 220kV and 110kV levels considering the economic feasibility and the XLPE is the more economical cable for lower voltage ranges, since the initial investment for HTS is very high.

2.2.4 "Optimization of Electrical Distribution Feeders Using Simulated Annealing"

In this paper [5], the simulated Annealing algorithm to deal with the electrical power distribution problem was discussed, where the objective is to minimize the sum of the total investment cost and of the total power loss cost. Afterwards, it was mainly discussed about the ways to minimize both the investment cost for feeders & substations and the power loss cost. Spanning Tree and Load Flow model was used to calculate the minimum investment cost for cables and further Spanning Tree methodology is used for connecting consumers radially to substations. Artificial node has introduced when connecting "n" consumers with "m" substations. Then a mathematical model was formulated subject to following conditions as the distribution network has radial configuration, each consumer is powered by a unique substation and feeder capacities. Both investment cost and power loss cost depend on the type and size of the feeders used on the arcs. It was mentioned that generally the investment cost increases and power loss decreases with the size of the feeder. Hence a tradeoff is required to minimize the total cost.

Further, it is worthy to introduce Ring arrangement to improve the reliability as it was limited to radial distributions, which facilitate to feed each customer by an alternative feeder. Optimum value for the medium voltage distribution is not considered during the objective function as it was based on the existing voltage. But power loss cost could be possibly minimized with higher distribution voltages and it will helpful to reduce the losses further.

2.2.5 "Research on Optimization Planning Method of Distribution Network Based on Spatial Load Forecast"

This paper [6], mainly discusses on load forecasting and power grid planning in urban area. Power grid planning is an important aspect in the development of power grid. With the rapid development of urban construction and electricity demand in the recent years, electric power construction is faced with more kind of pressure, such as land resources, environmental protection etc., which has impacted on a rapid increase of the difficulty of power grid planning. How to build a distribution network that the load and the urban construction can develop concordantly; has become a key issue to be solved in the future. The traditional methods of distribution network planning focus on the grasp of the overall, whereas lack consideration has paid on the spatial distribution of load and planning of urban development. Thus, this paper proposes a method based on spatial load forecasting of urban distribution network planning, and fully considers the load distribution of the space characteristics and urban construction. This method can be effectively used to make up the defects of traditional methods, which also has a certain value and reference significance.

In the traditional planning methods, the determination of substation capacity is based on the load forecasting results and capacity-load ratio, which belongs to the total forecast method. In this article, the substation capacity planning focuses on "bottom to top" thinking; by which it gives full consideration to the spatial distribution characteristic of the load. First of all, according to the load distribution and the main transformer power supply capacity, several power supply zones are divided reasonably in the whole planning area partition. According to main transformer capacity specification and the best economic operation load rate, the load of the transformer $P_n$is determined, as shown in the following equation:

$P_n = {}_n \times S_n \times \psi \times \beta$

Where, P_n=Transformer substation load,

S_n = Transformer Capacity

n = Number of Transformer units

ψ = power factor

β = Transformer load rate

It should be noted that the load rate of the main transformer should be closer to the level of economic operation of the main transformer, at the same time, it should consider the requirement of N-1 level of the MV power grid, which is related to the load transfer capacity of the network.

2.2.6 "Load Determination and Selection of Transformer Substations' Optimal Power for Tasks of Urban Networks' Development"

This paper [7] considers an approach to solve some problems of urban 110/10-20 kV network development until 2020 in Riga City under the constraints of information uncertainty. It reveals several information regarding; the forecast of the total load of the Riga city until 2020, the definition of loads of existing & new substations until 2020, the choice of 110/10-20 kV substations, the optimal power, the location of new substations etc.

The Urban Power Supply System (UPSS) is a system of continuous development. The elements of such system are objectives of long-term or medium-term design. In order to solve the problems of development on such a prospect, accurate background information and detailed guidelines should be projected. It means that the challenges of development occur under the limits of incomplete and uncertain information.

With the aim of forecasting the Riga electrical load, following concerns were taken into account;

- The actual load of 110 kV transformer substations by measurements from 2000 to 2008
- Load of consumers growing by years

- Marketable power of new objects
- Technical possibilities to cover new declared powers and another factors.
- A variant of forecasts are taken for:
  - 3% year load growing, beginning from 2008 till 2020 in favourable scenario of the economic development (AS Latvenergo forecast till beginning of crisis of the economics)
  - 2%, 1.7%, 1.3% and 1.1% year load growing in disadvantaged status of the economic development, without excluding the period of recession in the economy
  - 2%, 1.7%, 1.3% and 1.1% year load growing in disadvantaged status of the economic development with the period of recession from 2008 till 2012, without load growing and with improvement of economic situations since 2012.

However, the deteriorating economic situation leads to the need of periodically adjustments on the previously made predictions.

2.2.7 "A Review on Building Energy Consumption Information"

This paper [8] analyzes available information in relation to energy consumption in buildings and particularly related to HVAC systems. Many questions such as; Is the necessary information available? Which are the main building types? What end users should be considered in the break down? have arisen. Accordingly, this paper presents comparisons between different countries, especially for commercial buildings; and the office context is analysed in deeper detail. The rapidly growing world energy usage has already raised concerns over supply difficulties, exhaustion of energy resources and heavy environmental impacts (such as ozone layer depletion, global warming, climate change etc.). The global contribution from buildings towards energy consumption, both residential and commercial, has steadily increased reaching figures between 20% and 40% in developed countries, and has exceeded the other major sectors: industrial and transportation. Growth in population, increasing demand for building services and comfort levels, together with the rise of time spent inside buildings, assure the upward trend in energy demand will continue in the future. In addition, energy efficiency in buildings has become a prime objective today, which has resulted in creating energy policies at regional, national and international levels. Among building services, the growth of energy usage in HVAC systems is particularly significant (50% of building consumption and 20% of total consumption in the USA). However, available information is clearly insufficient and not proportional to its importance. It is not considered as an independent sector and there is a lack of consistent data which makes it difficult to understand the underlying changes that affect energy consumption in this sector. Therefore, it is essential to make available comprehensive building energy information to allow suitable analysis and efficiently plan energy policies for the future. In that respect, studies developed by the EIA (Energy Information Administration) on the energy consumption of residential and commercial buildings in the USA are a valuable reference.

The growing trend in building energy consumption will continue during the coming years, due to the expansion of built area and associated energy needs, as long as resource and environmental exhaustion or economic recession allows it. Private initiative, together with government intervention through the promotion of energy efficiency, new technologies for energy production, limiting energy consumption and raising social awareness on the rational use of energy will be essential to make the sustainable energy future, a possible.

2.2.8 "Building Energy Benchmarking Report, 2014"

The requirement of this report [9] prepared by Building and Construction Authority (BCA) of Singapore is to address the issues faced by building owners of the country regarding one of the requirements mandated for building owners; i.e. to complete the annual submission of their building information and energy consumption data through BCA's online submission portal (Building Energy Submission System - BESS). For the first year, commercial buildings consisting offices, hotels, retail buildings and mixed developments were targeted to complete the submission. The overall period of submission was between 1st July and 31st December 2013. In addition, BCA supported with extensive public outreach efforts to drive submissions.

To address the challenge of securing credible and quality data, energy consumption data were obtained directly from utility suppliers, while building information was furnished by building owners. However, following challenges encountered during this process, which includes;

- Lack of informative system-generated reports for building owners and policy makers via BESS
- Building owners' unfamiliarity with the information required by legislation
- Building owners' oversight, which led to data entry errors at the submission
- Inadequate knowledge of terminology used for technical fields in BESS submission form
- Lack of up-to-date contact information of targeted building owners
- Energy Utilisation Index (EUI) of commercial buildings
- Among the four main commercial building types, retail buildings recorded the highest median EUI (at 405 kWh/m2.yr), which could be attributed to the wide variety of tenant mix. Further, the design concept of retail shops requires a higher lux levels to enhance the demand of their products.
- Hotels recorded a lower median EUI (at 292 kWh/m2.yr) compared to retail buildings, and hotels demand a lower cooling load due to the lower human density and stable occupancy rate within its premises.
- Offices had the lowest median EUI (at 218 kWh/m2.yr), which was due to shorter operating hours and stable operations with a fairly fixed occupancy rate.
- The average EUI of Green Mark commercial buildings were lower than the average EUI of similar non-Green Mark commercial buildings.
- The average EUI of Green Mark commercial buildings ranged from 16% lower for offices, to 7% lower for retail buildings and 5% lower for hotels.

The above details are vital to calculate the total demand of any development that follows the Singapore building architecture.

2.3 Standard Values for the Medium Voltage (MV) Power Distribution

There are few MV values and bus bar ratings involve with the MV products of leading manufactures like Siemens, AG - Germany, ABB, Mitsubishi Electric, Tamco (Malaysia), Schneider Electric etc. The above manufactures are leading suppliers of MV products to Ceylon Electricity Board and to other utilities in the world [10]. Table 2.2 gives the commonly available MV values and bus bar ratings of the MV panels that are manufactured by above suppliers.

Table 2.2: Standard voltages for MV power distribution

Rated voltage kV rms	Rated lightning impulse withstand voltage 1.2/50 µs 50 Hz kV peak		Rated power-frequency withstand voltage 1 min kV rms	Normal operating voltage kV rms
	List 1	List 2		
7.2	40	60	20	3.3 to 6.6
12	60	75	28	10 to 11
17.5	75	95	38	13.8 to 15
24	95	125	50	20 to 22
36	145	170	70	25.8 to 36

Source: Table 1a of IEC 62271-1

There are few defined or commonly usable voltages for the MV distribution as per the Table "1a of IEC 62271-1" and few bus bar ratings are also commercially standardized as follows. Table 2.3 illustrates the applicable bus bar ratings for MV values.

Table 2.3: Standard Medium voltage values & Applicable Bus bar ratings

Medium Voltage Vi (kV)	Rated Bus bar Current - Ir (A)			
6.6	1250	1600	2500	3150
11	1250	1600	2500	3150
22	1250	1600	2500	3150
33	1250	1600	2500	3150

Bus bar ratings were varied from 1250A to 3250A according to the table 2.3, but it was noted that, the bus bar rating of 3150A is considered as very high due to the difficulties in cable handling, operation and maintenance activities. The cost of above range is also very high, as it is a special product that will produce only on request. Therefore, it shall not encourage using this rating for GSS in Sri Lanka and it is clearly beyond economical optimization.

Further, there are four major voltage classes, i.e. 5, 15, 25, and 35 kV, defined by IEEE and following study was conducted to identify the usage of MV values by the utilities in the world. A voltage class is a term applied to a set of distribution voltages and the equipment common to them and it is not the actual system voltage. Figure 2.1 illustrates the usage of MV values of various utilities in the world to cater their demand.

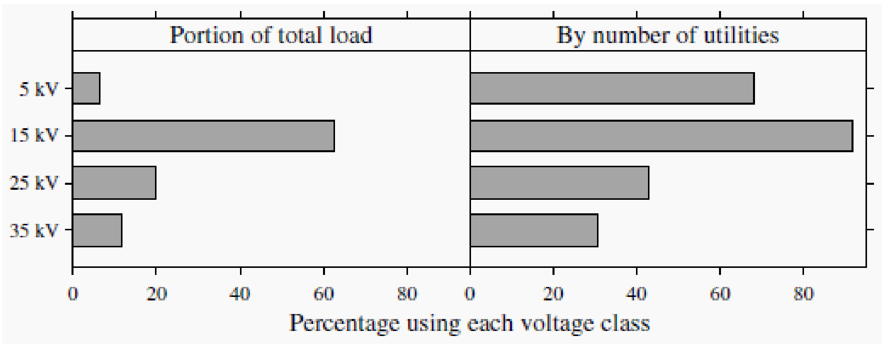


Figure 2.1: Usage of different distribution voltage Classes

Source: IEEE working group on distribution protection, 1995

2.4 Supply Record of few Leading Manufacturers in Last 10- 15 years of Period

The aim of this analyse is to study the applicability of various MV values which are used in other countries. Further, new trends and historical developments of MV distribution were also understood by referring such documents [10]. Availability of spares and supply record of spares are also very dominant factors to maintain smooth operation of the selected MV system. Few end user certificates were also referred to verify the records given by the manufactures, which includes;

- Supply record of Siemens – AG Germany
- Supply record of Mitsubishi Electric
- Supply record of Tamco Electric

The above supply records are clearly indicated that the usage 11kV, 22kV and 33kV are very high, but few other values were also manufactured like that 3.3kV, 6.6kV, 17kVetc. on the request of the customers.

2.5 Most Common MV Distribution Values in Sri Lanka

There are four MV values, which are indicated in table 2.3; and among them, only two values are generally being operated in Sri Lanka, i.e. 11kV and 33 kV [11]. But it was found that few industrial cities like that Ceylon Steel Corporation Ltd, Kabool Lanka Ltd and Pelwatta Sugar Ltd are being operated as 6.6 kV for the MV distribution value. The all above industrial cities were initially developed as planned cities.

2.6 Importance of Selection of Medium Voltage Value for Power Distribution

There are few commonly available voltage values for power transmission and distribution activities. Main purpose of an electrical utility in a country is to supply an un-interrupted power supply to the end users by maintaining the acceptable standards [1]. Hence, transmission and distribution network ensure the transferring of the generated electrical power to end users. Power transmission is done in High Voltage (HV) while power distribution is done in Medium Voltage (MV) and Low Voltage (LV) levels. In various countries, these HV, MV and LV levels are defined in various limits, but these are approximately same for all countries [10]. Majority of MV power distribution systems in the world are operated in the range of 11kV to 33kV and the values vary greatly from country to country, depends on historical development of technology, traditional methodologies and load conditions. In Sri Lanka, MV level is defined as 33 kV and 11kV for the utility [11]. When selecting the operating voltage of an MV system, it is also important to consider the availability of grid capacity, substation sites and their cost. In many situations, owing to the historic development in Sri Lanka, there are only two choices as standard voltages of 11 or 33kV [11] and the selection of the MV depends on the MV value of the vicinity area.

It needs more GSS when the MV value is less and vice versa. More GSS means that it needs more locations and very difficult to find suitable locations since allocation of land is a high cost activity due to overcrowded conditions in developing areas.

The MV distribution is mainly carried out via Aluminium / Steel conductors, copper conductors or HV underground cables. Few commonly used conductors and cables are known as ACSR, RACOON, ELM, ZEBRA, XLPE, Oil Impregnated etc. Most of MV underground cables are made of copper [12]. Over the past 10 – 12 years of period, the cost of copper has increased from $0.72/lb to $4/lb due to huge demand and scarcity of the material, which is shown in figure 2.2.

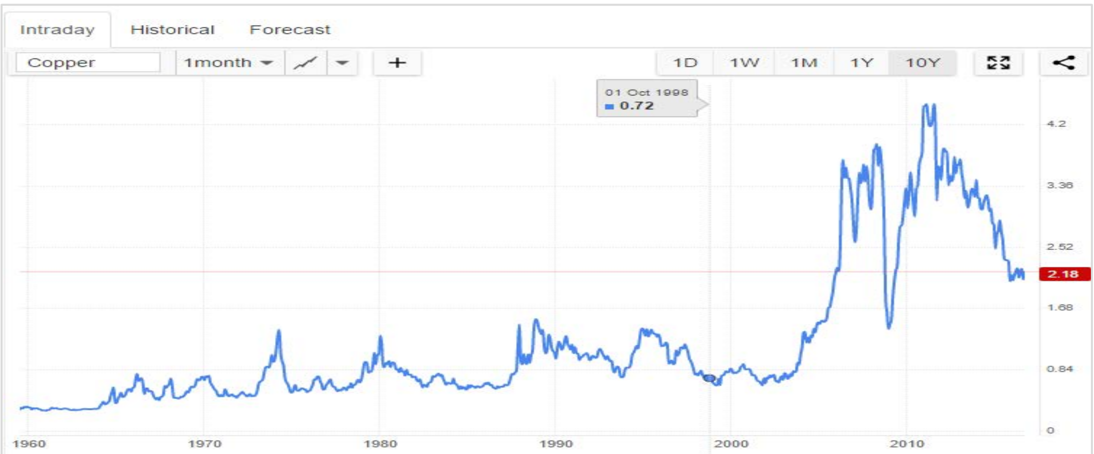


Figure 2.2: Historical variation of copper prices

Source - http://www.tradingeconomics.com/commodity/copper#historical

According to the figure 2.2, the highest increased of copper prices was more than a 400%, recording a maximum scenario [13]. As this cost continues to increase, Design Engineers are trying to find ways to reduce the amount of copper in the distribution systems. One method is implementing MV distribution systems or introducing HV for MV power distribution by selecting higher values of the table 2.3 of the normal operating voltage column. Then, the current load will reduce, resulting in less voltage drop. This smaller voltage drop eliminates the need to oversize conductors and it makes the overall system more efficient and cost effective. Smaller or fewer usage of conductors decreases the amount of copper and the related costs. It is necessary to consider the combined technological and financial effects of utilizing all the possible voltage levels, before determining the optimum voltage for the area under consideration [14]. Higher voltage leads to higher insulation costs, but also usually results in lower conductor and system loss costs; and substation cost will increase, but the number of substations required to supply the MV network will be less. In addition, a higher voltage level leads to a lower percentage voltage drop per unit length for a given loading, and thus longer feeder lengths are possible without using booster transformers or capacitors [15].

2.7 Environmental Issues Concerned of MV Power Distribution Networks in a Planned City

A MV distribution network is having its own green areas and planted trees along the roads and other suitable places to enhance the environmental beauty, aesthetic and architectural features. The impact to the environment due to the MV distribution network depends on its arrangement of overhead or underground cable system. Way-leaves clearance is the biggest effect to the environment in any overhead line arrangement, which anyhow will not applicable when the distribution network is based on underground cables. But the cost difference between construction of overhead lines and underground cable is considerably high [16] [17]. However, underground cable system could be considered as a positive exercise when the land value is extremely high, because it would then require smaller rights-of-way. Then it indicates that the total supply and installation cost of underground cable network is worth in case, when the land value is extremely high and when it is possible to minimize the hazards to the urban environment [16].

2.8 MV Distribution Arrangements

MV distribution arrangements will be selected as overhead distribution system or underground cable network that complies with other applicable factors to the area to be developed.

Overhead lines are generally mounted on wooden, concrete or steel poles which are arranged to carry distribution transformers in addition to the conductors. It was governed with applicable construction standards, such as clearance from ground and nearby buildings, including impact of EMF as well as swing of conductors to allow wind blowing across the lines at specific speeds. Usually, the line height is determined according to the applicable standards and the maximum sag between poles. When designing the GSS with overhead power lines, engineers should consider these factors as well as extreme weather conditions [18].

The underground system uses conduits, cables and manholes under the surface of streets and sidewalks. There are few methods for underground cable laying/ construction works as open ducting, horizontal direct drilling (HDD), laying in ducts, laying in common underground trench etc. HDD is trenchless technology for cable laying and can be a useful technique for installing cables where open excavation may prove uneconomical, restricted or difficult. There are few varying techniques which may be applied for HDD including impact mole boring, push rodding, auger boring etc. Careful planning is essential in determining the route with its launch and receive pits and in accurately locating the points at which existing underground services cross the route. If necessary, trial holes must be excavated at crossing points to ensure that no damage results from the passage of the mole.

2.9 Comparison of Overhead and Underground Power Distribution

The choice between overhead and underground system depends upon the number of widely differing factors. Therefore, it is desirable to make a comparison between the two arrangements, in relation to different factors.

I. <u>Public safety</u>

   The underground system is safer than overhead system because all distribution wiring is placed underground and there are little chances of any hazard.

II. <u>Initial cost</u>

   The underground system is more expensive due to the high cost of trenching conduits, cables, manholes and other special equipment.

III. <u>Flexibility</u>

   The overhead system is much more flexible than the underground system, because in the latter case, manholes, duct lines etc. are permanently placed once installed and the load expansion can only be met by laying new lines. However, on an overhead system, poles, wires, transformers etc. can be easily shifted to meet the changes in load conditions.

IV. Faults

The chances of faults in underground system are very rare as the cables are laid underground and are generally provided with better insulation.

V. Appearance

The general appearance of an underground system is better as all the distribution lines are invisible. This factor is exerting considerable public pressure on electric supply companies to switch over to underground system.

VI. Fault location and repairs

In general, there are little chances of faults in an underground system. However, if a fault does occur, it is difficult to locate and repair on this system. On an overhead system, the conductors are visible and easily accessible so that fault locations and repairs can be easily made.

VII. Current carrying capacity and voltage drop

An overhead distribution conductor has a considerably higher current carrying capacity than an underground cable conductor of the same material and cross-section. On the other hand, underground cable conductor has much lower inductive reactance than that of an overhead conductor because of closer spacing of conductors.

VIII. Useful life

The useful life of underground system is much longer than that of an overhead system.

IX. Maintenance cost

The maintenance cost of underground system is very low as compared with that of overhead system because of fewer chances of faults and service interruption from wind, storm, and lightning as well as from traffic hazards.

X. Interference with communication circuits

An overhead system causes electromagnetic interference with the telephone lines. The power line currents are superimposed on speech currents, resulting in the potential of the communication channel being raised to an undesirable level. However, there is no such interference with the underground system.

It is clear from the above comparison that each system has its own advantages and disadvantages. However, comparative economics is the most powerful factor influencing the choice between underground and overhead system. The greater capital cost of underground system prohibits its use for distribution. But sometimes non-economic factors (e.g. general appearance, public safety, right of the way etc.) exert considerable influence on choosing underground system. In general, overhead system is adopted for distribution and the use of underground system is made only where overhead construction is impracticable or prohibited by local laws.

Very recently Colombo Municipal Council (CMC) has taken a policy decision that they will not allow overhead construction for power distribution within the Colombo city limits. This decision will be followed by other urban areas also in near future as per the comments given by Colombo municipal commissioner. In the modern era, overhead transmission lines become irrelevant in the development of some new cities as underground cables become mandatory [16] and various advantages have been presented about underground cables. However, there are significant challenges in the underground network as same as it has benefits, it is essential to carefully design, implement and maintain an underground power network if it is the selected solution for development [16].

2.10 Selection of the Type of Underground Cable

Since there are several types of underground cables such as XLPE, Oil cables etc exists, a proper selection of an optimum cable is very critical. This is one of the main elements in designing underground power systems. Selecting the best available and reliable underground cable technology has the potential of overcoming many of the cost, safety and environment related issues. XLPE cable is the major developing technology and has wide industry acceptance at voltages up to extra high voltage levels. This type of cable uses vulcanized polyethylene insulation, which is solid insulation extruded onto the conductor during cable manufacture. For high quality insulating properties, the raw materials must be free of contaminants and vulcanizing process must ensure homogeneity and absence of voids and moisture in the insulation. Compared with traditional oil-filled cable, it is considered to be a simplified and advanced technology. During the last decade, no other power cables have had such a high rate of improvement as XPLE cable technology [19].

2.11 Cable Laying Methods and Arrangements

Proposed cable route, locations for cable jointing and the site shall be inspected by all the parties who involve in completing, and following mentioned factors will be carefully observed; [20] [21].

- Existing UG services
- River and canals to be crossed
- Identify hazards and assess risks that may result
- Decide control measures to prevent or minimise the level of the risks
- Implement control measures
- Traffic management
- Public and worker safety
- Potential weather conditions during the work

It is the responsibility of all staff engaged in underground cable installation to comply with appropriate legislation and applicable standards. The legal framework for health and safety at work is set down in a variety of legislations including Acts of Parliament and Statutory Regulations [20].

2.12 Details on Cable Trenches, Cable Laying and Testing

Unless it is ensured from co-ordination drawings that the route is relatively clear of obstructions, trial holes are taken at proposed joint locations and such other positions along the route, as it is necessary to ascertain the practical positioning of the cable. Trial holes should generally be at right angles to the run of cables and at least 150mm deeper than the proposed trench [20] [21]. Surface covers belonging to other utilities may give a guide to the location of their equipment. The actual width of the cable trench depend on,

- Type and size of the cable being laid
- Number of cables being laid in the same trench
- If low and high voltage cables being laid in same trench, the effect on the other cable rating must be considered.

As a result, the trenches should have,

- Lines, levels, and contours to suit continuous pulling of cable by winch.
- To be as straight as possible, where bends are unavoidable, the trench should allow the cable to be installed at not less than its minimum-bending radius using cable rollers.
- To be according to the approved dimensions and normally have vertical sides and should the ground be soft or loose.
- To be excavated with such precautions as are necessary to prevent damage to the highway or ground surface from a slip or breaking away of the sides of the trench. Accordingly, cutting by machine is preferred.
- To be excavated so that all railways, tramways, walls, roads, sewers, drains, pipes, cables, structures, places, shall be secure against risk of subsidence or damage, and shall be carried out to meet the requirements of the authorities concerned.
- Where they pass from a footway to a roadway or at other positions where a change of level is necessary, have a base that rises or falls gradually.
- The bed of the cable trench shall be free from water, stones, and pieces of rock that may cause damage to the cable.
- Crushed limestone dust 3mm to dust, or crushed granite, 3mm to dust, shall be imported and should be laid to provide suitable bedding for the cable or duct. Once the cable or duct has been laid onto the bedding, a further layer of crushed limestone dust or crushed granite dust shall be applied; this shall be for a depth of 75mm above the cable or duct.
- Positioning the rollers is necessary to avoid abrasion of the cable by keeping it clear of the ground and to reduce friction during pulling. The ramps built into the straight and corner cable rollers allow the cable end to ride over without being lifted. These rollers are, therefore, suitable for either winch or hand pulling.

- Cable Drums - Handling and Positioning

  When handling drums, suitable precautions should be taken to avoid damage to the cable and injury to people. Due regard should be paid to the mass of the drum, the method and direction of rolling and the method of lifting. It is preferable to move drums by special cable drum trailers for ease of handling & safety and whenever possible the cable should be laid direct from these. In certain cases it may be possible to lay cable from a drum trailer whilst it is being towed alongside the trench, thus giving a considerable saving in time and effort.
- Before laying a cable, proper locations for the proposed cable joints (if any) shall be decided, so that when the cable is actually laid, the joints are made in the most suitable places. As far as possible, water logged locations, carriage ways, pavements, proximity to telephone cables, gas or water mains, inaccessible places, ducts, pipes, racks etc. shall be avoided for locating the cable joints. Joint pits shall be of sufficient dimensions as to allow easy and comfortable working. The sides of the pit shall be well protected from loose earth falling into it. It shall also be covered by a tarpaulin to prevent dust and other foreign matter being blown on the exposed joints and jointing materials.
- Testing before laying all cables with a 500V mega for cables of 1.1KV grade, or with a 2500/5000V mega for cables of higher voltage should be performed. The cable cores shall be tested for continuity, absence of cross phasing, and insulation resistance from conductors to earth / armour and between conductors [21].
- All cables shall be subjected to the above mentioned tests, before covering the cables by protective covers and back filling and also before taking up any jointing operation.

