OPTIMAL REINFORCEMENT PROPOSALS TOWARDS LOSS REDUCTION IN THE DISTRIBUTION NETWORK

A dissertation submitted to the
Department of Electrical Engineering, University of Moratuwa
in partial fulfillment of the requirements for the
degree of Master of Science
Registration No: 07/8425

by
M.M.MOHAMEDSABRY

Supervised by: Prof. H.Y. Ranjit Perera

Department of Electrical Engineering
University of Moratuwa, Sri Lanka

2010

Abstract

Network losses represent a major cost in the delivery of electrical energy. As such they need to be carefully managed. Economic and environmental concerns compel a major focus of attention on any such waste of energy. A clear and accurate policy on loss evaluation and costing is required to ensure that limited capital resources are used to best advantage across the total power system. Distribution loss reduction is in many cases cheaper than commissioning generation plants and fuel for supplying losses over the life of a network. Distribution loss reduction requires a wide range of measures, such as: operations, design, major development projects and network reinforcements.

This study concentrates mainly on proposals for network reinforcements to the Medium voltage distribution system. It is a known fact that about two thirds of feeder losses arise in the first third of main feeder length. Re-conductoring or conversion of such sections can be extremely cost effective.

The objective of this study is to identify and formulate proposals for network reinforcement of the MY distribution system in order to:

(a) Operate at optimal level of losses
(b) Provide electricity in sufficient quantity and of acceptable quality
(c) Ensure efficient electricity distribution based on change of load
pattern of the large committed loads and general load growth.

This study has been carried out III the MY distribution network of the Western Province South-I of the Ceylon Electricity Board. SynerGEE computer software has been used to formulate the load flow study. The software model calculates the annual network energy and peak power demand forecast. Required reports and charts generated using the load flow with profile analysis. Load forecast is the primary factor for formulation of network reinforcement proposals. The reinforcement

proposals have been obtained for the years from 2009 to 2013 based on provincial requirement on bottom up approach.

The implementations of network reinforcement proposals incur substantial costs to the utility. With a view to lessen the burden on the utility, the network proposals have been spread throughout the planning period in such a manner that those are implemented exactly as and when necessary. This in turn stagger the investment and helps smooth cash flow. Economic evaluation has been carried out to asses the costs and benefits of the proposed investment. Calculations have been done based on data obtained from the load flow. Results of the economic evaluation of this study are satisfactory. However the performance figures are based on the load forecast and timely implementation of the proposals as scheduled.

Benefits are two folds; quantifiable and unquantifiable. Benefits from improvement of network voltage and supply reliability are difficult to quantify. The readily quantifiable benefit is the reduction of power and energy losses. Only this benefit has been considered for the analysis.

The techniques describes in this study allow a loss reduction strategy to be formulated, based on experience of a typical segment of the network under consideration. For planning purpose, the results of a well chosen pilot scheme can be applied to the entire network; thus allowing the total cost of the scheme and the resulting benefits to be evaluated.

Distribution system loss reduction presents an excellent opportunity for improved energy efficiency. Loss evaluation both difficult and complex. Development of policy and programme require both technical and judgemental analysis. This study summarizes approachesto reduce losses in power distribution systems.

DECLARATION

The work submitted in this dissertation is the result of my own investigation, except where otherwise stated.

It has not already been accepted for any degree, and is also not being concurrently submitted for any other degree.

UOM Verified Signature

M. M. Mohamed Sabry

I endorse the declaration by the candidate.

UOM Verified Signature

Prof. H.Y. Ranjit Perera

CONTENTS

ACKNOWLEDGEMENT

First and foremost, I pay my sincere gratitude to my supervisor Professor Ranjit Perera, Director-General of Public Utilities Commission of Sri Lanka and former Head, Dept. of Electrical Engineering of University of Moratuwa who encouraged and guided me to conduct this investigation and on preparation of the final dissertation.

I would like to take this opportunity to extend my sincere thanks to Mr.U.K.W. Silva, Deputy General Manager (Projects &Heavy Maintenance, Region 4), Dr. H. M. Wijekoon, Chief Engineer (Planning, Region 3) and Mr. L. G. Weerasekara, Chief Engineer (Planning & Development, Region 4)of Ceylon Electricity Board who gave valuable instructions and advice during the study and while preparing the final dissertation.

I would also like to thank my colleagues in the post graduate programme and friends for their support and encouragement.

It is a great pleasure to remember the kind co-operation extended by my wife and children who helped me to continue the studies from start to end.

ACKNOWLEDGEMENT

First and foremost, I pay my sincere gratitude to my supervisor Professor Ranjit Perera, Director-General of Public Utilities Commission of Sri Lanka and former Head, Dept. of Electrical Engineering of University of Moratuwa who encouraged and guided me to conduct this investigation and on preparation of the final dissertation.

I would like to take this opportunity to extend my sincere thanks to Mr.U.K.W. Silva, Deputy General Manager (Projects &Heavy Maintenance, Region 4), Dr. H. M. Wijekoon, Chief Engineer (Planning, Region 3) and Mr. L. G. Weerasekara, Chief Engineer (Planning & Development, Region 4)of Ceylon Electricity Board who gave valuable instructions and advice during the study and while preparing the final dissertation.

I would also like to thank my colleagues in the post graduate programme and friends for their support and encouragement.

It is a great pleasure to remember the kind co-operation extended by my wife and children who helped me to continue the studies from start to end.

ACKNOWLEDGEMENT

First and foremost, I pay my sincere gratitude to my supervisor Professor Ranjit Perera, Director-General of Public Utilities Commission of Sri Lanka and former Head, Dept. of Electrical Engineering of University of Moratuwa who encouraged and guided me to conduct this investigation and on preparation of the final dissertation.

I would like to take this opportunity to extend my sincere thanks to Mr.U.K.W. Silva, Deputy General Manager (Projects &Heavy Maintenance, Region 4), Dr. H. M. Wijekoon, Chief Engineer (Planning, Region 3) and Mr. L. G. Weerasekara, Chief Engineer (Planning & Development, Region 4)of Ceylon Electricity Board who gave valuable instructions and advice during the study and while preparing the final dissertation.

I would also like to thank my colleagues in the post graduate programme and friends for their support and encouragement.

It is a great pleasure to remember the kind co-operation extended by my wife and children who helped me to continue the studies from start to end.

List of Figures

List of Tables

Chapter 1

Introduction

1.1. Background

In the present energy crisis, saving power has become a major problem at an international level. Studies have shown that reduction of losses in the power network is much more beneficial than the increase of generating capacities, and energy efficiency represents the cheapest resources of all. Nowadays, it is univocally acknowledged that the reduction of losses - especially in the distribution networks leads to power and energy cheaper than building new capacities of generation and transmission. Energy efficiency is accepted by the specialists as the most available, the least pollutant and cheapest resources of all. In fact, it has been established that 1 installed kW is four times more expensive than 1 saved kW [8].

The International Energy Agency publishes electricity statistics for a range of countries, including data on transmission and distribution losses [5]. Although the methodology behind their estimates is not entirely transparent, they are reported on a consistent basis across the countries. Table 1.1 below summarizes transmission and distribution losses for countries that may be compared to the UK.

Country	1980	1990	1999	2000
Germany	5.3	5.2	5.0	5.1
Italy	10.4	7.5	7.1	7.0
Denmark	9.3	8.8	5.9	7.1
United States	10.5	10.5	7.1	7.1
Switzerland	9.1	7.0	7.5	7.4
France	6.9	9.0	8.0	7.8
Sweden	9.8	7.6	8.4	9.1
Australia	11.6	8.4	9.2	9.1
United Kingdom	9.2	8.9	9.2	9.4

Table 1.1 - Transmission and Distribution Loss % in Selected Countries

Electrical losses are an inevitable consequence of the transfer of energy across electricity distribution networks. The level of reported losses in any given year will be influenced by number of factors, both technical and operational.

Many utilities suffer with high technical and non-technical energy losses. Experience has shown that the optimal total power losses in the distribution network ranges between 6 and 12 percent. Sample studies of a number of utilities showed, however, that the secondary distribution network alone could have losses that exceed 12 percent.

1.2. Distribution System Losses of the Ceylon Electricity Board (C.E.B)

The distribution network of the CEB consists of about 24,000 km of 33kV/11kV lines, 95,000 km of low voltage lines (400/230V) and 19,700 distribution substations which feeds about 4.0 million customers [3].

Even though the total system losses in year 2000 was 21.4% over the last 8 years, the system losses have come down by about one third and the present system losses now stands at 14.98% (end of 2008)[1]. The total of the system losses of the CEB could be separated into generation auxiliary losses, transmission losses and distribution losses. The generation auxiliary losses are about 0.83% and the transmission losses now stands at 2.58%. Hence the overall distribution losses as a percentage of gross generation are about 11.57%.

	Percentage Loss
Generation	0.83
Transmission	2.58
Distribution	11.57
Total System Losses	**14.98**

Table 1.2 – System Losses of the CEB (Year 2008)

The distribution system losses could again be divided into technical and non-technical losses. Technical losses are due to the transformer losses, power losses in the medium voltage network (33kV &11kV) and low voltage line losses. The non-technical losses are due to unmetered supply connections, illicit tapings, tampering of meters, meter errors, unauthorized street illuminations etc.

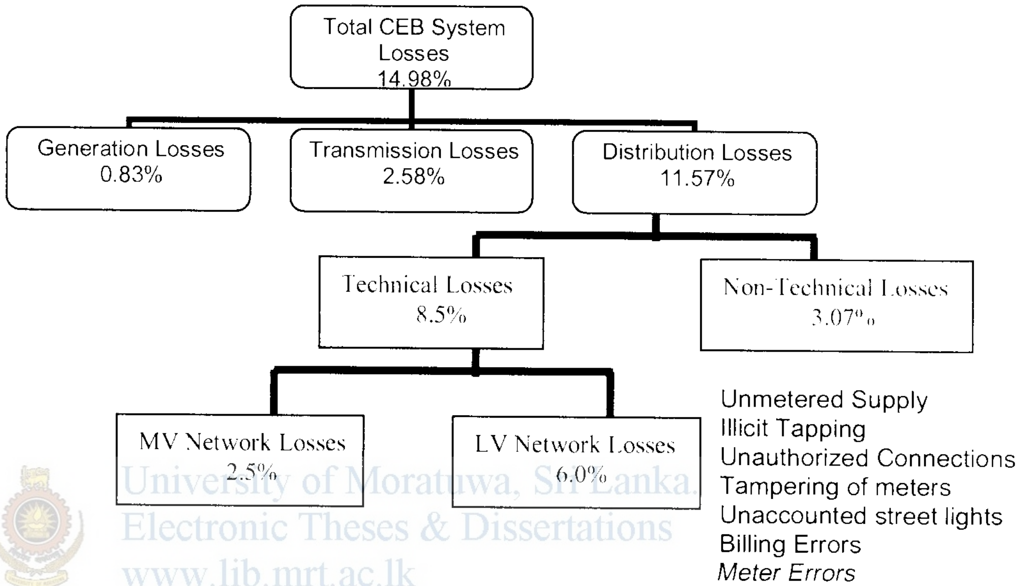

Figure 1.2 -System Losses :(2008)

1.2.1 MV Distribution Network and Losses

The 33kV medium voltage network of CEB is well spread over the island to reach the rural areas and consists about 24,000 km of lines. Since the transmission system is limited to certain load centers only, at certain times the connected 33 kV lines increase the medium voltage line losses [3].

Over the last decade the electrification level of Sri Lanka has increased from 29 % in 1990 to a level of 81 % at the end of year 2008 and the total number of consumers as at end of 2008 is about 4.0 Million.

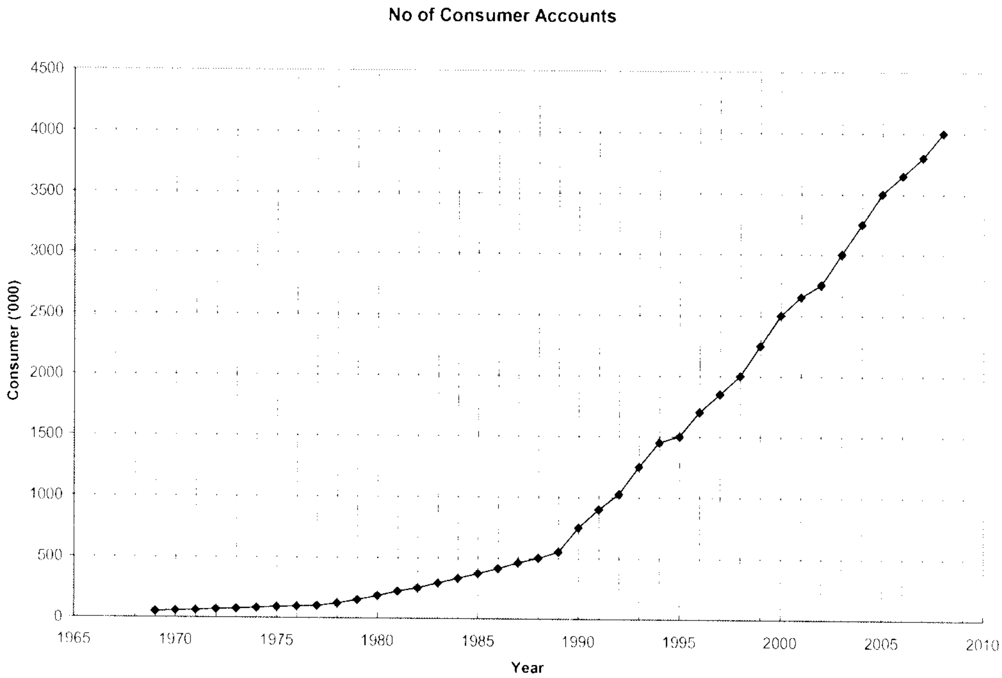

Figure 1.2.1 Number of Consumers Vs Years

About 75 % to 80 % of population of Sri Lanka lives in rural areas and the 33 kV network has been extended to greater distances to reach the rural population, thus increasing the 33 kV line losses in the system. There had been a rapid expansion in electrification in rural areas to meet the government objective of at least reaching a level of 75 % electrification by year 2006. As a result long lengths of 33 kV MV lines have been constructed without new grid substations, interconnections and express lines being built.

Under these circumstances, the MV distribution loss level still remains at 2.5 % and heavy investments are needed to reduce this level.

1.2.2 LV Distribution Network and Losses

LV Technical losses are mainly due to long length of LV lines from the distribution substations feeding the domestic and other retail consumers. In the past LV lines from a distribution substation were extended to a distance of about 2.4 km. and in certain instances even beyond. All LV extensions have been single phase construction and as a result 50% or more LV lines in the CEB distribution system are single phase lines contributing to high losses.

Island wide study was carried out in the year 2004 to collect data on all distribution substations and connected LV lines. The observations made from these studies are as follows [3].

1 60% of the LV schemes in Sri Lanka are having low voltage below 10% of the stipulated voltage of 230 V.

2 About 55% of the LV schemes have unbalanced 3 phase feeders.

3 The average voltage drop at the end of a LV distribution line is about 15%.

Taking into consideration, the status of LV distribution network as stated above and also based on certain studies carried out on rural electrification schemes, a reasonable estimate for average LV losses in the CEB system is 6.0% of gross generation.

In order to improve the supply voltage and to arrest the LV distribution losses, a decision has been taken to limit the LV 3 phase feeder distance to 1.8 km and to construct only 3 phase lines. The voltage drop and the level of energy losses vary with the distance of the 3 phase line from the distribution transformer and depend on the consumer density. The graph below shows the variations at 1.4 km, 1.8km and 2.4 km for rural schemes for different consumer densities.

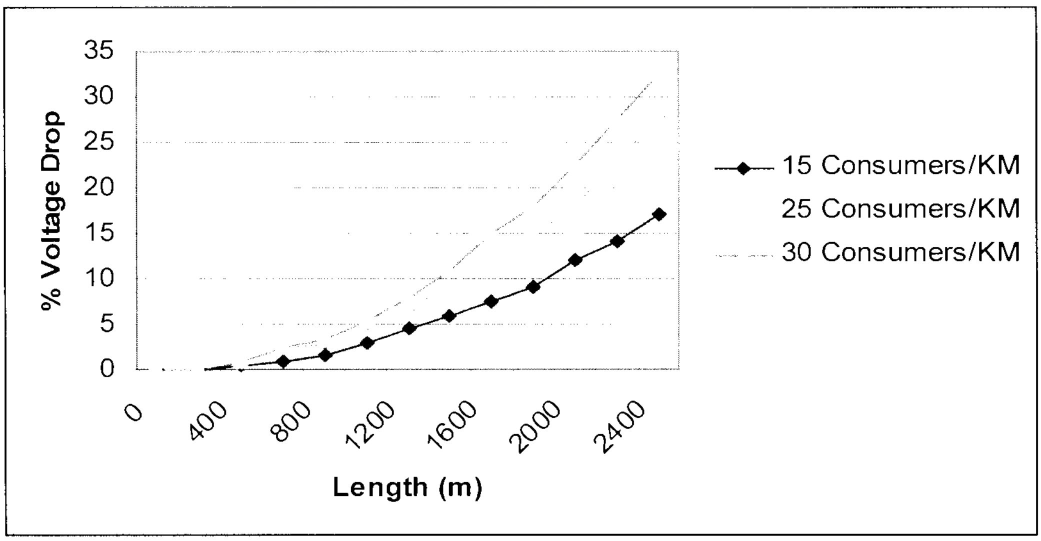

Figure 1.2.2 – Percentage Voltage Drop vs. Line Length

The feeder distance, after detailed studies were limited to 1.8 km in rural areas as th consumer density is low in RE schemes. However, the LV line distance in urban areas has to be below 1.0 km to maintain required voltage regulation and also to bring down LV losses. It was agreed that this length would be limited to 1.8 km initially and once that has been achieved, consider lowering this norm further to1.4 km. and beyond.

