EFFECTIVE FAULT ISOLATION METHODS TO IMPROVE 33kV NETWORK RELIABILITY

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by

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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.

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I endorse the declaration by the candidate.

UOM Verified Signature

Prof. H.Y.R. Perera

CONTENTS

ABSTRACT

Improving reliability in power system is very important to the utilities as well as to the country as it is an important attribute of the supply quality and increases the end user satisfaction.

The aim of this study is to investigate the fault identification and isolation techniques to improve reliability. This study focuses on the following;

1. Reliability status of 33kV network of C.E.B.
2. Type of faults in 33kV network and outage reduction methods.
3. Develop a mathematical model for reliability evaluation.
4. Analyze protection scheme of C.E.B 33kV network.
5. Design new protection scheme to reduce outages.

The analyzed reliability indices of C.E.B are far below compared to internationally accepted levels.

In this study reliability status of 33kV network is analyzed using event log data of reclosers and breakdown reports of Consumer Service Centers. The author is working at Region -04, C.E.B and two switching gantries of Region-04 are selected to analyze events one in wet zone and other in coastal zone.

It can be seen that outage time and fault frequency are high during both monsoon periods, 86% of faults are line to earth, 67% of faults are of transient nature and the repair time in case of overcurrent fault is high due to poor workmanship in line connections. With this study predominant causes of faults in the network can be identified by using event log of recloser.

The several methods for outage reduction are identified, installation of fault indicators for remote indication and remote operation of reclosers, using line sectionalize devices.

The protection scheme of 33kV network is analyzed to find techniques to reduce outages. The downstream protective devices (fuse on Spurs) beyond the recloser do not distinguish permanent and transient faults. It can be seen nuisance fuse blowing in spurs as well as nuisance recloser lockout affecting all customers in feeder.

A new protection scheme is designed to overcome the above problems. The developed method isolates unhealthy spurs from healthy sections, improves reliability and reduces maintenance cost and extent of unserved energy.

ACKNOWLEDGEMENT

First, I pay my sincere gratitude to Professor Ranjit Perera who encouraged and guided me to conduct this investigation and on perpetration of final dissertation.

I also thank to Eng. J. Karunanayake who gave the valuable instructions during the study and valuable advice for perpetration of final dissertation.

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Chapter 1

Introduction

1.1. Background

Electricity has become a fundamental commodity of modern life. Hence the quality of distribution of electricity has gained utmost concern. Distribution system consists of 33kV, 11kV networks and domestic service lines. Major portion of these networks is overhead lines and hence vulnerable to many a system fault. Faults in the distribution network lead to supply failure. Therefore, prevention of faults in the network is a primary concern in improving reliability of power supply.

1.2. Reliability status of 33kV network of C.E.B

The reliability statistics shown in Table 1.1 give an idea of present status and how the network behaved during the past five years [14]. It is difficult to find data for 10 years and available data are considered in this study. The data comprise only the reported breakdowns and actual values are slightly higher than the reported values.

Item	2003	2004	2005	2006	2007
No. of 33kV breakdowns	26345	26978	27678	29123	31200
Outage time due to breakdowns (hour)	54352	56789	58743	59765	61234

Table 1.1 – Reliability statistics of 33kV network

The internationally accepted reliability indices of SAIDI, SAIFI and ASAI can be used to get a clear idea regarding the performance.

SAIDI = System Average Interruption Duration Index
(Minutes/year per connected consumer)

SAIFI = System Average Interruption Frequency Index
(Interruptions/year per connected consumer)

ASAI = Average System Availability Index

- $$SAIDI = \frac{\sum \text{(Outage duration)} \times \text{(No.of customers affected)}}{\text{Total customers}}$$

- $$SAIFI = \frac{\sum \text{No.of customers interrupted}}{\text{Total customers}}$$

- $$ASAI = \frac{\text{Customer hours of service availability}}{\text{Customer hours of service demand}}$$

The reliability indices of 33kV network of whole country for 2003 to 2007 year are shown in Table 1.2. The indices are calculated without incorporating planned interruptions, the breakdowns which were not reported and the source side outage.