2.13 Major Cost Components of GSS

Following items were considered to prepare the engineering estimates for all GSS arrangements. Land cost shall be added to the total cost and it was not included to engineering estimate due to its variation based on the location.

- High Tension Indoor Switchgear
- MV Indoor Switchgear

- Auxiliary Supply
- Batteries, Chargers and Distribution Boards and Inverter Equipment
- Protection, Control, Metering and Monitoring
- SCADA and Communication System for NCC
- Substation Earthing
- Lightning Protection System
- Grounding System
- Power Cables, Control Cables, Termination Kits, Cable Trays and Supports
- Power Transformers
- Neutral Earthing Resisters, Disconnectors and Earthing Switches
- Diesel Generators
- Supporting Structures
- LV installation
- Miscellaneous works
- Spare parts
- Tools and Instruments
- Design services for substation
- Total cost of civil construction
- Building services installation cost
- Testing and commissioning

2.14 Estimates on Supply, Delivery, Installation and Commissioning of a GSS

Following offer was selected as the reference document, since it was the latest bid submission to CEB and the respective GSS which will be constructed in the city of Colombo. Therefore, the rates applicable to above offer is greatly reasonable to work in congested city / developing area.

- Successful offer to Greater Colombo Transmission & Distribution Loss Reduction Project of CEB, 2015 by “HYOSOUNG Corporation – KOREA” to supply, installation & commissioning of GSS in Colombo.

2.15 (N-1) Criteria for GSS

In transmission network, the typical design concept is the “N-1” reliability criteria. N-1 is referred to as any single component failure in the supply network will not affect the electricity supply. Hence in case of a failure of a transmission line, or a transformer connected to the distribution primary substation from the transmission source, the supply to the distribution network will not be affected. It is normally achieved with suitable protection and associated inter tripping or switching scheme to the distribution incoming from the transmission network. Generally GSS are designed to cater for the loss of critical network components (e.g. an incoming cable or a power transformer) without causing network overloads or unstable operation. Hence the primary substation is thus designed to supply the load based on the “N-1” criteria [22].

CHAPTER 03: RESEARCH METHODOLOGY

The objective of this research is to introduce the Optimal Design for Medium Voltage Power Distribution in a planned city under constrains. The applicable methodology to achieve the research objective and main milestones of the research area are described as follows,

1. Optimum Voltage selection criteria
2. Optimum Location selection criteria
3. Case study of Colombo port city

These milestones were further subdivided in to several steps for easy analysis and for creating feasible way towards the outcome. Accordingly, it can be employed for developing a suitable methodology to assist planners in order to build a correct design for MV power distribution in the right place with optimum features. Following factors have considered as key constraints when formulating a model for a planned city,

- MV Distribution Value
- Land Usage
- Power Loss
- Total Cost per KVA
- Optimum Location

A descriptive research methodology was used for this study, which is tabulated as follows,

- Familiarization of the development plan of a planned city
- Data collection of proposed city
- Demand calculation of proposed city
- Optimum voltage selection criteria
- Possible arrangements of GSS
- Total cost for GSS arrangements
- Calculation of Losses
- Optimum location for GSS
- Case study of Colombo port city
- Realize the optimum values for Colombo port city

This study discusses the modes of arranging the MV power distribution in a planned city under constrains in Sri Lanka, including a case study for easy reference and to make the thesis more presentable. The outcomes of the thesis are assorted to the traditional MV distribution arrangement, while keeping it in parity with applicable standards.

When a planned city is designed, first the conceptual master plan is prepared by Architects with the assistance of developers as the initial step. Therefore all detailed engineering work will be started and based on the above conceptual master plan subject to the applicable commercial policies of utilities and local authorities [23]. This was described as familiarization of the development plan of a planned city and required data collection of proposed city.

Subsequently, the individual and total demand is calculated, based on the applicable local or international standards and usage of the buildings / vendors or users [9]. If the calculated total demand is very high or if the capacity of existing network becomes inadequate to cope with the demand due to high load density, it needs to select the suitable MV distribution arrangement to cater the total demand. This shall be a MV distribution system with several substations and grid substations. The optimum value for MV distribution shall be selected and the selection process is called optimum voltage selection criteria. Therefore when it comes to the electrification of a country or an isolated area, for instance, a planned city, industrial park, large island etc; the distribution system and the medium voltage that need to be used within the proposed electricity network is a major factor to be taken in to account at the very early stage in the planning of the new network. Required number of GSS will vary and depend on the choice of the MV value and the respective bus bar rating of the MV side. All the criteria are further described in chapter 04.

When the MV value and the required number of GSS for the development are finalized, the next step is to find the optimum location/s for the installation of GSS. It may obtainable few lands / locations for the utility, but the cost and other related factors of the lands may vary and the cost variation also may be considerably affect to the final decision. Finally the land value will be a significant figure for the total cost. The total loss cost and annual cost of the MV network also depend on the locations of GSS. Therefore optimum locations for GSS become an important factor during the design stage of a planned city / industrial park or similar development. Besides, the main purpose of the optimum location selection criteria is to address the technical / non-technical requirements and financial conditions in an optimum manner. This is discussed in the chapter 05 of the research report.

The final aim of the thesis is to evaluate the situation, by selecting Colombo Port City as the case study. Accordingly, the conceptual master plan is illustrated in figure 3.1. and figure 3.2.

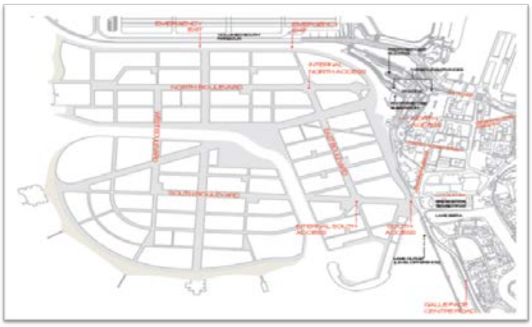


Figure 3.1

Figure 3.2

The conceptual master plan of Colombo Port City complex
Source: “PORT CITY CONCEPTUAL MASTER PLAN” [24]

Colombo Port City will be developed under three main stages from (I) to (III). All the findings of the research were applied to the conceptual master plan [24] of the Colombo Port City development project, in order to determine the required number of GSS, optimum value for MV power distribution, optimum locations and its cost involvements. The key benefit of the above methodology is that it provides a set of optimal solutions, subject to relevant constraints, that may be considered simultaneously. This is especially important when planning a MV distribution system, where the optimization problem is multi objective. Finally, this will facilitate the city planners to select a suitable solution / arrangement, depending on the cost involvement and other related factors.

CHAPTER 04: OPTIMUM VOLTAGE SELECTION CRITERIA

4.1 Importance of Optimum Voltage

The power transmission and distribution networks ensure the transfer of electricity from points of generation to substations / end users. The points of generation are power stations that generate electrical energy from various primary energy sources. Power transmission lines are utilized to deliver the generated electrical energy to GSS which are stepped down the transmission voltage to Medium Voltage. These GSSs are the places which the energy is delivered to end users /customers. This process is taken place via the "Medium Voltage Distribution Network" which is a main object of this optimization process. But the traditional arrangement, i.e. single medium voltage substation with one point of supply from the existing network and one or more distribution transformers for supplying low voltage loads is not sufficient in large infrastructure projects. Instead, an internal, separately operated MV system with several substations, along with planning of MV GSS are required, because there are high load concentrations in different areas of a large building complexes (such as high-rise buildings used in the infrastructure) or the distribution of loads over large areas (such as industrial plants, production plants, hotels, mixed developments and hospitals etc.). Those arrangements were unable to cater from the traditional arrangement and; moreover, the feeding arrangement was varied according to the total demand [23].

Therefore, when electrifying a country or an isolated area (such as a planned city, industrial park or large island), the distribution system and medium voltage to be used within the proposed electricity network, have to be taken in to account as the key factors at the very early stages in the planning process of new network. It is also necessary to consider an appropriate higher voltage, when an existing network voltage becomes inadequate to cope with high load density, such as in developing city areas, planned cities etc [23]. Thus, it is necessary to conduct a techno economic evaluation to identify the most economical value for MV distribution, irrespective of implementing the traditional arrangements.

4.2 Demand Calculation

The traditional planning method of distribution networks is “from top to bottom”, which determines the total demand and grid structure of distribution network through the supply capacity and distribution of the main network [6]. However, some adequate capacity for future demand is not there in the traditional planning method. Generally, all power distribution systems need continuous development due to the addition of loads to various locations and growth of existing demand. The requirement of such developments focuses on achieving the objectives of long term or medium term power distribution development plans. This is mainly based on load forecasting due to the conditions of incomplete and uncertain information [6].

The electricity demand in many developing countries in Asia and the Pacific will continue to rise, probably due to rapid urbanization, expanding economies, unplanned development activities etc. If the demands are finalized or planned, then the distribution system could be finalized very accurately with reasonable margin for future expansions. Thus, in the context of a planned city, the demands are well defined, subject to minor variations. Therefore, the total demand shall be calculated with reasonable accuracy, but it is necessary to cater the future demand also. Load forecasting is vitally important for the electricity industry, due to the deregulated nature of economy. It has many applications including energy purchasing & generation, load switching, contract evaluation and infrastructure development [6] [23]. Hence, the demand calculation is a key activity to finalize the MV power distribution arrangement of any development process or planned city with various kinds of buildings, parks and other activities.

Demand calculation for any development is based on country’s standards or respective international standards. Sri Lanka Sustainable Energy Authority has prepared a comprehensive document [25], to calculate the energy demand of few selected sectors based on the average consumption of the buildings, hotels, industries etc. But the average energy consumption of Sri Lankan buildings is very much less, comparing to the buildings in developed countries like that Singapore [9]. Therefore, it is prudent to verify what building architecture will be followed for the development and its usage. If the building architecture and its activities will be created following the famous Singapore buildings, it shall be calculated the demand based on the Singapore standards, i.e. by referring the Building Energy Benchmarking Report, Singapore [9]. Electricity consumption in most of the developments is constantly increasing, while several authorities are being conducted energy efficiency improvement programs. Further, some regulations have been made towards energy demand reduction and energy systems improvement. Since the electricity demand affects the operation of the supply and distribution plants and the thermal loads of buildings, the importance of keeping a proper allowance / additional amount for initial demand is essential. Therefore it was added 10% margin to the calculated demand as future expansion and unforeseen loads [8] [26].

4.3 Possible Arrangement of Grid Substations

There are many GSS and different bus bar system schemes with various capacities, but the selection of a particular scheme depends upon the system voltage, position of substation, flexibility needed in system and cost to be expended. Further, the commercial policy of the respective utility is also very important [23]. If the total demand of the extension exceeds 1MVA, it is necessary to arrange high tension metering arrangement with panel substation for power distribution activities. When the demand exceeds 10MVA, it is necessary to have a GSS as per the commercial policy of the utility [23]. Therefore, the distribution arrangement exclusively depends on the demand of the extension / new development and the applicable commercial policy.

When it comes to a planned city or industrial zone, the value of total demand will be very high and it needs few GSS to cater the maximum demand. This is mainly depending on the total demand and space availability of the entire complex or the selected section to be developed. The total demand of the complex shall be calculated as per the standard guidelines published by relevant authorities. If necessary, the proposed area could be divided into few sections, depending on the demand, geographical condition, administrative requirements or population to propose a more customized arrangement.

Sometimes there may not be strong recommendations for internal divisions; therefore, each planned city needs to develop its own innovative and appropriate way based on the other factors such as cost and availability of land, preferences of developers etc. Once that process and load calculations are finalized, possible arrangements of GSS need to be considered. There are few acceptable MV values with respective bus bar ratings for standard GSS arrangements, which are shown in table 4.1; and the single bus bar arrangement is considered for it.

Table 4.1: Commonly available MV values against Bus Bar Ratings of MV side for GSS

Medium Voltage Vi (kV)	Rated Bus bar Current - Ir (A)			
6.6	1250	1600	2500	3150
11	1250	1600	2500	3150
22	1250	1600	2500	3150
33	1250	1600	2500	3150

However, GSS with very high bus bar rating as 3150A for MV side is normally not recommended, due to practical difficulties for cable laying, cable handling, and operation & maintenance activities on huge arrangements. Further, 3150A rated Bus bar is generally not available with most of the leading manufactures and it is available for special orders or designs, and similarly, the unit cost is comparatively higher [27]. Therefore, the designs with that rating may not feasible and it is advisable to avoid it.

4.4 Required Number of GSS

Required number of GSS will vary and depend on the selection of MV value and the respective bus bar rating of the MV side. Electrical power system planning models have usually considered a single objective function, subject to some common constraints such as power demand requirements and maximum power capacity constraints of feeders and substations. Reliable power supply is an important factor when developing a planned city or industrial park, as there are more consumers in such places and their demands are in MVA range. It is not possible to maintain the standby power generators for the consumers those who are consuming MVA range due to practical difficulties.

By considering above facts, a norm is introduced as the required number of GSS shall be greater than one (01) per stage or selected area, even the utility is maintained the N-1 criteria for GSS [22]. Therefore, it is necessary to find the minimum requirement of GSS, to cater the complete demand under above constraints. The proposed methodology to determine the required number of GSS is illustrated under figure 4.1

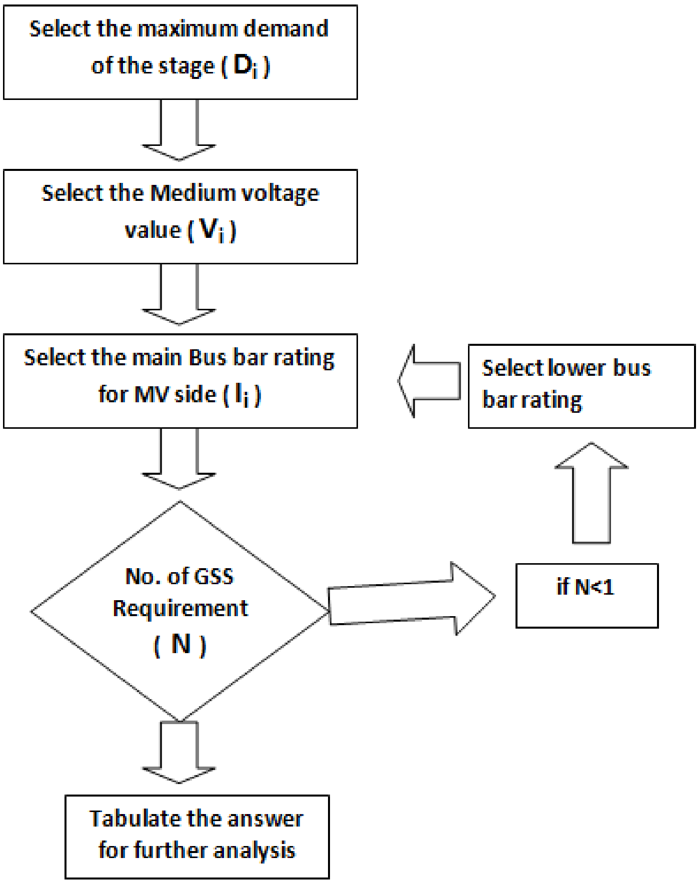


Figure 4.1: Methodology to determine the required number of GSS

Following equation could be used to calculate the total current requirement of the complete development or the selected segment, depending on the choice of the designer. The total demand (D_T) and the independent demands shall be calculated according to the methods shown in chapter 4.2. Then the total requited current value of the respective medium voltage network could be calculated as follows,

$$\text{Total Current } (I_T) = \frac{\text{Total Demand}}{\sqrt{3} \text{ x Medium Voltage } (V_i)}$$

There are few values for total current requirement depending on the selected value for the medium voltage (V_i) from the table 4.1. Once the total required current (I_T) of the development is finalized under various MV values, the next step is to calculate the required number of GSS to cater the demand under various bus bar ratings, which were given in figure 4.1. Accordingly, the formula for calculation of the required number of GSS in mentioned below.

$$\text{No. of Required GSS to cater the demand } (N) = \frac{\text{Total Current } (I_T)}{\text{Bus bar Rating } (I_r)}$$

The results from above formulae are necessary to tabulate for further analysis, according to the given format in table 4.2. Required number of GSS shall be an integer and shall be round up to the nearest higher integer in case of the answer is not an integer.

Table 4.2: Required number of GSS against MV value and bus bar rating of MV side

	No. of GSS (N) at each I_r			
Voltage (V_i)	1250A	1600A	2500A	3150A
6.6 kV	x	x	x	x
11 kV	x	x	x	x
22 kV	x	x	x	x
33 kV	x	x	x	x

Key: x- No. of GSS requirement.

After that, it is possible to observe that the required numbers of GSS are varied with the applicable MV value and the rating of the bus bar of the MV side. Generally, it is proved that the requirement of GSS is lesser with higher MV values as well as higher bus bar rating for the MV side. Minimum number of GSS arrangement for the development is the least cost option, but there are other factors to be considered to define the optimum value. After obtaining the table 4.2, it needs to compare the demand per grid substation and it's firm capacity. If the demand exceeds the firm capacity, the selection shall be revised.

Thereafter, one or two values can be selected as feasible MV values for power distribution in the complete city by considering the above details. After identifying few values / arrangements as feasible values for MV distribution, it is necessary to consider the cost involvement for the selected values; and it will be filtered based on following conditions to determine the most economical value for MV distribution.

- Panel cost variation with MV value
- Transformer cost variation
- Total cost of GSS
- Cost per MVA under GSS arrangement

Least cost option is the most economical voltage for the design. This complete process is called 'The optimal voltage selection criteria".

4.5 Price Variation of Panels, Cables and Power Transformers against the Medium Voltage Value

Market survey was conducted to collect the required price details from reputed manufactures, as it is necessary to analyze the prices of essential components against the MV value of GSS, in order to determine the optimum cost arrangement. This study provides strategic analysis of the variation of prices and forecasts, against the MV value of global MV switchgear, underground power cable and power transformer cost.

Adaptation of smart grid technology in power sector of both developed and developing countries will increase the growth of MV switchgear market, according to the forecasts for the period of 2016 to 2024 [10]. Rapid electrification in rural and urban areas of countries in Asia Pacific and Africa has also triggered the growth of LV and MV switchgear market. Further in developed countries, renewal of old and faulty transmission and distribution network has estimated to boost up the demand for LV and MV switchgear market according to the forecasts for the period of 2016 to 2024 [10]. All of these incidents will make a positive impact on the demand for MV switchgears, which are being used for switching, isolation & protection of electric transmission and distribution network. However, bottom line growth of switchgear manufacturers will be negatively affected due to the increase in the extent of price-based competition in MV switchgear manufacturers. It was noted that some bottom line manufactures have provided poor quality and retrofit products at comparatively lower prices during the evaluation of bids at CEB. The quality and type tested products or manufactures, having a good customer base and supply record shall be selected or pre-qualified to avoid the possible issues of bottom line manufacturers.

- Based on product standards, MV switchgear market is segmented into International Electro- technical Commission (IEC) standards, American National Standards Institute (ANSI) standards and several other standards (such as JIS, NEMA, GOST etc.).
- Based on voltages, the market is divided in into, 1kV - 5kV, 6kV - 15kV, 16kV - 27kV and 28kV - 38kV segments.
- Based on components, MV switchgear market is segmented into circuit breaker, relays and others (such as enclosure, fuses, bus bars and switches).
- Based on insulation, the market is divided into air insulated switchgear, gas insulated switchgear and others (such as oil and solid).
- Based on application, MV switchgear market is segmented into power plants, oil & gas and petrochemical industry, pulp and paper industry and utilities sector.
- Based on geography, the market is segmented in to North America, Europe, Asia Pacific, Middle East & Africa (MEA) and Latin America [10].

After considering all above details, prices were collected from reputed manufactures based on utility approved specifications for GIS Panels, XLPE Cables and Power Transformers.

4.5.1 Cost of Medium Voltage GIS Panels

Few major suppliers / bidders were selected depending on the historical details collected from the utility and other procurement divisions and comparative to the details mentioned in chapter 4.5. Siemens AG Germany, Tamco (Malaysia) and ABB were selected as appropriate panel manufactures and they were the major suppliers for CEB during last few years. Among the collected price details from above suppliers, the offer of Siemens is selected to prepare the engineering estimates, since it shows approximately average value of all the offers. The collected prices were tabulated in table 4.3 for further analysis.

Table 4.3: Variation of MV Panel Cost Vs Voltage

Panel Type	**Cost (USD)**		
	11 kV	**22kV**	**33kV**
Transformer Feeder Bay	42,650.00	44,150.00	54,150.00
Generator Feeder Bay	39,350.00	41,250.00	51,750.00
Outgoing Line Feeder Bay (Type I)	38,150.00	40,150.00	50,150.00
Outgoing Line Feeder Bay (Type II)	37,500.00	39,750.00	49,750.00
Auxiliary Transformer Feeder Bay	40,150.00	41,150.00	51,150.00
Bus Section Bay	33,650.00	35,150.00	49,150.00

(Details were provided by SIEMENS AG, Germany)

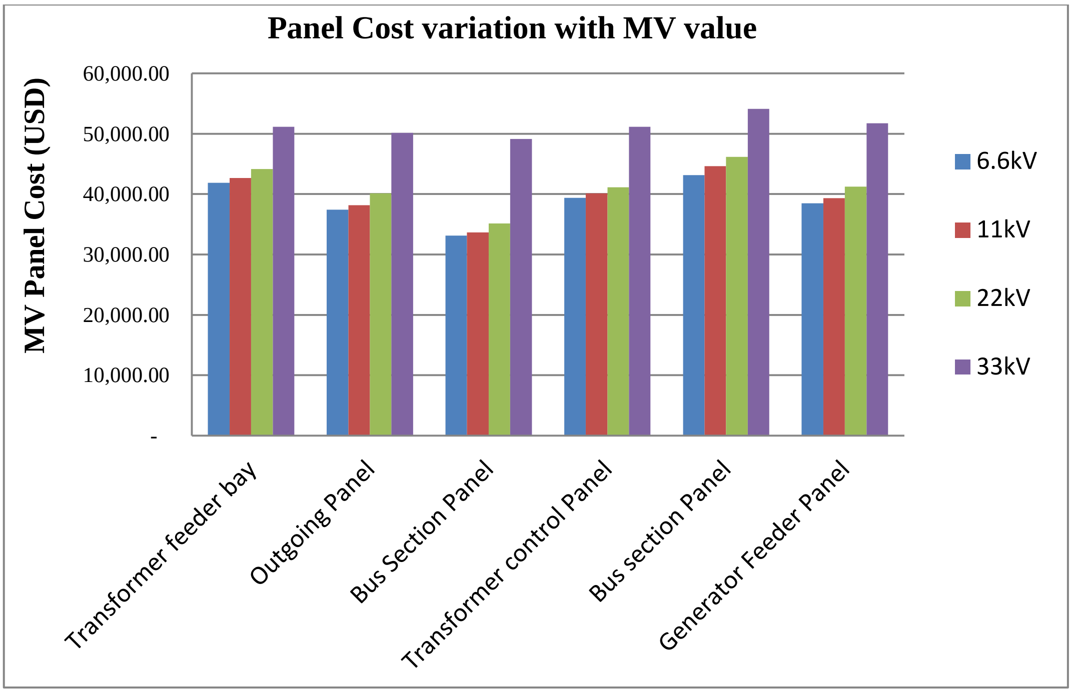


Figure 4.2: Variation of MV Panel Cost Vs Voltage (Details were provided by SIEMENS AG, Germany)

Figure 4.2 indicates the variation of the panel cost of important models against the MV value. It varies from minimum to maximum with the voltage from 6.6kV to 33kV. The increase of cost difference among 6.6kV, 11kV and 22kV is a small value and the cost jump from 22kV to 33 kV is considerably high.

4.5.2. Underground Cable Cost Variation with MV Value

According to the Chapter 4.5, a market survey was conducted to collect the required price details from reputed manufactures as it is essential to analyze the price variation of UG cable against the MV value. There are several types of UG cables providing by the leading manufactures. Anyway, Cu, XLPE cables were selected, as it is being installed in Sri Lanka since early 1990 for MV range. Therefore, it is not necessary to conduct additional training sessions and other deep trainings programs for the staff including cable jointers.

ABBARDERE cable (India), Leader cable (Malaysia) and Phelps Dodge (Thailand) were selected as suitable UG cable manufactures and they were the major suppliers for the utility during last few years. Among the collected price, the offer of Leader cable (Malaysia) was selected to prepare the engineering estimates, since it shows an approximately average value of all the offers. The collected prices were tabulated in table 4.4 for further analysis.

Table 4.4: Variation of MV cable Cost Vs Voltage

Cross section & Core Details of XLPE Cable	Medium Voltage cable			
	6.6kV	11kV	22kV	33kV
1C, 400mm^2,	28.12	31.68	32.5	36.95
1C, 240mm^2,	20.05	23.85	25.55	28.32
3C, 240mm^2	62.65	74.52	78.46	86.4
1C, 185mm^2	14.12	16.56	19.95	25.14
3C, 185mm^2	64.3	67.12	71.56	77.35
1C, 95mm^2	9.05	9.52	12.8	16.2
3C, 95mm^2	28.95	30.31	37.4	47.57
1C, 70mm^2	7.69	8.25	9.14	9.95
3C, 70mm^2	24.54	25.21	27.12	30.5

The above costs are given in USD per meter length and the details were provided by Leader cable (Malaysia).