1.3 Technical Losses in the Distribution Network

The reason for the technical loss is due to following one or more [6]:

- I^2R losses or heat loss
- High peak load current
- Un-optimized location of transformers
- Lengthy single-phase lines
- Phase imbalance
- Sparking at loose joints
- Low power factor at off peak hours
- Overloading of LT lines
- High harmonics
- Low quality of insulators and conductors
- Low quality earthing at consumer premises

The technical losses of the distribution network are 8.5% of the gross generation. The technical losses are divided into two categories as follows;

1. MV Technical Losses
2. LV Technical Losses

MV technical losses are 2.5% and LV technical losses are 6.0% of the gross generation in the year 2008.

1.4 Technical Loss Reduction Measure

The long term objective of the loss reduction programme is to reduce distribution system losses to half their present level. Our load is continuing to grow at a rate of about 7 percent per annum. It has traditionally doubled over 15 years. Therefore, holding losses at their present level in kWh terms over this period will achieve this objective.

Distribution system loss reduction requires a wide range of measures spanning a large number of mostly small projects. An overall programme is required to integrate the effort and deploy available capital as effectively as possible. Specific and measurable targets are required to ensure progress. We have short term and long term programmes. These details targets in specific areas, such as operational sectionalizing, additional investment in major developments to optimize loss savings, etc. Additional capital requirements and loss savings are estimated, to re-deploy some capital from generation to network development

The optimal losses level of a distribution network would depend on many factors including:

* Long run marginal cost of capacity and energy
* Discount rate
* Capital cost of equipment
* Existing loading
* Load growth rate
* Cost of power and energy losses

These factors affect the optimal specification and design of the components used in distribution systems. The optimal losses level of a distribution network will be the accumulated optimal losses levels of these components. There are number of principal measures that can be taken to reduce the losses in a distribution system. These include;

* MV network reinforcements
* Installing capacitors on primary lines to correct the power factor to 95% or better
* Replacing the high impedance power transformers
* Managing the distribution transformer load
* Reduce the primary conductor loading
* Reduce the secondary conductor loading

In general, the principles of optimal component size and loading are based on evaluation of the operational costs over a number of years, the capital cost of equipment, and any benefit associated with the different options. Analysis using software models allows the effectiveness of various solutions to be evaluated.

1.4.1 MV Network Loss Reduction Measure

The medium voltage network of any power system needs further strengthening and expansion to cater the increasing electricity demand as well as to overcome the weaknesses of the existing MV system. These strengthening and expansions are generally known as network reinforcements.

The MV network reinforcements are needed in timely manner depending on the demand growth of the power system. The proposals for network reinforcements are broadly classified as short term proposals and long term proposals. The short term proposals are those which need to be implemented within the first two years of the planning horizon, where as the long term proposals are those which are to be implemented during the rest of the planning period.

Capacitors are widely used in distribution system for voltage regulation and power factor improvement [13]. Capacitor banks are usually placed near load to provide reactive power locally. The reduced amount of reactive power flowing on distribution lines between the capacitor and the source allows lower current and improve power factor. Thus line losses are smaller and voltage becomes higher at the load.

1.4.2 LV Loss Reduction Measure

In order to overcome the above problems, it was decided to add new distribution transformers to the system and to convert the loaded single phase feeders to three phases. Provision of new distribution transformers will reduce the transformer loading, LV feeder distance and feeder loading while the conversion of single phase lines to 3 phases will improve the line end voltage and the unbalance situation of LV feeders, which cause low voltage.

It is necessary to distribute load evenly across the three phases in order to have a better system performance. As a part of this work, decision must be made about how single and two phase laterals are connected. For example a single phase lateral could be connected to either phase A, B, or C of the main feeder. Making decisions as to how the laterals should be connected is referred to as lateral phase balancing design. Lateral phase balancing will also referred to as just "phase balancing (PB)." PB determines phasing modifications that will produce a more efficient system (i.e.

system with less loss). In addition to efficiency, PB affects the performance, peak load and the cost of the power delivery system.

It is common to find electric utilities that did not record the phasing information of the laterals in the system. This is a major deficiency because such information on the way laterals are connected is vital for any systematic study and analysis of power flows and voltages on power system components.

However, this problem can be tackled. Utilities usually record voltage, current, power factor or real/reactive power measurements taken at some important three phase locations. Furthermore, information associated with loads connected to the laterals is likely to be available. Thus one can use these load and measurement data to determine the unknown phases.

In an electrical distribution system that operates radially, every segment of the system gets its power from only one substation with a unique path from it to the associated substation. This path involves feeders, switches, transformers, etc. Almost always the distribution system has more than one substation and a substation in the system has more than one feeder. This multi-substation, multi-feeder design means that for a segment in the system there might be more than one option regarding from what substation or feeder to obtain power.

Switching operations are used to transfer load from one feeder to another while keeping the system radial. In doing so, system losses are reduced and load balancing can be achieved. Reconfiguration is the process of altering the topological structures of distribution feeders by changing the open/close status of the sectionalizing and tie switches.

During emergency situations such as fault conditions and equipment failures, transferring load and or reconfiguring the system is then performed to isolate the problem area while retaining service to as many customers as possible. This type of action is known as restoration, but is based upon reconfiguration. The reconfiguration tool will affect the reliability, peak load and cost of power delivery system.

1.5 Non-Technical Losses and Reduction Measure

Non-technical losses, sometimes referred to as commercial losses, are those associated with:

- Faulty meters
- Uneven revenue collection
- Tree touching
- Pilferage and theft
- Inadequate metering and billing

Such losses manifest themselves in a mismatch between generated and sold energy that cannot be accounted for by the technical loss component. Reduction of non-technical losses will contribute directly to the revenue receivable. The present total distribution losses are at 11.57% and of which 8.5% is attributed to technical losses. Hence the non-technical losses of the CEB system are estimated at 3.07%.

As non-technical losses are substantial amount of distribution losses, measures have already been taken to bring down non-technical losses to an acceptable level.

Meters are being installed at distribution substations. This will facilitate to carry out an energy audit every month to assess the energy delivered and energy billed. If large discrepancies of energy delivered to energy billed are shown, the electricity scheme should be investigated to find any possible losses or theft [12].

1.6 Motivation

Network losses are a major issue for power utilities, particularly on distribution networks. The scale of losses on distribution system is documented in CEB statistics. 11.57 percent of the power input at time of system peak is dissipated as distribution system loss [4]. These are significant quantities of energy in national term. The cost of such losses is very high. Measures to be taken to reduce these loss rate to about half of this level in relative term over the next 10 years or so.

The outcome of this project will identify and formulate CEB - Western Province South I medium voltage distribution network`s, reinforcement proposals for the years 2010, 2011, 2012 and 2013 in order to operate at minimal level of losses to provide electricity in sufficient quantity and acceptable quality based on change of load pattern of the large committed loads and general load growth.

In addition, the production of additional energy has a significant environmental impact. It is estimated that, a reduction in losses of 1 percent might contribute to 4 percent of reduction in Carbon dioxide emission.

Furthermore, the transportation of additional energy would huge investment in necessary infrastructure development.

Chapter 2

Problem Statement

2.1 Identification of the problem

Energy losses are intrinsic to the process of power utility. Some of the energy flowing through the electricity networks is dissipated as heat in the conductors and transformers in the system. Such loss of energy clearly needs to be controlled and minimized as far as possible [7]. It is not practically possible neither economically viable to eliminate energy losses totally. This optimal level is the threshold point where the value of the energy saved goes below the cost of further loss reduction.

Today both public and private sector power companies to reduce the technical and commercial losses during distribution to reduce the rising energy shortage. Power sector had made substantial progress in recent years, distribution services to be modernized and made consumer sensitive. The power reform programmes would be further strengthened. Procedures should be adopted by the government to provide incentives to utilities to encourage reducing their losses [26].

The importance of reducing losses in the power system is well known. This aspect receives topmost priority. Additional investment in the distribution system to reduce power losses would have a high rate of return and is absolutely necessary and should be given high priority [6].

Reduction of technical losses in the MV distribution network, which are due to inadequacies in the components and performance of the distribution system, will result in an improvement in better voltage quality to the consumers and higher sales [2]. The evaluation of technical losses should be based on information from system records and site measurements associated with the system. The purpose of the information gathering stage is to construct a model of the system in its existing state, showing sources of power supply and load distribution.

The study is aimed at finding the ways and means of management of electricity distribution for improving system efficiency to ascertain the customer satisfaction.

Minimum system loss, maximum supply availability, minimum cost of operation and maintenance and maximum customer satisfaction are identified as Key parameters.

2.2 Objective of the study

The objective of this project is to identify and formulate proposals for network reinforcement of the MV distribution system in order to design in such a way to operate at optimal level of losses and to provide electricity in sufficient quantity and of acceptable quality to ensure efficient electricity distribution based on change of load pattern of the large committed loads and general load growth.

2.3 Importance of the study

The proposals provided in this study are essential for the reduction of MV distribution losses and provide the following advantages too.

- Adequate grid substation capacity will be made available for the network.
- Satisfactory level of voltage will be maintained in the MV network.
- Network configuration will be improved to provide adequate facilities to operate the network at a reasonable level of reliability.
- The proposed network development would also provide the basis for the expansion of Electricity distribution network to support rural electrification and for the industrial development. Power related projects proposed by the ministry of National Planning, Industrial estates proposed by the Ministry of Industries, BOI and UDA have been considered in this studies.

Distribution system loss reduction presents an excellent opportunity for improved energy efficiency. Economics and environmental pressures now compel a major focus of attention on such losses. Loss evaluation can be both difficult and complex. Development of policy and programmes requires a lot of both technical and judgmental analysis.

Chapter 3

Methodology

3.1 Network Analysis Approach

A variety of computer aided tools are available to perform data manipulation, load flow analysis, power loss assessment, fault level calculation and appraisal of loss reduction measures. Power system analysis software package and spreadsheet software are two fundamental tools for establishing a successful loss reduction strategy.

The technical viability of proposed loss reduction strategies can be assessed by performing a range of analysis for various operating scenarios before and after the implementation of the measures. The difference in power losses obtained from the load flow studies can be used to calculate the annual energy losses, which can then be used to assess the economic and financial viability of alternative options.

The following empirical formulae are used commonly to estimate the annual energy losses. In these equations, constant losses associated with transformer cores are accounted for separately from the distribution line losses [11].

$$L_{lf} = 0.3 A_{lf} + 0.78 A_{lf}^2 \quad (1)$$

where, L_{lf} and A_{lf} are represented by loss of load factor and annual load factor respectively.

$$A_{el} = 8760 \left(L_{lf} \; P_{pl} + T_{cl} \right) \quad (2)$$

where, A_{el}, P_{pl} and T_{cl} are represented by annual energy loss, peak power loss and transformer core loss respectively. *(The annual load factor is derived from the load duration curve of the concerned network)*

The loss load factor is extensively used to calculate the average distribution loss based on the maximum loss (at peak load). The accuracy and suitability of the LLF methodology is limited as it is assumed that the loads are homogenous and vary uniformly at all busbars. The stochastic nature of load is not directly accounted for and the time-of-use (TOU) characteristic of the load is not known [20].

Consumer load profiles are used for load calculation. However, the loss calculations are based on the mean load during each time interval. The load variance within time intervals is ignored, and the errors may be large with stochastic loads such as in LV networks [20].

The majority of loss evaluations differentiate between no-load and load losses and no-load and loss costs are typically based on base- load and peak-load generation costs respectively. The major limitation of this approach is that the TOU characteristic of the load loss energy is not considered. Generation costs vary significantly between peak and off-peak periods. The use of average loss costs may result in large errors as the load shapes in individual distribution networks can vary significantly from that of the total generation system [20].

3.2 Bottom Up Approach

Distribution networks extend to every geographic location covered by the utility providing final connection between the utility and the customer. They are therefore considered the most suitable system to capture localized customer requirements, demand and growth patterns etc. For example, demand growth will be different in different areas, certain areas need high supply reliability etc. Effective planning process therefore begins from distribution system. System requirements are then worked out in upward direction, from identification of distribution network reinforcements / expansions, substation augmentation & new substations to meet these distribution system requirements, and transmission line development to meet substation requirement, all of which converging on final objectives; meeting the customer needs and techno-economic optimization. This is known as the 'bottom-up' approach in utility planning. In modern utility approach, this process is carried out through computer aided network modeling and analysis tools [16].

3.3 Short and Long Term Proposals

The proposals of the study consist of short term proposals and long term proposals.

Short term proposals have been formulated, during the study in order to satisfy the requirements arising out of the micro area development and could be implemented in a shorter period of time as either permanent or temporary solution to network problems. Short term proposals generally include the following improvements. The proposals are expected to be completed during a period of one to two years [2].

- 11kV to 33kV conversions
- MV line reconductoring
- Short interconnection lines
- Temporary primary substations

Long term proposals have been identified, for reinforcement of MV network at macro *level. These proposals include:*

- MV lines and gantries
- MV lines (long lines)
- Enhancement of primary feeding facilities (Primary Substations)
- 33 kV new grid substations

3.4 Technical Loss Reduction Strategy for the MV Distribution network

Technical loss reduction strategy for the MV distribution network can be devised by first establishing the existing losses. The information gathered from system records for the load flow models should include power demand, power factor and sending end voltage. Even when good historic data are available, it is prudent to carry out some measurements to verify this information, thus increasing confidence in the resulting system model.

The study has been carried out based on provincial MV network model of Western Province South I of CEB, which constitute Dehiwala, Ratmalana and Kalutara CEB distribution areas using SynerGEE Electric computer software. The sequence of steps followed in this study is as follows.

Step 1: Updating of mapping information of the MV distribution network of Western Province South I of CEB.

Step 2: Collection of load data, network data, feeder current, boundary current etc.

Step 3: Computer modeling and network analysis of present system using SynerGEE Electric computer software.

Step 4: Load forecast based on provincial requirements and trend based on a bottom up approach.

Step 5: Future system analysis based on forecasted loads and evaluation of possible options to derive optimal solution of system improvements using SynerGEE Electric computer software.

Step 6: Formulation of short term and long term proposals for the improvement of the MV distribution network.

The following block diagram illustrates the approach of the overall study at a glance.

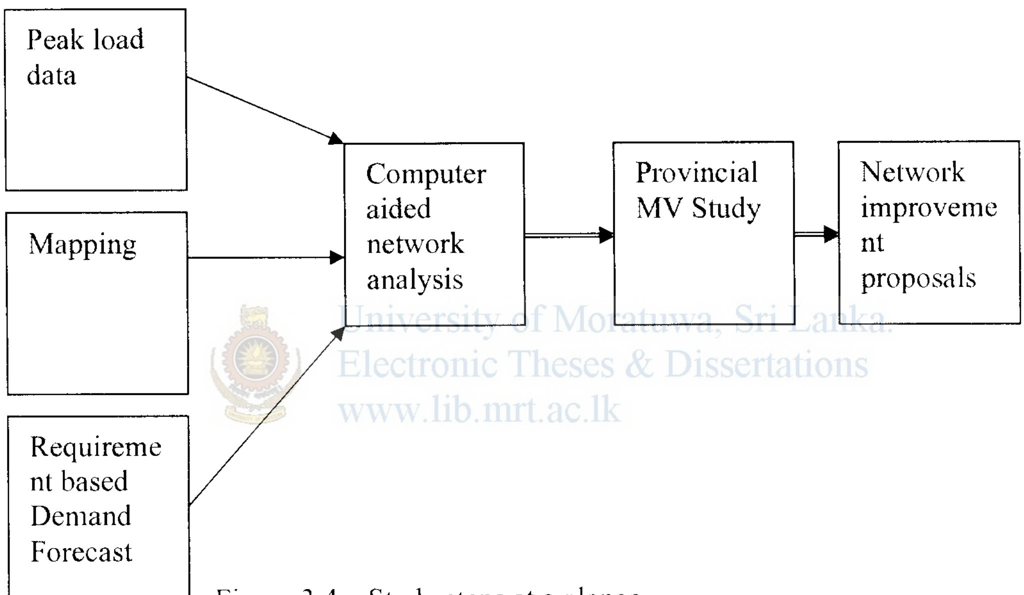

Figure 3.4 - Study steps at a glance

3.5 SynerGEE Electric Computer Software

SynerGEE Electric is a software package designed to aid in the simulation, analysis and planning of power distribution feeders, networks and substations [15]. The package is a modular collection of tools built on a by-phase simulation engine. The simulation engine is based on an object-oriented design consisting of highly detailed models for power system devices such as lines, transformer banks, regulator banks, switched capacitors, active generators and others. The models for these devices are built to reflect the actual construction of real power system equipment.