Item	2003	2004	2005	2006	2007
Average SAIDI(min/yr)	1023	1167	1244	1456	1567
SAIFI (int/yr)	7.1	7.5	7.8	8.2	8.5
ASAI	0.99805	0.99778	0.99763	0.99723	0.99702

Table 1.2 – Reliability indices

The reliability targets of the United States of America are as follows. These indices of C.E.B are far below.

SAIDI = 95.9 min/yr
SAIFI = 1.18 int/yr
ASAI = 0.99983

1.3. Motivation

The outcome of this project will develop an effective fault isolating methodology and sets guide lines for proper planning of maintenance schedules.

The understanding of reliability concepts and its proper application would lead to improve the consumer satisfaction. Also the reliability improvement will have a definite positive effect on industries which in turn improve economy of the country.

Chapter 2

Problem statement

2.1. Identification of the problem

The analysis of reliability figures mentioned in Chapter-01 clearly shows the present condition of overhead network of C.E.B and annual outages without incorporating the planned interruptions and the breakdowns which were not reported. The poor condition of the network is highlighted in public media and the criticism leveled against C.E.B.

2.2. Objective of the study

All 33kV switching gantries are equipped with reclosers and the only purpose they serve today is just to respond to faults. Although these modern reclosers are equipped with data storing facilities (event log), this facility is not used at present in the C.E.B network. This study explores the possibilities of using these data to;

Improve reliability of network by reducing outage time in the network.

2.3. Importance of the study

The average operation and maintenance cost of distribution sector of C.E.B is about LKR 1,800 million in year 2007 and the cost of unserved energy is about LKR 520,000 million in year 2007. The reliability status of 33kV network shows present condition of the system. Therefore it is essential to investigate the reliability status of the network and see how to improve it.

This study will help to find a feasible solution for the above problems and the results obtained through this study could be used to develop proper maintenance schedules. It also identifies fault isolating methodologies.

Chapter 3

Reliability analysis of 33kV network

3.1. Recloser events analysis

Modern reclosers are equipped with data storing facility (Event log) and this facility could be used to evaluate reliability of network and identify faults in the network. When the status of the control electronics or switchgear changes, events are generated which are recorded in an Event Log for display to the operator. More than 3000 events are recorded in recloser control unit. A typical event log of recloser data is as follows (This particular event list shows activation of earthfault).

Date & Time	Event
18/05/2008 10:29:22.39	Panel Close Req
18/05/2008 10:09:04.36	Load Supply OFF
18/05/2008 10:08:59.41	E Max 492 Amp
18/05/2008 10:08:59.41	C Max 534 Amp
18/05/2008 10:08:59.41	Lockout
18/05/2008 10:08:59.31	Prot Trip 3
18/05/2008 10:08:59.31	Earth Prot Trip
18/05/2008 10:08:59.31	Prot Group A Active
18/05/2008 10:08:59.31	Pickup
18/05/2008 10:08:59.19	Automatic Reclose
18/05/2008 10:08:57.24	E Max 499 Amp
18/05/2008 10:08:57.24	C Max 513 Amp
18/05/2008 10:08:57.19	Prot Trip 2
18/05/2008 10:08:57.19	Earth Prot Trip
18/05/2008 10:08:57.19	Prot Group A Active
18/05/2008 10:08:57.18	Pickup
18/05/2008 10:08:56.81	Automatic Reclose
18/05/2008 10:08:56.37	E Max 498 Amp
18/05/2008 10:08:56.37	C Max 500 Amp
18/05/2008 10:08:56.31	Prot Trip 1
18/05/2008 10:08:56.31	Earth Prot Trip
18/05/2008 10:08:56.31	Prot Group A Active

3.1.1. Review of events

A switching gantry is fed by grid substation and 33kV reclosers are fitted to 33kV feeders. A typical switching arrangement is shown in Figure 3.1.

Two Switching Gantries are selected for analysis of events. One is Kithulgoda gantry, WPS-1 Province –Region-04 close to wet zone and other is Dickwella gantry, Southern Province-Region -04 close to coastal zone of Ceylon Electricity Board. One year (2007) data are reviewed. The permanent faults (Lockouts) and temporary faults (reclosing) are identified. Then above faults are analyzed as to check whether they are Over Currents (OC) or Earth Faults (EF).