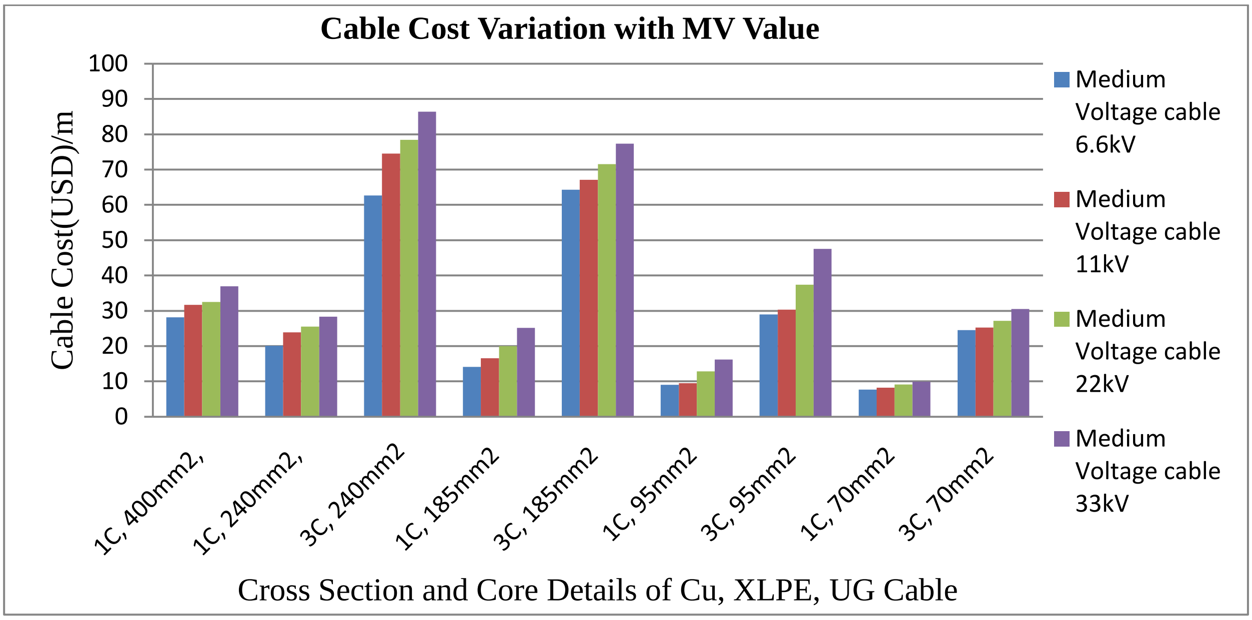


Figure 4.3: Variation of MV Underground Cable Cost Vs Voltage

(Details were provided by Leader cable (Malaysia)

Figure 4.3 indicates the variation of the UG cable cost of all models / Cross sections against the MV value. It varies from minimum to maximum with the voltage from 6.6kV to 33kV. The increase cost difference among 6.6kV, 11kV and 22kV become a small value and the cost jump from 22kV to 33 kV is considerably high.

4.5.3. Power Transformer Cost Variation with MV (Secondary Side) Value

Similarly to previous data collection methods, a market survey was conducted to collect the required price details from reputed manufactures as it is essential to analyze the price variation of cost of power transformers against the MV value. The offer provided by PTCG Power systems (Indonesia) was selected to prepare the engineering estimates, since it shows approximately average value of all the offers. The collected prices were tabulated in table 4.5 for further analysis.

Table 4.5: Transformer Cost Vs Capacity and MV value

	Cost (USD) and Capacity of the Power Transformer					
Ratio	16 MVA	22.5 MVA	30 MVA	31.5 MVA	45 MVA	80 MVA
132/11	225,000	320,000	440,000	450,000	620,000	930,000
132/11	230,000	340,000	450,000	460,000	630,000	950,000
132/11	295,000	365,000	450,000	470,000	630,000	960,000

(Details were provided by PTCG Power systems - Indonesia)

The cost variations of power transformers are mostly depend on the capacity of the transformer and slightly on the value of the secondary side voltage (Medium Voltage) value. Figure 4.4 indicates the cost variation of above power transformers. But all other products contain different pricing patterns according to the medium voltage.

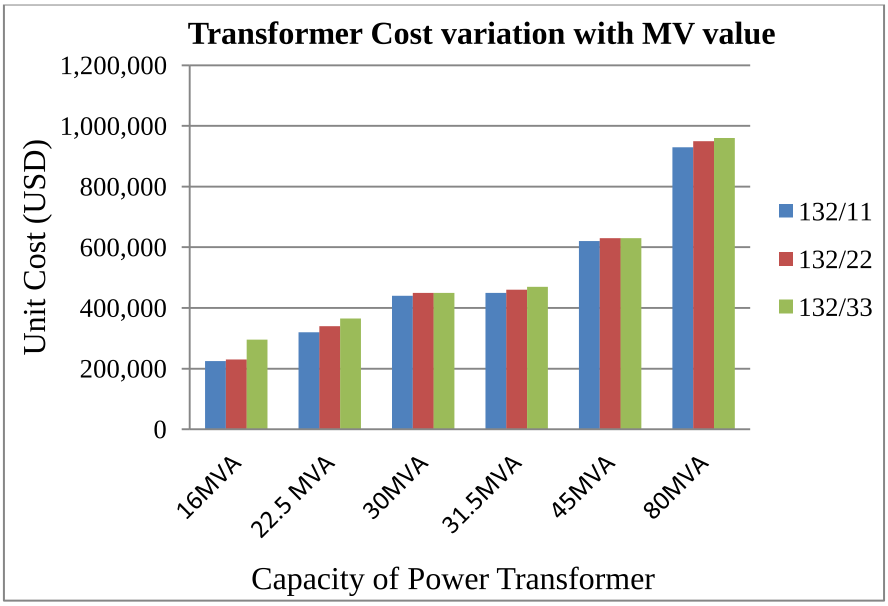


Figure 4.4: Variation of Transformer Cost Vs Capacity & MV side Voltage

(Details were provided by PTCG Power systems - Indonesia)

4.6 Total Cost of few GSS Arrangements

There are few commonly available MV values and bus bar ratings for standard GSS arrangements as described in chapter 4.3; and it is necessary to find the total cost involvement for the above GSS arrangements. But there were no any readily available sources (such as submitted bid documents or ongoing projects) to extract the total cost. Therefore, it was decided to prepare few engineering estimates for all required types of GSS, based on the collected price details in section 4.5. Hence, in depth interviews and discussions were conducted with a wide range of key industry participants and consultants, which provided first - hand information on labour rates, market trends, the methods to select a base estimate for references and the modification procedure. Further, key suppliers' product literature, annual reports, updates and other relevant documents regarding competitive analysis were reviewed, in order to understand the cost involvement of GSS.

Accordingly, actual estimates which were submitted to Greater Colombo Transmission & Distribution Loss Reduction project (GCTDLRP) by a reputed firm in year 2015 were referred to prepare the Engineering estimate. The GCTDLRP was formulated to implement GSS in Colombo city limit. Therefore, the rates offered by the bidders to this project were very reasonable to prepare the engineering estimates for GSS projects in city limits or congested areas. The successful offer to that project was selected as the base estimate and required adjustments were identified and the changes were made for each substation, which didn't match with base estimate. This is a more reliable, effective and successful approach for obtaining accurate Engineering estimate.

Table 4.6: Summary of the Engineering Estimates of few GSS arrangements

	Cost of GSS Arrangement (LKR –Mn.)		
HV/MV (kV)	**2 x 25.5 MVA**	**2 x 31.5MVA**	**2 x 45 MVA**
132/11	1,188	1,233	1,345
132/22	1,222	1,264	1,354
132/33	1,288	1,325	1,393

(Main Source- CEB Colombo city project, 2014~2015)

The engineering estimates were summarized in Table 4.6 and figure 4.5; however, the land cost for GSS has not included, as it varies based on the location. The manufacture recommended spares for 10years of operation and onsite staff training were included to the estimations. Engineering estimates were annexed as Annexure 01.

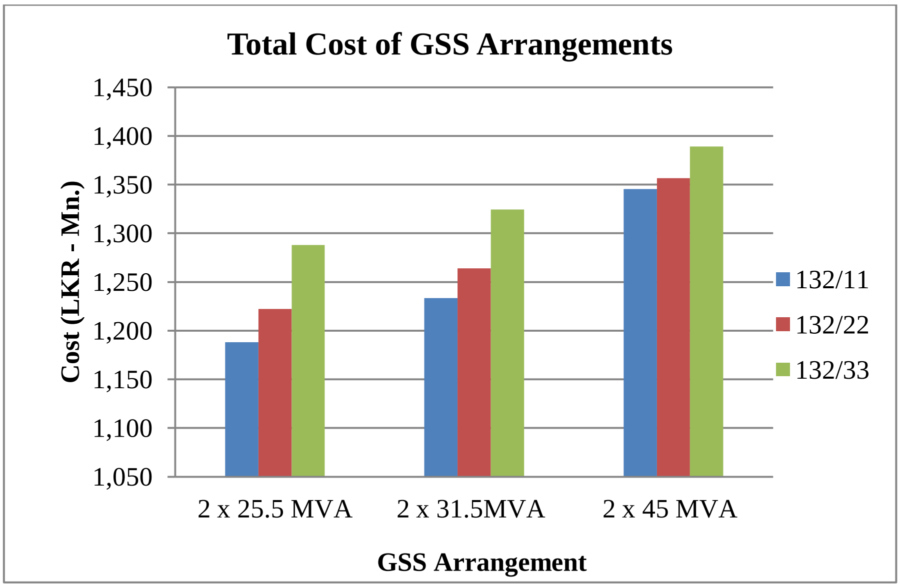


Figure 4.5: Total Cost of GSS Arrangements

4.7 Total Cost Variation of GSS / MVA

The above figure 4.5 presents the total cost of GSS under various arrangements. But, the most economical arrangement is not indicated there, because, the indicated costs were based on various grid capacities and MV values. Therefore, a separate analysis is required, based on the total cost variation of GSS on MVA basis. The table 4.7 demonstrates relevant values for the total cost of GSS / MVA as per the Engineering estimates.

Table 4.7: Total cost of GSS/ MVA in LKR Million

HV/MV(kV)	2x22.5 MVA Arrangement	2x31.5 MVA Arrangement	2x45 MVA Arrangement
132/11	26.40	19.58	14.95
132/22	27.16	20.07	15.04
132/33	28.62	21.02	15.47

Optimum voltage value for the MV network could be found by considering the cost of GSS / MVA value.

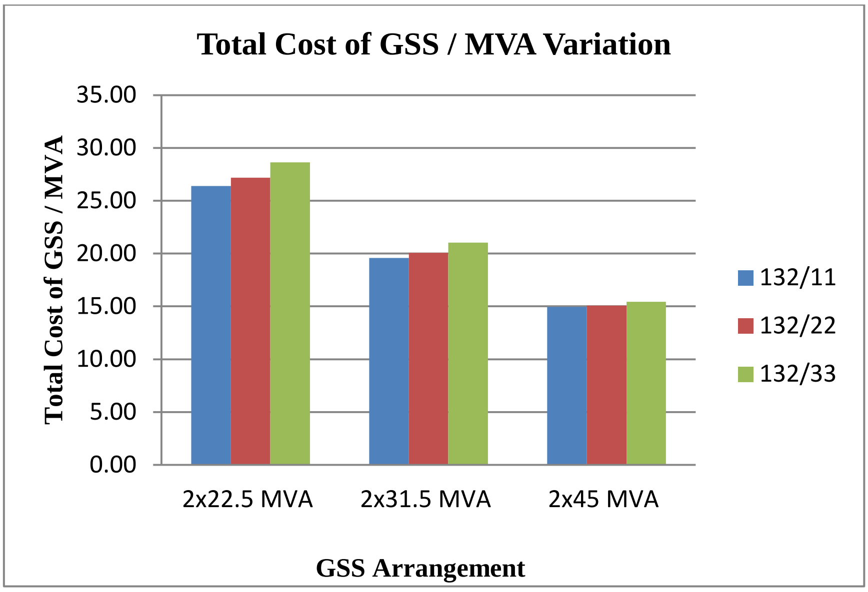


Figure 4.6: Total Cost of GSS/ MVA

As shown in the figure 4.6, the 2x45MVA arrangement seems more economical than other arrangements of the above combination. If it is required to evaluate other ratings, it is necessary to follow the same procedure for required capacities as well.

CHAPTER 05: OPTIMUM LOCATION SELECTION CRITERIA

After finalizing the MV value and the required number of GSS for the development, the optimum locations for the installation of GSS should be determined. Even though few lands / locations are available for utilization, the cost and other related factors of the lands may vary, which may create a considerable effect on the final decision as well as on the total cost. The total investment cost and annual cost of the MV network also depend on the locations of GSS. Therefore, optimum locations for GSS can be mentioned as an imperative factor at the design stage of a planned city / industrial park or similar development. Nonetheless, the main purpose of the optimum location selection criteria to achieve the optimum location, according to the technical / non-technical requirements and financial conditions. Some of the non-technical requirements regarding location selection include,

- Easy approach ways to sites for smooth movement of machineries and equipment
- In order to avoid unnecessary cost increments due to soil filling, earth removal etc., the lands / locations have to be carefully selected
- Historical data of worst flood is taken in to account, to avoid flood conditions
- Atmospheric conditions have to be considered
- Heritage areas should be selected, with the approval of relevant authorities
- Environmental considerations (if any)

The requirements for the optimum location selection are based on the location, which are planned to select and they are determined by practicalities and possibilities of engineering constraints, construction costs, environmental issues, impacts of social attributes and the non-technical issues as mentioned above. Traditionally, the location, in which a substation is to be sited, is dictated by load location and transmission line arrangements for connecting the substation to the grid, and the substation to the place where the connection is required. But it may not the optimum location for substation since other important factors are omitted during the above selection procedure. If there are any matters relating to environment, natural disasters or to any non-technical conditions, they can have a significant impact on the timely completion of the project and then total cost of the project.

Therefore it is vital to identify locations without such matters. Accordingly, a methodology is developed to find the optimum location for any development process / planned city, which is called optimum location selection criteria and it is illustrated in figure 5.1.

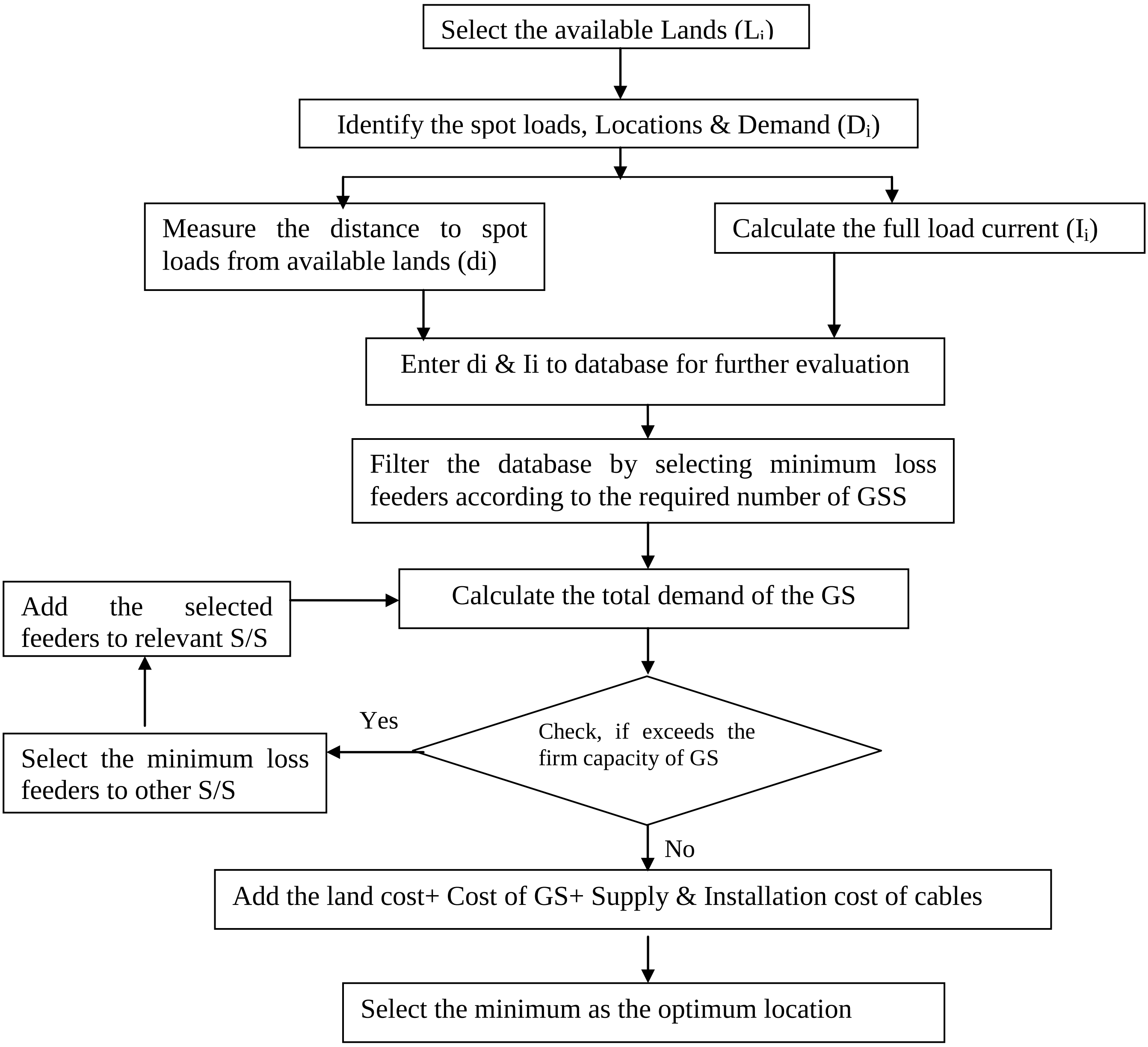


Figure 5.1: Optimum location selection criteria

However, above criteria will not address non-technical reasons. Therefore, it is essential to study about the non-technical reasons as well, before applying the proposed criteria to new development / planned city.

5.1. Typical Arrangement of a Planned City During The Planning Stage

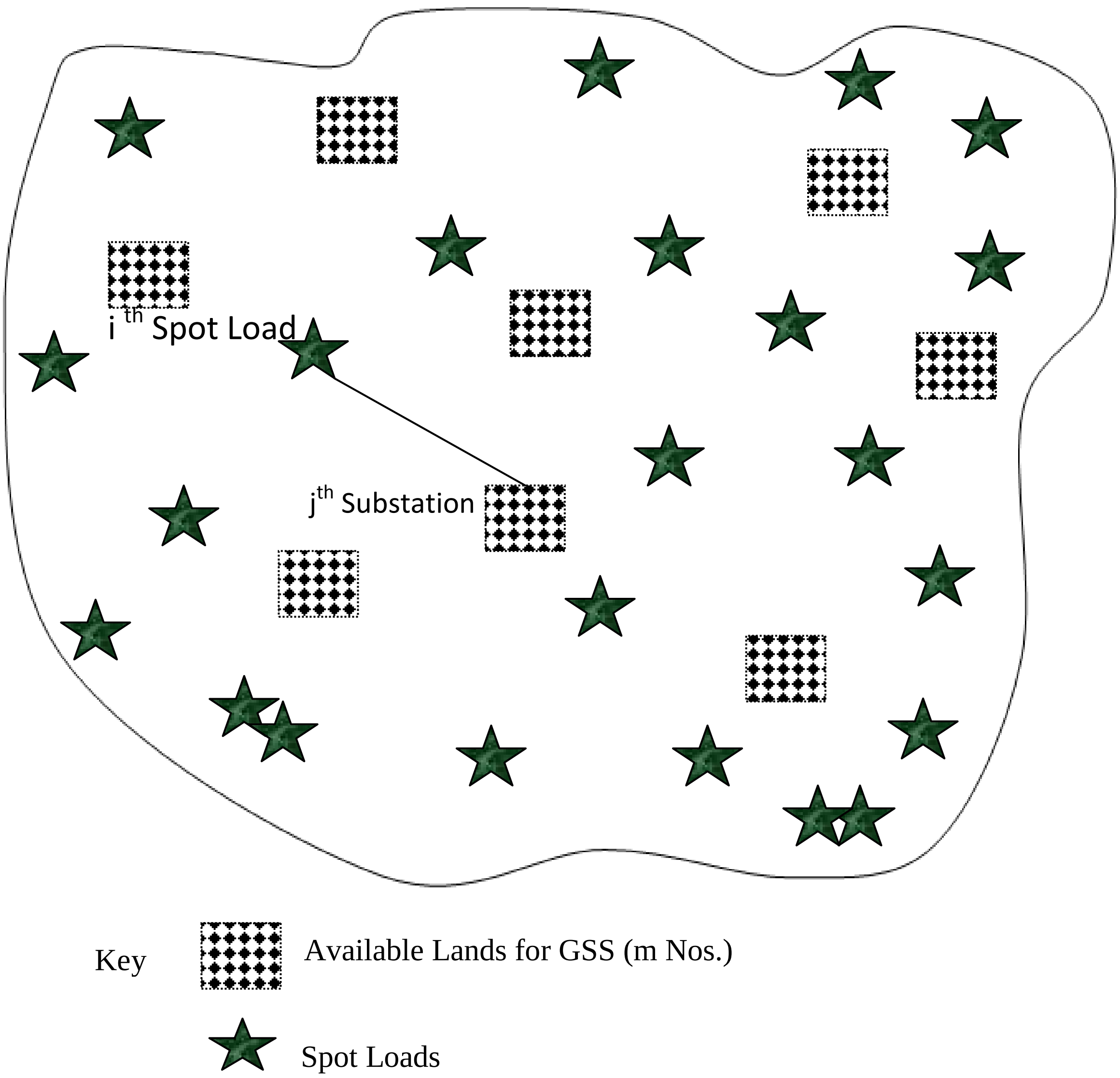


Figure 5.2: Typical Area to be developed as a Planned City during the planning stage

Initially, it may be consists with number of bare lands and it will be distinguished during the surveying stage, in order to allocate the lands for development activities depending on the preference of the developers.

Current trend of any development process is to allocate the lands to developers on their choices according to the importance, value, preference of location etc; and the utilities are allocated among the rest of the places/lands.

Figure 5.2 indicates the reality of the city during the planning stage. Some land slots were already allocated to developers depending on their choices, which are identified as spot loads and rest of the lands are indicated as available lands for GSS (m Nos.). Therefore, it is necessary to follow the proposed methodology (according to figure 5.1) in order to find the suitable location/s depending on the applicable variables. Further, it is necessary to identify the lands to the installation of GSS depending on the demand of the development and the required number of GSS.

5.2 Losses of the Medium Voltage Network

Minimization of losses in MV and LV network is very critical for any utility in the world. Therefore, in recent decades, many researchers have been focused on the distribution planning, mostly on the MV level. However, a considerable amount of distribution system losses are being reduced in low voltage networks in Sri Lanka, after introducing energy management units to all provinces / divisions of the utility [28]. But the losses in MV network are not still addressed by the above units. Therefore, minimization of MV losses is very important for the utility. If the losses of the MV network could be minimized at the initial stage of network planning, this will be a definite advantage for the utility. This is not a more practical exercise for unplanned cities, but it is more user friendly exercise for a planned city. Since power loss cost, supply and installation cost are the major costs components of MV cable network, the location of substation needs to be selected in a way to minimize those costs.

Regarding the case in figure 5.3, a GSS needs to be installed in the j^{th} land, in order to arrange the power supply to i^{th} spot load. The distance from GSS location to spot load, cost of losses, land value and demand are considered as d_{ij}, L_i, D_i and $C_{land\ j}$ respectively.

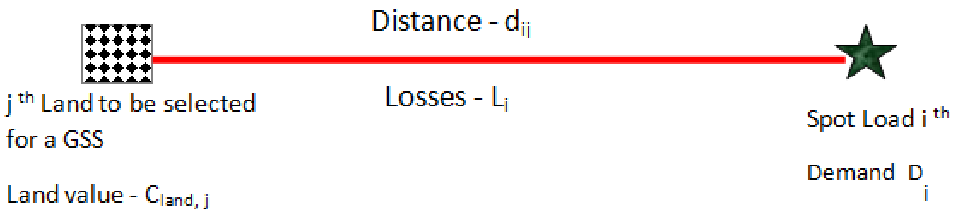


Figure 5.3: Location of land, spot load and MV cable

Distance from j^{th} substation to i^{th} spot load $= d_{ij}$

Demand of i^{th} Spot load $= D_i$

Loss of Energy $= L_i$

Total Cable losses when feeding j^{th} Substation= Peak Energy Loss x UTL kWh/year [31]

$$\textbf{UTL} = \frac{e^2 (2+e^2) \times 365 \times 24}{(1 + 2e)} \ \textbf{hrs / year}$$

Where, e-Load Factor

UTL – Utilization Time of Losses

Calculation of cost of losses, [31]

Cost of Losses = Capacity Cost + Energy Cost

= C_c x Peak power Loss + Ec x Energy Loss

Where,

Cc – Investment per year through generation to distribution required for supplying an incremental 1kW at the point of distribution

Ec - Operation & Maintenance cost of generation, transmission and distribution of 1kW at distribution point.

Land cost of j^{th} substation $= C_{Land,j}$

Supply & Installation cost of MV power cable from j^{th} substation to i^{th} spot load $= C_{ji}$

Total supply & installation cost $= \sum_{i=1}^{n} Cji$

Supply & Installation cost of GS $= C_{gi}$

Total cost of the Grid Substation $= \mathbf{C_{Land,j} + \sum_{i=1}^{n} Cji + C_{gi}}$

5.3 Operation & Maintenance Cost of UG Cable Network

Due to greater costs in relation to bury cables, the undergrounding is considered as more expensive than overhead power lines. Similarly, the life-cycle cost of an underground power cable is worth two to four times than the cost of an overhead power line. When considering highly urbanized areas, the cost of underground transmission becomes ten to fourteen times as expensive as overhead construction [29]. Failure rate shows that mostly underground distribution cable faults are of external type, i.e. third party failure which can be controlled by proper maintenance; especially patrolling. Failure cost of UG cables is based on deterministic and probability approach. A greater amount of statics is essential, regarding the failure of events, along with specifications of failure modes and subsequent costs for repairing, in order to increase the confidence level of a correct assessment effort.

However, once the XLPE UG cables are properly installed, it provides a hassle free operation for a complete lifecycle [14]. But, locating and repairing of underground cables consume a greater time as it was included excavation and reinstatement works as well. Further a competent team also will be available for the operations and maintenance activities. Hence the operation and maintenance cost of underground cable network is considered as 2% from the cost for supply, delivery and installation purposes to create a complete network [4].