SynerGEE is very user-friendly and allows quick construction and maintenance distribution models. The tools, utilities and features such as graphical editing tools are designed to get feeders modeled quickly and accurately. Data requirements are clearly marked in dialog boxes and are kept to a minimum so that the models can be specified with basic nameplate parameters. The device models and calculations used within SynerGEE conform to those methods accepted and depended upon.

SynerGEE provides a user-friendly modeling interface designed to make modeling convenient and easy. Using advanced drag-and-drop capabilities, SynerGEE allows users to create models quickly that accurately depict the actual distribution system.

Sections are used as the basic building blocks of the distribution system model. A section represents an electrical path between two end points (nodes), and can use vertices to simulate geographic attributes. It is composed of an overhead or underground conductor segment and perhaps a group of devices and /or load models. *There are no limits to the length of a section, or to the number of sections in a system.*

When a section is first added, the section length is calculated based on the map view's current unit of measure setting. If it connects to an existing section, it inherits the phase configuration, conductor type, phase spacing, load connection value and equivalent height above ground attributes of the adjacent section.

SynerGEE has been designed to provide an outstanding line model without complicated data requirements. It captures the effects of electric and magnetic field coupling by using the full set of Carson's equations and its methods. SynerGEE's by-phase impedance and admittance calculations and reduction techniques can handle coupling between conductors, and between conductors and the earth. SynerGEE considers one, two and three phase lines with and without a neutral return, and can handle bare overhead lines as well as cables.

3.6 Load Allocation

Loads in SynerGEE are represented by the standard real and reactive components, kW and kvar, at the section level. Once properly set up, load handling is generally straight forward and intuitive . SynerGEE identifies two basic types of loads:

Distributed loads are the "normal" loads in the system, often represented by the capacity of the distribution transformers. Usually, distributed load in a model represents a good averaging of system loading, but does not represent pinpoint accuracy, section by section.

Spot loads are special, stable loads assign in addition to distributed load. A spot load often represents a predictable and substantially large load, such as an industrial customer, have accurate information about and would not be represented by distributed load [15].

Load allocation adjusts all distributed loads on a feeder so that the total load into a feeder after a balanced or by phase analysis matches the feeder demands specified in the feeder dialog. Individual section loads are calculated based upon the feeder demands. The value of these distributed loads is determined by running a load flow analysis, then looking at the difference between the specified feeder demand values and actual power into the feeder. This mismatch is divided among the sections and phases [17].

Robust and efficient power flow solution method must be able to model features of distribution system with sufficient accuracy [24],[25].

The following items should be noted.

The sections without kVA values (or kWh if selected allocation based on (kWh) do not receive portions of the allocated loads.

Losses are included in the allocation since the SynerGEE load-flow analysis is used during each iteration.

Capacitors and generators increase the amount of load that is allocated since they, in fact, supply real and reactive values of power to the feeder.

Once a state of convergence is reached, if resulting distributed loads for each section are to replace the existing ones in the database. If the response is not to replace the database loads, a report is generated but no permanent changes are made to the feeder.

The steps of this iterative process are listed below:

1 Remove all distributed loads from feeder
2 Run balanced or by-phase load-flow
3 $\triangle S^i = S_{specified} - S^i_{into\ feeder}$
4 Add $\triangle S^i$ to feeder distributed loads
5 If $|\triangle S^i|$ > Tolerance, go back to Step 2.

If balanced allocation is selected, balanced analysis is used. Otherwise, by-phase analysis is used. The distribution of $\triangle S^i$ among sections depends on allocation factors for each section [15]

SynerGEE supports three allocation models. They are by-phase allocation using by-phase demands, by-phase allocation using total demands and balanced allocation. These options are designed to facilitate the various levels of detail in feeder models, phasing and feeder load meter readings [15].

Load allocation can treat the feeder and substation transformer demands in different ways. It can also base its analysis on balanced or by-phase load flow.

* By-phase allocation - This analysis uses a by-phase load flow. It allocates load by phase and uses the by-phase demands to proportion values.
* By-phase allocation, use total demand – This option still uses a by-phase load flow. It allocates load by phase. By-phase loads are determined from the ratio to by-phase information to the feeder total. Feeder or substation demands are shifted to be proportional to the total by-phase allocation parameters such as kWh or kVA.
* Balanced allocation - This option uses balanced load flow analysis. It allocates evenly across all phases of a line. It also totals feeder and substation transformer demands.

SynerGEE allows demands to be specified in the following formats[15]:

* Amps and power factor
* kW and kVAR
* kVA and power factor
* kW and power factor

The demands are stored in the database as kW and kVAR values. The values are converted to the various formats in the Demands dialog using the nominal voltage of the feeder or substation transformer. Therefore, if the feeder or substation transformer nominal voltage is changed, the demands specified in Amps, pf will also be changed.

Power systems sometimes have multiple solutions that are numerically achievable. To avoid reaching an unrealistic solution, the initial load flow used on the feeder model is simplified. An initial estimate of the total load to allocate is found using the following equation:

$$\boldsymbol{L_T} = \frac{\boldsymbol{F_d} - \boldsymbol{S_l} - \boldsymbol{L} + \boldsymbol{G_i} + \boldsymbol{C_i}}{\boldsymbol{D_l}} \qquad (3)$$

Here, $\boldsymbol{L_T}$ denotes initial estimate of the *total load to allocate* and F_d the specified feeder demand. $\boldsymbol{S_l}, \boldsymbol{L}, \boldsymbol{G_i}, \boldsymbol{C_i}$ and $\boldsymbol{D_l}$ respectively represent the estimated spot load, losses, generated injection, capacitor injection and initial distributed load to allocate.

This initial estimate of distributed load is spread out using the allocation factors discussed above.

This factor corresponds to the ratio of the section's by-phase kVA values to the by-phase total values for the entire feeder. A section must have connected kVA values in order to pick up allocated load.

This factor corresponds to the ratio of the section's by-phase kWh values to the by-phase total kWh values for the entire feeder. A section must have kWh values in order to pick up allocated load.

When allocating on substation transformers, the substation transformer demands are recognized as occurring on the secondary of the transformer. After allocating and viewing a load flow report, the power into the primary side will not match the demands. The power out of the substation transformer should match the specific demands.

3.7 Load Flow Analysis

Load flow analysis calculates current flows, voltage drops, losses and loading of lines, equipment, switches and protective devices. If a substation is selected, all feeders of the substation are analyzed as well as the substation transformers, buses, equipment and switches. There are no limits on the number of sections that can be included in load flow analysis. The calculated results for each section or substation bus are saved in the database, and a detailed report is produced. These reports can be viewed, saved, and printed [15].

The load flow engine is object-oriented, driven by a robust algorithm used to enforce Kirchhoff's laws between object representing power system devices. The objects respond to various messages supplied by the load-flow algorithm. They contain the complicated and highly nonlinear models for various types of distribution equipment such as voltage regulators, transformers and switched capacitors.

Section: 01-1216248

Sect | Cnfg | Dist | Spot | Ext | Misc | Coord | Results

Result	A/AB	B/BC	C/CA	Bal/Tot
Amp Reserve	0	0	0	0
MAIFI	0.0	0.0	0.0	0.0
SAIDI	0.0	0.0	0.0	0.0
SAIFI	0.0	0.0	0.0	0.0
Ph-Ph	---	---	---	0.0
Max LG	---	---	---	0.0
Min LG	---	---	---	0.0
3 Phase	---	---	---	0.0
Volts Into	92.8	92.8	92.8	92.8
Volts Out	92.8	92.8	92.8	92.8
Amps Into	1	1	1	1
Pct pf	98.0	98.0	98.0	98.0
kvar Load	0	0	0	0
kW Load	0	0	0	0
Nom kV	---	---	---	33.00
kvar Loss	-1.3	-1.3	-1.3	-3.8
kW Loss	0.0	0.0	0.0	0.0
Volt Drop	0.0	0.0	0.0	0.0
kVar Into	3	3	3	10

Table 3.7 –Results of a section after load flow study

Table 3.7 is a specimen which shows the results of a section after a load flow analysis. Highlighted figures are the voltages in and out of the section.

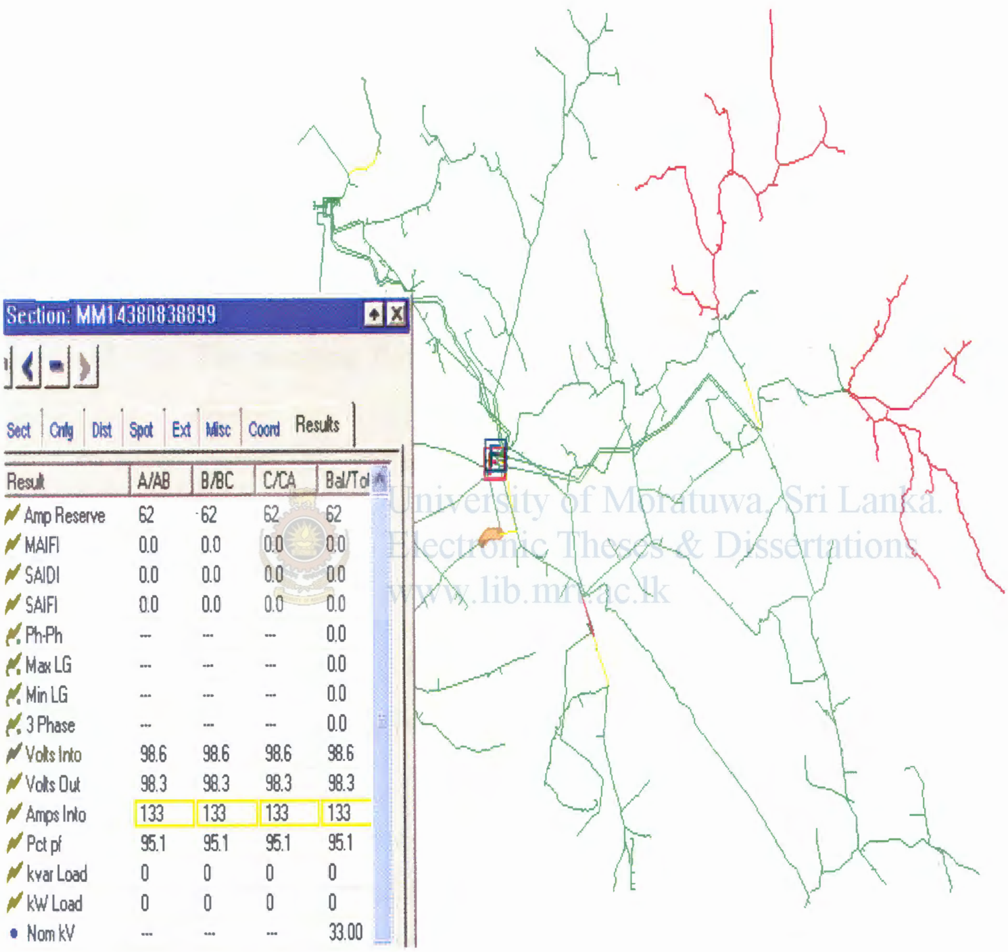

Figure 3.7 (a) Load Flow Results

The radial load-flow engine of SynerGEE has many advantages over the traditional Gauss- Seidel and Newton-Raphson method for two reasons. First, SynerGEE does not rely on a matrix representation or an abstract mathematical representation of the power system. This allows the model of a power system to simply be a collection of device models. Furthermore, there is no limit to the size of system synerGEE can model. Analysis can also be run directly from the database. The second advantage is that it can make coupled three-, two-, or one phase representation of power lines and power equipment. Unbalanced loading, long single phase laterals, ungrounded systems, non-symmetrical transformer banks, mutual coupling, earth return and device controller actions can all be modeled in a manner consistent with the actual construction and physical behavior of these devices. These advantages make SynerGEE a powerful tool for the simulation and analysis of power distribution systems.

In most situations, balanced analysis will produce results representing a single line model of the distribution system. Loads are averaged over the phases of the associated line section. Currents are averaged at section intersections.

To achieve the balanced analysis, SynerGEE follows the following steps.

* Loads are averaged over the phases in each sections.
* The SynerGEE by-phase engine is used to analyze the system.
* The resulting flows and voltages are vectorially averaged over valid phases

In a balanced system, the voltage drop calculation can be expressed vectorially as follows:

$$\boldsymbol{V}_{ctr} = \boldsymbol{V}_{src} - \frac{1}{2}\boldsymbol{Z}\,\boldsymbol{I}_{\mathbf{into}} \quad (4)$$

Here, $\boldsymbol{V}_{ctr}$ and $\boldsymbol{V}_{src}$ denote the voltages at the center and source, $\boldsymbol{Z}$ the impedance and $\boldsymbol{I}_{\mathbf{into}}$ the current entering the line section.

Equation no (4) shows how the voltage in the centre of the section is found from a line's source voltage, its impedance, and the current entering the line section. Losses are calculated for the sections and devices by the analysis. These losses are determined from the difference in the complex power into the device and the complex power out of the device. Values of complex power S are calculated using the necessary voltage and current values. The power into a phase of a grounded section, for example, is calculated as equation no (5).

$$\boldsymbol{S}_{\mathbf{into}} = \boldsymbol{k} \cdot \boldsymbol{V}_{\mathbf{into}} \cdot \boldsymbol{I}_{\mathbf{into}} \quad (5)$$

where, $\boldsymbol{S}_{\mathbf{into}}$ is the value of complex power into a phase of a grounded section, $\boldsymbol{k}$ a constant and $\boldsymbol{V}_{\mathbf{into}}$ is the voltage value.

Values for the various voltages and currents associated with a line, its load, and attached devices are maintained in the temporary database during analysis. SynerGEE load flow analysis is performed using only voltages and currents. Nonlinear loads are linearized during each iteration. The values of power flow are calculated after the load flow solution has been reached. This supports a very robust and precise calculating engine within SynerGEE.

The continuous and emergency ratings of conductors are used to calculate percentage loading and exception coloring. These values are taken from the manufacturer's data. The values are used for comparison of conductor loading for the analytical outputs.

The solution of radial power systems is found using methods of network flows based on walks along directed in and directed out trees having arcs composed of the devices on sections such as power lines, regulators and transformers. Each section is connected radially so that it has one predecessor and possibly multiple descendants. There are two types of walks, an inward walk and an outward walk.

An inward walk is achieved by starting at the end component and passing inward so that every device is passed over before its predecessor. An outward walk is achieved by starting at the source that is either the substation or feeder and passing outward so that every section's predecessor is passed over before the section itself. These walks can be shown in the following simple feeder. Sections on the feeder are labeled with letters.

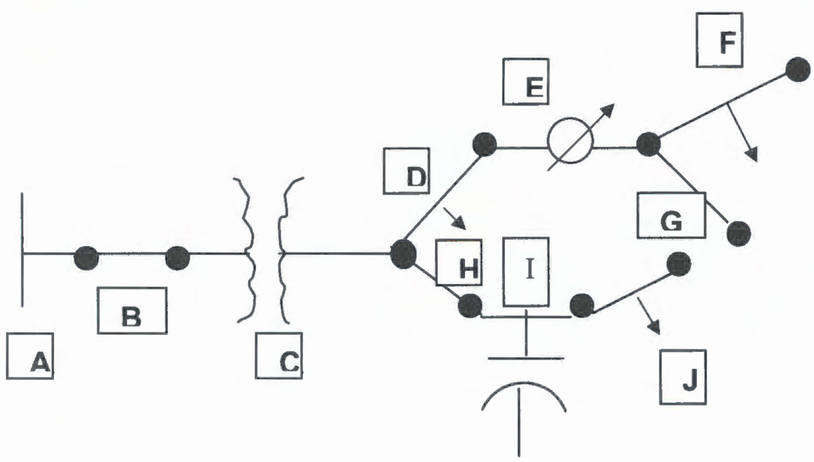

Figure 3.7 (b) Sample of feeder

The first iteration step involves load flow outward propagation. The purpose of the outward propagation is to transmit the fixed voltage specified at the feeder or substation source through each of components of the feeder. When a device is recognized along the outward walk, it subtracts its voltage drop from its predecessor's voltage to get a voltage at its outward end. This voltage is then available to be used as source voltage by the device's descendants when they are recognized during the remining of the walk.