1. Wet zone-Kithulgoda Gantry, which is situated in Kalutara Area and fed by Mathugama Grid, has three outgoing feeders called Pellawatta, Sirikadura, Kalumale.
2. Coastal Zone-Dickwella Gantry, which is situated in Matara Area and fed by Matara Grid Substation, has two outgoing 33kV feeders called Dandeniya and Thangalle.

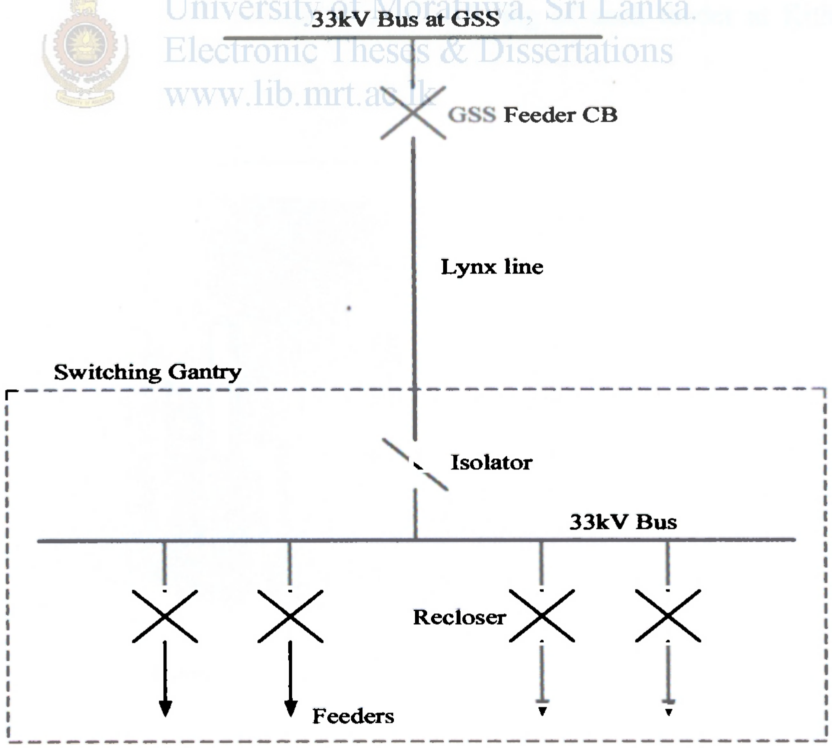

Figure 3.1 - Feeding arrangement of 33kV Switching Gantry

Figure 3.2 shows bar chart presentation of outage period of each feeder at Kithulgoda Gantry and Table 3.1 represents rainfall data at Kithulgoda area for comparison [10].