5.4 Optimum Location for GSS

Following methodologies are applied to find the optimum location for GSS.

a) <u>Select the available lands for substation construction</u>

This is the initial selection of land/s among the available land slots, based on non-technical reasons mentioned in Chapter 5. After selecting the lands while considering the above mentioned facts, these lands are called suitable lands to build substations. The proposed criterion figure 5.1 is applied to the pre-selected lands to select the optimum locations.

b) Calculate the total cost of losses of MV arrangement based on the available locations

The MV distribution is completely based on the underground cable network. The UG cable network is radiated from the respective GSS to spot loads. Hence the total length of the UG cable network varies with the GSS location. The scope of this step is to calculate the associated cable loss of the MV network. In generally, there are two types of power losses generated in a cable, i.e. current dependent and voltage dependent components. The energy generated by the above mentioned powers is converted to other energy forms; predominantly heat. Heating power is identical to an electrical power loss and occurs during the cable operation. Finally, the calculated full load energy loss shall be converted to total energy loss cost, by multiplying the average electricity selling price. In addition, this shall be calculated based on each available land slots, which could be utilized for constructing a GSS.

c) Cost of land also shall be considered

Cost of land becomes a significant value for development processes, which are closer to urban areas. In some cases the land cost may varies in huge amounts from one land slot to other land slot in the same development project, depending on the location and other related commercial factors. In this kind of a scenario, it is necessary to select the best option after considering all the effective factors. If there is a necessity for massive filling and rearrangement of the land in order to convert it to a suitable location, it increases the total cost of the land and the required additional costs also have to be added to the selling price of the land.

d) Minimum Total cost shall be identified

The total cost consists of following items [5],

- Cost of GSS
- Cost of MV cable network
- Full load copper loss cost of MV cable network
- Cost of land

The above calculation will give the total costs for relevant GSS or for other combinations depending on the GSS requirements. Accordingly, the city planners are able to select the required location/s or combination as per their views and according to the applicable cost.

When it is required to construct two or more GSS to cater the complete demand of the development or planned city, the spot loads should be allocated to the respective GSS, depending on the length of the feeder cable, losses and loading condition of the GSS, subject to the firm capacity or predefined maximum allocated load of the GSS [6]. The predefined maximum value could be based on the experience of the network planners of the utility and the provision kept for the future expansion / load growth.

5.5. Methodology to Allocate Spot Loads to GSS

It is necessary to collect following details to allocate all spot loads to respective GSS;

a) All available lands that are selected to construct GSS need to be identified and named as A, B, C etc. for better identification
b) All spot loads need to be identified and number system needs to be introduced for better identification
c) Demand of all spot loads needs to be calculated
d) Distance to each spot load needs to be measured along the available roads from all available lands to build GSS
e) The full load loss cost of the underground cable needs to be calculated, which provides the power supply to the spot load from respective GSS. Full load loss cost of the cable was calculated considering the 12hrs of operation per day and 35 years as life time. These figures was used only for the comparison of losses & select the minimum loss feeders for each combination and the exact value of the system losses shall be calculated as per the jungs formula [31].
f) All the above details are tabulated in Table 5.1 for further analysis.

Table 5.1: Format to collect details of all spot loads, Available lands, Losses and Order of Losses

Spot Load No.	Demand D_1 (MVA)	Current I_1	Distance to spot load from lands (m)				Full load copper loss of the cable from respective GSS to spot load (W)				Order of minimum loss feeder			
			A	B	C	D	A^1	B^1	C^1	D^1	1st	2nd	3rd	4th
1														
2														
3														
4														
5														

It was assumed that four lands are available and the number of spot load is fifteen for this hypothetical case. After collecting of all required details to the above database, the next step is to select the order of minimum loss feeders to each spot load from GSS.

g) Required number of GSS to cater the complete demand need to be calculated (as per the chapter 4)

h) If the required number of GSS is more than 1, there will be a land combination to find the optimum condition.

   E.g. If the required number of GSS is two (2), then the land combinations are AB, AC, AD, CB, BD and CD. It needs to allocate the spot loads to each combination to find the total cost involvement, in order to select the minimum cost arrangement.

   If the load allocation for land combination "AB" is considered,

   The above data base needs to be filtered to allocate the feeders to GSS A&B according to the losses of the UG cable and to the minimum loss feeder of a spot load relevant to a substation. The results are shown in table 5.2 and table 5.3.

Table 5.2 Table 5.3

Format for allocation of spot loads to GSS A&B according to the full load loss of UG cable

		Land - A			
Spot Load Number	Demand of the spot load (MVA)	Distance from "A" to spot load (m)	Distance from "B" to spot load (m)	Full load Cu loss of the cable from "A"(w)	Full load Cu loss of the cable from "B"(w)
No.	**D_i (MVA)**	**A**	**B**	**A'**	**B'**
Total Demand, Length & Losses	xx	xx	xx	xx	xx

		Land - B			
Spot Load Number	Demand of the spot load (MVA)	Distance from "A" to spot load (m)	Distance from "B" to spot load (m)	Full load Cu loss of the cable from "A"(w)	Full load Cu loss of the cable from "B"(w)
No.	**D_i (MVA)**	**A**	**B**	**A'**	**B'**
Total Demand, Length & Losses	xx	xx	xx	xx	xx

i) Total demand on the both GSS needs to be calculated and it is necessary to compare with the predefined maximum load that could be loaded the respective substation. If the maximum load is less than that, it will be allowed for the next step.

j) If any of GSS will be loaded more than the predefined value, then it will not be allowed for loading and it is necessary to transfer few spot loads to other substation

k) In case of exceeding the predefined value for a GSS, selected spot loads need to be transferred to other GSS as follows,

If the overloaded substation is “A”, then select minimum loss values of feeders of substation B from the Land “A” chart (Table 5.2, Full load Cu loss of the cable from "B"). Add this to Land “B” chart to avoid the overloading of the substation to be built on Land “A”. The same procedure will be applicable until it reaches the acceptable value of the total load on the substation “A”

l) After completing the spot load allocation, following details need to be considered to calculate the total cost of the combination.

Table 5.4: Format to tabulate total cost of GSS combination A&B to cater the total demand

GSS	Total Demand (MVA)	Land cost (LKR-Mn)	Total Cable length(m)	Supply & Installation cost of cables (LKR - Mn)	Full load copper loss cost	Total Cost (LKR-Mn)
A						
B						
Total Cost of combination						

m) It is necessary to calculate the total cost for all other GSS combinations and need to be tabulated as follows in table 5.5, in order to find the minimum value.

Table 5.4: Format to summarize the total cost of all GSS combinations

GSS Combination	Total Cost (LKR - Mn)
AB	
BC	
CD	
DA	
BD	
AC	

CHAPTER 06: CASE STUDY OF COLOMBO PORT CITY

6.1 Introduction to the Development Process of Colombo Port City

The opportunity to invest and work with the land preparation for Colombo Port City development in Sri Lanka was received by China Harbor Engineering Company. This project can be identified as an extension related to the landfill of approximately 2.75 km^2, connected to the Fort district and CBD area in Central Colombo, which is also closer to the industrial harbor.

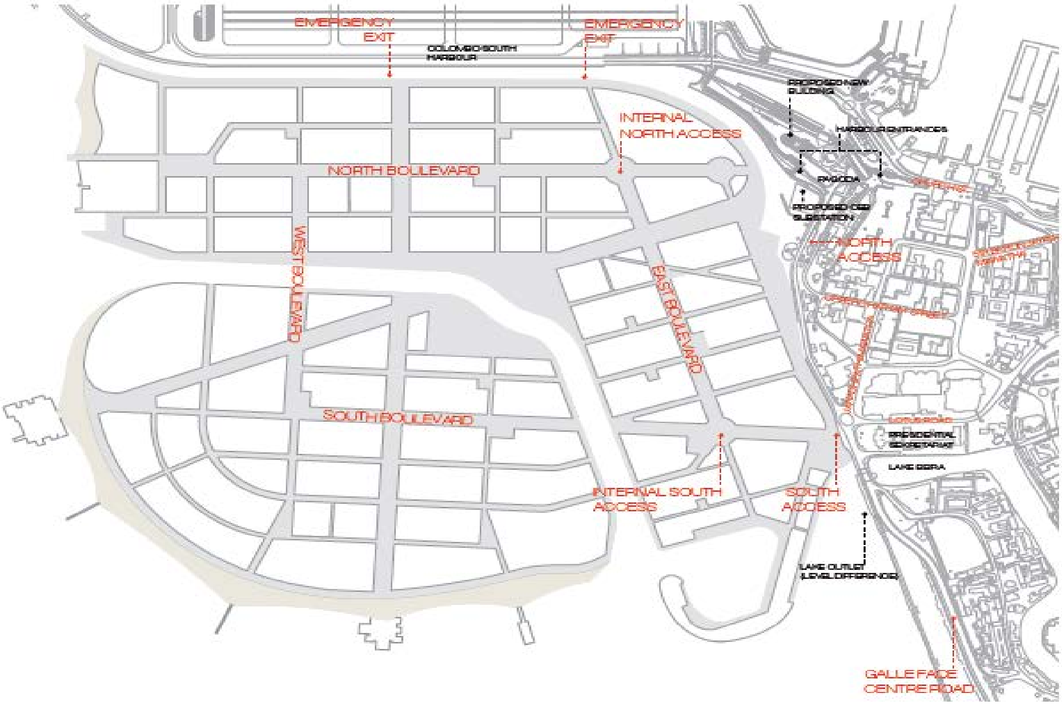


Figure 6.1: Topographical Plan for Colombo Port City Complex [24]

According to the rough time plans, the land preparation including landfill and all infrastructure construction will be completed in 3 - 4 years' time. The land lease as well as further construction will take about 10 years' time. The addition of a city of 2.75 km^2 brings an exciting opportunity to start from scratch, to innovate and design a new world-leading city development, based on the best practices and international experiences, which however grasps special Sri Lankan contexts and climate. Further, this unprecedented opportunity will create a world-class community, which fosters a living, working and learning environment in a quality environmental and social context.

Figure 6.2: Conceptual Master Plan [24]

The city will be developed under three main stages from stage (i) to (iii), adding a novel concept to the Sri Lankan developmental field. The lands with the highest commercial value in the country will be located in this complex. Under the present capacity, the medium voltage network of Ceylon Electricity Board (CEB) in Colombo city is not adequate to cater the electricity demand of Colombo Port City [11]. Therefore, it is essential to implement a new grid substations and transmission lines to meet the demand [5].

6.2 Load Calculation of Colombo Port City

The new project will create a need for reclaiming the lands, stage wise as shown in table 6.1 [24],

Table 6.1: Extent of Landfills in each stage

Reclaimed stage	**Area (Hectare)**
Stage 01	59
Stage 02	110
Stage 03	96
Beach	11
Total	**275**

Facilities to be built in reclaimed land are as follows and project architects had confirmed the floor area (m^2) of all the facilities mentioned below for each stage.

I. An Iconic Building for each stage
II. Commercial Buildings
III. Commercial Buildings (Special)
IV. Educational Facilities/Buildings
V. Hotel
VI. Mixed development
VII. Residential
VIII. Public Facilities
IX. Cultural Facilities
X. University
XI. Others

Stage wise power requirement/demand needs to be calculated, for calculating the total demand of the development, which will facilitate to design the MV power distribution system for the development. The developers of this complex follow Singapore building architecture [24]. Thus, per square meter demand used for estimation of total energy demand in port city is based on figures for energy demand in Singapore buildings. Standard figures for energy consumption of Singapore buildings were given in Building Energy Benchmarking Report, Singapore, 2016 [8] [9].

6.3. Calculation of Total Demand - For Stage 01

A section of reclaimed lands will be developed under stage – 01and the main components of the development were given below in the figure 6.3.

11.b GFA PHASE 01	
Land Use	GFA from mass floo
Commercial	217 014,2 m²
Commercial 90/10	495 959,7 m²
Educational	27 253,0 m²
Hotel	68 887,0 m²
MU Commercial 70/30	240 120,2 m²
MU Residential 70/30	95 998,1 m²
MU Residential 90/10	371 246,9 m²
Public Facilities	43 981,5 m²
	1 560 460,6 m²

Figure 6.3: Pictorial view of stage – 01

Details of the energy demand for proposed buildings in stage – 01 are summarized below in table 6.2 and 6.3.

Table 6.2: Details of the Energy Demand of Commercial & Educational Buildings

Building Category	Commercial				Educational
No. of Levels	40.00	25.00	20.00	10.00	10.00
Approximate area per floor (m^2)	800.00	500.00	1500.00	2000.00	1500.00
No. of Buildings	1.00	5.00	9.00	30.00	2.00
Total floor Area (m2)	32000.00	62500.00	270000.00	600000.00	30000.00
Energy Consumtion (as per singapore buildg) - kWh/yr	12960000.00	25312500.00	109350000.00	243000000.00	6540000.00
Power consumtion (as per singapore buildg) - kW	2958.90	5779.11	24965.75	55479.45	1791.78
Demand (as per singapore buildg) - kVA	3287.67	6421.23	27739.73	61643.84	1990.87
Demand per Building	3287.67	1284.25	3082.19	2054.79	995.43

Table 6.3: Details of the Energy Demand of Hotel, Public Facilities & Residential Buildings

Building Category	Hotel		Public Facilities			Residential	
No. of Levels	25.00	6.00	1.00	2.00	4.00	10.00	6.00
Approximate area per floor (m^2)	800.00	1600.00	4000.00	2000.00	1000.00	4000.00	7000.00
No. of Buildings	3.00	1.00	6.00	4.00	1.00	1.00	10.00
Total floor Area (m2)	60000.00	9600.00	24000.00	16000.00	4000.00	40000.00	420000.00
Energy Consumtion (as per singapore buildg) - kWh/yr	17520000.00	2803200.00	5232000.00	3488000.00	872000.00	10560000.00	110880000.00
Power consumtion (as per singapore buildg) - kW	4800.00	768.00	1791.78	1194.52	298.63	2893.15	30378.08
Demand (as per singapore buildg) - kVA	5333.33	853.33	1990.87	1327.25	331.81	3214.61	33753.42
Demand per Building	1777.78	853.33	331.81	331.81	331.81	3214.61	3375.34

Accordingly the total demand of the stage 01 is 147.88 MVA.

6.4. Calculation of Total Demand - For Stage 02

A section of reclaimed lands will be developed under stage – 02 and the main components of the development were shown below in the figure 6.4.

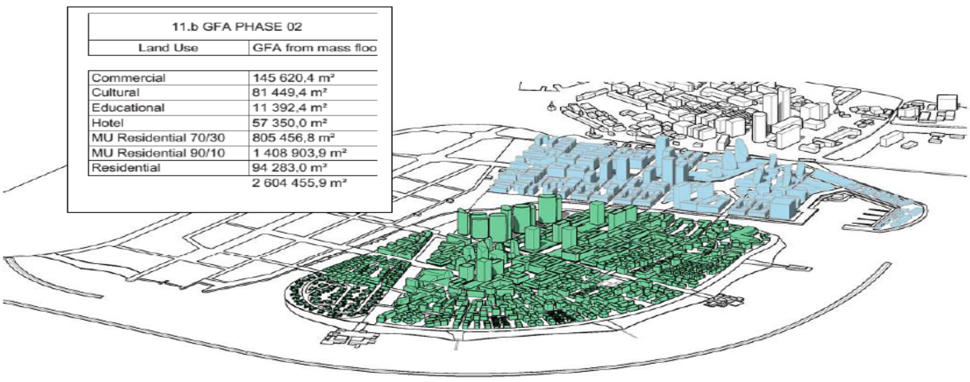


Figure 6.4: Pictorial view of stage - 02

Details of the energy demand for proposed buildings in stage – 02 are summarized below in table 6.4 and 6.5.

Table 6.4: Details of the Energy Demand of Commercial, Educational & Hotel Buildings

Building Category	Commercial				Educational	Hotel	
No. of Levels	40.00	25.00	10.00	1.00	10.00	25.00	6.00
Approximate area per floor (m^2)	800.00	510.00	2000.00	4000.00	2000.00	765.00	1600.00
No. of Buildings	2.00	2.00	3.00	1.00	6.00	3.00	1.00
Total floor Area (m2)	64000.00	25500.00	60000.00	4000.00	120000.00	57375.00	9600.00
Energy Consumtion (as per singapore buildg) - kWh/yr	25920000.00	10327500.00	24300000.00	1620000.00	26160000.00	16753500.00	2803200.00
Power consumtion (as per singapore buildg) - kW	5917.81	2357.88	5547.95	369.86	7167.12	4590.00	768.00
Demand (as per singapore buildg) - kVA	6575.34	2619.86	6164.38	410.96	7963.47	5100.00	853.33
Demand per Building	3287.67	1309.93	2054.79	410.96	1327.25	1700.00	853.33

Table 6.5: Details of the Energy Demand of Residential & MU Residential Buildings

Building Category	Residential		MU Residential 70/30			MU Residential 90/30		
No. of Levels	2.00	4.00	6.00	4.00	2.00	8.00	4.00	2.00
Approximate area per floor (m^2)	2500.00	2470.00	4000.00	2000.00	1600.00	4000.00	2000.00	1600.00
No. of Buildings	9.00	5.00	5.00	32.00	134.00	10.00	32.00	134.00
Total floor Area (m2)	45000.00	49400.00	120000.00	256000.00	428800.00	320000.00	256000.00	428800.00
Energy Consumtion (as per singapore buildg) - kWh/yr	11880000.00	13041600.00	15840000.00	33792000.00	56601600.00	42240000.00	33792000.00	56601600.00
Power consumtion (as per singapore buildg) - kW	4068.49	4466.30	5424.66	9258.08	15507.29	11572.60	9258.08	15507.29
Demand (as per singapore buildg) - kVA	4520.55	4962.56	6027.40	10286.76	17230.32	12858.45	10286.76	17230.32
Demand per Building	502.28	992.51	1205.48	321.46	128.58	1285.84	321.46	128.58

Accordingly the total demand of the stage 02 is 113.09 MVA

6.5. Calculation of Total Demand - For Stage 03

A section of reclaimed lands will be developed under stage – 03 and the main components of the development were shown below in the figure 6.5.

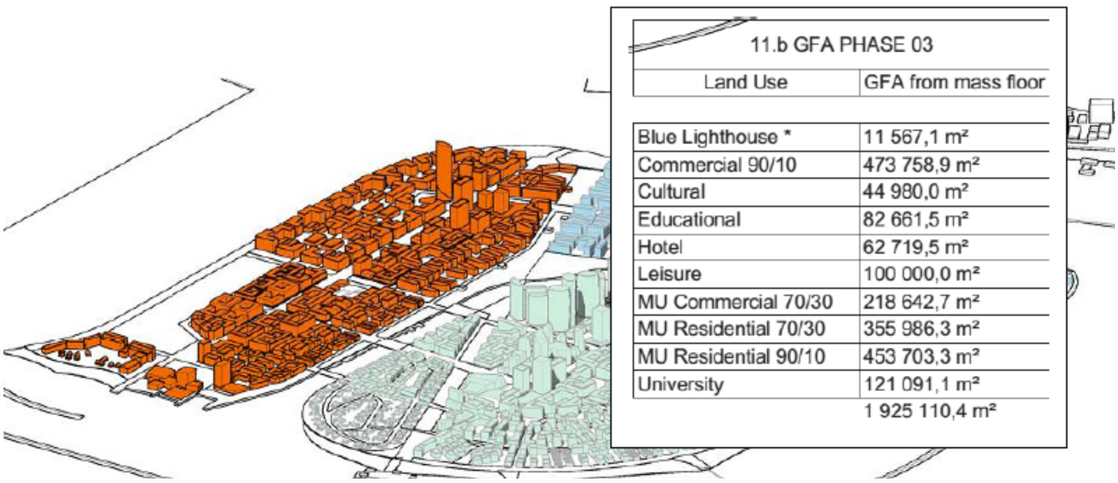


Figure 6.5: Pictorial view of stage – 03

Table 6.6: Details of the Energy Demand of Commercial, Educational & Hotel Buildings

Building Category	Commercial				Educational	Hotel
No. of Levels	40.00	25.00	10.00	6.00	10.00	25.00
Approximate area per floor (m^2)	800.00	750.00	2400.00	3670.00	4000.00	836.00
No. of Buildings	1.00	2.00	6.00	12.00	5.00	3.00
Total floor Area (m2)	32000.00	37500.00	144000.00	264240.00	200000.00	62700.00
Energy Consumtion (as per singapore buildg) - kWh/yr	12960000.00	15187500.00	58320000.00	107017200.00	43600000.00	18308400.00
Power consumtion (as per singapore buildg) - kW	2958.90	3467.47	13315.07	24433.15	11945.21	5016.00
Demand (as per singapore buildg) - kVA	3287.67	3852.74	14794.52	27147.95	13272.45	5573.33
Demand per Building	3287.67	1926.37	2465.75	2262.33	2654.49	1857.78

Table 6.7: Details of the Energy Demand of MU Residential & University Buildings

Building Category	MU Residential 70/30			MU Residential 90/10			University
No. of Levels	6.00	4.00	2.00	8.00	4.00	2.00	18.00
Approximate area per floor (m^2)	6000.00	2000.00	1600.00	4000.00	2450.00	1600.00	6750.00
No. of Buildings	5.00	30.00	48.00	4.00	8.00	57.00	1.00
Total floor Area (m2)	180000.00	240000.00	153600.00	128000.00	78400.00	182400.00	121500.00
Energy Consumtion (as per singapore buildg) - kWh/yr	23760000.00	31680000.00	20275200.00	16896000.00	10348800.00	24076800.00	37081800.00
Power consumtion (as per singapore buildg) - kW	6509.59	8679.45	5554.85	4629.04	2835.29	6596.38	11288.22
Demand (as per singapore buildg) - kVA	7232.88	9643.84	6172.05	5143.38	3150.32	7329.32	12542.47
Demand per Building	1446.58	321.46	128.58	1285.84	393.79	128.58	12542.47

Accordingly, the total demand of the stage 03 is 134.14 MVA.

6.6. Summary of the Demands of the Development

The total power demand of the city is 395.13 MVA, which is shown in table 6.8.

Table 6.8: Summary of the Demands of the development

Reclaimed Land section	Calculated Demand (MVA)
Stage (I)	147.89
Stage (II)	113.09
Stage (III)	134.14
Total Demand	**395.13**

6.7. Required Number of GSS for Stage - 01

Total demand of the stage (I) is 147.89 MVA and the relevant total current will be calculated under the available MV values and respective bus bar ratings. Calculated current and required number of GSS for stage (I) is tabulated in table 6.9 [7].

Table 6.9: Calculated current and required number of GSS for stage (I)

Demand of the stage (MVA)	**Medium Voltage (kV)**	**Total Current (A)**	**Required Number of GSS at rated Bus bar current**		
			1250A	**1600A**	**2500A**
147.89	6.6	12937	11	9	6
	11	7762	7	5	4
	22	3881	4	3	2
	33	2587	3	2	2

It is noted that the required number of GSS for stage (I) varies with the applicable MV value and the respective bus bar current (A) of the arrangement. But it is not possible to find the exact number of GSS requirement by only referring to the table 6.9 as it gives less number of values on the case study. Therefore, a deeper analysis is needed to identify the optimum voltage for MV distribution and the exact requirement of GSS for the development. Further, few feasible options are selected from table 6.9, (i.e. few minimum values of GSS requirements to cater the demand) for further evaluation. In addition, any of the above arrangements in table 6.9 is technically comply with the demand requirements, but the total cost of implementation varies according to the selected MV value and the bus bar rating of the GSS arrangement. A complete study of cost variation was conducted under section 4.6 and 4.7, and its details were used to select following arrangements which are shown in table 6.10, for further consideration to determine the most economical arrangement.

Table 6.10: Selected GSS arrangements to further consideration

(1)

Medium Voltage (kV)	11
Rated Bus bar Current(A)	2500
Required Number of GSS	4
Proposed GSS Arrangement	2x22.5 MVA

(2)

Medium Voltage (kV)	22
Rated Bus bar Current(A)	2500
Required Number of GSS	2
Proposed GSS Arrangement	2x45 MVA

(3)

Medium Voltage (kV)	33
Rated Bus bar Current(A)	1600
Required Number of GSS	2
Proposed GSS Arrangement	2x45 MVA

6.8. Further Analysis of Selected GSS Arrangements

There are three GSS arrangements that are considered for further evaluation while the total demand for the stage 01 is 147.89 MVA. Suitable arrangements to cater the above demand are summarized and shown in the table 6.11 below

Table 6.11: GSS Arrangements to cater the total demand of stage 01

Medium Voltage (kV)	11	22	33
Rated Busbar Current (A)	2500	2500	1600
Required Number of GSS	4	2	2
Proposed GSS Arrangement	2x22.5 MVA	2x45 MVA	2x45 MVA
Firm Capacity of Arrangement (MVA)	56.25	112.5	112.5
Total Demand per GSS (MVA)	36.97	73.95	73.95

It is necessary to compare the cost involvement for the above arrangements in order to identify the most economical GSS arrangement. Total cost involvement for the selected GSS arrangements were calculated and shown in the table 6.12 and the respective engineering estimates were annexed as annexure -01 and summary of the above engineering estimates were given in section 4.6 of this document.

Table 6.12: Total cost involvement for the selected GSS arrangements

Medium Voltage (kV)	11	22	33
GSS Arrangement(MVA)	2x22.5	2x45	2x45
Required No. of GSS	4	2	2
Designed Capacity	180	180	180
Cost Per GSS	1188.13	1354.07	1389.16
Total Cost (LKR Million)	4752.52	2708.14	2778.32
Total Cost per MVA (LKR Million)	26.40	15.05	15.44

It is mentioned that the land cost is to be added to the respective GSS as it was not included to above calculation, considering the variation of land cost from one location to other location in the same development based on the sea view and other architectural features.

6.9. Optimum Value for MV Distribution

According to the measurements and statistics, the least cost option is 132/22 kV, 2x45MVA arrangement for the development. Therefore the optimum voltage for medium voltage distribution in Colombo port city is considered as 22kV and the optimum arrangement as 132/22 kV, 2x45MVA.

6.10. Land Cost Variation of Colombo Port City

Generally, the land cost is very high in Colombo and suburbs in the country as Colombo is the commercial capital of Sri Lanka and it is the urban centre as well, where many people are gathered to live and work in comfort. Developing of Colombo port city complex is a key activity of the present development processes, which will result in increasing the land prices more and more in Colombo city.