This outward propagation process is used to emulate Kirchhoff's voltage law. At the conclusion of the propagation, the sum of the voltages and voltage drops around any path of the feeder is zero.

The second step of the iteration process involves load flow inward propagation. During the outward propagation, values of current are held constant and information about voltage is transmitted outward along the feeder. During the inward propagation, voltage values are held constant and information about current is transmitted inward along the feeder using inward walk.
This process of propagating load current inward toward the feeder's source is used to satisfy Kirchhoff's current law. At the completion of the propagation, the total current into either the inward or outward end of any device is zero.

The third step of the iteration process includes linearization. The processes outlined in step 1 and 2 above are linear processes. That is nonlinear operations on or between the state variables of current and voltage is never performed during the inward or outward propagations.

During the linearization step, however, currents and voltages obtained from the most recent inward and outward propagation are used to perform a number of operations. Some of these operations are listed below.

- Compound loads are evaluated with the most recent component voltage. The load current archived from the linearization step is maintained and used to represent the load during the inward propagation of the feeder. The current remains constant until the next linearization step.

- Active devices such as switched capacitor controllers and regulator LTC's are activated. Regulators may change taps and switched capacitor modules may be tripped or closed.

- Devices may report back the change in state from the last linearization step due to the last iteration of inward and outward propagations. This determines if the state of the feeder is satisfactorily near the load flow solution.

The steps outlined in the previous sections are invoked during each iteration of the load flow analysis. The diagram below demonstrates how the load flow steps fit together within iterations to determine the solution of a feeder.

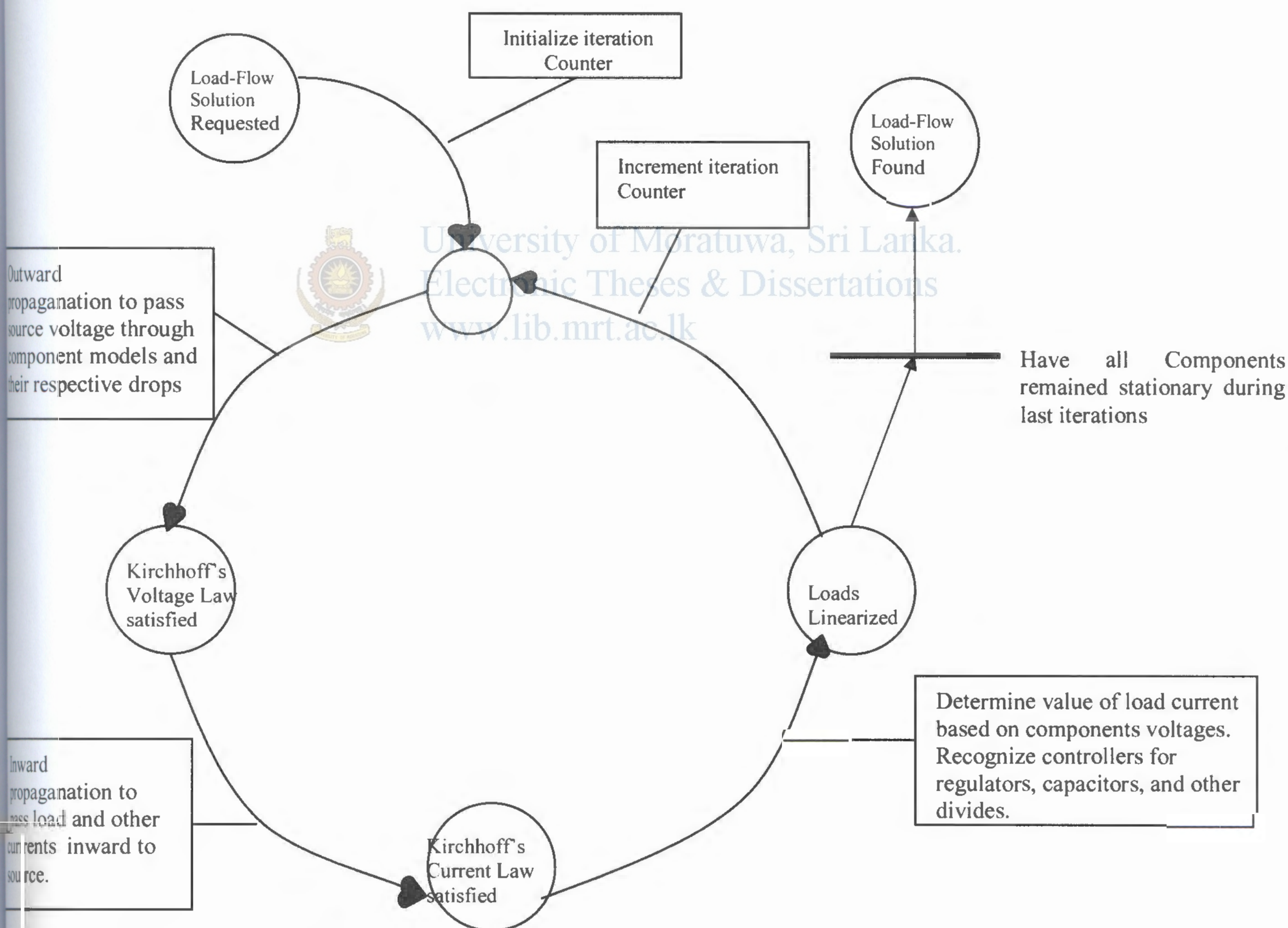

Figure 3.7 (c)-Load –flow diagram

Chapter 4

Collection of Data and Load Forecast

4.1 Collection of Data

This study covers the loss reduction measures for the medium voltage network of Western Province South-I of Ceylon Electricity Board (CEB). The models of years 2009, 2010, 2011, 2012 and 2013 are considered in this study.

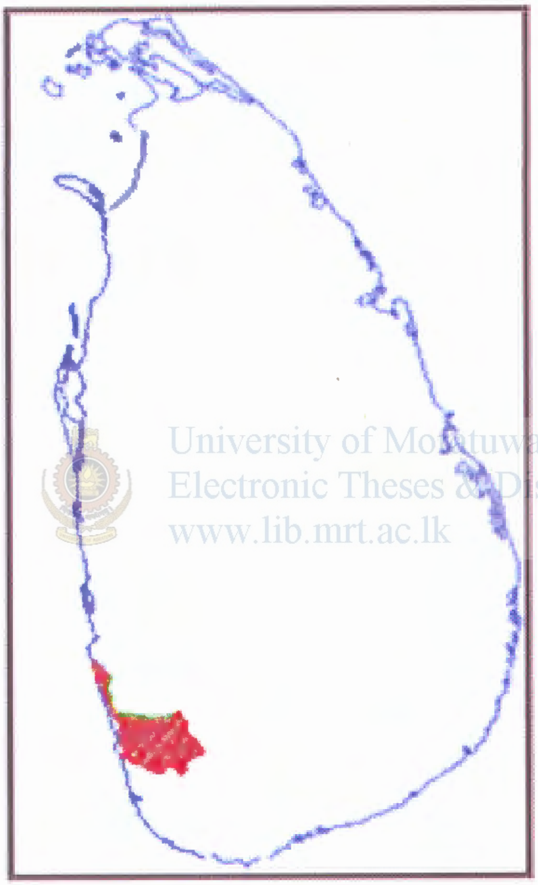

Figure 4.1 – Western Province South –I of CEB

The highlighted section in figure 4.2 shows the Western Province South –I of CEB. It is a part of Western Province of Sri Lanka, which accounts for the highest revenue in the Region 4 of CEB and has the highest consumption per consumer in the country excluding Colombo City. The Western Province South-I consists of three CEB areas, such as Dehiwala, Ratmalana and Kalutara.

Dehiwala area is densely populated with luxury apartment complexes and commercial establishments while Ratmalana area is the traditional industrial base with large scale industries. Kalutara area covers on one side a coastal belt with well developed hotel industry and on the other side developing hilly area. Province has fairly strong medium voltage network with four grid substations with total capacity of 330 MVA, 18 primary substations of total capacity of 200 MVA and 834 km of 33kV/11kV lines. The distribution network operates at 11kV level as well as at 33 kV level.

4.1.1 Western Province South –I, General Data (Year 2008)

- Land area :1230 sq km
- Geographical demarcation : Part of Colombo District (Dehiwala & Ratmalana CEB areas) and Part of Kalutara District (Kalutara CEB area)
- Population :1.4 Million
- Households :395,000
- Electrified Houses :351,000 (including LECO)
- Electrification :88%
- Peak Power demand :177 MW
- Energy Demand :850 GWh/Year
- Average Load Factor :65 %

The MV and the LV Distribution Network details of the Western Province South-I is shown in the table 4.1.1

33 kV Network	**11 kV Network**	**LV Dist. Network**
GSS feeding GSS in WPS I: 4 GSS Capacity of WPS I: 330MVA	PSS feeding province: 18 PSS total capacity:200MVA	33kV/LV substations: 760 11kV/LV substations: 304 Total LT substations: 1064
33 kV lines: 764 km	11kV lines: 70 km	LT Lines: 3,010 km

Table 4.1.1- MV & LV Distribution Network Details of WPS-I

4.1.2 Western Province South-I, MV Distribution Network (Geographical)

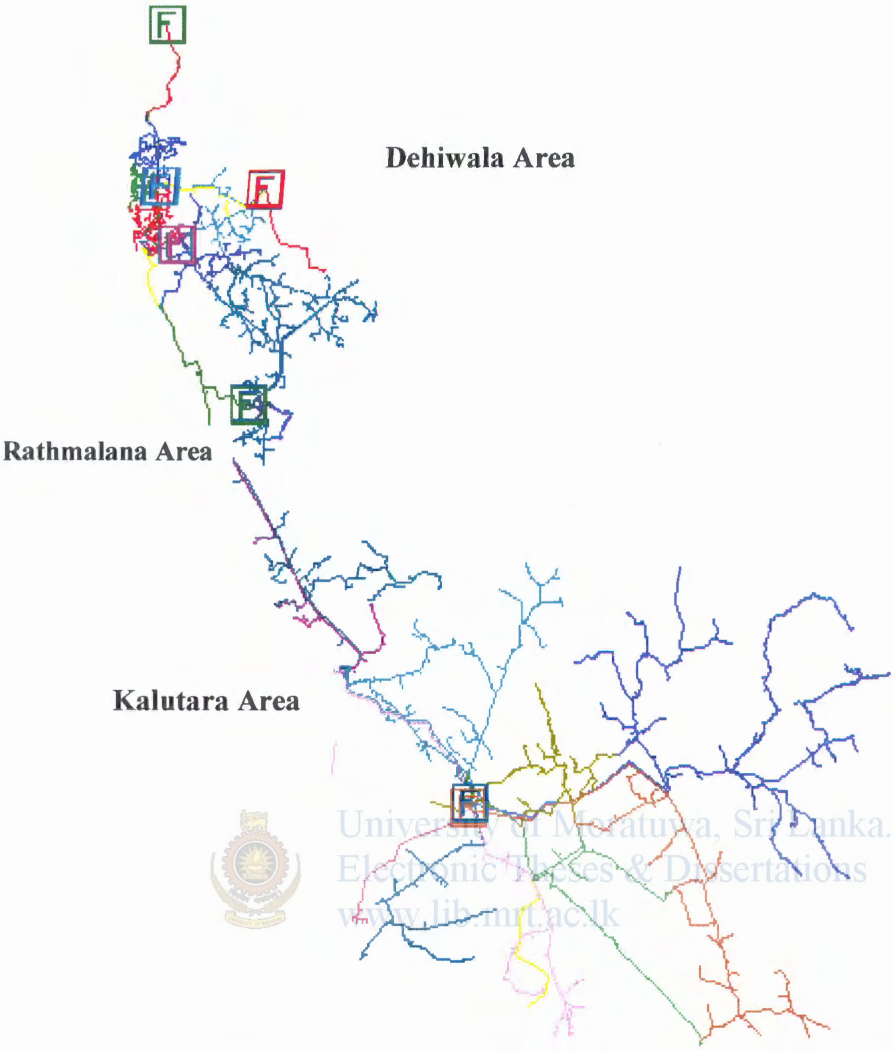

Figure 4.1.2 (a) Western Province South-I, MV Distribution Network (Geographical)

The names and capacities of grid substations in Western Province South – I are:

Grid Substation	Capacity in MVA
Mathugama	90
Panadura	90
Ratmalasna	90
Dehiwala	60
Total Capacity	**330**

Table 4.1.2. (a) – Western Province South-I Grid Substations and the Capacities.

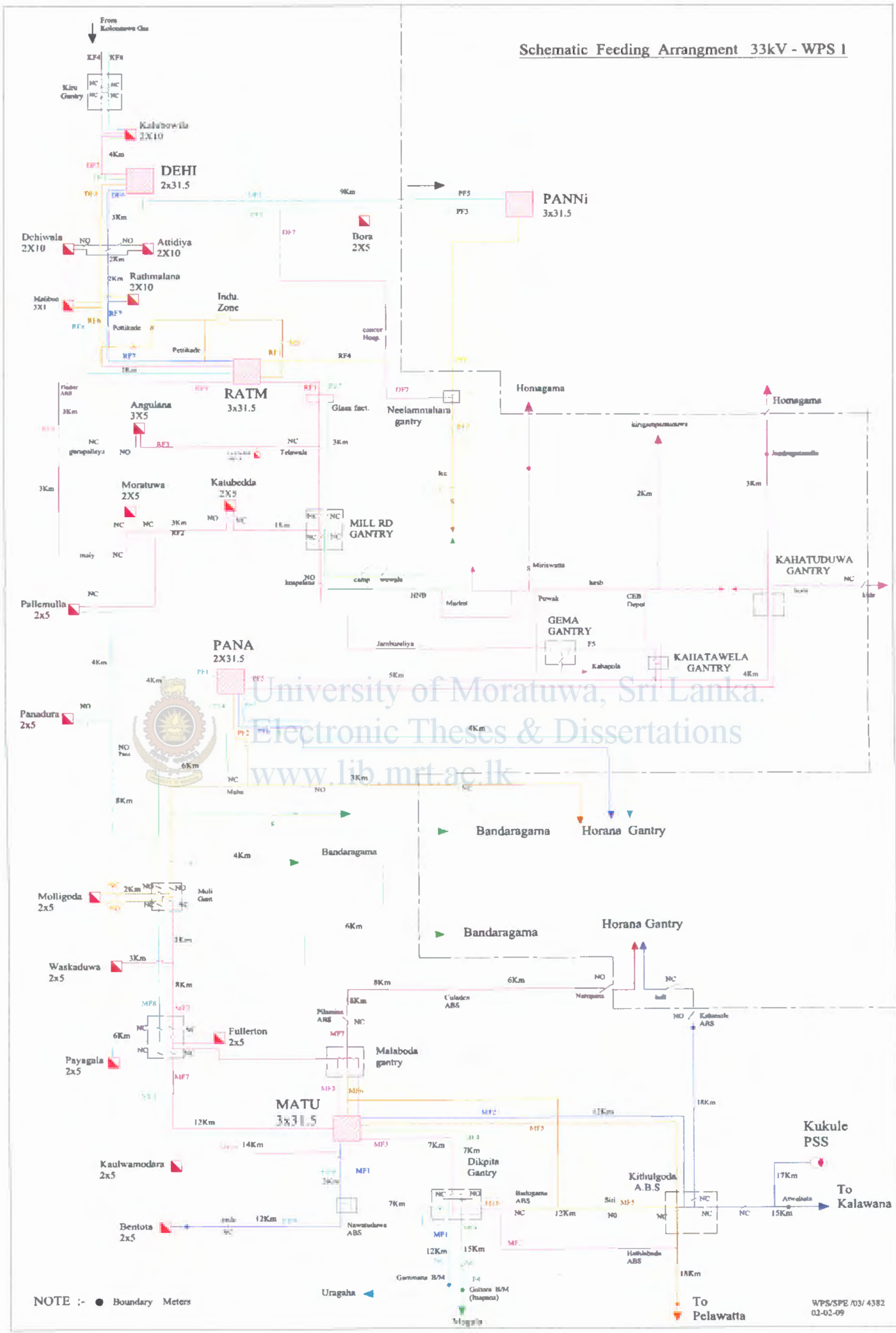

Figure: 4.1.2.(b) Schematic Diagram of Western Province South I

The power demand and energy sales figures of Western Province South-I has been shown in table 4.1.2.(b)

Area	No. of Consumers	Power Demand (MW)	Energy Sales GWh/Yr -2008			
			Retail	Bulk	LECO	Total
Dehiwala	41,000	25.7	94	37	-	131
Ratmalana	77,100	68.3	102	134	157	392
Kalutara	95,790	82.8	74	25	227	326
Total	213,890	176.8	270	196	384	850

Table 4.1.2.(b) Power Demand and Energy Sales Figures of Western Province South-I

4.1.3 Present Status of the MV Network

The load flow analysis study conducted on the MV system models simulated, using the SynerGEE Electric computer software has shown the peak readings as shown below

- Peak power demand (MW) : 190.6
- Peak power loss (MW) : 5.7
- Peak power loss % : 3.0
- Energy demand (GWh/Year) : 916.4
- Energy loss (GWh/Year) : 18.2
- *Energy loss % : 2.0*

Load flow analysis of the MV network model shows heavy voltage drops at curtain areas of the network particularly during peak hours. Table 4.2.2.2 shows some of the areas being affected by voltage drops. The voltages given in the table have been computed assuming 100% of voltage at the 33 kV bus bar of grid substations. Many voltage drops in Kalutara area shall be improved when the new grid substation at Ambalangoda is energized and put into service with its due share of the load.