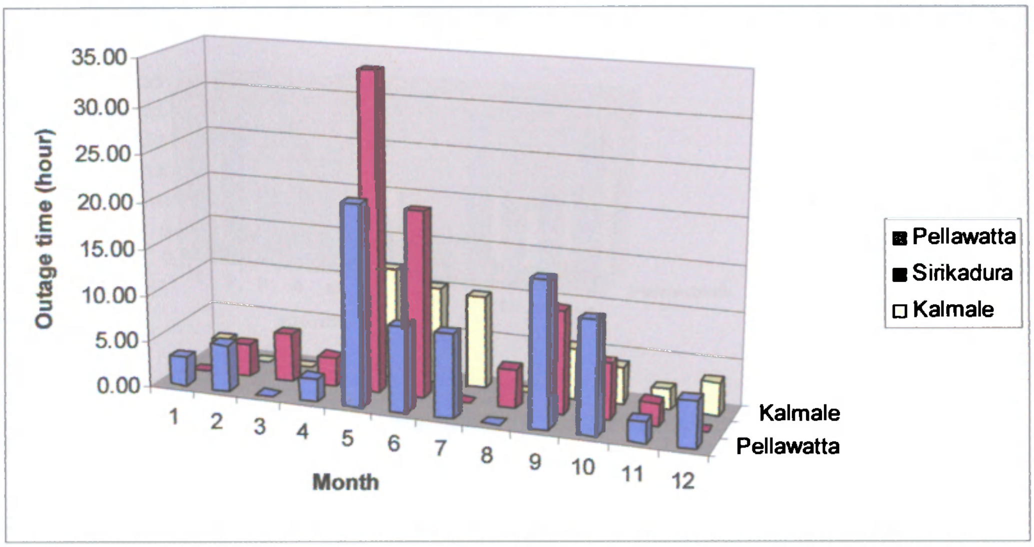

Figure 3.2- Outage period of feeders at Kithulgoda Gantry

Figure 3.3 shows bar chart presentation of reclosing of each feeder at Kithulgoda Gantry.

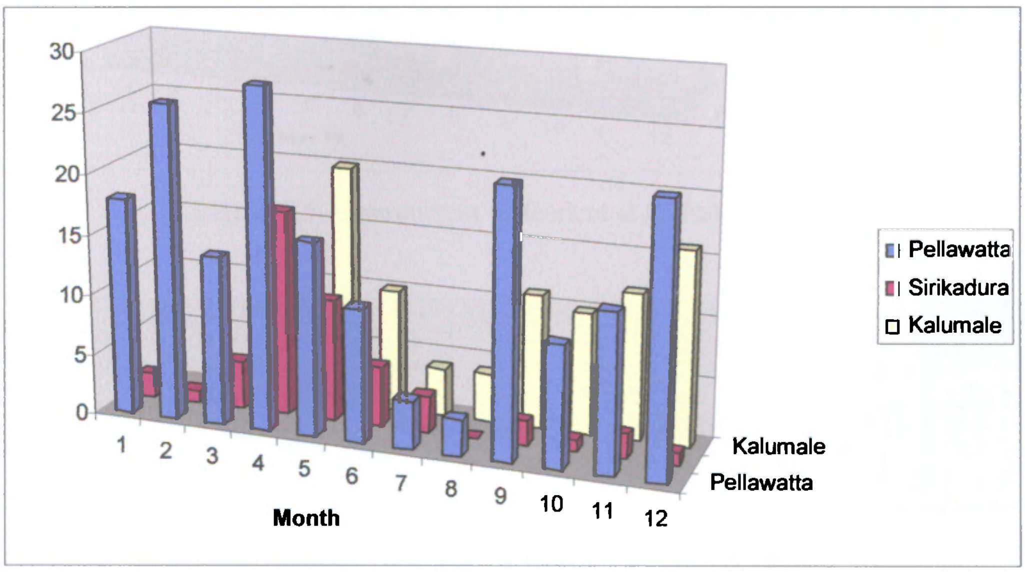

Figure 3.3- Reclosing of feeders at Kithulgoda Gantry

Figure 3.4 shows bar chart presentation of earthfaults of each feeder at Kithulgoda Gantry.

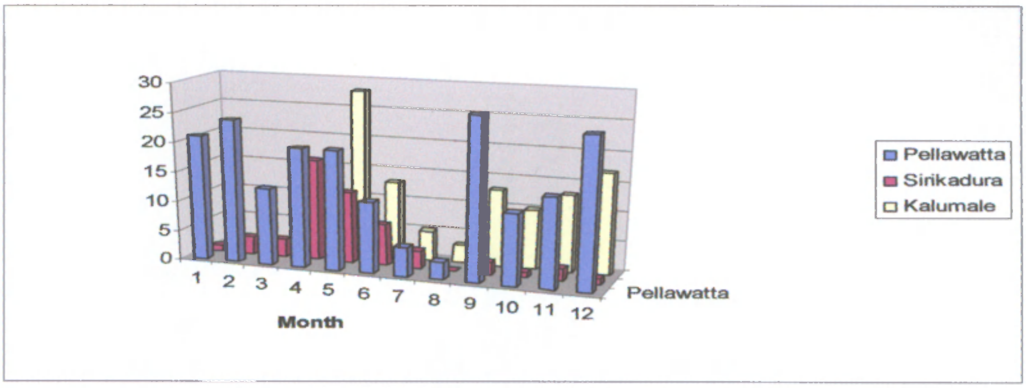

Figure 3.4- Eathfault of feeders at Kithulgoda Gantry

Figure 3.5 shows bar chart presentation of overcurrent of each feeder at Kithulgoda Gantry.