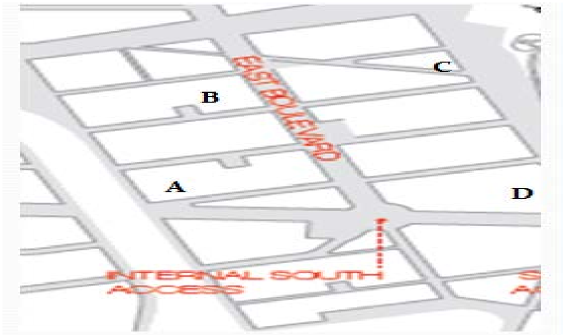


Figure 6.6: Locations of Available lands for constructing GSS on the stage – 01

Source: PORT CITY CONCEPTUAL MASTER PLAN

Figure 6.7: Available locations for GSS in Conceptual Master Plan

Source: PORT CITY CONCEPTUAL MASTER PLAN

Correspondingly, land usage for any utility activity is a considerable and costly factor for this kind of developments. Therefore, the selection of the optimum location is very important for the construction of MV distribution and GSS in Colombo port city complex. The locations and tentative prices of the available land slots of stage – 01 of Colombo port city is given in figure 6.6, figure 6.7 and table 6.13 respectively.

Table 6.13: The tentative prices of the available land slots of stage – 01

Land Identification	Tentative price (LKR Mn./Perch)	Total Cost (LKR Mn.)
A	21.6	475.2
B	18	396
C	12	264
D	14.4	330

The highest value land is Lot “A” among four available blocks, because it is the closet land to sea and a nice sea view is available for high rise building on lot “A”. The least cost land is lot “C”. However, it is not possible to select the location, based only on the land cost, since there are other effective factors such as cable cost and power loss.

It is necessary to lay Underground cables from GSS locations to consumers (spot loads) in order to provide the MV power supply to the consumer ends. When selecting the locations for GSS, it is necessary to minimize the distances to load centres and the power losses of the cable. Both of these factors need to be taken in to account to select the optimum location. The minimum required land area for a GSS is 25x30m [30] and it is approximately 22 perches as per the CEB specifications.

6.11. Available Lands for Construction of GSS

There are four available lands in stage (I) and it is required to select two locations as the optimum locations for the installation of GSS. All available lands were named as A, B, C & D and the relevant locations were marked on the plan as shown in figure 6.6 and figure 6.7. Since two GSS locations are needed to cater the complete demand of the stage (I), it is necessary to find the associated cable lengths, associated power losses, land cost of selected lands etc in order to provide the power supply to spot loads. Land cost is given in the table 6.13. All land combinations to find the optimum solution for the case study can be mentioned as,

AB, AC, AD, BC, CD & BD

6.12. Supply & Installation Cost of Under Ground Cables

As a policy, all the spot loads that exceed the contract demand more than 1MVA are fed through a radial cable to improve the reliability, which it is called as a dedicated feeder [23]. Reliability is extremely important for a planned city and especially when the consumers are in MVA range [3] it is not possible to maintain a stand by generator for total demand of the premises. Table 6.14 presents the supply and installation cost of underground cables for the case study and the rates were based on the GCTDLRP, 2015 and as per the given guidelines by CMC/RDA [20].

Table 6.14: Supply and installation cost of underground cables

Item	Cost
Cable & Accessories Cost (1km route length)	12,418,595.74
Excavation & Road reinstatement cost (LKR/km)	8,703,000.00
Installation Cost – LKR/km	658,500.00
Sub Total	21,780,095.00
Operation & Maintenance Cost (2% of Investment cost)	248,371.91
Total Cost per km length	22,028,467.65
Total Cost per meter length	22,028.47

6.13. Calculation of Total Cost of GSS Combinations

Total cost of GSS consists of,

- Cost of GSS
- land cost
- Cost of MV cable network
- Full load copper loss cost of MV cable network

Minimum value of the above costs is the optimum condition.

6.14. Optimum Location for GSS

Following methodology is applicable to identify the optimum location / Land combination for the installation of GSS for Colombo port city.

- Tabulate the demand and distances to each spot load from the available land blocks. Demand of each and every spot load was calculated as per the figures 6.2, 6.3, 6.4, 6.5 and as per the standard ratings. Relevant figures are given under table 6.2, 6.3, 6.4, 6.5, 6.6 and 6.7.
- There are 58 spot loads in the stage -01 to be catered from the GSS of stage -01 and it was numbered from No.01 to 58.

All the distances were measured from relevant land blocks to the spot load along the proposed public roads. Table No. 6.15 indicates the basic details required for further evaluation.

- Afterwards, the full load current and full load copper loss is calculated, which is shown in Table 6.16.

- The order of minimum loss feeder for each and every spot load is selected by filtering the full load copper loss values, which is shown in Table 6.17.
- Since there are six land combinations to find the optimal locations in lot – 01, the table should be filtered by allocating minimum loss feeders to all land combinations which are shown in Table 6.18 and Table 6.19.

Table 6.15: Spot load, Demand & Distances to spot loads from GSS

Spot Load	Demand	Current	Distance to spot load from the available land (m)				Copper loss of the cable at full load from GSS to spot load(W)				**Order of Minimum Loss feeder**			
No.	**D_i (MVA)**	**I_i**	**A**	**B**	**C**	**D**	**A'**	**B'**	**C'**	**D'**	**1^{st}**	**2^{nd}**	**3^{rd}**	**4^{th}**
1	3.30		950	500	320	850								
2	1.20		880	400	360	900								
3	3.00		810	200	450	920								
4	2.00		750	200	540	960								
5	1.80		700	240	620	980								
6	3.20		780	270	660	1040								
7	3.30		810	295	710	1100								
8	3.30		840	310	740	1150								
9	1.80		870	350	800	1190								
10	2.00		920	400	840	1230								
11	2.00		940	420	860	1300								
12	3.00		850	320	920	1350								
13	1.20		780	300	960	900								
14	2.00		720	290	910	960								
15	2.00		650	300	850	800								
16	1.20		610	280	750	820								
17	3.00		590	320	700	840								
18	2.00		570	360	680	880								
19	2.00		540	400	660	700								
20	1.80		520	450	640	750								
21	3.30		540	470	720	860								
22	2.00		480	500	760	890								
23	2.00		290	510	840	910								
24	1.20		180	520	750	800								
25	3.00		100	580	700	720								
26	2.00		160	600	800	650								
27	2.00		200	740	900	600								
28	3.30		210	750	950	580								
29	2.00		270	800	980	570								
30	3.00		320	890	1030	560								
31	3.30		270	840	980	500								
32	1.20		200	810	850	460								
33	2.00		180	760	800	400								
34	2.00		300	700	740	350								
35	3.30		340	760	680	300								
36	2.00		360	800	650	340								
37	2.00		420	880	600	440								
38	3.00		510	860	580	220								
39	2.00		580	900	560	200								
40	2.00		650	940	520	180								
41	2.00		550	860	470	140								
42	3.00		420	800	400	100								
43	3.30		340	740	360	90								
44	2.00		250	650	300	150								
45	2.00		340	600	250	200								
46	3.00		420	550	180	250								
47	3.30		460	510	120	300								
48	2.00		510	490	100	320								
49	2.00		580	470	90	380								
50	3.00		620	450	60	460								
51	2.00		680	470	80	480								
52	3.00		720	480	120	510								
53	3.30		780	490	160	560								
54	2.00		820	550	180	620								
55	2.00		860	540	200	680								
56	2.00		890	520	240	700								
57	2.00		910	500	260	720								
58	2.00		940	450	300	750								
Total	**135.60**		**32730**	**31335**	**33230**	**37560**	**0**	**0**	**0**	**0**				

Table 6.16: Details of demand, distances, full load current & full load copper loss of MV feeders to spot loads from available lands

Spot Load	Demand	Current (A)	Distance to spot load from the available land (m)				Copper loss of the cable at full load from GSS to spot load(W)				Order of Minimum Loss feeder			
No.	D_i (MVA)	I_i	A'	B'	C'	D'	A	B	C	D	1^{st}	2^{nd}	3^{rd}	4^{th}
1	3.30	86.61	950	500	320	850	1760	926.3	592.8	1574.72				
2	1.20	31.49	880	400	360	900	215.58	97.99	88.19	220.476				
3	3.00	78.73	810	200	450	920	1240.2	306.2	689	1408.6				
4	2.00	52.49	750	200	540	960	510.36	136.1	367.5	653.261				
5	1.80	47.24	700	240	620	980	385.83	132.3	341.7	540.166				
6	3.20	83.98	780	270	660	1040	1358.8	470.3	1150	1811.71				
7	3.30	86.61	810	295	710	1100	1500.6	546.5	1315	2037.87				
8	3.30	86.61	840	310	740	1150	1556.2	574.3	1371	2130.5				
9	1.80	47.24	870	350	800	1190	479.53	192.9	441	655.915				
10	2.00	52.49	920	400	840	1230	626.04	272.2	571.6	836.991				
11	2.00	52.49	940	420	860	1300	639.65	285.8	585.2	884.625				
12	3.00	78.73	850	320	920	1350	1301.4	489.9	1409	2066.96				
13	1.20	31.49	780	300	960	900	191.08	73.49	235.2	220.476				
14	2.00	52.49	720	290	910	960	489.95	197.3	619.2	653.261				
15	2.00	52.49	650	300	850	800	442.31	204.1	578.4	544.385				
16	1.20	31.49	610	280	750	820	149.43	68.59	183.7	200.878				
17	3.00	78.73	590	320	700	840	903.34	489.9	1072	1286.11				
18	2.00	52.49	570	360	680	880	387.87	245	462.7	598.823				
19	2.00	52.49	540	400	660	700	367.46	272.2	449.1	476.336				
20	1.80	47.24	520	450	640	750	286.62	248	352.8	413.392				
21	3.30	86.61	540	470	720	860	1000.4	870.7	1334	1593.24				
22	2.00	52.49	480	500	760	890	326.63	340.2	517.2	605.628				
23	2.00	52.49	290	510	840	910	197.34	347	571.6	619.237				
24	1.20	31.49	180	520	750	800	44.095	127.4	183.7	195.978				
25	3.00	78.73	100	580	700	720	153.11	888	1072	1102.38				
26	2.00	52.49	160	600	800	650	108.88	408.3	544.4	442.312				
27	2.00	52.49	200	740	900	600	136.1	503.6	612.4	408.288				
28	3.30	86.61	210	750	950	580	389.05	1389	1760	1074.51				
29	2.00	52.49	270	800	980	570	183.73	544.4	666.9	387.874				
30	3.00	78.73	320	890	1030	560	489.95	1363	1577	857.406				
31	3.30	86.61	270	840	980	500	500.2	1556	1816	926.304				
32	1.20	31.49	200	810	850	460	48.995	198.4	208.2	112.688				
33	2.00	52.49	180	760	800	400	122.49	517.2	544.4	272.192				
34	2.00	52.49	300	700	740	350	204.14	476.3	503.6	238.168				
35	3.30	86.61	340	760	680	300	629.89	1408	1260	555.783				
36	2.00	52.49	360	800	650	340	244.97	544.4	442.3	231.363				
37	2.00	52.49	420	880	600	440	285.8	598.8	408.3	299.412				
38	3.00	78.73	510	860	580	220	780.85	1317	888	336.838				
39	2.00	52.49	580	900	560	200	394.68	612.4	381.1	136.096				
40	2.00	52.49	650	940	520	180	442.31	639.7	353.8	122.487				
41	2.00	52.49	550	860	470	140	374.26	585.2	319.8	95.2673				
42	3.00	78.73	420	800	400	100	643.05	1225	612.4	153.108				
43	3.30	86.61	340	740	360	90	629.89	1371	666.9	166.735				
44	2.00	52.49	250	650	300	150	170.12	442.3	204.1	102.072				
45	2.00	52.49	340	600	250	200	231.36	408.3	170.1	136.096				
46	3.00	78.73	420	550	180	250	643.05	842.1	275.6	382.77				
47	3.30	86.61	460	510	120	300	852.2	944.8	222.3	555.783				
48	2.00	52.49	510	490	100	320	347.05	333.4	68.05	217.754				
49	2.00	52.49	580	470	90	380	394.68	319.8	61.24	258.583				
50	3.00	78.73	620	450	60	460	949.27	689	91.86	704.298				
51	2.00	52.49	680	470	80	480	462.73	319.8	54.44	326.631				
52	3.00	78.73	720	480	120	510	1102.4	734.9	183.7	780.852				
53	3.30	86.61	780	490	160	560	1445	907.8	296.4	1037.46				
54	2.00	52.49	820	550	180	620	557.99	374.3	122.5	421.898				
55	2.00	52.49	860	540	200	680	585.21	367.5	136.1	462.727				
56	2.00	52.49	890	520	240	700	605.63	353.8	163.3	476.336				
57	2.00	52.49	910	500	260	720	619.24	340.2	176.9	489.946				
58	2.00	52.49	940	450	300	750	639.65	306.2	204.1	510.361				

Table 6.17: Details of demand, distances, full load current, full load copper loss of MV feeders & order of power loss of feeders to spot loads from available lands

Spot Load	Demand	Current (A)	Distance to spot load from the available land (m)				Copper loss of the cable at full load from GSS to spot load(W)				Order of Minimum Loss feeder			
No.	D_i (MVA)	I_i	A'	B'	C'	D'	A	B	C	D	1^{st}	2^{nd}	3^{rd}	4^{th}
1	3.30	86.61	950	500	320	850	1760	926.3	592.8	1574.72	C	B	D	A
2	1.20	31.49	880	400	360	900	215.58	97.99	88.19	220.476	C	B	A	D
3	3.00	78.73	810	200	450	920	1240.2	306.2	689	1408.6	B	C	A	D
4	2.00	52.49	750	200	540	960	510.36	136.1	367.5	653.261	B	C	A	D
5	1.80	47.24	700	240	620	980	385.83	132.3	341.7	540.166	B	C	A	D
6	3.20	83.98	780	270	660	1040	1358.8	470.3	1150	1811.71	B	C	A	D
7	3.30	86.61	810	295	710	1100	1500.6	546.5	1315	2037.87	B	C	A	D
8	3.30	86.61	840	310	740	1150	1556.2	574.3	1371	2130.5	B	C	A	D
9	1.80	47.24	870	350	800	1190	479.53	192.9	441	655.915	B	C	A	D
10	2.00	52.49	920	400	840	1230	626.04	272.2	571.6	836.991	B	C	A	D
11	2.00	52.49	940	420	860	1300	639.65	285.8	585.2	884.625	B	C	A	D
12	3.00	78.73	850	320	920	1350	1301.4	489.9	1409	2066.96	B	A	C	D
13	1.20	31.49	780	300	960	900	191.08	73.49	235.2	220.476	B	A	D	C
14	2.00	52.49	720	290	910	960	489.95	197.3	619.2	653.261	B	A	C	D
15	2.00	52.49	650	300	850	800	442.31	204.1	578.4	544.385	B	A	D	C
16	1.20	31.49	610	280	750	820	149.43	68.59	183.7	200.878	B	A	C	D
17	3.00	78.73	590	320	700	840	903.34	489.9	1072	1286.11	B	A	C	D
18	2.00	52.49	570	360	680	880	387.87	245	462.7	598.823	B	A	C	D
19	2.00	52.49	540	400	660	700	367.46	272.2	449.1	476.336	B	A	C	D
20	1.80	47.24	520	450	640	750	286.62	248	352.8	413.392	B	A	C	D
21	3.30	86.61	540	470	720	860	1000.4	870.7	1334	1593.24	B	A	C	D
22	2.00	52.49	480	500	760	890	326.63	340.2	517.2	605.628	B	A	C	D
23	2.00	52.49	290	510	840	910	197.34	347	571.6	619.237	A	B	C	D
24	1.20	31.49	180	520	750	800	44.095	127.4	183.7	195.978	A	B	C	D
25	3.00	78.73	100	580	700	720	153.11	888	1072	1102.38	A	B	C	D
26	2.00	52.49	160	600	800	650	108.88	408.3	544.4	442.312	A	B	D	C
27	2.00	52.49	200	740	900	600	136.1	503.6	612.4	408.288	A	D	B	C
28	3.30	86.61	210	750	950	580	389.05	1389	1760	1074.51	A	D	B	C
29	2.00	52.49	270	800	980	570	183.73	544.4	666.9	387.874	A	D	B	C
30	3.00	78.73	320	890	1030	560	489.95	1363	1577	857.406	A	D	B	C
31	3.30	86.61	270	840	980	500	500.2	1556	1816	926.304	A	D	B	C
32	1.20	31.49	200	810	850	460	48.995	198.4	208.2	112.688	A	D	B	C
33	2.00	52.49	180	760	800	400	122.49	517.2	544.4	272.192	A	D	C	B
34	2.00	52.49	300	700	740	350	204.14	476.3	503.6	238.168	A	D	B	C
35	3.30	86.61	340	760	680	300	629.89	1408	1260	555.783	D	A	C	B
36	2.00	52.49	360	800	650	340	244.97	544.4	442.3	231.363	D	A	C	B
37	2.00	52.49	420	880	600	440	285.8	598.8	408.3	299.412	A	D	C	B
38	3.00	78.73	510	860	580	220	780.85	1317	888	336.838	D	A	C	B
39	2.00	52.49	580	900	560	200	394.68	612.4	381.1	136.096	D	A	C	B
40	2.00	52.49	650	940	520	180	442.31	639.7	353.8	122.487	D	C	A	B
41	2.00	52.49	550	860	470	140	374.26	585.2	319.8	95.2673	D	C	A	B
42	3.00	78.73	420	800	400	100	643.05	1225	612.4	153.108	D	C	A	B
43	3.30	86.61	340	740	360	90	629.89	1371	666.9	166.735	D	A	C	B
44	2.00	52.49	250	650	300	150	170.12	442.3	204.1	102.072	D	A	C	B
45	2.00	52.49	340	600	250	200	231.36	408.3	170.1	136.096	D	C	A	B
46	3.00	78.73	420	550	180	250	643.05	842.1	275.6	382.77	C	D	A	B
47	3.30	86.61	460	510	120	300	852.2	944.8	222.3	555.783	C	D	A	B
48	2.00	52.49	510	490	100	320	347.05	333.4	68.05	217.754	C	D	B	A
49	2.00	52.49	580	470	90	380	394.68	319.8	61.24	258.583	C	D	B	A
50	3.00	78.73	620	450	60	460	949.27	689	91.86	704.298	C	B	D	A
51	2.00	52.49	680	470	80	480	462.73	319.8	54.44	326.631	C	B	D	A
52	3.00	78.73	720	480	120	510	1102.4	734.9	183.7	780.852	C	B	D	A
53	3.30	86.61	780	490	160	560	1445	907.8	296.4	1037.46	C	B	D	A
54	2.00	52.49	820	550	180	620	557.99	374.3	122.5	421.898	C	B	D	A
55	2.00	52.49	860	540	200	680	585.21	367.5	136.1	462.727	C	B	D	A
56	2.00	52.49	890	520	240	700	605.63	353.8	163.3	476.336	C	B	D	A
57	2.00	52.49	910	500	260	720	619.24	340.2	176.9	489.946	C	B	D	A
58	2.00	52.49	940	450	300	750	639.65	306.2	204.1	510.361	C	B	D	A

Table 6.18: Allocated spot loads to Land – B

Spot Load Number	Demand of the spot load (MVA)	Distance from "A" to load (m)	Distance from "B" to load (m)	Full load Cu loss of the cable from "A"(w)	Full load Cu loss of the cable from "B"(w)
No.	**D_i (MVA)**	**A'**	**B'**	**A**	**B**
3	3.00	810	200	1240.18	306.22
4	2.00	750	200	510.36	136.10
5	1.80	700	240	385.83	132.29
6	3.20	780	270	1358.78	470.35
7	3.30	810	295	1500.61	546.52
8	3.30	840	310	1556.19	574.31
9	1.80	870	350	479.53	192.92
10	2.00	920	400	626.04	272.19
11	2.00	940	420	639.65	285.80
12	3.00	850	320	1301.42	489.95
13	1.20	780	300	191.08	73.49
14	2.00	720	290	489.95	197.34
15	2.00	650	300	442.31	204.14
16	1.20	610	280	149.43	68.59
17	3.00	590	320	903.34	489.95
18	2.00	570	360	387.87	244.97
19	2.00	540	400	367.46	272.19
20	1.80	520	450	286.62	248.04
21	3.30	540	470	1000.41	870.73
22	2.00	480	500	326.63	340.24
1	3.30	950	500	1759.98	926.30
2	1.20	880	400	215.58	97.99
50	3.00	620	450	949.27	688.99
51	2.00	680	470	462.73	319.83
52	3.00	720	480	1102.38	734.92
53	3.30	780	490	1445.03	907.78
54	2.00	820	550	557.99	374.26
55	2.00	860	540	585.21	367.46
56	2.00	890	520	605.63	353.85
57	2.00	910	500	619.24	340.24
58	2.00	940	450	639.65	306.22
48	2.00	510	490	347.05	333.44
49	2.00	580	470	394.68	319.83
Total	75.70	24410	12985		12487.41

Table 6.19: Allocated spot loads to Land – A

Spot Load Number	Demand of the spot load (MVA)	Distance from "A" to load (m)	Distance from "B" to load (m)	Full load Cu loss of the cable from "A"(w)	Full load Cu loss of the cable from "B"(w)
No.	D_i (MVA)	A'(m)	B'(m)	A	B
23	2.00	290	510	197.34	347.05
24	1.20	180	520	44.10	127.39
25	3.00	100	580	153.11	888.03
26	2.00	160	600	108.88	408.29
27	2.00	200	740	136.10	503.56
28	3.30	210	750	389.05	1389.46
29	2.00	270	800	183.73	544.38
30	3.00	320	890	489.95	1362.66
31	3.30	270	840	500.20	1556.19
32	1.20	200	810	48.99	198.43
33	2.00	180	760	122.49	517.17
34	2.00	300	700	204.14	476.34
37	2.00	420	880	285.80	598.82
35	3.30	340	760	629.89	1407.98
36	2.00	360	800	244.97	544.38
38	3.00	510	860	780.85	1316.73
39	2.00	580	900	394.68	612.43
43	3.30	340	740	629.89	1370.93
44	2.00	250	650	170.12	442.31
40	2.00	650	940	442.31	639.65
41	2.00	550	860	374.26	585.21
42	3.00	420	800	643.05	1224.87
45	2.00	340	600	231.36	408.29
46	3.00	420	550	643.05	842.09
47	3.30	460	510	852.20	944.83
Total	59.90	8320	18350	8900.52	

Once all the details are filtered to the table 6.17, table 6.18 and 6.19, it is necessary to check the total demand of each substation, in order to ensure that it will not exceed the firm capacity or pre-defined maximum value. If it exceeds the predefined value, it is necessary to select few loads to transfer to other substation based on the full load loss value.

Table 6.20: Summary of GSS in Land A and B

	GS in Land A	GS in Land B
Total Demand (MVA)	59.90	75.70
Total cable length of MV network (m)	8320	12985

Complete cost calculation for the land combination of AB is given in table 6.23 below,

Table 6.21: Complete cost calculation for the GSS combination AB

GSS	Total Demand (MVA)	Land cost (LKR-Mn)	Total Cable length(m)	Supply & Installation cost of cables (LKR - Mn)	Full load copper loss cost	Total Cost (LKR-Mn
A	59.90	475.20	8,320.00	183,272,690.89	23,195,638.25	681.70
B	75.70	396.00	24,410.00	537,702,747.70	32,543,433.02	966.20
Total Cost of combination						1,647.90

Similarly all other calculations for other combinations also have been completed and shown in tables 6.22, 6.23, 6.24, 6.25 and 6.26

<u>Summary of complete cost calculation for the land combination BC</u>

Table 6.22: Complete cost calculation for the land combination BC

GSS	Total Demand (MVA)	Land cost (LKR-Mn)	Total Cable length(m)	Supply & Installation cost of cables (LKR - Mn)	Full load copper loss cost	Total Cost (LKR-Mn
B	70.90	396.00	14,415.00	317,533,187.55	37,053,723.11	750.50
C	64.70	264.00	8,940.00	196,930,051.80	23,425,736.99	484.30
Total Cost of combination						1,234.80

Summary of complete cost calculation for the land combination CD

Table 6.23: Complete cost calculation for the land combination CD

GSS	Total Demand (MVA)	Land cost (LKR-Mn)	Total Cable length(m)	Supply & Installation cost of cables (LKR - Mn)	Full load copper loss cost	Total Cost (LKR-Mn
C	85.00	264.00	18,020.00	396,944,019.40	46,377,310.96	707.20
D	50.60	330.00	8,730.00	192,304,178.10	20,379,344.88	542.60
Total Cost of combination						1,249.80

Summary of complete cost calculation for the land combination DA

Table 6.24: Complete cost calculation for the land combination DA

GSS	Total Demand (MVA)	Land cost (LKR-Mn)	Total Cable length(m)	Supply & Installation cost of cables (LKR - Mn)	Full load copper loss cost	Total Cost (LKR-Mn
D	59.50	330.00	9,500.00	209,265,715.00	26,675,937.19	565.80
A	76.10	475.20	18,250.00	402,010,452.50	44,885,260.26	922.01
Total Cost of combination						1,487.81

Summary of complete cost calculation for the land combination BD

Table 6.25: Complete cost calculation for the land combination BD

GSS	Total Demand (MVA)	Land cost (LKR-Mn)	Total Cable length(m)	Supply & Installation cost of cables (LKR - Mn)	Full load copper loss cost	Total Cost (LKR-Mn
B	79.90	396.00	14,235.00	313,568,152.95	35,455,711.71	744.80
D	55.70	330.00	7,630.00	168,073,411.10	20,920,675.45	518.97
Total Cost of combination						1,263.77

Summary of complete cost calculation for the land combination – AC

Table 6.26: Complete cost calculation for the land combination AC

GSS	Total Demand (MVA)	Land cost (LKR-Mn)	Total Cable length(m)	Supply & Installation cost of cables (LKR - Mn)	Full load copper loss cost	Total Cost (LKR-Mn
A	68.10	475.20	12,330.00	271,604,870.10	30,128,571.08	776.90
C	67.50	264.00	10,630.00	234,157,321.10	28,734,456.42	526.80
Total Cost of combination						1,303.70

Summary of the total cost of GSS combination for all land combinations are given in table 6.27

Table 6.27: Summary of the total cost of GSS combinations

GSS Combination	Total cost (LKR- Mn)
AB	1,647.90
BC	1,234.80
CD	1,249.80
DA	1,487.81
BD	1,263.77
AC	1,303.70

6.15. Outcome of the Case Study

As per the table 6.27, the minimum cost option is the land combination BC. Therefore the optimum locations are B and C for the above case study and the optimum value for the MV power distribution is 22kV. The key benefit of the above methodology is that it provides a set of solutions (optimal or near optimal) that may be considered simultaneously.

This is especially important in the case of planning of MV distribution system, where the optimization problem is multi objective. Thus, city planner can select a suitable solution / arrangement depending on the cost involvement and other related factors. The optimum arrangement was modelled in synergee software to check the technical feasibility of the design and found that the voltage profile and other technical requirements are in line with applicable standards. All the results were annexed as Annexure (07).