Area	Location	Voltage %
Dehiwala	William junction	94
Kalutara	Payagala PSS	94
Kalutara	Magala boundary	93
Kalutara	Pelawatte boundary	93
Kalutara	Uragaha boundary	95

Table 4.1.3 MV Voltage Drops at Different Locations

4.2 Load Forecast

Load forecast is the primary factor for formulation of network reinforcement proposals. Electricity demand of any society, if not in a huge recession, continues to grow as a result of changing or improving of human needs. It's growing demand to be assessed in a reasonably accurate manner so that necessary provisions could be taken to meet such demands. This is one of the most complicated tasks that the planners have to handle because exact prediction of future is rather impossible. This becomes further difficult when the country's economy is subjected to sudden changes. The exercise of assessing the growing pattern of the customer demand is termed as Load forecast. In this study Time trend analysis method is used for load forecast. It is important that the load forecast should be reasonably accurate and the growth rates applied are realistic. The load forecast is the most sensitive area of this study [2].

In the absence of network peak power data for the previous years, the energy sales data are normally used for determination of the time trend growth. The growth rates of power and energy are considered same on the assumption that the variation of system load factor is very small. Sales data of past ten years is considered for calculation of growth rates.

Load forecast have been carried out dividing the loads into two categories. Domestic and commercial tariffs in one category and the industrial tariff in the other. The reason for this division is that the two categories show different growing patterns in the past.

Western Province South –I has been divided into two geographic zones for calculation of growing trends of loads because the growing patterns of different zones are different. Kalutara, Mathugama, Agalawatte areas are in one zone and Moratuwa, Ratmalana, Mt Lavinia, Dehiwala are in another zone.

4.2.1 Regression Analysis

Regression is the study of relationships among variables, a principal purpose of which is to predict the one variable from known or assumed values of other variables related to it. A regression using only one predictor is called a simple regression. In this study we deal with simple regression [21, 23].

Year	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Demand(GWh/Yr)	256	286	317	342	367	422	457	513	550	570

Table 4.2.1.(a) – Past ten year Energy Demand data – Domestic/Commercial Sector

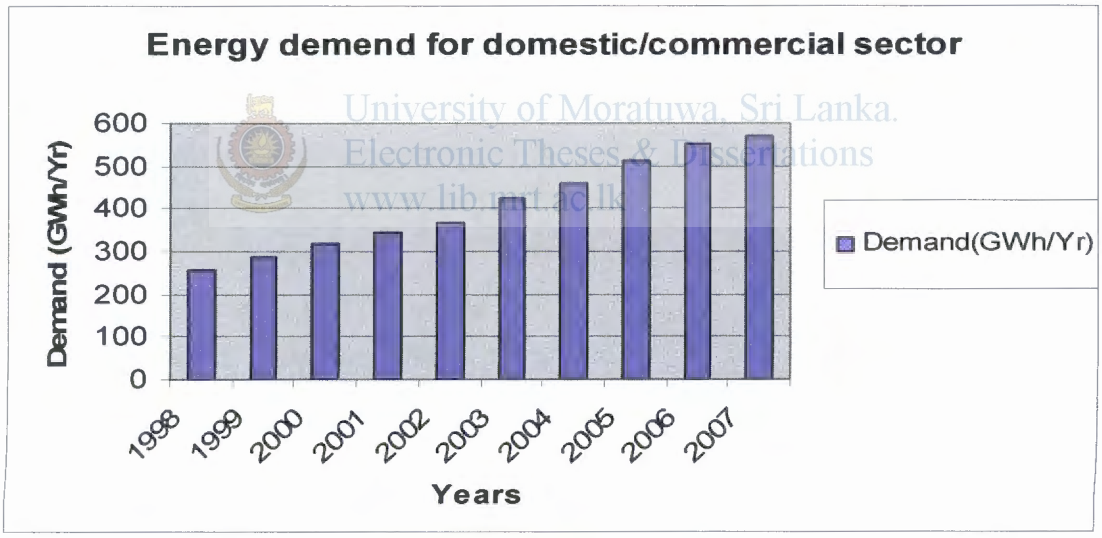

Figure 4.2.1. (a) – Past ten year Energy Demand data – Domestic/Commercial Sector

Regression Analysis Growth

Dehiwala & Ratmalana Areas – 5.0 %

Kalutara Area - 11.0 %

Estimated Growth for the first five years:

Dehiwala & Ratmalana Areas – 5.0 %

Kalutara Area - 11.0 %

Year	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Demand (GWh/Yr)	185.2	195.2	216.2	207.2	208.5	228.5	242.5	263	275.7	282.2

Table 4.2.1.(b) Past ten year Energy Demand data – Industrial Sector

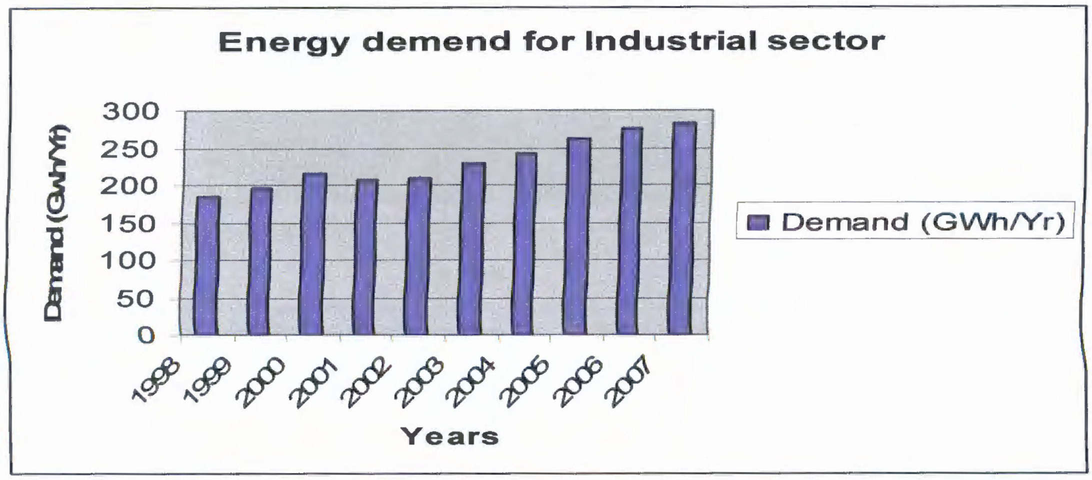

Figure 4.2.1.(b) Past ten year Energy Demand data – Industrial Sector

Regression Analysis Growth

Dehiwala & Ratmalana Areas – 3.0 %

Kalutara Area - 11.0 %

Estimated Growth for the first five years:

Dehiwala & Ratmalana Areas – 3.0 %

Kalutara Area - 11.0 %

From the regression analysis it is found that the load growth at Dehiwala and Ratmalana, for Domestic and Commercial sectors are 5% and the Industrial sector is 3%, where as the Kalutara area's growth rate is 11% in all three categories.

4.2.2 Forecasted Energy Demand

Energy demand forecast was derived using the SynerGEE software based on the growth rate of each category of consumers. The forecasted energy demands are given in the table 4.4.

Year	2009	2010	2011	2012	2013
Energy Demand (GWh/Yr	916	1022	1109	1203	1311

Table 4.2.2 –Forecasted Energy Demand

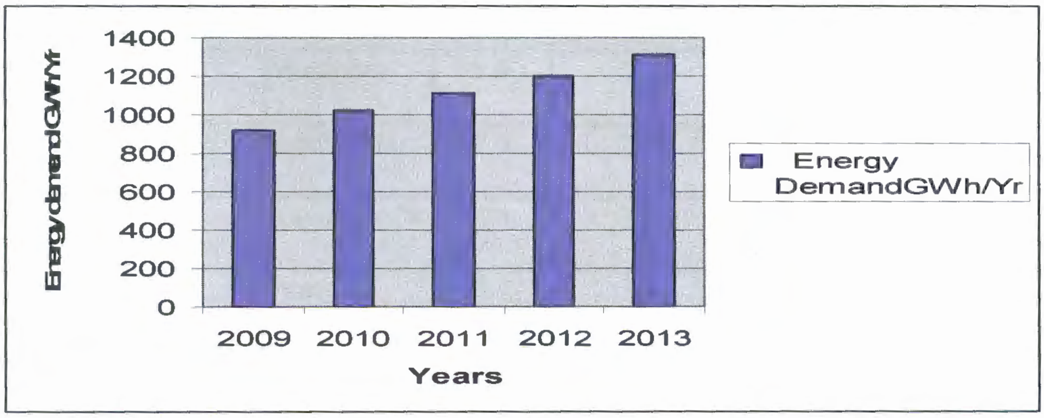

Figure 4.2.2 – Forecasted Energy Demand

4.2.3 Forecasted Peak Power Demand

Peak power demand forecast was derived using the SynerGEE software based on the growth rate of each category of consumers. The forecasted peak power demands are given in the table 4.3.4

Year	2009	2010	2011	2012	2013
Peak Power Demand (GWh/Yr	190.6	210.1	226.1	245.1	266.1

Table 4.2.3 –Forecasted Peak Power Demand

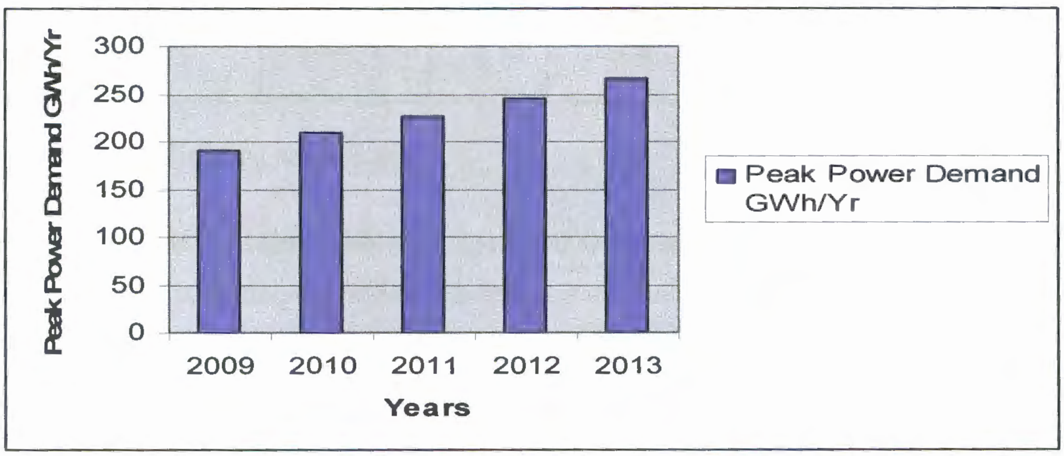

Figure 4.2.3 –Forecasted Peak Power Demand

4.2.4 Existing Major Loads and Assumed Growth Percentages

Existing major loads of the network with assumed growth rates are given in table 4.2.4

Consumer	Location	Max Demand (MVA)	Energy Demand GWh/month	Load Factor %	Assumed Growth %
Moratuwa PSS - LECO	Moratuwa	8.9	3.1	48	3
Katubedda PSS - LECO	Katubedda	7.0	2.8	56	3
Angulana PSS - LECO	Angulana	8.4	2.8	46	3
Panadura PSS - LECO	Panadura	10.0	3.5	49	11
Pallimulla PSS - LECO	Pallimulla	7.3	2.7	51	11
Molligoda PSS - LECO	Molligoda	4.2	1.7	56	11
Waskaduwa PSS - LECO	Kalutara North	4.3	1.4	45	11
Fullrton PSS - LECO	Nagoda, Kalutara	7.9	3.1	55	11
Payagala PSS - LECO	Payagala	7.6	2.6	48	11
Kaluwamodara PSS - LECO	Kaluwamodara	6.7	2.7	56	11
Bentota PSS	Bentota	2.8	0.6	30	11
Maliban	Ratmalana	2.9	0.9	47	3
Asbestos Cement Industries	Ratmalana	1.9	0.8	61	3
ACL Cables Ltd	Piliyandala	1.1	0.4	47	3
Richard Pieris Rubber Compound	Maharagama	5.7	1.6	41	3

Table 4.2.4 – Existing major loads

4.2.5 Anticipated Major loads with Assumed Growth Percentages

Power related projects proposed by the Ministry of National Planning, Industrial estates proposed by the Ministry of Industries, BOI and UDA and other expected major loads are considered as anticipated major loads.

Consumer	Location	Max. Demand (MW)	Anticipated Year	Assumed Initial Load (MW)	Assumed growth %
L. H. Piyasena	Dehiwala	1.6	2010	1.0	3
Industrial Estate Matugama	Matugama	1.0	2010	1.0	11
Industrial Estate Fullerton	Nagoda	2.0	2010	2.0	11
Zeus Housing Complex	Mt. Lavinia	1.5	2011	1.0	3
Buddhist Centre	Kesbewa	1.0	2011	0.5	3

Table 4.2.5 –Anticipated major loads with assumed growth rates.

Chapter 5

MV Network Analysis and Reinforcement Proposals

5.1 Planning Criteria

During the analysis following CEB planning criteria will be adopted in order to obtain the optimal reinforcements proposals.

Transformers of Grid substations and Primary Substations	
	Firm Capacity to meet n-1 criteria with 25% overloading for remaining transformers
Overhead Lines	
	Voltage +/_ 6% of the nominal voltage
	Loading 70% of the thermal rating
Underground Lines	
	Voltage +/_ 6% of the nominal voltage
	Loading 90% of the thermal rating

5.2 Analysis

The growth rates calculated from time trend analysis are input to the software model of the network together with the anticipated future major loads.

The software model calculates the forecasted annual network energy and peak power demand and technical losses taking into account the geographic locations of various loads and growing trends.

For economic optimization of conductors, some technical factors are to be considered. Thermal limit due to nominal current circulation, thermal limit due to short circuit calculation, voltage drop, cross sectional area etc. The economic cross sectional area that minimizes the total cost of installation.

The analysis allows to:

- Run a voltage drop analysis as a day-type or as a time-range simulation.
- Use the historical data validates the network model.

- Accurately model the loading conditions (load curves) at any moment in time at strategic points on the networks.
- Identify off-peak overloads and abnormal voltage conditions that often go undetected using traditional peak condition system analysis.
- Evaluate actual kW using customer consumption profiles and customer type load curves.
- Verify device settings adjustments such as voltage regulators, switching capacitors and load tap changers over a period of time and loading.
- Verify capacitor placement recommendations over a period of time and loading.

5.2.1 Charts and Reports

Using the load flow with profiles analysis, can generate several reports and charts based on monitored device and summary networks results. Also can generate reports and charts such as [22]:

- Network summary reporting total system losses, peak voltage and peak power
- Abnormal conditions reporting overloads and abnormal voltage conditions in duration and percentage of a period, such as the number of hours/days that equipment has been overloaded.
- Tabular reports with customized values for monitored devices.
- Load duration curves for a distribution transformer or any monitored devices displaying the loading of the device in percentage.

Analysis has been carried out to the network models of the years 2010, 2011, 2012 and 2013. The following figure shows a part of a SynerGEE software applied model during an analysis. The figure 5.2.1 indicates the results of the highlighted section during the load flow of a network model.

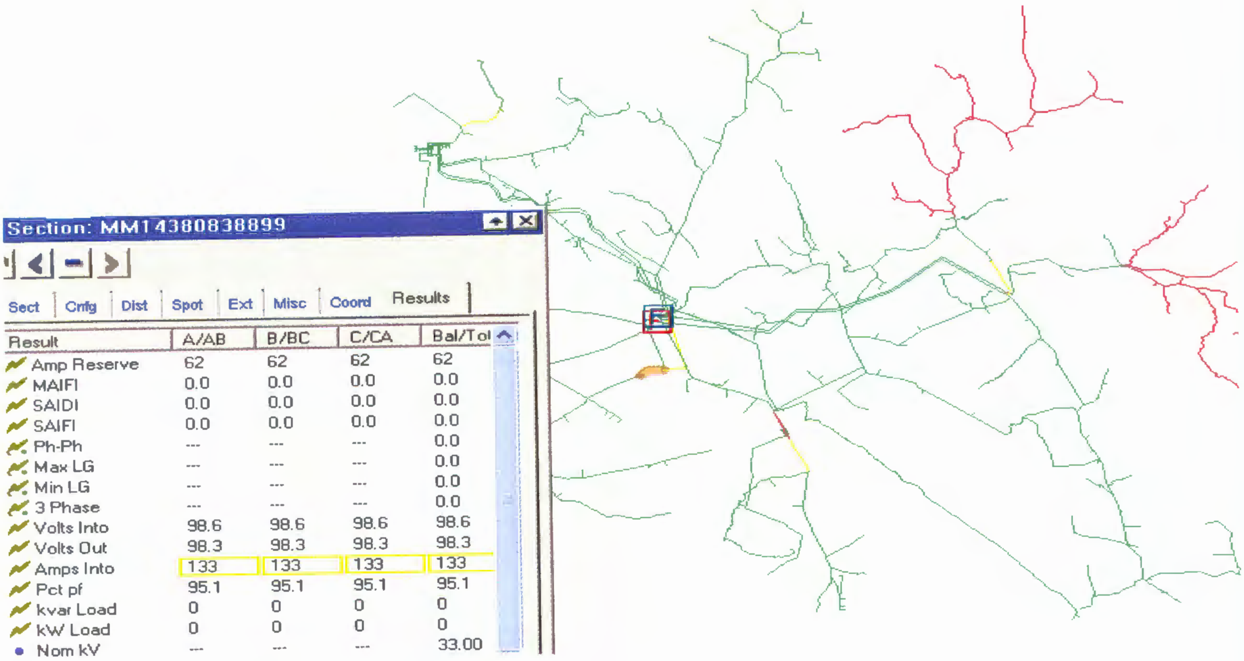

Figure 5.2.1 Load flow results

5.3 Analysis of Year 2010 Network and the Proposed Reinforcements

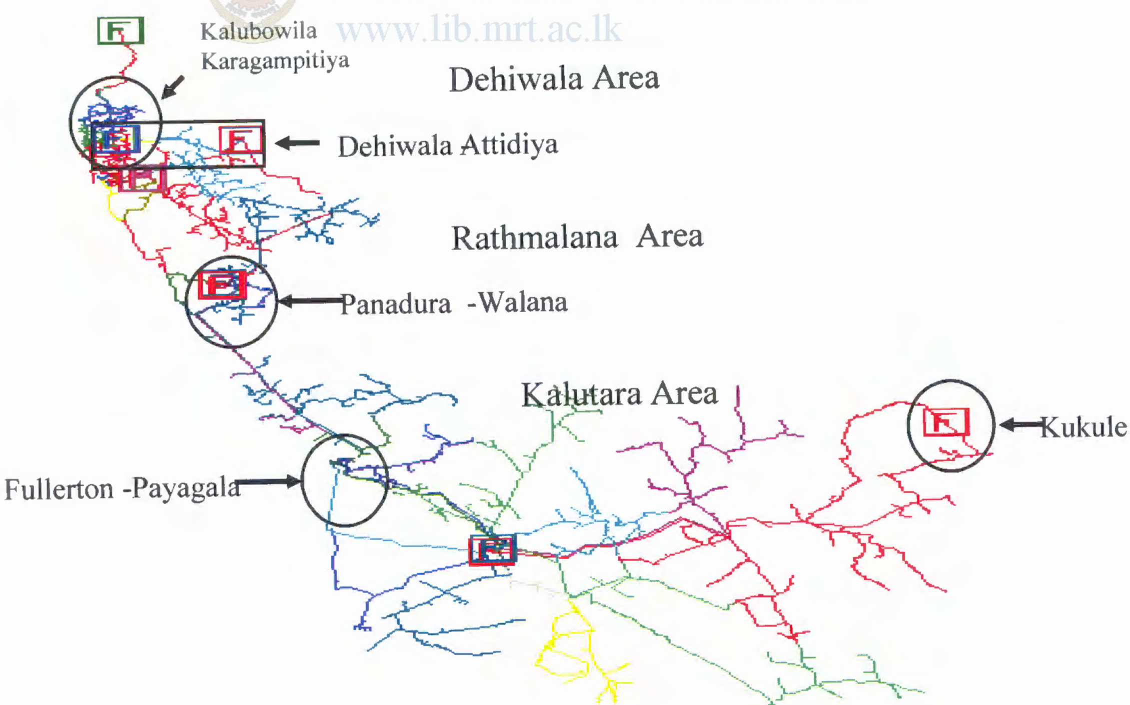

Figure: 5.3- Year 2010 network where highlighted locations require reinforcements

Year 2010 network's model has been analyzed by using SynerGEE software. The table 5.3 indicates the problems in the existing system during the analysis and the optimal reinforcement proposals required overcoming the problem.

Problem	Proposed Action
Overloading of Lynx SC line from Panadura GSS to Walana	Augmenting (4.5 km) Lynx SC to Lynx DC
Low Voltage experienced in Fullerton & Payagala PSS	Rearrangement of the network by transferring part of the load on Matugama F7 to Matugama F3
Racoon SC line from Kalubowila PSS to Karagampitiya loaded more than 70%	Transfer loads on section from K056 to K058 to Dehiwala PSS feeder 1 by closing switch at K056 and opening from K058
Dehiwala PSS 11 kV F2 loaded more than 70%	Sections from M058 to M077 transferred to Attidiya PSS
33 kV Racoon line from Attidiya PSS to Dehiwala PSS loaded more than 70%	33 kV Underground cable of 240 sqmm between the two PSS. Because there is a proposal to have U/G system in Dehiwala
Low Voltage at the ends of Mathugama feeders around Kukule and Athweltota	New 132/33 kV, 10 MVA transformer to be installed at Kukule switchyard

Table 5.3 Problems and proposals for year 2010.

5.3.1 Comparison of Technical Losses for the Year 2010 (in kW)

The table shows the figures obtained for the existing and proposed models line, transformer and total losses and the loads of Grid substations.

EXISTING SYSTEM **PROPOSED SYSTEM**

GSS	Line	T/F	Total	Load	%		Line	T/F	Total	Load	%
Dehiwala	650	101	751	32650	2.30		449	94	543	31821	1.71
Matugama	3740	197	3937	62379	6.31		1420	114	1534	54900	2.79
Panadura	2482	249	2731	72939	3.74		1714	145	1859	72465	2.57
Ratmalana	936	119	1055	42538	2.48		653	110	763	40894	1.87
Kukule	0	0	0	0	0		73	37	110	5007	2.20
Total	7808	666	8474	210506	4.03		4309	500	4809	205087	2.34

Table 5.3.1 Comparison of Technical Losses for the Year 2010

It is to be noted that % loss has been reduced from 4.03 to 2.34 by introducing the reinforcement proposals given in the table 5.3.

5.4 Analysis of Year 2011 Network and the Proposed Reinforcements

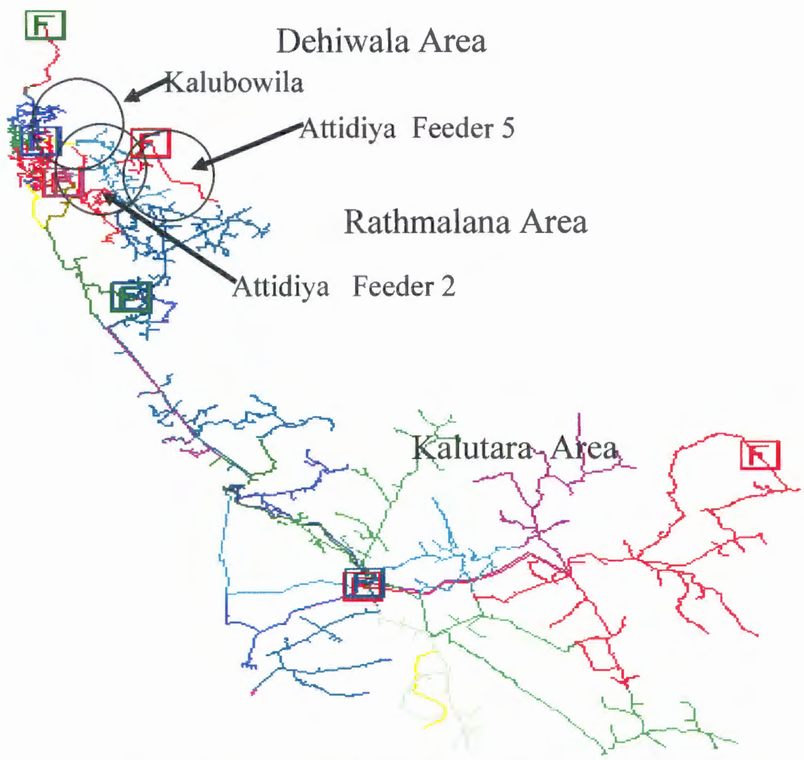

Figure: 5.4- Year 2011 network where highlighted locations require reinforcements

Similarly, Year 2011 network's model has been analyzed by using SynerGEE software. The table 5.4 indicates the problems in the existing system during the analysis and the optimal reinforcement proposals required overcoming the problem.

Problem	Proposed Action
Attidiya PSS Feeder 2 Racoon SC loaded more than 70% upto M011	Re-conductor to Lynx SC approximately 1.5 km line from PSS to Galle Road (near M113)
Attidiya PSS feeder 5 Racoon line towards Attidiya loaded over 70%	Convert 1 km length of Racoon line from Attidiya PSS to Lynx
Racoon DC line from Kalubowila PSS to Kohuwala gantry loaded more than 70%	Conversion of this section to Lynx DC

Table 5.4 Problems and proposals for year 2011.

5.5 Analysis of Year 2012 Network and the Proposed Reinforcements

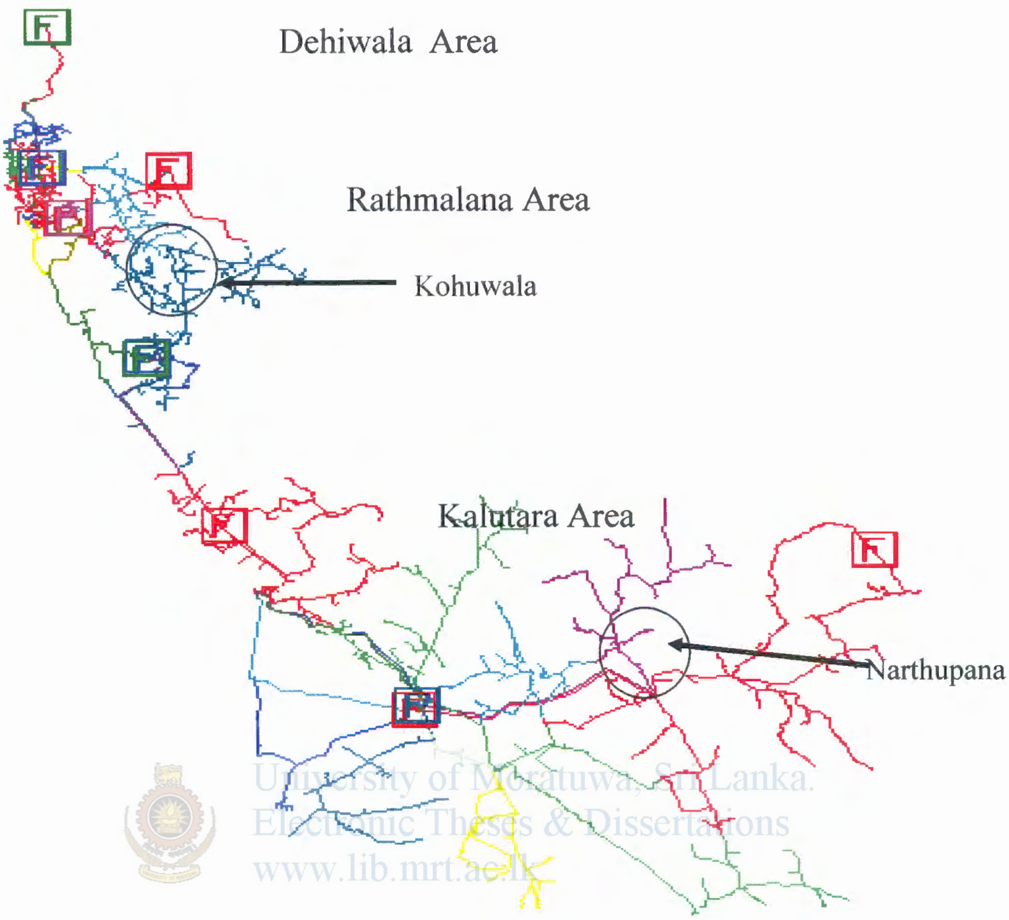

Figure: 5.5- Year 2012 network with highlighted locations for reinforcement

Similarly, Year 2012 network's model has been analyzed by using SynerGEE software. The table 5.5 indicates the problems in the existing system during the analysis and the optimal reinforcement proposals required overcoming the problem.

Problem	Proposed Action
Low Voltage around Narthupana area	Change the feeding arrangement at Kithulgoda Gantry so that the Lynx DC incoming lines are as far as possible loaded equally

Line capacity of Racoon SC line between Kahawala Gantry and Gama Gantry above 70%	Re-conductor Racoon Sc to Lynx SC (3.5 km)

Table 5.5 Problems and proposals for year 2012

5.6 Analysis of Year 2013 Network and the Proposed Reinforcements.

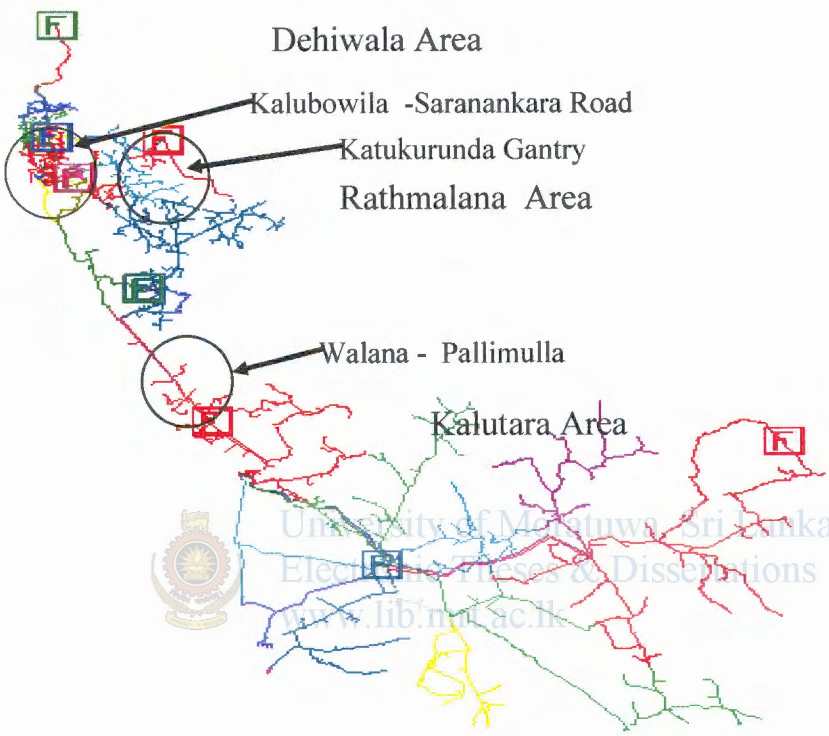

Figure: 5.6- Year 2013 network with highlighted locations for reinforcement

Year 2013 network's model has been analyzed by using SynerGEE software. The table 5.6 indicates the problems in the existing system during the analysis and the optimal reinforcement proposals required overcoming the problem.

Problem	Proposed Action
Attidiya PSS 11kv feeder 3 towards Katukurunda Gantry line capacity exceeds 70%	Transfer loads from B069 to M103 & M126 to Attidiya feeder 2

Kalubowila PSS 11kV feeder 4 towards Saranankara Road line capacity exceeds 70%	To be re-conductored to Lynx SC
Lynx SC line from Walana to Pallimulla PSS of 1.0 km loaded more than 70%	To be re-conductored to Lynx SC line

Table 5.6 Problems and proposals for year 2013

5.7 Percentage Voltage at Selected Locations in the Proposed Network

In order to check the voltage profiles, percentage voltages were checked at the ends of the proposed networks in each year. The results are as follows.