CHAPTER 07: CONCLUSION AND RECOMMENDATION

This dissertation describes and proposes a methodology of optimum MV power distribution for a planned city under certain constrains. Therefore the major result from the research performed for this dissertation can be used to develop a general model to assist city planners to arrange the MV power distribution for a planned city. Following requirements / algorithms were identified as key elements of the research.

- Required number of GSS per stage
- Optimum voltage selection criteria
- Optimum location selection criteria
- Application of the developed model as a case study to Colombo Port City

Currently, many cities in the world face challenges of rapid population growth, resource scarcity, rural-urban migration, severe poverty and socioeconomic inequality. As a developing country in Asia, Sri Lanka is also encountering above challenges severely since the beginning of last decade. Major cities are rapidly commercializing and becoming predominantly urban cities. This has resulted in arising huge problems in following sectors due to the unplanned nature of city development activities,

- Infrastructure
- Potable water and sanitation
- Electricity
- Housing development etc.

Mega cities or planned cities have been introduced with solutions for complex process of urban planning which consists of social, technical and political demands with the use of land and design of the urban environment including all infrastructure facilities. Early scheduling and anticipating the future leads to better living standards and comfortable future.

Therefore a new approach is proposed in the thesis to address the MV development for a planned city. The outcomes of the thesis are diverse to the traditional MV distribution arrangement, but it is in par with applicable standards.

MV distribution arrangements shall be selected as either overhead distribution system or underground cable network that complies with other applicable factors to the area to be developed. The power transmission and distribution networks ensure the transfer of electricity from points of generation to substations / end users. The distribution process which is taken place via the "MV distribution network" and implementing GSS, are among the main objects of this optimization process. There are many GSS and different bus bar system schemes with various capacities, but selection of a particular scheme depends upon the system voltage, position of substation, flexibility needed in system and cost to be incurred. The commercial policy of the respective utility is also very important. Following methodology, which is illustrated in figure 7.1, is proposed to determine the required number of GSS

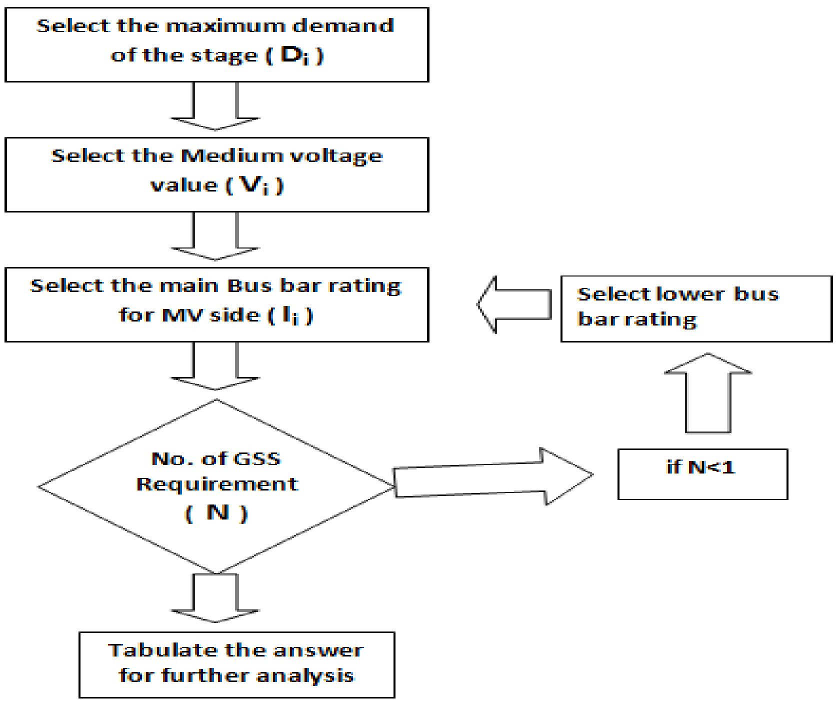


Figure 7.1: Methodology to determine the required No. of GSS

It is necessary to consider the cost involvement for the selected values of GSS and it will be evaluated based on following conditions to find out the most economical value for MV distribution.

- Panel cost variation with MV value
- Transformer cost variation
- Total cost of GSS
- Cost per MVA under GSS arrangement

Lowest cost option is the most economical voltage for the design. This complete process is called the optimal voltage selection criteria.

Once the optimum voltage has been finalized, the next step is to find the optimum location / s for GSS, which is shown in figure 6.2.

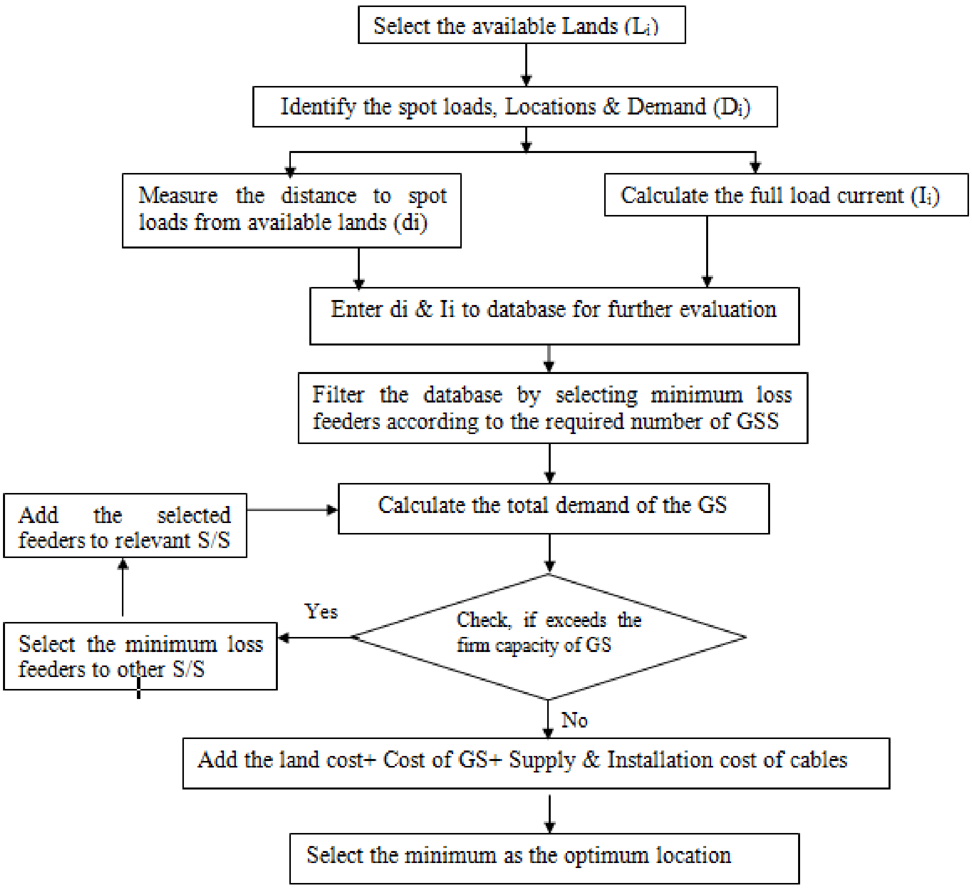


Figure 7.2: Optimum location selection criteria

The main purpose of optimum location selection criteria is to adhere with the technical / non-technical requirements and financial conditions. If the losses of the MV network can be minimized at the initial stage of network planning, this will be a definite advantage for the utility. This is not a practical scenario for unplanned cities, but it is more applicable and cost effective for a planned city. Minimum total cost shall be identified for the selected arrangement and the total cost consists of,

- Cost of GSS
- Cost of MV cable network
- Full load loss cost of MV cable network
- Cost of Land

It will provide the total cost for relevant GSS or combination depending on the GSS requirement. Based on this, city planners are able to select the required location/s or combination as per their view and the applicable cost. This methodology has been applied to Colombo Port City complex, and the relevant data has taken from the developer and the draft port city development document by sweco international, 2013.

7.1. Optimum Arrangement for Colombo Port City

This will be developed under three main stages, i.e. stage (i), (ii) and (iii). This is a novel concept to Sri Lanka and the highest commercially valued lands in the country will be in this complex. Since the existing capacity of the CEB Colombo city network is not adequate to cater the port city demand, it is essential to implement new GSS and transmission lines to meet the demand. Accordingly, the stage wise power requirement / demand are calculated, in order to evaluate the total demand of the development; and afterwards, the MV power distribution system is designed based on the findings and guidelines of the thesis.

Table 7.1: Summary of the Demands of the development

Reclaimed Land section	Calculated Demand (MVA)
Stage (I)	147.89
Stage (II)	113.09
Stage (III)	134.14
Total Demand	**395.13**

Calculated current values and required number of GSS for stage (I) is tabulated and given under the table 7.2

Table 7.2: Calculated currents & required number of GSS for stage (I)

Demand of the stage (MVA)	Medium Voltage (kV)	Total Current (A)	Required Number of GSS at rated Bus bar current		
			1250A	1600A	2500A
147.89	6.6	12937	11	9	6
	11	7762	7	5	4
	22	3881	4	3	2
	33	2587	3	2	2

It is apparent that the required number of GSS for stage (I) varies with the applicable MV value and the respective bus bar current of the arrangement. Three GSS arrangements are considered for further evaluation in this thesis, while the total demand for the stage 01 is 147.89 MVA.

According to the above evaluation, it is necessary to compare the cost involvement for the separate arrangements to identify the most economical GSS arrangement, which is shown in table 7.3.

Table 7.3: GSS Arrangements to cater the total demand of stage (I)

	Medium Voltage Value(V_i)		
	11kV	**22kV**	**33kV**
Bus Bar Rating	2500A	2500A	1600A
Suitable GSS Arrangement	04Nos, 2x22.5MVA	02Nos, 2x45MVA	02Nos, 2x45MVA

Table 7.4: Total cost involvement for the selected GSS arrangements

Medium Voltage (kV)	11	22	33
GSS Arrangement(MVA)	2x22.5	2x45	2x45
Required No. of GSS	4	2	2
Designed Capacity	180	180	180
Cost Per GSS	1188.13	1354.07	1389.16
Total Cost (LKR Million)	4752.52	2708.14	2778.32
Total Cost per MVA (LKR Million)	26.40	15.05	15.44

Accordingly, the lowest cost option is 132/22 kV, 2x45MVA arrangement for the development, which requires two lands to construct two GSS. Optimum locations were selected and calculated the total cost involvement, which is summarized as follows, in table 7.5.

Table 7.5: Summary of the total cost of GSS combinations

GSS Combination	Total cost (LKR- Mn)
AB	1,647.90
BC	1,234.80
CD	1,249.80
DA	1,487.81
BD	1,263.77
AC	1,303.70

7.2. Recommendations

As per the table 7.5, the minimum cost option is the land combination BC. Therefore, the optimum locations are B and C for the above case study and the optimum value for the MV power distribution is 22kV. The main benefit of the above methodology is that it provides a set of solutions (optimal or near optimal) that can be considered simultaneously. This is especially important when planning the MV distribution system where the optimization problem is multi objective which facilitate the city planner to select a suitable solution / arrangement depending on the cost involvement and other related factors.

7.3. Limitations and Future Work

The research has achieved the desired outcome but there were some unavoidable limitations which includes,

- The primary outcome of the research was to determine the optimum voltage for a planned city. However, the study was conducted under three limited MV values, but it was apparent that few other values are being practiced in power systems all over the world. Those medium voltages are not commonly used voltages as per the supply records of leading manufactures.
- When calculating the required number of GSS per stage, it was considered only the standard or frequently used rating for the MV side bus bar. But there were some other non-standard or customized values also available with leading manufactures. It is always advisable to select only type tested products, if a nonstandard rating is selected.
- When allocating the spot loads to GSS, it was loaded up to 70% of the firm capacity of the GSS. This could further increase or decrease depending on the choice of the requirement of the utility.
- If the total demand of the development including the load forecasting is very small, it is prudent to extend the existing network, i.e. the total demand including load forecast shall be well enough to put up a GSS.
- Selection of lands for GSS is very important. But before applying the proposed optimum location selection criteria, the user shall study about the non-technical reasons such as the environmental issues, floods or any non-technical reasons associated with available lands. These issues can have a significant impact on the timely completion of the project and the total cost of the project as well. However, the proposed optimum location selection criteria have not addressed the non-technical reasons. Therefore the user needs to study about the non-technical reasons before applying the proposed criteria to new development / planned city.
- The entire research was based on IEC standards and CEB accepted policies. But there are other accepted standards available in the world.
- While this thesis has demonstrated the potential of MV power distribution in a planned city under constraints, the power distribution arrangement was mainly

radial feeding / open ring arrangement to spot loads. There is a possibility to further optimize the proposed methodology by introducing closed ring arrangement to the MV distribution network.

REFERENCES

[1] Public Utilities Commission of Sri Lanka, July, 2012, “Distribution Code of Sri Lanka”

[2] Ignacio J. Ramirez - Rosado, Member IEEE and Jose L. Bernal – Agustin “Reliability & Cost optimization for distribution networks expansion using an Evolutionary Algorithm” *IEEE Transaction on power systems*, Vol 16, No 1, February 2001, pp111-118

[3] Gregory Levitin, Shmuel Mazal - Tov, David Elmakis, “Genetic Algorithm for open loop distribution system design” *Electrical Power system research* 32 (1995) 81-87

[4] Li Ren, Yuejin Tang, Jing Shi, Liang Li, Jingdong Li and shijie Cheng Senior Member IEEE, “Techno – Economic feasibility study on HTS power cables” *IEEE Transaction on Applied Super Conductivity*, Vol 19, No 03, June 2009, PP 1774-1779

[5] Victor Parada, Jacques A Ferland, Miguel Arias Senior Member IEEE and Keith Daniels, “Optimization of Electrical Distribution Feeders using simulated Annealing” *IEEE Transaction on power delivery*, Vol 19, No 3, July 2004, pp1135-1141

[6] Libin Wang, Chunghui Li, Jiawei Wang, Jing Guo, Zeyuan Shen, Haibo Zhao and Qiang Li, “Research on Optimization Planning Method of Distribution Network based on Spatial Load Forecast” *Economic and Electrical Research Institute of Shanxi Electrical Power Company of SGCC*

[7] Svetlana Guseva, OlegsBorscevskis, Nataly Skobeleva and LubovKozireva of Riga Technical University, "Load Determination and Selection of Transformer Substations' Optimal Power for Tasks of Urban Networks' Development" *Scientific Journal of Riga Technical University*, Volume 27, 2010

[8] LuisPérez-Lombard, José Ortiz, ChristinePout, "A review on buildings energy consumption information" *Science Direct, Energy and Buildings* 40 (2008) 394- 398

[9] Building and Construction Authority (BCA) of Singapore, Green Building Policy Department, "Building Energy Benchmarking Report, 2014"

[10] Transparency Market Research, India, "Low Voltage (LV) and Medium Voltage (MV) Switchgear Market: Global Forecast, Market Share, Size, Growth and Industry Analysis 2014 – 2020"

[11] Medium Voltage distribution plan, CEB Colombo City, 2015

[12] Supply record of Medium voltage manufactures submitted to GCTDLRP, by the pre-qualified bidders, 2015

[13] Trading economics, Historical data on copper prices

[14] Preet Khandelwal1 and ArunPachori, "A comparative analysis on life cycle operation and maintenance cost of EHV new generation XLPE insulated cable versus conventional overhead lines" *ISSN: 2319-7463 Vol. 2 Issue 5, May-2013, pp: (12-17)*

[15] E. Lakervi and E.J. Holmes "Electricity Distribution Network Design", 2nd Edition, IEE Power Engineering series 21,

[16] Hassan Al-Khalidi, “Technical Consideration and Impact of Converting Overhead Power Lines to Underground Power Cables”, *Victoria University, Australia, 2009*

[17] Standard construction cost - 2016, Published by Ceylon Electricity Board

[18] Ceylon Electricity Board, 2006, “Construction Standards for MV and LV overhead lines”.

[19] Saurav S Sengupta, Tiomthy J Person; Paul J Caronia, “A new generation of tree-retardant cross linked polyethylene (TR-XLPE) insulation” *IEEE Xplore, Electrical Insulation (ISEI),* Conference Record of 2010 Symposium, August 2010

[20] The guide lines given by CMC /RDA for road excavation and reinstatement of public roads for utility activities

[21] The guide lines given by CEB Colombo city for trail pit excavation and cable laying works

[22] Transpower, New Zealand Limited, February, 2005 “ Main Transmission System Planning Guideline”.

[23] Commercial policy, Ceylon Electricity Board, 2016

[24] Sweco International AB, “PORT CITY CONCEPTUAL MASTER PLAN”

[25] Energy consumption Benchmark Analysis, Published by Sri Lanka Sustainable Energy Authority, 2015

[26] Dr. WDAS Rodrigo, *Lecture Notes, MSc (Eng.) in Electrical Installation*, University of Moratuwa, 2013

[27] Price details provided by Siemens AG – Germany

[28] NR Ramasinghe, “Analysis of Non-technical losses in distribution networks, Mitigation methods and costs”, MSc dissertation, Department of Electrical Engineering, University of Moratuwa, 2014.

[29] “Undergrounding”, Wikipedia, the free encyclopaedia”

[30] Ceylon Electricity Board, “Approved Bid document for Greater Colombo Transmission &Distribution Loss Reduction Project, 2015”.

[31] Ceylon Electricity Board, Division – 1, “Medium Voltage Development Plan 2008-2017”.

ANNEXTURES

Annex 01: Engineering Estimate for Supply, Delivery, Installation & Commission of complete 132kV/11kV substation with 02 Nos. 22.5MVA Transformers

Item	Description	Qty	Unit	Unit Price		Total Price	
				Foreign	Local LKR	Foreign	Local LKR
1.00	**145 kV Indoor Switchgear**						
1.01	145 kV GIS Single Busbar with Busbar VT/ES Bay	1	No	341,181.00	341,309.00	341,181.00	341,309.00
1.02	145 kV GIS Line Feeder Bay	2	Nos	116,921.00	116,965.00	233,842.00	233,930.00
1.03	145 kV GIS Transformer Feeder Bay	2	Nos	114,923.00	114,966.00	229,846.00	229,932.00
1.04	145kV Bus Section Bay	1	No	111,421.00	111,463.00	111,421.00	111,463.00
2.00	**12 kV Indoor Switchgear**						
2.01	12 kV GIS Transformer Feeder Bay	2	Nos	42,650.00	80,263.00	85,300.00	160,526.00
2.02	12 kV GIS Generator Feeder Bay	2	Nos	39,350.00	51,701.00	78,700.00	103,402.00
2.03	12 kV GIS Outgoing Line Feeder Bay	13	Nos	38,150.00	49,690.00	495,950.00	645,970.00
2.04	12 kV GIS Outgoing Line Feeder Bay	5	Nos	37,500.00	55,822.00	187,500.00	279,110.00
2.05	12 kV GIS Auxiliary Transformer Feeder Bay	2	Nos	40,150.00	40,657.00	80,300.00	81,314.00
2.06	12 kV GIS Bus Section Bay	2	Nos	33,650.00	76,958.00	67,300.00	153,916.00
3.00	**Auxiliary Supply**						
3.01	400 V AC Main Switchboard	1	No	8,818.00	8,821.00	8,818.00	8,821.00
3.02	400 V AC Distribution Panel	1	No	2,672.00	2,673.00	2,672.00	2,673.00
4.00	**Batteries, Chargers and Distribution Boards and Inverter Equipment**						
4.01	110 V Battery System	1	No	98,586.00	98,623.00	98,586.00	98,623.00
4.02	Inverter System for Substation Automation System	1	No	31,510.00	31,522.00	31,510.00	31,522.00
5.00	**Protection, Control, Metering and Monitoring**						
5.01	Substation Automation System	1	Lot	289,349.00	289,457.00	289,349.00	289,457.00
5.02	Digital Disturbance Recorder with Analysis Computers	1	Lot	171,618.00	171,682.00	171,618.00	171,682.00
5.03	Power Quality Analyzer	1	Lot	60,058.00	60,080.00	60,058.00	60,080.00
5.04	Remote Work Stations	1	Lot			0.00	0.00
5.05	145 kV Protection and Control					0.00	0.00
5.06	Protection for 145kV Line Feeder Bays	2	Nos	72,025.00	72,052.00	144,050.00	144,104.00

5.07	Control for 145kV Line Feeder Bays	2	Nos			0.00	0.00
5.08	Protection for 145kV Transformer Feeder Bays	2	Nos	93,694.00	93,729.00	187,388.00	187,458.00
5.09	Control for 145kV Transformer Feeder Bays	2	Nos			0.00	0.00
5.10	Automatic Voltage Control 145kV Transformer Feeder	2	Nos			0.00	0.00
5.11	Protection for Bus Section Bay	1	No	125,635.00	125,682.00	125,635.00	125,682.00
5.12	Control for 145kV Bus Section Bay	1	No			0.00	0.00
5.13	Gas Pressure Monitoring System	1	No			0.00	0.00
5.14	12 kV Protection and Control					0.00	0.00
5.15	Protection for 12kV Transformer Feeder Bays	2	Nos	68,892.00	68,918.00	137,784.00	137,836.00
5.16	Control for 12kVTransformer Feeder Bays	2	Nos			0.00	0.00
5.17	Protection for 12kV Generator Feeder Bays	2	Nos			0.00	0.00
5.18	Control for 12kV Generator Feeder Bays	2	Nos			0.00	0.00
5.19	Protection for 12kV Line Feeder Bays	13	Nos			0.00	0.00
5.20	Protection for 12kV Line Feeder Bays	5	Nos			0.00	0.00
5.21	Control for 12kV Line Feeder Bays	18	Nos			0.00	0.00
5.22	Protection for 12kV Auxiliary Transformer Feeder Bays	2	Nos			0.00	0.00
5.23	Control for 12kV Auxiliary Transformer Feeder Bays	2	Nos			0.00	0.00
5.24	Protection for 12kV Bus Section Bay	2	Nos			0.00	0.00
5.25	Control for 12kV Bus Section Bay	2	Nos			0.00	0.00
5.26	12kV Frequency & Voltage Relays to Install in Bus Bar	1	Lot			0.00	0.00
5.27	Gas Pressure Monitoring System	1	No			0.00	0.00
5.28	Alarm Facility for Common Substation Alarm	1	No			0.00	0.00
5.29	Manual Synchronism Facility	1	No			0.00	0.00
6.00	**SCADA and Communication System for NCC**						
6.01	Fiber Optic Communication Equipment and Accessories	1	Lot	120,316.00	120,361.00	120,316.00	120,361.00
6.02	Hot Line Telephone System Administrative Telephone System	1	Lot			0.00	0.00
6.03	Positive Grounded – 48 V DC Power Supply	1	Lot			0.00	0.00

6.04	SCADA System	1	Lot	64,259.00	64,283.00	64,259.00	64,283.00
7.00	**Substation Earthing**	1	Lot		4,221,763.00	0.00	4,221,763.00
8.00	**Lightning Protection System**	1	Lot	2,511.00	2,512.00	2,511.00	2,512.00
9.00	**Grounding System**	1	Lot	3,917.00	3,918.00	3,917.00	3,918.00
10.00	**Power Cables, Control Cables, Termination Kits, Cable Trays and Supports**						
10.01	145 kV Power Cables and Terminations	1	Lot	378,084.00	378,226.00	378,084.00	378,226.00
10.02	12 kV Power Cables and Terminations	1	Lot	108,429.00	108,470.00	108,429.00	108,470.00
10.03	All Low Voltage 1/0.6 kV AC Power Cables and Terminations	1	Lot			0.00	6,985,830.00
10.04	All DC Power and Control Cables and Terminations	1	Lot			0.00	2,666,671.00
10.05	All cables required for Protection, Control, Instrumentation, Communication, SCADA and Terminations	1	Lot			0.00	16,132,215.00
10.06	All cables required for Station Lighting, Small Power, Fire Protection, Ventilation Equipment	1	Lot			0.00	278,734.00
11.00	**Transformers**						
11.01	31.5 MVA, 132/11 kV Power Transformers	2	Nos	384,000.00	1,000,000.00	768,000.00	2,000,000.00
11.02	160 kVA, 11/0.4 kV Auxiliary Transformers	2	Nos	25,173.00	25,183.00	50,346.00	50,366.00
12.00	Neutral Earthing Resisters, Disconnectors and Earthing Switches	1	Lot	7,909.00	7,912.00	7,909.00	7,912.00
13.00	Diesel Generators	1	No	11,029.00	11,033.00	11,029.00	11,033.00
14.00	Supporting Structures	1	Lot	3,189.00	3,190.00	3,189.00	3,190.00
15.00	Miscellaneous Works	1	Lot	168,582.00	168,645.00	168,582.00	168,645.00
16.00	Spare Parts	1	Lot				65,659,723.00
17.00	Tools and Instruments	1	Lot			745,284.00	745,566.00
18.00	Design Services for substation	1	Lot				2,047,679.00
19.00	Total cost of Civil construction	1	Lot				213,000,000.00
20.00	Building Services	1	Lot				23,375,949.00
21.00	Testing & Commissioning	1	Lot				34,404,045.00
	Sub Total - Local Cost (LKR)						376,035,901.00
	Price Adjustment						0.00
	Total Local Cost (LKR)						**376,035,901.00**
	Total Foreign Cost (USD)					**5,600,663.00**	
	Total Cost						**1,188,132,036.00**

Annex 02: Engineering Estimate for Supply, Delivery, Installation & Commission of complete 132kV/22kV substation with 02 Nos. 22.5MVA Transformers