	2009	2010	2011	2012	2013
Piliyandala	98	98	98	97	97
Dehiwala	98	98	98	97	97
Atweltota	97	96	99	98	98
Pelawatte	94	96	95	95	94
Agalawatte	98	97	96	96	95
Kalumale	97	97	96	96	95

Table 5.7 -Percentage Voltage at Selected Locations

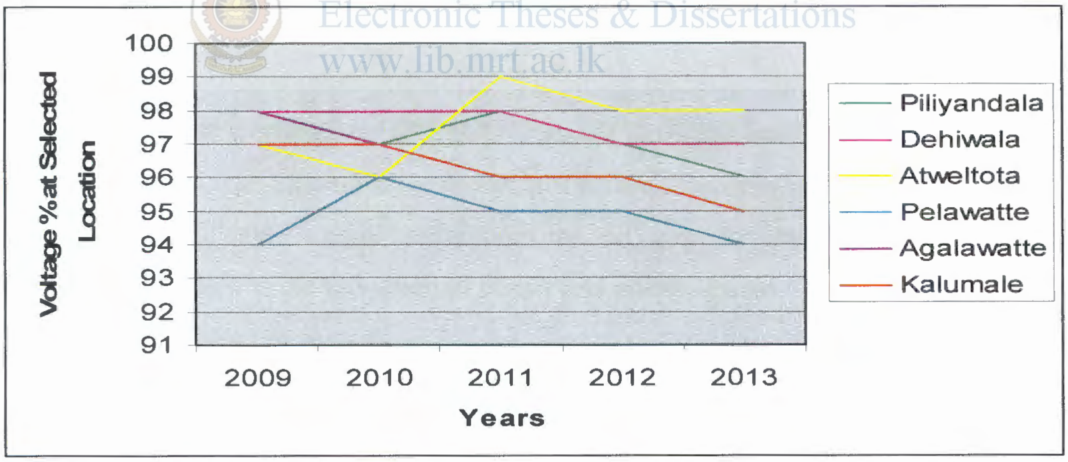

Figure 5.7- Percentage Voltage at Selected Locations

Voltage levels in the network can be considered as a rough measure access availability of network capacity. Table 5.7 and figure 5.7 indicate expected voltage levels in the network at different locations assuming timely implementation of proposed network reinforcements. Locations with voltage below 94% mean that those locations experiences low voltage problems.

For all the cases. Benefit/Cost Ratio was less than 1. Therefore it is not economically feasible to construct 400kV transmission network configuration with compare to 220kV transmission network configuration.

Chapter 6

Economic Evaluation

The implementation of network reinforcement proposals incurs substantial costs to the utility. With a view to lessen the burden on the utility, the network reinforcement proposals have been spread throughout the planning period in such a manner that those are implemented exactly as and when necessary. This in turn stagger the investments and helps smooth cash flow.

Network reinforcements improve the safety and reliability of the network and quality of power. Further, it enhances the capacity of the network, thus improving the distribution requirement to satisfy the demand for electricity. All those improvements are contributing to higher productivity, better living standards and customer satisfaction. Therefore the cost involved shall be viewed as a highly beneficial investment.

Economic evaluation has been carried out to assess the costs and benefits of the proposed investment. Costs have been estimated using the CEB standard rates and the individual rates of components purchased/installed recently. Network reinforcement costs required for enhancement of LECO demands have also been added for the costs. Benefits are two folds; quantifiable and unquantifiable. Benefits from improvement of network voltage and supply reliability are difficult to quantify. The readily quantifiable benefit is the reduction of power and energy losses. Only this benefit has been considered for the analysis.

In fact the plant and equipment (grid substations, MV tower lines etc) proposed to be installed have longer life spans for beyond the current planning period. For a proper analysis of benefits, the life cycle costs and benefits should be also considered. However in this study this matter has not been considered.

The implementation of the reinforcement proposals will reduce the required power and the energy of the proposed networks. These figures have been obtained by load flow studies.

6.1 Power Loss Reduction and Savings

Year	**2009**	**2010**	**2011**	**2012**	**2013**
Power Demand (MW)					
Existing Network	190.6	210.1	226.6	245.6	266.1
Proposed Network	190.6	205.1	222.4	240.6	259.2
Power Loss (MW)					
Existing Network	5.7	8.4	11.1	13.5	16.5
Proposed Network	5.7	4.7	5.6	5.3	6.2
Power Savings (MW)	0	3.7	5.5	8.2	10.3
Power Loss %					
Existing Network	3.0	4.0	4.9	5.5	6.2
Proposed Network	3.0	2.3	2.5	2.2	2.4
Cost of Power Savings (MRs)	0	73.9	109.8	163.7	205.6

Table - 6.1 Power Loss Reduction and Savings

In the table 6.1, Cost of Power saving is calculated using CEB's capacity cost Rs 19,961.00 per kW.

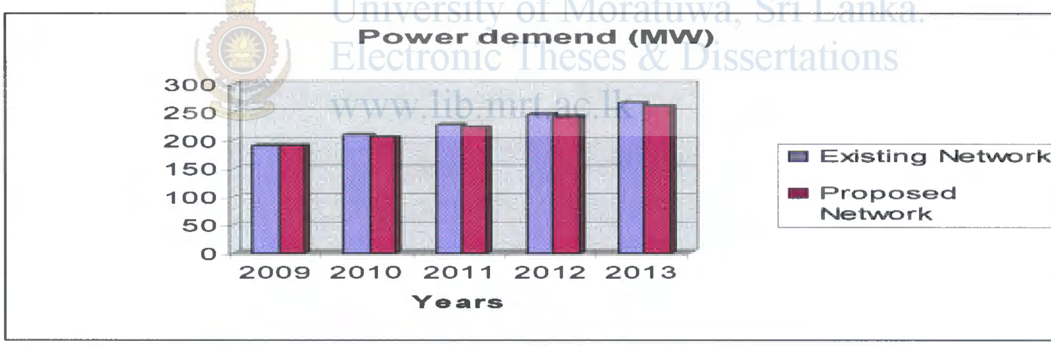

Figure 6.1(a) Power Demand Vs Years

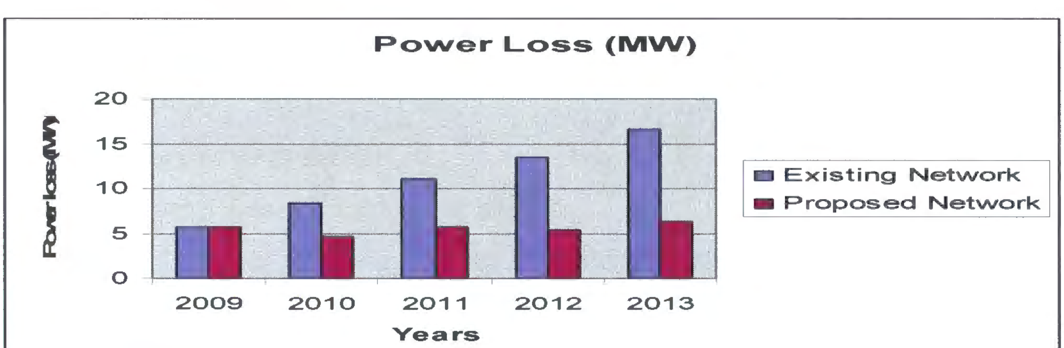

Figure 6.1(b) Power Loss Vs Year

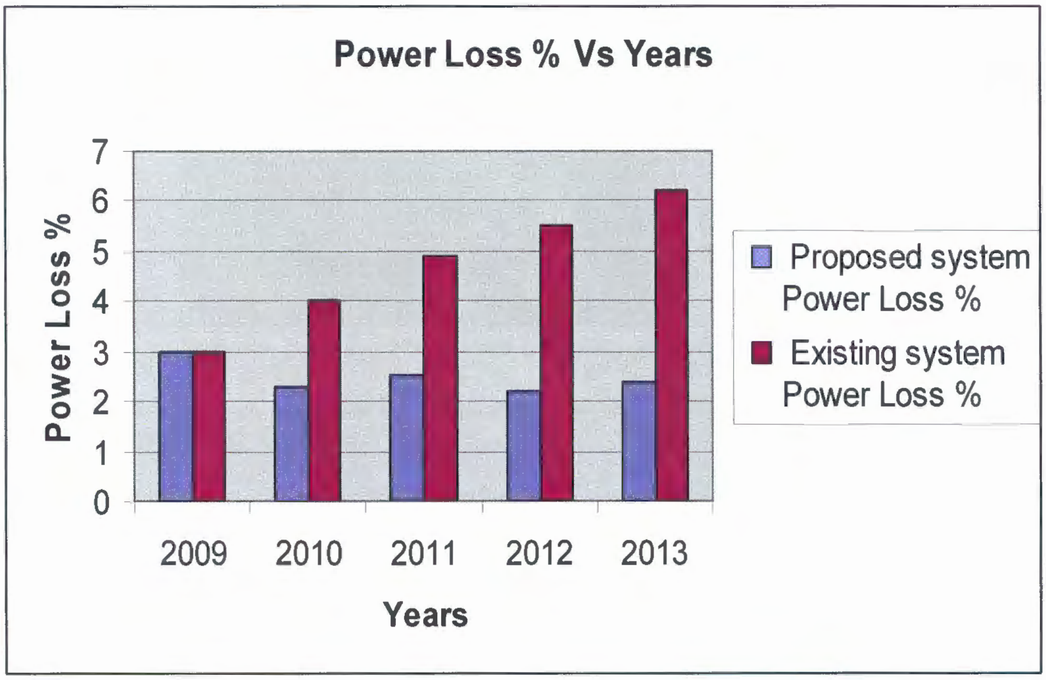

Figure 6.1 (c) Peak Power Loss % Vs Years

6.2 Energy Loss Reduction and Savings

Year	**2009**	**2010**	**2011**	**2012**	**2013**
Energy Demand (GWh/Year)					
Existing Network	916.4	1022.1	1108.9	1203.3	1310.7
Proposed Network	916.4	1018.3	1107.3	1201.1	1304.1
Energy Loss (GWh/Year)					
Existing Network	18.2	22.4	26.6	31.9	38.2
Proposed Network	18.2	12.1	13.8	15.0	16.0
Energy Savings (GWh/Year)	0	10.3	12.8	16.9	22.2
Enegy Loss %					
Existing Network	2.0	2.2	2.4	2.7	2.9
Proposed Network	2.0	1.2	1.2	1.2	1.2
Cost of Energy Savings (MRs)	0	71.4	88.7	117.1	153.9

Table - 6.2 Energy Loss Reduction and Savings

In the table 6.2, Cost of Energy saving is calculated using CEB's energy cost Rs 6.93/kWh.

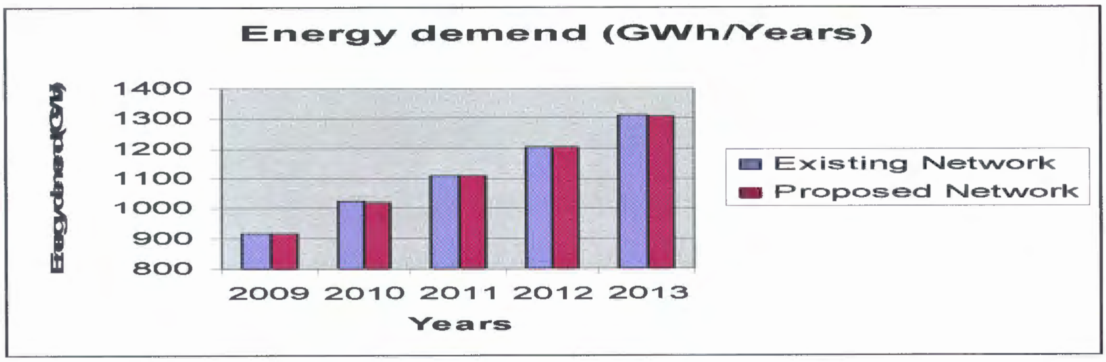

Figure 6.2(a) Energy Demand Vs Years

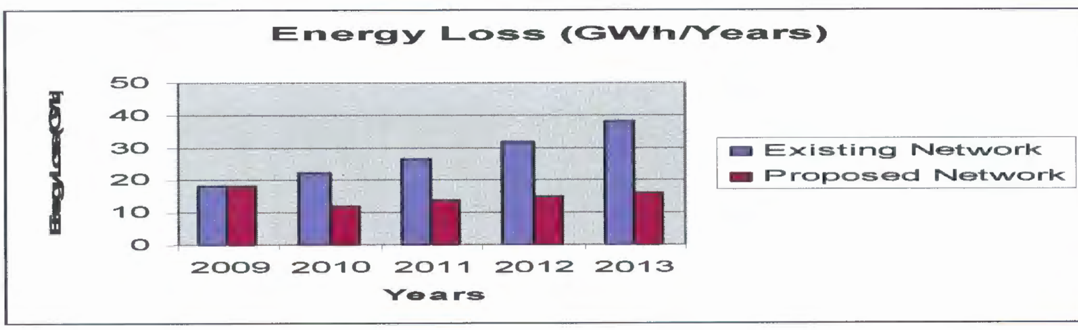

Figure 6.2 (b) Energy Loss Vs Years

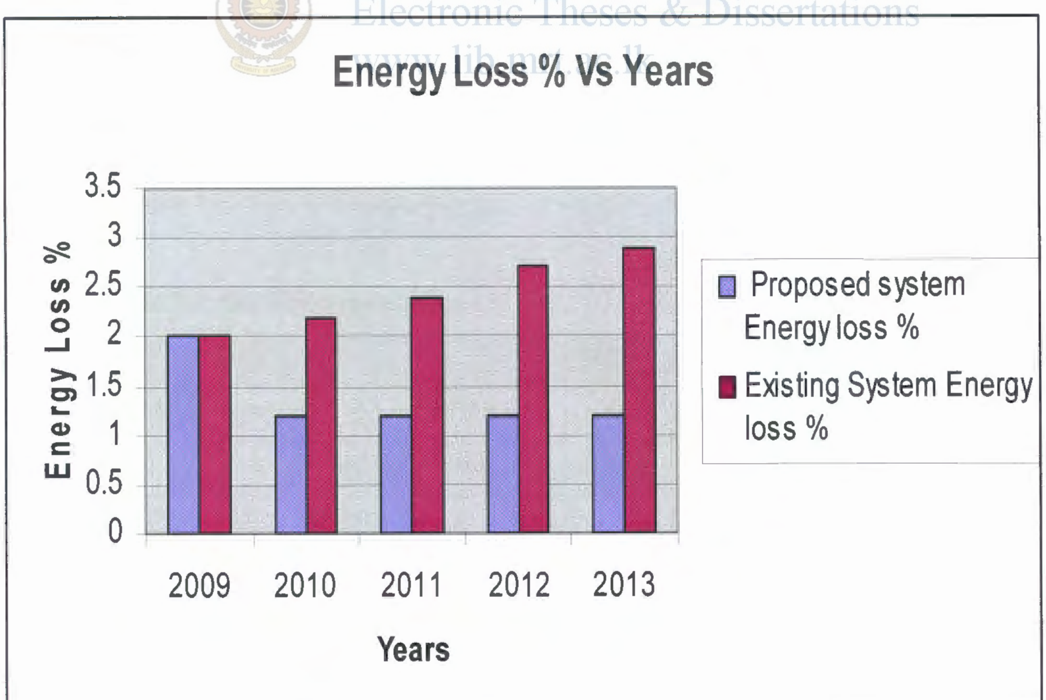

Figure 6.2 (c) Energy Loss % Vs Years

6.3 Overall Scope of Implementation

The total implementation of the reinforcement proposals are given in the table 6.3

No	Item	2010	2011	2012	2013	Total
1	New GSS (Nos)	01	-	-	-	01
2	New 33 kV UG cable (km)	05	-	-	-	05
3	Reconductoring Racoon to Lynx SC (km	-	1.5	3.5	5	10
4	Conversion Lynx SC to Lynx DC (km)	4.5	-	-	-	4.5
5	Conversion Racoon DC to Lynx DC (km)	-	4	-	-	4

Table 6.3 Overall Scope of Implementation

6.4 Cost of Implementation

Item	Unit	Cost (Rs)
New Grid Substation (2X 10 MVA)	Nos	160 M
New 33 kV Underground cable line	km	40 M
Reconductoring – Racoon SC to Lynx SC	km	4.5 M
Conversion – Lynx SC to Lynx DC	km	8.0 M
Conversion – Racoon SC to Lynx DC	km	6.0 M
Energy cost	kWh	6.93
Capacity cost (depreciation and interest)	kW	19,961.00
Rate of interest for NPV calculation	10% per annum.	

6.5 Costs for the Implementation (MRs)

	Item	2010	2011	2012	2013	Total
1	New Grid Substation (2X 10 MVA)	160	-	-	-	160
2	New 33 kV Underground cable line	200	-	-	-	200
3	Reconductoring – Racoon SC to Lynx SC	-	6.8	15.8	22.5	45.1
4	Conversion – Lynx SC to Lynx DC	27	-	-	-	27
5	Conversion – Racoon SC to Lynx DC	-	32	-	-	37
	Total	**387**	**38.8**	**15.8**	**22.5**	**464.1**

Table 6.5 Cost for the Implementation (MRs)

6.6 Total Loss Reduction and Savings (MRs)

Year	2009	2010	2011	2012	2013	Total
Cost of Power Savings	0	73.9	109.8	163.7	205.6	553.0
Cost of Energy Savings	0	71.4	88.7	117.1	153.9	431.1
Total Cost of Power & Energy Savings	0	145.3	198.5	280.8	359.5	984.1
Discounted Cost of Savings	0	132.1	164.1	211.0	245.5	752.7
Cost of proposed reinforcement @ current prices	0	387	38.8	15.8	22.5	464.1

Table 6.6 Total Loss Reduction and Savings

6.7 Calculation of Benefit / Cost Ratio

Expected quantifiable benefit from the implementation of the proposals = Rs 752.7 M

Estimated cost for the proposed reinforcement @ current prices = Rs 464.1 M

Therefore benefit/ cost ratio = 752.7/464.1 = 1.62

Therefore this project is viable. In fact the plant and equipment proposed to be installed have longer life spans for beyond the current planning period. For a proper analysis of benefits the life cycle costs and benefits should be also considered. However in this study this matter has not been considered.

6.8 Unquantifiable Benefits

Upgrading the network capacity is achieved by reinforcing the network with new grid substations, MV lines etc., so that the network shall be able to supply the increased power demand, maintaining the proper voltage levels at minimum losses. Implementation of network reinforcement proposals of this study would ensure adequate level of upgrading of the overall network capacity to the future demand effectively and efficiently.

According to this study for 2009 -2013, within Western Province South-I, the overall network capacity will be upgraded to handle a demand of 260 MW in year 2013 from the present level of 190 MW (in the year 2009).

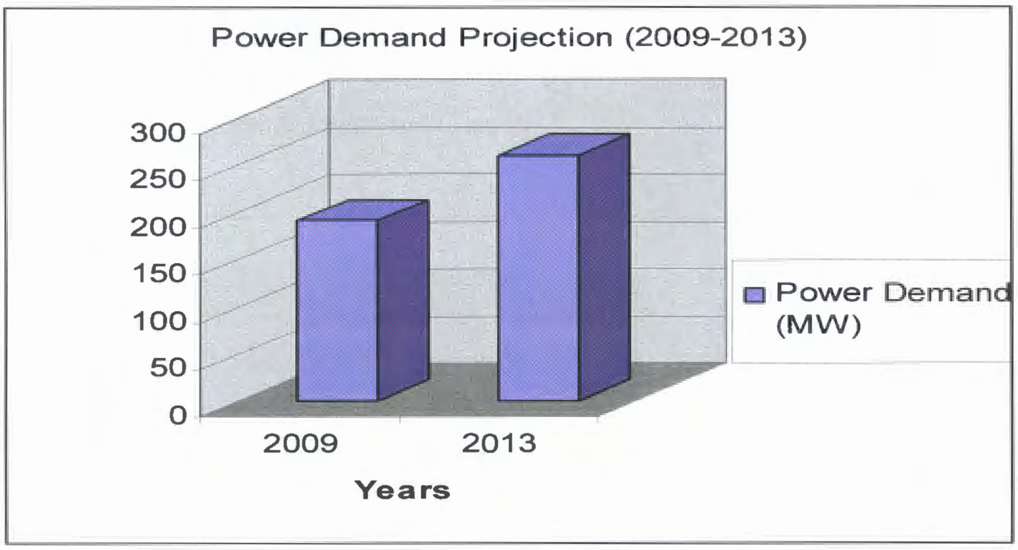

Figure 6.8(a) Power demand Projections

It is important to ensure adequate capacity is available at each individual locations of the network. Voltage levels in the network can be considered as a rough measure access availability of network capacity.

Voltage at some locations cannot be improved to accepted levels owing to the fact that those are far away from the grid substation. For such locations specific solutions such as voltage compensation techniques (E.g.: voltage regulators, feeding from primary substations with automatic tap changers) should be considered in addition to implementation of proposals given in this study.

Other such projects include installing capacitors on MV lines. Capacitor installation is very cost-effective. It is economical for to correct MV network power factor close to unity. This does not reduce losses very significantly, however, would be a minor element in the total loss reduction programme.

Based on the load forecast and grid substations enhancement proposals, system demand and available grid capacity compare as follows [table 6.8 and figure 6.8(b)].

Year	2009	2010	2011	2012	2013
Power Demand (MW)	190.6	205.1	222.4	240.6	259.2
Total GSS Capacity (MVA)	330	350	350	350	350

Table 6.8 –Power Demand and Grid Capacity

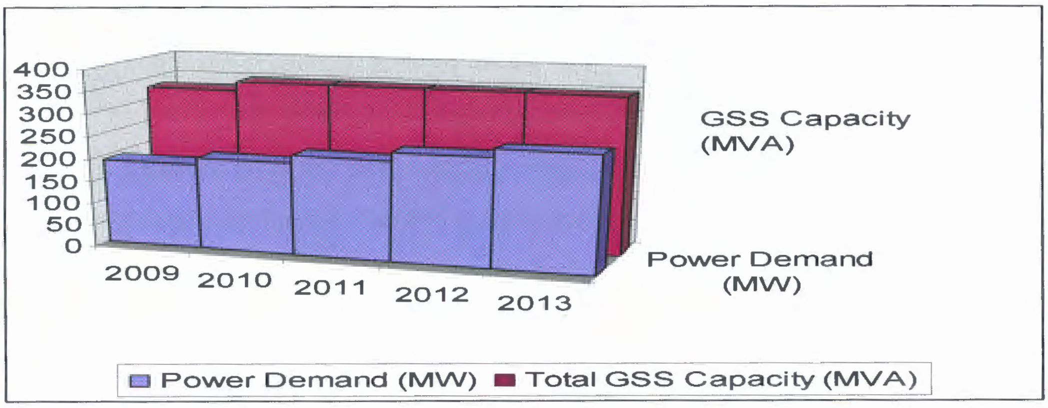

Figure 6.8 (b) - Power Demand and Grid Capacity

Chapter 7

Conclusion and Recommendation

7.1 Conclusion

The objective of this study is to identify and formulate proposals for network reinforcements of the MV distribution network in order to:

(a) Operate at optimal level of losses

(b) Provide electricity in sufficient quantity and acceptable quality

(c) Ensure efficient electricity distribution based on change of load pattern of the large committed load and general load growth

The results of the study is subject to the limitation that future demand growth has been estimated assuming that the growth occurs uniformly over the selected zone for any given category of consumers (i.e. domestic, industrial or commercial). The other limitation is the inaccuracies in input data, mainly those used to obtain the load pattern. As these data were manually recorded an error of about10% is estimated due to time mismatch and human errors in reading and recording.

The techniques described in this study allow a loss reduction strategy to be formulated, based on experience of a typical segment of the network under consideration. The benefit is that loss reduction measures can be targeted to have the most impact on the system. For planning purpose, the results of a well chosen pilot scheme can be applied to the entire network, thus allowing the total cost of the scheme and the resulting benefits to be evaluated.

Distribution feeders usually have a tapering load distribution along their length. Experience shows that about two third of losses on these feeders arises in the first third of the main feeder length. Small projects may be undertaken solely to reduce these losses. The most significant of these measures include reconductoring heavily loaded feeder sections. Reconductoring is really viable mainly for overhead networks. It could be viable for underground circuits only when the cable is ducted and can be easily removed. It is generally not viable to replace direct buried circuits solely for loss reduction.

The expected performance of the MV network achievement figures are based on the load forecast and timely implementation of the proposals as scheduled.

One of the primary objectives of this study is to design the MV network to operate at optimal level of losses and to ensure an efficient power distribution system. From the results of the study it was observed that percentage power loss has been reduced from 3.0 to 2.3 percent and energy loss from 2.0 to 1.2 percent.

Upgrading the network capacity is achieved by reinforcing the network with new grid substations, MV lines etc., so that the network shall be able to supply the increased power demand, maintaining the proper voltage levels at minimum losses. Implementation of network reinforcement proposals of this study would ensure adequate level of upgrading of the overall network capacity to the future demand effectively and efficiently.

Proposals are made with reliability considerations to the attention in feeding arrangements during power failures.

Distribution system loss reduction presents an excellent opportunity for improved energy efficiency. Economic and environmental pressures now compel a major focus of attention on such losses. Loss evaluation can be both difficult and complex. Development of policy and programme requires a lot of both technical and judgmental analysis. This study summarizes approaches to reduce losses in power distribution system.

7.2 Recommendation

Distribution loss is quite high in rural areas. Therefore urgent improvement measures are to be taken to reduce this loss. The main problem of the rural distribution system is its large number of low load consumers distributed over a large area. This is a consequence of the habitat pattern of the region where the distance between homesteads is comparatively large. Another problem is that the length of LV lines far outweighs the length of MV lines. For optimum loss reduction, the MV to LV ratio must be 1:1. Another factor is the lengthy single phase lines that also contribute for the I^2R loss.

7.2.1 Optimization of Distribution System

The optimum distribution system is the economical combination of medium voltage lines, distribution transformers and low voltage lines which depend on the location, load density, diversity of the system and the capital cost. These factors vary from area to area. Lower the MV/LV line length ratio, the higher will be the voltage drop and the line loss. To reduce this loss and improve voltage, MV/LV line length ratio should be optimized.

This calls for decentralization, wherein the high capacity transformers (viz 160 KVA, 250 KVA) are replaced by low capacity (100 KVA), which would result in optional placement of transformers, thereby reducing distribution loss through optimization of MV/LV line length ratio.

Moreover, in the existing system it is seen that the LV lines are extending up to kilometers of length with the transformer at one end. In this condition, the transformer position is to be shifted to the centre of the distribution load. This will improve regulation and at the same time reduce losses.

7.2.2 Loss Management Policy

The policy on losses is to manage them as a real distribution cost. It is required to balance the system development so as to minimize the total cost of supply to the customers and thereby to optimize economic efficiency. This means that losses are considered as a cost in decisions affecting the system, for example in the sizing of new circuits, network development projects, operational sectionalizing, etc.

The cost of reducing losses is balanced with the long term cost of supplying them. The policy shall recognize that a kW of network losses is equivalent to committing a kW of generation, transmission and distribution system, over the long term. Adjustments are of course made for load diversity and the compounding effect of losses up through the power system, a kW of distribution losses itself causes further losses upstream.

In costing losses the long run marginal cost of supply shall be used. This is differentiated into capacity or plant (per kW) and energy or fuel (per kWh) components. It is recommended to use a capitalization period of 25 years and a discount rate of about 10% for economic analysis. The capacity cost of losses is quickly recovered from an investment in loss reduction. The upstream capacity is released straight away and in most cases is quickly utilized. The energy cost is spread out over time and is gradually recovered.

There shall be an active Demand Side Management programme to encourage end use efficiency. The tariffs shall be based on the long run marginal cost of supply. The economic benefits of end use efficiency shall reasonably and accurately be reflected to the customers. The effect of this programme will be reflected in the growth rates used.

7.2.3 Loss Reduction Programme

Loss reduction guidelines shall be formulated to assist in implementing loss reduction policy in the planning and in the design stages. The technical loss component of the distribution loss can be reduced considerably by adopting system improvement measures such as:

- (i) MV network reinforcement
- (ii) Capacitor placement in MV distribution network
- (iii) Conversion of single phase line to three phase line
- (iv) Balancing of lines
- (v) Phase prediction and phase reconfiguration etc.

Replacement of faulty energy meters would further reduce the non-technical loss. The energy consumption tendency is higher if the meter is faulty.

Extensive briefing and training are required to win the attention and support of a large number of people at every level in the distribution function. Load and network databases have to be streamlined to facilitate annual audits of system loss levels and annual reviews of optimal sectionalizing on the major networks.

7.3 Further Research Areas

Distribution loss reduction requires a wide range of measures.

- Network reinforcements
- Operations
- Design
- Major development projects

7.3.1 Network Reinforcements

This topic has already been discussed in the report. Other research areas are:

7.3.2 Operations

Optimal sectionalizing of networks, balancing of loads across feeders and transformer switching are the cheapest measures for reducing losses. These can be complicated exercise, but simple formulae can be used to realize most of the benefits. The degree to which losses can be reduced by these measures is small. However all opportunities must be availed of to optimize network efficiency.

7.3.3 Design

Loss reduction can be achieved by optimal sizing of new equipment being added to a power system. This relates to selecting sizes to minimize the total cost of supply rather than selecting the minimum equipment rating to accommodate the load in question. The main issue here is economic sizing of conductors and transformers and MV/LV line construction.

7.3.4 Major Projects

The most significant means of reducing distribution system losses is through major development projects. These are undertaken for a number of reasons. The primary reason is usually to provide additional capacity to supply major new load. Other reasons include relieving load congestion, improving standby capacity or improving quality of supply. These projects usually target heavily loaded networks and cause significant reduction in losses. Such loss reductions, though usually not the primary reason for development, provide substantial benefits and help to justify the project capital expenditure.

References

[1] Ceylon Electricity Board, Statistical Unit, General Manager's branch, "Statistical Digest, 2008".

[2] Ceylon Electricity Board - Distribution Division 04, "Medium Voltage Distribution Development Plan, 2009-2017", 2009, pp 2-4 .

[3] Ceylon Electricity Board, Distribution Planning branch, "Distribution System Loss Reduction", 2004, pp 2-5.

[4] Ceylon Electricity Board, System Control branch, "Annual Report,2008", Annex 7B..

[5] "Electricity Distribution Losses", A consultation document, Office of Gas and Electricity Markets, 03/03, January 2003, page 12.

[6] P. R. Suresh & Shanavas Elachola, "Distribution Loss of Electricity and Influence of Energy Flows", A case study of a Major Section in Kerala, Discussion Paper No. 23, September 2000, pp 28 & 37.

[7] Noel P. Tobin and Mark Lyons, "Practical Electricity Distribution System Loss Reduction", Electricity Supply Board, Ireland, conference proceedings, 1993, pp 272-285.

[8] LUPESCU Maria & LECA Aureliu, "Improving the Energy Efficiency in Power Distribution Networks through Loss Reduction", CIRED, 19th International Conference on Electricity Distribution, Vienna, 21-24 May, 2007, Paper 0518, pp 1-3.

[9] A.K. Verma, " Management of Electricity Distribution for Improving System Efficiency", Indian Institute of Technology, Bombay, 07/03/2005.

[10] "Power System Efficiency Study", Sri Lanka United Nations Development Programme, 1983, pp 42 & 48.

[11] Johan Stalmans & Godalming, UK, "Transmission & Distribution Loss Reduction in Distribution Networks", Network, Power Engineering, Issue No 48 * Volume XV * Number 3, November 2000, pp 1-5.

[12] "Electric Utilities Turn to ESRI for GIS Solutions", ArcNews Spring 2006 Issue, page 4.

[13] H. M. Wijekoon, "Capacitor Placement in Medium Voltage Distribution Network", Distribution Planning Branch, Region 3, Ceylon Electricity Board, March 2007, pp 1-12.

[14] M. Skok, D. Skrlec and S. Krajear, "Dynamic Planning of Medium Voltage Open Loop Distribution Networks under Uncertainty", University of Zagreb, Croatia, 2005, pp 551- 556.

[15] Technical references ," SynerGEE Electric 3.6", pp 11,1-11,15 & 13,1-13,9.

[16] http://www.adea.net.au/planning.html, "Distribution Planning", Adea Power Consulting, Australia.

[17] User Guide, "SynerGEE Electric 3.6", pp19,20,112-114,257,497-503.

[18] William H. Kersting, "Distribution System Modeling and Analysis",New Mexico State University, New Mexico, pp 125-141

[19] Nelson Bacalao, Juan Carlos Ledezma & Carlos A. Dortolina , " Siemens PTI in Turkey to Deliver Results of Technical Due Diligence Analysis of Distribution Companies", Siemens PTI eNewsletter issue 102, Schenectady.

[20] C. G. Carter-Brown, S. W, Heunis & C. T. Gaunt, " Distribution Technical Loss Calculation and Costing for Network Planning and Design", CIRED,

18th International conference on Electricity Distribution, Turin, South Africa, Session No 5, 6-9 June 2005.

[21] http://www.statisticalforecasting.com/forecasting-regression-analysis.php, "How to Forecast using Regression Analysis", Statistical Forecasting, 2006.

[22] "Distribution System Analysis", CYME International, October 2008.

[23] "Regression Model Statistics", Metrix ND Newsletter, volume14, October 2002, page 5.

[24] http://www.etap.com/distribution-systems/unbalanced-load-flow.htm.

[25] http://etap.com/smart-grid/distribution-load-flow.htm

[26] http://www.hindu.com/2004/07/11/stories/2004071106011000.htm.