Item	Description	Qty	Unit	Unit Price		Total Price (Calculated)	
				Foreign (USD)	Local(LKR)	Foreign (USD)	Local (LKR)
1.00	**145 kV Indoor Switchgear**						
1.01	145 kV GIS Single Busbar with Busbar VT/ES Bay	1	No	341,181.00	341,309.00	341,181.00	341,309.00
1.02	145 kV GIS Line Feeder Bay	2	Nos	116,921.00	116,965.00	233,842.00	233,930.00
1.03	145 kV GIS Transformer Feeder Bay	2	Nos	114,923.00	114,966.00	229,846.00	229,932.00
1.04	145kV Bus Section Bay	1	No	111,421.00	111,463.00	111,421.00	111,463.00
2.00	**22 kV Indoor Switchgear**						
2.01	22 kV GIS Transformer Feeder Bay	2	Nos	44,150.00	80,263.00	88,300.00	160,526.00
2.02	22 kV GIS Generator Feeder Bay	2	Nos	41,250.00	51,701.00	82,500.00	103,402.00
2.03	22 kV GIS Outgoing Line Feeder Bay	13	Nos	40,150.00	49,690.00	521,950.00	645,970.00
2.04	22 kV GIS Outgoing Line Feeder Bay	5	Nos	39,750.00	55,822.00	198,750.00	279,110.00
2.05	22 kV GIS Auxiliary Transformer Feeder Bay	2	Nos	41,150.00	40,657.00	82,300.00	81,314.00
2.06	22 kV GIS Bus Section Bay	2	Nos	35,150.00	76,958.00	70,300.00	153,916.00
3.00	**Auxiliary Supply**						
3.01	400 V AC Main Switchboard	1	No	8,818.00	8,821.00	8,818.00	8,821.00
3.02	400 V AC Distribution Panel	1	No	2,672.00	2,673.00	2,672.00	2,673.00
4.00	**Batteries, Chargers and Distribution Boards and Inverter Equipment**						
4.01	110 V Battery System	1	No	98,586.00	98,623.00	98,586.00	98,623.00
4.02	Inverter System for Substation Automation System	1	No	31,510.00	31,522.00	31,510.00	31,522.00
5.00	**Protection, Control, Metering and Monitoring**						
5.01	Substation Automation System	1	Lot	289,349.00	289,457.00	289,349.00	289,457.00
5.02	Digital Disturbance Recorder with Analysis Computers	1	Lot	171,618.00	171,682.00	171,618.00	171,682.00
5.03	Power Quality Analyzer	1	Lot	60,058.00	60,080.00	60,058.00	60,080.00
5.04	Remote Work Stations	1	Lot			0.00	0.00
5.05	145 kV Protection and Control					0.00	0.00
5.06	Protection for 145kV Line Feeder Bays	2	Nos	72,025.00	72,052.00	144,050.00	144,104.00
5.07	Control for 145kV Line Feeder Bays	2	Nos			0.00	0.00
5.08	Protection for 145kV Transformer Feeder Bays	2	Nos	93,694.00	93,729.00	187,388.00	187,458.00
5.09	Control for 145kV Transformer Feeder Bays	2	Nos			0.00	0.00
5.10	Automatic Voltage Control 145kV Transformer Feeder	2	Nos			0.00	0.00
5.11	Protection for Bus Section Bay	1	No	125,635.00	125,682.00	125,635.00	125,682.00

5.12	Control for 145kV Bus Section Bay	1	No			0.00	0.00
5.13	Gas Pressure Monitoring System	1	No			0.00	0.00
5.14	22 kV Protection and Control					0.00	0.00
5.15	Protection for 22kV Transformer Feeder Bays	2	Nos	72,336.60	68,918.00	144,673.20	137,836.00
5.16	Control for 22kVTransformer Feeder Bays	2	Nos			0.00	0.00
5.17	Protection for 22kV Generator Feeder Bays	2	Nos			0.00	0.00
5.18	Control for 22kV Generator Feeder Bays	2	Nos			0.00	0.00
5.19	Protection for 22kV Line Feeder Bays	13	Nos			0.00	0.00
5.20	Protection for22kV Line Feeder Bays	5	Nos			0.00	0.00
5.21	Control for 22kV Line Feeder Bays	18	Nos			0.00	0.00
5.22	Protection for 22kV Auxiliary Transformer Feeder Bays	2	Nos			0.00	0.00
5.23	Control for 22kV Auxiliary Transformer Feeder Bays	2	Nos			0.00	0.00
5.24	Protection for 22kV Bus Section Bay	2	Nos			0.00	0.00
5.25	Control for 22kV Bus Section Bay	2	Nos			0.00	0.00
5.26	22kV Frequency & Voltage Relays to Install in Bus Bar	1	Lot			0.00	0.00
5.27	Gas Pressure Monitoring System	1	No			0.00	0.00
5.28	Alarm Facility for Common Substation Alarm	1	No			0.00	0.00
5.29	Manual Synchronism Facility	1	No			0.00	0.00
6.00	**SCADA and Communication System for NCC**						
6.01	Fiber Optic Communication Equipment and Accessories	1	Lot	120,316.00	120,361.00	120,316.00	120,361.00
6.02	Hot Line Telephone System Administrative Telephone System	1	Lot			0.00	0.00
6.03	Positive Grounded – 48 V DC Power Supply	1	Lot			0.00	0.00
6.04	SCADA System	1	Lot	64,259.00	64,283.00	64,259.00	64,283.00
7.00	**Substation Earthing**	1	Lot		4,221,763.00	0.00	4,221,763.00
8.00	**Lightning Protection System**	1	Lot	2,511.00	2,512.00	2,511.00	2,512.00
9.00	**Grounding System**	1	Lot	3,917.00	3,918.00	3,917.00	3,918.00
10.00	**Power Cables, Control Cables, Termination Kits, Cable Trays and Supports**						
10.01	145 kV Power Cables and Terminations	1	Lot	378,084.00	378,226.00	378,084.00	378,226.00
10.02	22 kV Power Cables and Terminations	1	Lot	108,429.00	108,470.00	108,429.00	108,470.00
10.03	All Low Voltage 1/0.6 kV AC Power Cables and Terminations	1	Lot			0.00	6,985,830.00
10.04	All DC Power and Control Cables and Terminations	1	Lot			0.00	2,666,671.00

10.05	All cables required for Protection, Control, Instrumentation, Communication, SCADA and Terminations	1	Lot			0.00	16,132,215.00
10.06	All cables required for Station Lighting, Small Power, Fire Protection, Ventilation Equipment	1	Lot			0.00	278,734.00
11.00	**Transformers**						
11.01	31.5 MVA, 132/22 kV Power Transformers	2	Nos	408,000.00	1,000,000.00	816,000.00	2,000,000.00
11.02	160 kVA,22/0.4 kV Auxiliary Transformers	2	Nos	26,431.65	25,183.00	52,863.30	50,366.00
12.00	**Neutral Earthing Resisters, Disconnectors and Earthing Switches**	1	Lot	7,909.00	7,912.00	7,909.00	7,912.00
13.00	**Diesel Generators**	1	No	11,029.00	11,033.00	11,029.00	11,033.00
14.00	**Supporting Structures**	1	Lot	3,189.00	3,190.00	3,189.00	3,190.00
15.00	**Miscellaneous Works**	1	Lot	168,582.00	168,645.00	168,582.00	168,645.00
16.00	**Spare Parts**	1	Lot				65,659,723.00
17.00	**Tools and Instruments**	1	Lot			745,284.00	745,566.00
18.00	**Design Services for substation**	1	Lot				2,047,679.00
19.00	**Total cost of Civil construction**	1	Lot				213,000,000.00
20.00	**Building Services**	1	Lot				23,375,949.00
21.00	**Testing & Commissionoing**	1	Lot				34,404,045.00
	Sub Total - Local Cost (LKR)						376,035,901.00
	Price Adjustment (5% of LKR Cost)						
	Total Local Cost (LKR)						**394,837,696.05**
	Total Foreign Cost (USD)					**5,707,119.50**	
	Total Cost						**1,222,370,023.55**

Annex 03: Engineering Estimate for Supply, Delivery, Installation & Commission of complete 132kV/33kV substation with 02 Nos. 22.5MVA Transformers

Item	Description	Qty.	Unit	Unit Price		Total Price (Calculated)	
				Foreign (USD)	Local (LKR)	Foreign (USD)	Local (LKR)
1.00	**145 kV Indoor Switchgear**						
1.01	145 kV GIS Single Busbar with Busbar VT/ES Bay	1	No	341,181.00	341,309.00	341,181.00	341,309.00
1.02	145 kV GIS Line Feeder Bay	2	Nos	116,921.00	116,965.00	233,842.00	233,930.00
1.03	145 kV GIS Transformer Feeder Bay	2	Nos	114,923.00	114,966.00	229,846.00	229,932.00
1.04	145kV Bus Section Bay	1	No	111,421.00	111,463.00	111,421.00	111,463.00
2.00	**33 kV Indoor Switchgear**						
2.01	33 kV GIS Transformer Feeder Bay	2	Nos	54,150.00	80,263.00	108,300.00	160,526.00
2.02	33 kV GIS Generator Feeder Bay	2	Nos	51,750.00	51,701.00	103,500.00	103,402.00
2.03	33 kV GIS Outgoing Line Feeder Bay	13	Nos	50,150.00	49,690.00	651,950.00	645,970.00
2.04	33 kV GIS Outgoing Line Feeder Bay	5	Nos	49,750.00	55,822.00	248,750.00	279,110.00
2.05	33 kV GIS Auxiliary Transformer Feeder Bay	2	Nos	51,150.00	40,657.00	102,300.00	81,314.00
2.06	33 kV GIS Bus Section Bay	2	Nos	49,150.00	76,958.00	98,300.00	153,916.00
3.00	**Auxiliary Supply**						
3.01	400 V AC Main Switchboard	1	No	8,818.00	8,821.00	8,818.00	8,821.00
3.02	400 V AC Distribution Panel	1	No	2,672.00	2,673.00	2,672.00	2,673.00
4.00	**Batteries, Chargers and Distribution Boards and Inverter Equipment**						
4.01	110 V Battery System	1	No	98,586.00	98,623.00	98,586.00	98,623.00
4.02	Inverter System for Substation Automation System	1	No	31,510.00	31,522.00	31,510.00	31,522.00
5.00	**Protection, Control, Metering and Monitoring**						
5.01	Substation Automation System	1	Lot	289,349.00	289,457.00	289,349.00	289,457.00
5.02	Digital Disturbance Recorder with Analysis Computers	1	Lot	171,618.00	171,682.00	171,618.00	171,682.00
5.03	Power Quality Analyzer	1	Lot	60,058.00	60,080.00	60,058.00	60,080.00
5.04	Remote Work Stations	1	Lot			0.00	0.00
5.05	145 kV Protection and Control					0.00	0.00
5.06	Protection for 145kV Line Feeder Bays	2	Nos	72,025.00	72,052.00	144,050.00	144,104.00
5.07	Control for 145kV Line Feeder Bays	2	Nos			0.00	0.00
5.08	Protection for 145kV Transformer Feeder Bays	2	Nos	93,694.00	93,729.00	187,388.00	187,458.00
5.09	Control for 145kV Transformer Feeder Bays	2	Nos			0.00	0.00
5.10	Automatic Voltage Control 145kV Transformer Feeder	2	Nos			0.00	0.00
5.11	Protection for Bus Section Bay	1	No	125,635.00	125,682.00	125,635.00	125,682.00
5.12	Control for 145kV Bus Section Bay	1	No			0.00	0.00
5.13	Gas Pressure Monitoring System	1	No			0.00	0.00

5.14	33 kV Protection and Control					0.00	0.00
5.15	Protection for 33kV Transformer Feeder Bays	2	Nos	91,626.36	68,918.00	183,252.72	137,836.00
5.16	Control for 33kVTransformer Feeder Bays	2	Nos			0.00	0.00
5.17	Protection for 33kV Generator Feeder Bays	2	Nos			0.00	0.00
5.18	Control for 33kV Generator Feeder Bays	2	Nos			0.00	0.00
5.19	Protection for 33kV Line Feeder Bays	13	Nos			0.00	0.00
5.20	Protection for 33kV Line Feeder Bays	5	Nos			0.00	0.00
5.21	Control for 33kV Line Feeder Bays	18	Nos			0.00	0.00
5.22	Protection for 33kV Auxiliary Transformer Feeder Bays	2	Nos			0.00	0.00
5.23	Control for 33kV Auxiliary Transformer Feeder Bays	2	Nos			0.00	0.00
5.24	Protection for 33kV Bus Section Bay	2	Nos			0.00	0.00
5.25	Control for 33kV Bus Section Bay	2	Nos			0.00	0.00
5.26	33kV Frequency & Voltage Relays to Install in Bus Bar	1	Lot			0.00	0.00
5.27	Gas Pressure Monitoring System	1	No			0.00	0.00
5.28	Alarm Facility for Common Substation Alarm	1	No			0.00	0.00
5.29	Manual Synchronism Facility	1	No			0.00	0.00
6.00	**SCADA and Communication System for NCC**						
6.01	Fiber Optic Communication Equipment and Accessories	1	Lot	120,316.00	120,361.00	120,316.00	120,361.00
6.02	Hot Line Telephone System Administrative Telephone System	1	Lot			0.00	0.00
6.03	Positive Grounded – 48 V DC Power Supply	1	Lot			0.00	0.00
6.04	SCADA System	1	Lot	64,259.00	64,283.00	64,259.00	64,283.00
7.00	**Substation Earthing**	1	Lot		4,221,763.00	0.00	4,221,763.00
8.00	**Lightning Protection System**	1	Lot	2,511.00	2,512.00	2,511.00	2,512.00
9.00	**Grounding System**	1	Lot	3,917.00	3,918.00	3,917.00	3,918.00
10.00	**Power Cables, Control Cables, Termination Kits, Cable Trays and Supports**						
10.01	145 kV Power Cables and Terminations	1	Lot	378,084.00	378,226.00	378,084.00	378,226.00
10.02	33 kV Power Cables and Terminations	1	Lot	144,210.57	108,470.00	144,210.57	108,470.00
10.03	All Low Voltage 1/0.6 kV AC Power Cables and Terminations	1	Lot			0.00	6,985,830.00
10.04	All DC Power and Control Cables and Terminations	1	Lot			0.00	2,666,671.00
10.05	All cables required for Protection, Control, Instrumentation, Communication, SCADA and Terminations	1	Lot			0.00	16,132,215.00

10.06	All cables required for Station Lighting, Small Power, Fire Protection, Ventilation Equipment	1	Lot			0.00	278,734.00
11.00	**Transformers**						
11.01	31.5 MVA, 132/33 kV Power Transformers	2	Nos	438,000.00	1,000,000.00	876,000.00	2,000,000.00
11.02	160 kVA, 33/0.4 kV Auxiliary Transformers	2	Nos	25,173.00	25,183.00	50,346.00	50,366.00
12.00	**Neutral Earthing Resisters, Disconnectors and Earthing Switches**	1	Lot	7,909.00	7,912.00	7,909.00	7,912.00
13.00	**Diesel Generators**	1	No	11,029.00	11,033.00	11,029.00	11,033.00
14.00	**Supporting Structures**	1	Lot	3,189.00	3,190.00	3,189.00	3,190.00
15.00	**Miscellaneous Works**	1	Lot	168,582.00	168,645.00	168,582.00	168,645.00
16.00	**Spare Parts**	1	Lot				65,659,723.00
17.00	**Tools and Instruments**	1	Lot			745,284.00	745,566.00
18.00	**Design Services for substation**	1	Lot				2,047,679.00
19.00	**Total cost of Civil construction**						213,000,000.00
20.00	**Building Services**						23,375,949.00
21.00	**Testing & Commissioning**						34,404,045.00
	Sub Total - Local Cost (LKR)						376,035,901.00
	Price Adjustment (7% of LKR Cost)						26,322,513.07
	Total Local Cost (LKR)						402,358,414.07
	Total Foreign Cost (USD)					6,107,963.29	
	Total Cost						1,288,013,091.12

Annex 04: Engineering Estimate for Supply, Delivery, Installation & Commission of complete 132kV/11kV substation with 02 Nos. 45MVA Transformers

Item	Description	Qty	Unit	Unit Price		Total Price	
				Foreign	Local LKR	Foreign	Local LKR
1.00	**145 kV Indoor Switchgear**						
1.01	145 kV GIS Single Busbar with Busbar VT/ES Bay	1	No	341,181.00	341,309.00	341,181.00	341,309.00
1.02	145 kV GIS Line Feeder Bay	2	Nos	116,921.00	116,965.00	233,842.00	233,930.00
1.03	145 kV GIS Transformer Feeder Bay	2	Nos	114,923.00	114,966.00	229,846.00	229,932.00
1.04	145kV Bus Section Bay	1	No	111,421.00	111,463.00	111,421.00	111,463.00
2.00	**12 kV Indoor Switchgear**						
2.01	12 kV GIS Transformer Feeder Bay	2	Nos	42,650.00	80,263.00	85,300.00	160,526.00
2.02	12 kV GIS Generator Feeder Bay	2	Nos	39,350.00	51,701.00	78,700.00	103,402.00
2.03	12 kV GIS Outgoing Line Feeder Bay	13	Nos	38,150.00	49,690.00	495,950.00	645,970.00
2.04	12 kV GIS Outgoing Line Feeder Bay	5	Nos	37,500.00	55,822.00	187,500.00	279,110.00
2.05	12 kV GIS Auxiliary Transformer Feeder Bay	2	Nos	40,150.00	40,657.00	80,300.00	81,314.00
2.06	12 kV GIS Bus Section Bay	2	Nos	33,650.00	76,958.00	67,300.00	153,916.00
3.00	**Auxiliary Supply**						
3.01	400 V AC Main Switchboard	1	No	8,818.00	8,821.00	8,818.00	8,821.00
3.02	400 V AC Distribution Panel	1	No	2,672.00	2,673.00	2,672.00	2,673.00
4.00	**Batteries, Chargers and Distribution Boards and Inverter Equipment**						
4.01	110 V Battery System	1	No	98,586.00	98,623.00	98,586.00	98,623.00
4.02	Inverter System for Substation Automation System	1	No	31,510.00	31,522.00	31,510.00	31,522.00
5.00	**Protection, Control, Metering and Monitoring**						
5.01	Substation Automation System	1	Lot	289,349.00	289,457.00	289,349.00	289,457.00
5.02	Digital Disturbance Recorder with Analysis Computers	1	Lot	171,618.00	171,682.00	171,618.00	171,682.00
5.03	Power Quality Analyzer	1	Lot	60,058.00	60,080.00	60,058.00	60,080.00
5.04	Remote Work Stations	1	Lot			0.00	0.00
5.05	145 kV Protection and Control					0.00	0.00
5.06	Protection for 145kV Line Feeder Bays	2	Nos	72,025.00	72,052.00	144,050.00	144,104.00
5.07	Control for 145kV Line Feeder Bays	2	Nos			0.00	0.00
5.08	Protection for 145kV Transformer Feeder Bays	2	Nos	93,694.00	93,729.00	187,388.00	187,458.00
5.09	Control for 145kV Transformer Feeder Bays	2	Nos			0.00	0.00
5.10	Automatic Voltage Control 145kV Transformer Feeder	2	Nos			0.00	0.00
5.11	Protection for Bus Section Bay	1	No	125,635.00	125,682.00	125,635.00	125,682.00
5.12	Control for 145kV Bus Section Bay	1	No			0.00	0.00

5.13	Gas Pressure Monitoring System	1	No			0.00	0.00
5.14	12 kV Protection and Control					0.00	0.00
5.15	Protection for 12kV Transformer Feeder Bays	2	Nos	68,892.00	68,918.00	137,784.00	137,836.00
5.16	Control for 12kVTransformer Feeder Bays	2	Nos			0.00	0.00
5.17	Protection for 12kV Generator Feeder Bays	2	Nos			0.00	0.00
5.18	Control for 12kV Generator Feeder Bays	2	Nos			0.00	0.00
5.19	Protection for 12kV Line Feeder Bays	13	Nos			0.00	0.00
5.20	Protection for 12kV Line Feeder Bays	5	Nos			0.00	0.00
5.21	Control for 12kV Line Feeder Bays	18	Nos			0.00	0.00
5.22	Protection for 12kV Auxiliary Transformer Feeder Bays	2	Nos			0.00	0.00
5.23	Control for 12kV Auxiliary Transformer Feeder Bays	2	Nos			0.00	0.00
5.24	Protection for 12kV Bus Section Bay	2	Nos			0.00	0.00
5.25	Control for 12kV Bus Section Bay	2	Nos			0.00	0.00
5.26	12kV Frequency & Voltage Relays to Install in Bus Bar	1	Lot			0.00	0.00
5.27	Gas Pressure Monitoring System	1	No			0.00	0.00
5.28	Alarm Facility for Common Substation Alarm	1	No			0.00	0.00
5.29	Manual Synchronism Facility	1	No			0.00	0.00
6.00	**SCADA and Communication System for NCC**						
6.01	Fiber Optic Communication Equipment and Accessories	1	Lot	120,316.00	120,361.00	120,316.00	120,361.00
6.02	Hot Line Telephone System Administrative Telephone System	1	Lot			0.00	0.00
6.03	Positive Grounded – 48 V DC Power Supply	1	Lot			0.00	0.00
6.04	SCADA System	1	Lot	64,259.00	64,283.00	64,259.00	64,283.00
7.00	**Substation Earthing**	1	Lot		4,221,763.00	0.00	4,221,763.00
8.00	**Lightning Protection System**	1	Lot	2,511.00	2,512.00	2,511.00	2,512.00
9.00	**Grounding System**	1	Lot	3,917.00	3,918.00	3,917.00	3,918.00
10.00	**Power Cables, Control Cables, Termination Kits, Cable Trays and Supports**						
10.01	145 kV Power Cables and Terminations	1	Lot	378,084.00	378,226.00	378,084.00	378,226.00
10.02	12 kV Power Cables and Terminations	1	Lot	108,429.00	108,470.00	108,429.00	108,470.00
10.03	All Low Voltage 1/0.6 kV AC Power Cables and Terminations	1	Lot			0.00	6,985,830.00
10.04	All DC Power and Control Cables and Terminations	1	Lot			0.00	2,666,671.00
10.05	All cables required for Protection, Control, Instrumentation, Communication, SCADA and Terminations	1	Lot			0.00	16,132,215.00

10.06	All cables required for Station Lighting, Small Power, Fire Protection, Ventilation Equipment	1	Lot			0.00	278,734.00
11.00	**Transformers**						
11.01	45 MVA, 132/11 kV Power Transformers	2	Nos	744,000.00	1,287,124.00	1,488,000.00	2,574,248.00
11.02	160 kVA, 11/0.4 kV Auxiliary Transformers	2	Nos	25,173.00	25,183.00	50,346.00	50,366.00
12.00	**Neutral Earthing Resisters, Disconnectors and Earthing Switches**	1	Lot	7,909.00	7,912.00	7,909.00	7,912.00
13.00	**Diesel Generators**	1	No	11,029.00	11,033.00	11,029.00	11,033.00
14.00	**Supporting Structures**	1	Lot	3,189.00	3,190.00	3,189.00	3,190.00
15.00	**LV installation**	1	Lot			0.00	24,200,794.00
16.00	**Miscellaneous Works**	1	Lot	168,582.00	168,645.00	168,582.00	168,645.00
17.00	**Spare Parts**	1	Lot				65,659,723.00
18.00	**Tools and Instruments**	1	Lot			745,284.00	745,566.00
19.00	**Design Services for substation**	1	Lot				2,047,679.00
20.00	**Total cost of Civil construction**	1	Lot				213,000,000.00
21.00	Building Services cost	1	Lot				23,375,949.00
22.00	Testing & Commissioning	1	Lot				34,404,045.00
	Sub Total - Local Cost (LKR)						400,810,943.00
	Price Adjustment						28,056,766.01
	Total Local Cost (LKR)						428,867,709.01
	Total Foreign Cost (USD)					6,320,663.00	
	Total Cost						1,345,363,844.01

Annex 05: Engineering Estimate for Supply, Delivery, Installation & Commission of complete 132kV/22kV substation with 02 Nos. 45MVA Transformers

Item	Description	Qty	Unit	Unit Price		Total Price	
				Foreign	Local LKR	Foreign	Local LKR
1.00	**145 kV Indoor Switchgear**						
1.01	145 kV GIS Single Busbar with Busbar VT/ES Bay	1	No	341,181.00	341,309.00	341,181.00	341,309.00
1.02	145 kV GIS Line Feeder Bay	2	Nos	116,921.00	116,965.00	233,842.00	233,930.00
1.03	145 kV GIS Transformer Feeder Bay	2	Nos	114,923.00	114,966.00	229,846.00	229,932.00
1.04	145kV Bus Section Bay	1	No	111,421.00	111,463.00	111,421.00	111,463.00
2.00	**22 kV Indoor Switchgear**						
2.01	22 kV GIS Transformer Feeder Bay	2	Nos	43,267.00	80,263.00	86,534.00	160,526.00
2.02	22 kV GIS Generator Feeder Bay	2	Nos	40,425.00	51,701.00	80,850.00	103,402.00
2.03	22 kV GIS Outgoing Line Feeder Bay	13	Nos	39,347.00	49,690.00	511,511.00	645,970.00
2.04	22 kV GIS Outgoing Line Feeder Bay	5	Nos	38,955.00	55,822.00	194,775.00	279,110.00
2.05	22 kV GIS Auxiliary Transformer Feeder Bay	2	Nos	41,150.00	40,657.00	82,300.00	81,314.00
2.06	22 kV GIS Bus Section Bay	2	Nos	35,150.00	76,958.00	70,300.00	153,916.00
3.00	**Auxiliary Supply**						
3.01	400 V AC Main Switchboard	1	No	8,818.00	8,821.00	8,818.00	8,821.00
3.02	400 V AC Distribution Panel	1	No	2,672.00	2,673.00	2,672.00	2,673.00
4.00	**Batteries, Chargers and Distribution Boards and Inverter Equipment**						
4.01	110 V Battery System	1	No	98,586.00	98,623.00	98,586.00	98,623.00
4.02	Inverter System for Substation Automation System	1	No	31,510.00	31,522.00	31,510.00	31,522.00
5.00	**Protection, Control, Metering and Monitoring**						
5.01	Substation Automation System	1	Lot	289,349.00	289,457.00	289,349.00	289,457.00
5.02	Digital Disturbance Recorder with Analysis Computers	1	Lot	171,618.00	171,682.00	171,618.00	171,682.00
5.03	Power Quality Analyzer	1	Lot	60,058.00	60,080.00	60,058.00	60,080.00
5.04	Remote Work Stations	1	Lot			0.00	0.00
5.05	145 kV Protection and Control					0.00	0.00
5.06	Protection for 145kV Line Feeder Bays	2	Nos	72,025.00	72,052.00	144,050.00	144,104.00
5.07	Control for 145kV Line Feeder Bays	2	Nos			0.00	0.00
5.08	Protection for 145kV Transformer Feeder Bays	2	Nos	93,694.00	93,729.00	187,388.00	187,458.00
5.09	Control for 145kV Transformer Feeder Bays	2	Nos			0.00	0.00
5.10	Automatic Voltage Control 145kV Transformer Feeder	2	Nos			0.00	0.00
5.11	Protection for Bus Section Bay	1	No	125,635.00	125,682.00	125,635.00	125,682.00

5.12	Control for 145kV Bus Section Bay	1	No			0.00	0.00
5.13	Gas Pressure Monitoring System	1	No			0.00	0.00
5.14	22 kV Protection and Control					0.00	0.00
5.15	Protection for 22kV Transformer Feeder Bays	2	Nos	72,336.60	68,918.00	144,673.20	137,836.00
5.16	Control for 22kVTransformer Feeder Bays	2	Nos			0.00	0.00
5.17	Protection for 22kV Generator Feeder Bays	2	Nos			0.00	0.00
5.18	Control for 22kV Generator Feeder Bays	2	Nos			0.00	0.00
5.19	Protection for 22kV Line Feeder Bays	13	Nos			0.00	0.00
5.20	Protection for22kV Line Feeder Bays	5	Nos			0.00	0.00
5.21	Control for 22kV Line Feeder Bays	18	Nos			0.00	0.00
5.22	Protection for 22kV Auxiliary Transformer Feeder Bays	2	Nos			0.00	0.00
5.23	Control for 22kV Auxiliary Transformer Feeder Bays	2	Nos			0.00	0.00
5.24	Protection for 22kV Bus Section Bay	2	Nos			0.00	0.00
5.25	Control for 22kV Bus Section Bay	2	Nos			0.00	0.00
5.26	22kV Frequency & Voltage Relays to Install in Bus Bar	1	Lot			0.00	0.00
5.27	Gas Pressure Monitoring System	1	No			0.00	0.00
5.28	Alarm Facility for Common Substation Alarm	1	No			0.00	0.00
5.29	Manual Synchronism Facility	1	No			0.00	0.00
6.00	**SCADA and Communication System for NCC**						
6.01	Fiber Optic Communication Equipment and Accessories	1	Lot	120,316.00	120,361.00	120,316.00	120,361.00
6.02	Hot Line Telephone System Administrative Telephone System	1	Lot			0.00	0.00
6.03	Positive Grounded – 48 V DC Power Supply	1	Lot			0.00	0.00
6.04	SCADA System	1	Lot	64,259.00	64,283.00	64,259.00	64,283.00
7.00	**Substation Earthing**	1	Lot		4,221,763.00	0.00	4,221,763.00
8.00	**Lightning Protection System**	1	Lot	2,511.00	2,512.00	2,511.00	2,512.00
9.00	**Grounding System**	1	Lot	3,917.00	3,918.00	3,917.00	3,918.00
10.00	**Power Cables, Control Cables, Termination Kits, Cable Trays and Supports**						
10.01	145 kV Power Cables and Terminations	1	Lot	378,084.00	378,226.00	378,084.00	378,226.00
10.02	22 kV Power Cables and Terminations	1	Lot	108,429.00	108,470.00	108,429.00	108,470.00
10.03	All Low Voltage 1/0.6 kV AC Power Cables and Terminations	1	Lot			0.00	6,985,830.00
10.04	All DC Power and Control Cables and Terminations	1	Lot			0.00	2,666,671.00
10.05	All cables required for Protection, Control, Instrumentation, Communication, SCADA and Terminations	1	Lot			0.00	16,132,215.00

10.06	All cables required for Station Lighting, Small Power, Fire Protection, Ventilation Equipment	1	Lot			0.00	278,734.00
11.00	**Transformers**						
11.01	45 MVA, 132/11 kV Power Transformers	2	Nos	744,000.00	1,287,124.00	1,488,000.00	2,574,248.00
11.02	160 kVA, 11/0.4 kV Auxiliary Transformers	2	Nos	25,173.00	25,183.00	50,346.00	50,366.00
12.00	**Neutral Earthing Resisters, Disconnectors and Earthing Switches**	1	Lot	7,909.00	7,912.00	7,909.00	7,912.00
13.00	**Diesel Generators**	1	No	11,029.00	11,033.00	11,029.00	11,033.00
14.00	**Supporting Structures**	1	Lot	3,189.00	3,190.00	3,189.00	3,190.00
15.00	**LV installation**	1	Lot			0.00	24,200,794.00
16.00	**Miscellaneous Works**	1	Lot	168,582.00	168,645.00	168,582.00	168,645.00
17.00	**Spare Parts**	1	Lot				65,659,723.00
18.00	**Tools and Instruments**	1	Lot			745,284.00	745,566.00
19.00	**Design Services for substation**	1	Lot				2,047,679.00
20.00	**Total cost of Civil construction**	1	Lot				213,000,000.00
21.00	Building Services cost	1	Lot				23,375,949.00
22.00	Testing & Commissioning	1	Lot				34,404,045.00
	Sub Total - Local Cost (LKR)						400,810,943.00
	Price Adjustment						28,056,766.01
	Total Local Cost (LKR)						428,867,709.01
	Total Foreign Cost (USD)					6,320,663.00	
	Total Cost						1,345,363,844.01

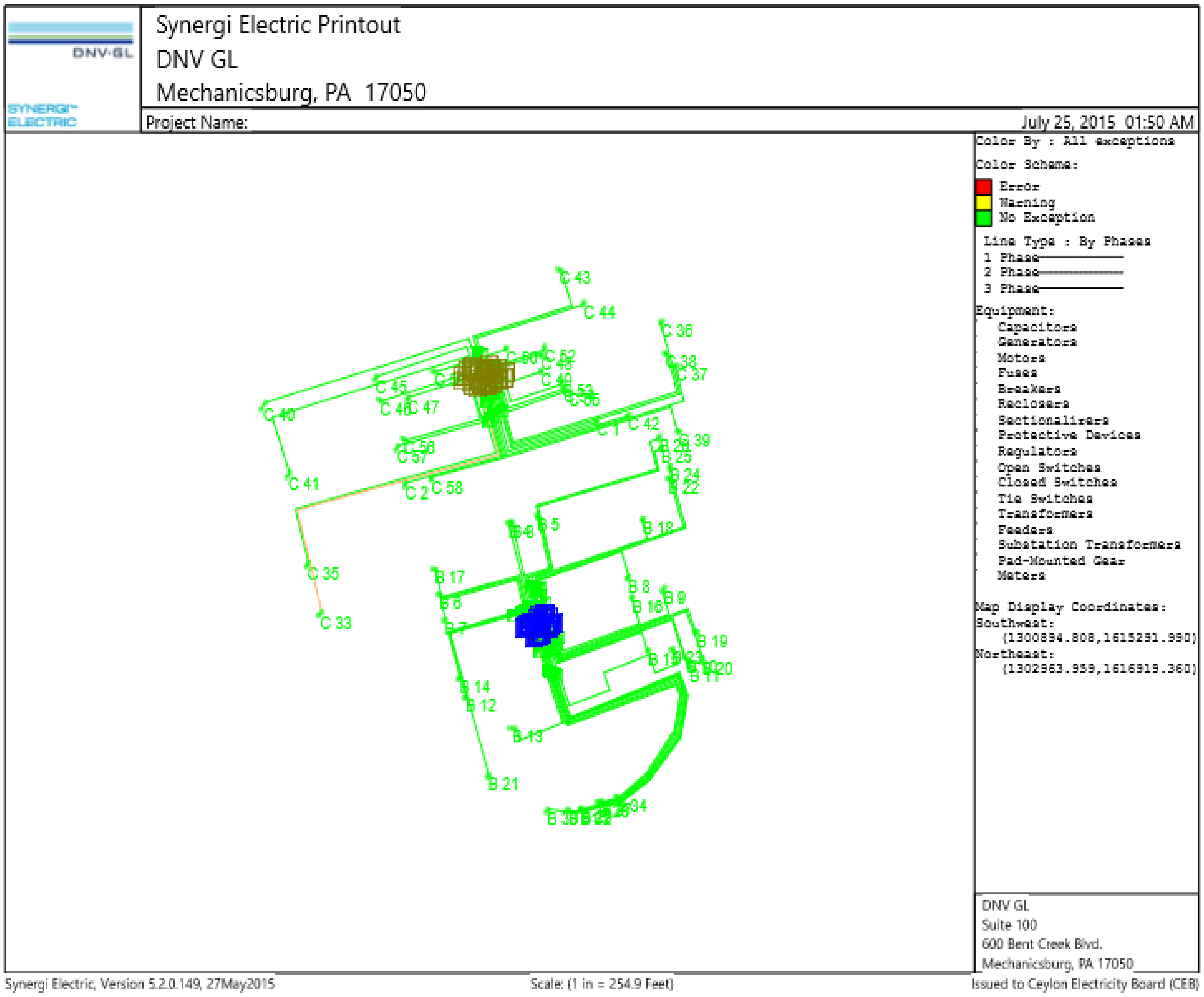
Annex 06: Engineering Estimate for Supply, Delivery, Installation & Commission of complete 132kV/33kV substation with 02 Nos. 45MVA Transformers

Item	Description	Qty	Unit	Unit Price		Total Price (Calculated)	
				Foreign	Local (LKR)	Foreign	Local (LKR)
	Colombo M Substation						
1.00	**145 kV Indoor Switchgear**						
1.01	145 kV GIS Single Busbar with Busbar VT/ES Bay	1	No	341,181.00	341,309.00	341,181.00	341,309.00
1.02	145 kV GIS Line Feeder Bay	2	Nos	116,921.00	116,965.00	233,842.00	233,930.00
1.03	145 kV GIS Transformer Feeder Bay	2	Nos	114,923.00	114,966.00	229,846.00	229,932.00
1.04	145kV Bus Section Bay	1	No	111,421.00	111,463.00	111,421.00	111,463.00
2.00	**33 kV Indoor Switchgear**						
2.01	33 kV GIS Transformer Feeder Bay	2	Nos	54,150.00	80,263.00	108,300.00	160,526.00
2.02	33 kV GIS Generator Feeder Bay	2	Nos	51,750.00	51,701.00	103,500.00	103,402.00
2.03	33 kV GIS Outgoing Line Feeder Bay	13	Nos	50,150.00	49,690.00	651,950.00	645,970.00
2.04	33 kV GIS Outgoing Line Feeder Bay	5	Nos	49,750.00	55,822.00	248,750.00	279,110.00
2.05	33 kV GIS Auxiliary Transformer Feeder Bay	2	Nos	51,150.00	40,657.00	102,300.00	81,314.00
2.06	33 kV GIS Bus Section Bay	2	Nos	49,150.00	76,958.00	98,300.00	153,916.00
3.00	**Auxiliary Supply**						
3.01	400 V AC Main Switchboard	1	No	8,818.00	8,821.00	8,818.00	8,821.00
3.02	400 V AC Distribution Panel	1	No	2,672.00	2,673.00	2,672.00	2,673.00
4.00	**Batteries, Chargers and Distribution Boards and Inverter Equipment**						
4.01	110 V Battery System	1	No	98,586.00	98,623.00	98,586.00	98,623.00
4.02	Inverter System for Substation Automation System	1	No	31,510.00	31,522.00	31,510.00	31,522.00
5.00	**Protection, Control, Metering and Monitoring**						
5.01	Substation Automation System	1	Lot	289,349.00	289,457.00	289,349.00	289,457.00
5.02	Digital Disturbance Recorder with Analysis Computers	1	Lot	171,618.00	171,682.00	171,618.00	171,682.00
5.03	Power Quality Analyzer	1	Lot	60,058.00	60,080.00	60,058.00	60,080.00
5.04	Remote Work Stations	1	Lot			0.00	0.00
5.05	145 kV Protection and Control					0.00	0.00
5.06	Protection for 145kV Line Feeder Bays	2	Nos	72,025.00	72,052.00	144,050.00	144,104.00
5.07	Control for 145kV Line Feeder Bays	2	Nos			0.00	0.00
5.08	Protection for 145kV Transformer Feeder Bays	2	Nos	93,694.00	93,729.00	187,388.00	187,458.00
5.09	Control for 145kV Transformer Feeder Bays	2	Nos			0.00	0.00
5.10	Automatic Voltage Control 145kV Transformer Feeder	2	Nos			0.00	0.00
5.11	Protection for Bus Section Bay	1	No	125,635.00	125,682.00	125,635.00	125,682.00
5.12	Control for 145kV Bus Section Bay	1	No			0.00	0.00

5.13	Gas Pressure Monitoring System	1	No			0.00	0.00
5.14	33 kV Protection and Control					0.00	0.00
5.15	Protection for 33kV Transformer Feeder Bays	2	Nos	91,626.36	68,918.00	183,252.72	137,836.00
5.16	Control for 33kVTransformer Feeder Bays	2	Nos			0.00	0.00
5.17	Protection for 33kV Generator Feeder Bays	2	Nos			0.00	0.00
5.18	Control for 33kV Generator Feeder Bays	2	Nos			0.00	0.00
5.19	Protection for 33kV Line Feeder Bays	13	Nos			0.00	0.00
5.20	Protection for 33kV Line Feeder Bays	5	Nos			0.00	0.00
5.21	Control for 33kV Line Feeder Bays	18	Nos			0.00	0.00
5.22	Protection for 33kV Auxiliary Transformer Feeder Bays	2	Nos			0.00	0.00
5.23	Control for 33kV Auxiliary Transformer Feeder Bays	2	Nos			0.00	0.00
5.24	Protection for 33kV Bus Section Bay	2	Nos			0.00	0.00
5.25	Control for 33kV Bus Section Bay	2	Nos			0.00	0.00
5.26	33kV Frequency & Voltage Relays to Install in Bus Bar	1	Lot			0.00	0.00
5.27	Gas Pressure Monitoring System	1	No			0.00	0.00
5.28	Alarm Facility for Common Substation Alarm	1	No			0.00	0.00
5.29	Manual Synchronism Facility	1	No			0.00	0.00
6.00	**SCADA and Communication System for NCC**						
6.01	Fiber Optic Communication Equipment and Accessories	1	Lot	120,316.00	120,361.00	120,316.00	120,361.00
6.02	Hot Line Telephone System Administrative Telephone System	1	Lot			0.00	0.00
6.03	Positive Grounded – 48 V DC Power Supply	1	Lot			0.00	0.00
6.04	SCADA System	1	Lot	64,259.00	64,283.00	64,259.00	64,283.00
7.00	**Substation Earthing**	1	Lot		4,221,763.00	0.00	4,221,763.00
8.00	**Lightning Protection System**	1	Lot	2,511.00	2,512.00	2,511.00	2,512.00
9.00	**Grounding System**	1	Lot	3,917.00	3,918.00	3,917.00	3,918.00
10.00	**Power Cables, Control Cables, Termination Kits, Cable Trays and Supports**						
10.01	145 kV Power Cables and Terminations	1	Lot	378,084.00	378,226.00	378,084.00	378,226.00
10.02	33 kV Power Cables and Terminations	1	Lot	144,210.57	108,470.00	144,210.57	108,470.00
10.03	All Low Voltage 1/0.6 kV AC Power Cables and Terminations	1	Lot			0.00	6,985,830.00
10.04	All DC Power and Control Cables and Terminations	1	Lot			0.00	2,666,671.00
10.05	All cables required for Protection, Control, Instrumentation, Communication, SCADA and Terminations	1	Lot			0.00	16,132,215.00

10.06	All cables required for Station Lighting, Small Power, Fire Protection, Ventilation Equipment	1	Lot			0.00	278,734.00
11.00	**Transformers**						
11.01	45 MVA, 132/33 kV Power Transformers	2	Nos	756,000.00	1,287,124.00	1,512,000.00	2,574,248.00
11.02	160 kVA, 33/0.4 kV Auxiliary Transformers	2	Nos	25,173.00	25,183.00	50,346.00	50,366.00
12.00	Neutral Earthing Resisters, Disconnectors and Earthing Switches	1	Lot	7,909.00	7,912.00	7,909.00	7,912.00
13.00	**Diesel Generators**	**1**	**No**	**11,029.00**	**11,033.00**	**11,029.00**	**11,033.00**
14.00	**Supporting Structures**	**1**	**Lot**	**3,189.00**	**3,190.00**	**3,189.00**	**3,190.00**
15.00	**Miscellaneous Works**	**1**	**Lot**	**168,582.00**	**168,645.00**	**168,582.00**	**168,645.00**
16.00	**Spare Parts**	**1**	**Lot**				**65,659,723.00**
17.00	**Tools and Instruments**	**1**	**Lot**			**745,284.00**	**745,566.00**
18.00	**Design Services for substation**	**1**	**Lot**				**2,047,679.00**
19.00	**Total cost of Civil construction**	**1**	**Lot**				**220,770,708.00**
20.00	**Building Services cost**	**1**	**Lot**				**23,375,949.00**
21.00	**Testing & Commissioning**	**1**	**Lot**				**34,404,045.00**
	Sub Total - Local Cost (LKR)						384,380,857.00
	Price Adjustment						30,750,468.56
	Total Local Cost (LKR)						**415,131,325.56**
	Total Foreign Cost (USD)					**6,743,963.29**	
	Total Cost						**1,393,006,002.61**

Annex 07: Load Flow Analysis



Project Name: July 25, 2015 01:27 AM

Feeder Summary

Source	Demand				Amps				Volts		Connected		Load		Loss		Generation		
Id	kW	kvar	kVA	pf	Avg	%	% Imb	Neut	Avg	% Imb	c.Cust	c.kVA	kW	kvar	kW	%	Tot kW	PV kW	PV %
Feeders for New B																			
AAN_B to 10	1840	764	1992	92	52	---	0.00	0	100.00	0.00	0	0	1839	784	1	0.04	0	0	0.0
AAN_B to 11	1840	761	1991	92	52	---	0.00	0	100.00	0.00	0	0	1839	783	1	0.05	0	0	0.0
AAN_B to 12	2760	1157	2993	92	79	---	0.00	0	100.00	0.00	0	0	2759	1176	1	0.03	0	0	0.0
AAN_B to 13	1104	454	1194	92	31	---	0.00	0	100.00	0.00	0	0	1104	470	0	0.02	0	0	0.0
AAN_B to 14	1840	769	1994	92	52	---	0.00	0	100.00	0.00	0	0	1839	784	1	0.03	0	0	0.0
AAN_B to 15	1840	769	1994	92	52	---	0.00	0	100.00	0.00	0	0	1839	784	1	0.03	0	0	0.0
AAN_B to 16	1104	456	1194	92	31	---	0.00	0	100.00	0.00	0	0	1104	470	0	0.02	0	0	0.0
AAN_B to 17	2760	1156	2992	92	79	---	0.00	0	100.00	0.00	0	0	2759	1175	1	0.03	0	0	0.0
AAN_B to 18	1840	765	1993	92	52	---	0.00	0	100.00	0.00	0	0	1839	784	1	0.04	0	0	0.0
AAN_B to 19	1840	764	1992	92	52	---	0.00	0	100.00	0.00	0	0	1839	784	1	0.04	0	0	0.0
AAN_B to 20	1656	682	1791	92	47	---	0.00	0	100.00	0.00	0	0	1655	705	1	0.05	0	0	0.0
AAN_B to 21	3036	1265	3289	92	86	---	0.00	0	100.00	0.00	0	0	3034	1292	2	0.06	0	0	0.0
AAN_B to 22	1840	758	1990	92	52	---	0.00	0	100.00	0.00	0	0	1839	783	1	0.06	0	0	0.0
AAN_B to 23	1840	762	1991	92	52	---	0.00	0	100.00	0.00	0	0	1839	783	1	0.05	0	0	0.0
AAN_B to 24	1104	445	1190	93	31	---	0.00	0	100.00	0.00	0	0	1104	470	0	0.03	0	0	0.0
AAN_B to 25	2759	1176	2999	92	79	---	0.00	0	100.00	0.00	0	0	2756	1174	3	0.10	0	0	0.0
AAN_B to 26	1840	754	1988	93	52	---	0.00	0	100.00	0.00	0	0	1839	783	1	0.06	0	0	0.0
AAN_B to 27	1840	751	1987	93	52	---	0.00	0	100.00	0.00	0	0	1838	783	1	0.07	0	0	0.0
AAN_B to 28	3035	1249	3282	92	86	---	0.00	0	100.00	0.00	0	0	3033	1292	3	0.09	0	0	0.0
AAN_B to 29	1840	746	1985	93	52	---	0.00	0	100.00	0.00	0	0	1838	783	2	0.08	0	0	0.0
AAN_B to 3	2760	1162	2995	92	79	---	0.00	0	100.00	0.00	0	0	2759	1175	1	0.02	0	0	0.0
AAN_B to 30	2759	1122	2979	93	78	---	0.00	0	100.00	0.00	0	0	2757	1174	3	0.09	0	0	0.0
AAN_B to 31	3035	1243	3280	93	86	---	0.00	0	100.00	0.00	0	0	3032	1291	3	0.10	0	0	0.0
AAN_B to 32	1104	429	1184	93	31	---	0.00	0	100.00	0.00	0	0	1103	470	1	0.05	0	0	0.0
AAN_B to 34	1840	749	1986	93	52	---	0.00	0	100.00	0.00	0	0	1838	783	1	0.08	0	0	0.0
AAN_B to 4	1840	774	1996	92	52	---	0.00	0	100.00	0.00	0	0	1839	784	0	0.02	0	0	0.0
AAN_B to 5	1656	693	1795	92	47	---	0.00	0	100.00	0.00	0	0	1656	705	0	0.02	0	0	0.0
AAN_B to 6	2944	1240	3194	92	84	---	0.00	0	100.00	0.00	0	0	2943	1254	1	0.03	0	0	0.0
AAN_B to 7	3036	1276	3293	92	86	---	0.00	0	100.00	0.00	0	0	3035	1292	1	0.03	0	0	0.0
AAN_B to 8	3036	1275	3292	92	86	---	0.00	0	100.00	0.00	0	0	3035	1292	1	0.04	0	0	0.0
AAN_B to 9	1656	696	1796	92	47	---	0.00	0	100.00	0.00	0	0	1656	705	0	0.02	0	0	0.0
New B Totals	65221	27060	70612	92	N/A	N/A	N/A	N/A	N/A	N/A	0	0	65188	27765	33	0.05	0	0	0.0

Synergi Electric, Version 5.2.0.149, 27May2015 Issued to Ceylon Electricity Board (CEB)

	Project Name:	July 25, 2015 01:27 AM
	Feeder Summary	

Source	Demand				Amps				Volts		Connected		Load		Loss		Generation		
Id	kW	kvar	kVA	pf	Avg	%	% Imb	Neut	Avg	% Imb	c.Cust	c.kVA	kW	kvar	kW	%	Tot kW	PV kW	PV %
Feeders for New C																			
AAN_C to 1	3036	1268	3290	92	86	---	0.00	0	100.00	0.00	0	0	3035	1286	1	0.04	0	0	0.0
AAN_C to 2	1104	449	1192	93	31	---	0.00	0	100.00	0.00	0	0	1104	468	0	0.02	0	0	0.0
AAN_C to 33	1840	686	1964	94	34	---	0.00	0	100.00	0.00	0	0	1839	780	1	0.04	0	0	0.0
AAN_C to 35	3036	1251	3283	92	86	---	0.00	0	100.00	0.00	0	0	3033	1286	2	0.07	0	0	0.0
AAN_C to 36	1840	747	1986	93	52	---	0.00	0	100.00	0.00	0	0	1838	779	1	0.07	0	0	0.0
AAN_C to 37	1840	749	1987	93	52	---	0.00	0	100.00	0.00	0	0	1839	779	1	0.07	0	0	0.0
AAN_C to 38	2760	1136	2984	92	78	---	0.00	0	100.00	0.00	0	0	2758	1169	2	0.06	0	0	0.0
AAN_C to 39	1840	749	1986	93	52	---	0.00	0	100.00	0.00	0	0	1839	779	1	0.07	0	0	0.0
AAN_C to 40	1840	753	1988	93	52	---	0.00	0	100.00	0.00	0	0	1839	779	1	0.06	0	0	0.0
AAN_C to 41	1840	773	1995	92	52	---	0.00	0	100.00	0.00	0	0	1840	780	0	0.02	0	0	0.0
AAN_C to 42	2760	1146	2988	92	78	---	0.00	0	100.00	0.00	0	0	2759	1169	1	0.04	0	0	0.0
AAN_C to 43	3036	1264	3288	92	86	---	0.00	0	100.00	0.00	0	0	3034	1286	1	0.05	0	0	0.0
AAN_C to 44	1840	764	1992	92	52	---	0.00	0	100.00	0.00	0	0	1839	780	1	0.04	0	0	0.0
AAN_C to 45	1840	766	1993	92	52	---	0.00	0	100.00	0.00	0	0	1839	780	1	0.03	0	0	0.0
AAN_C to 46	2760	1159	2993	92	79	---	0.00	0	100.00	0.00	0	0	2759	1170	1	0.02	0	0	0.0
AAN_C to 47	3036	1266	3289	92	58	---	0.00	0	100.00	0.00	0	0	3036	1287	0	0.01	0	0	0.0
AAN_C to 48	1840	775	1996	92	52	---	0.00	0	100.00	0.00	0	0	1840	780	0	0.01	0	0	0.0
AAN_C to 49	1840	777	1997	92	52	---	0.00	0	100.00	0.00	0	0	1840	780	0	0.01	0	0	0.0
AAN_C to 50	2760	1166	2996	92	79	---	0.00	0	100.00	0.00	0	0	2760	1170	0	0.01	0	0	0.0
AAN_C to 51	1840	773	1996	92	52	---	0.00	0	100.00	0.00	0	0	1840	780	0	0.01	0	0	0.0
AAN_C to 52	2760	1160	2994	92	79	---	0.00	0	100.00	0.00	0	0	2759	1170	1	0.03	0	0	0.0
AAN_C to 53	3036	1282	3295	92	86	---	0.00	0	100.00	0.00	0	0	3036	1287	0	0.01	0	0	0.0
AAN_C to 54	1840	772	1995	92	52	---	0.00	0	100.00	0.00	0	0	1840	780	0	0.02	0	0	0.0
AAN_C to 55	1840	770	1994	92	52	---	0.00	0	100.00	0.00	0	0	1839	780	0	0.02	0	0	0.0
AAN_C to 56	1840	767	1993	92	52	---	0.00	0	100.00	0.00	0	0	1839	780	0	0.03	0	0	0.0
AAN_C to 57	1840	766	1993	92	52	---	0.00	0	100.00	0.00	0	0	1839	780	1	0.03	0	0	0.0
AAN_C to 58	1840	764	1992	92	52	---	0.00	0	100.00	0.00	0	0	1839	780	1	0.03	0	0	0.0
New C Totals	59519	24697	64440	92	N/A	N/A	N/A	N/A	N/A	N/A	0	0	59499	25223	20	0.03	0	0	0.0