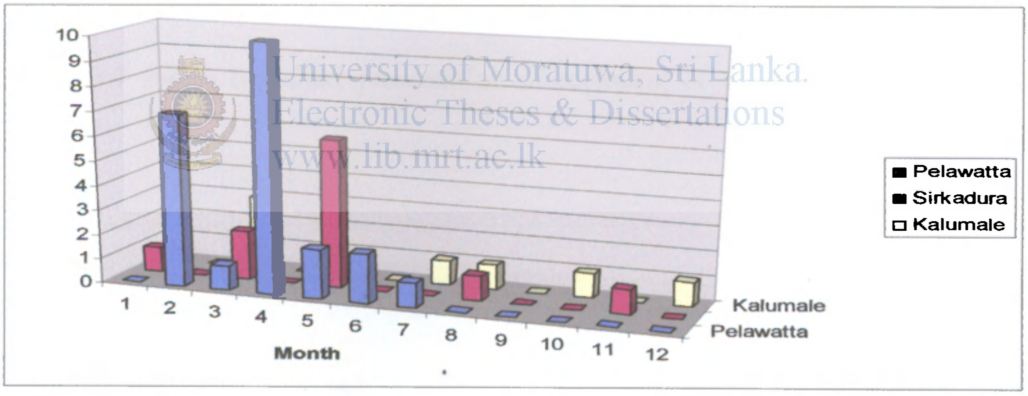

Figure 3.5- Overcurrent of feeders at Kithulgoda Gantry

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rain fall in mm	196	38	91	445	814	425	245	368	434	700	264	205

Table 3.1 – Rainfall data at Kithulgoda Gantry

Figure 3.6 shows bar chart presentation of outage period of each feeder at Dickwella Gantry and Table 3.2 represents rainfall data at Dickwella area for comparison [10].

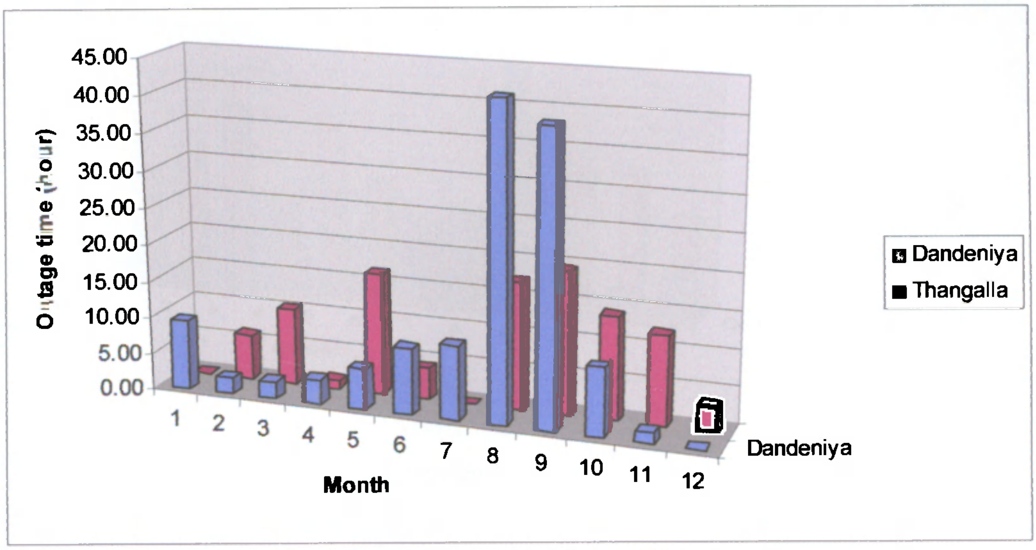

Figure 3.6- Outage period of feeders at Dickwella Gantry

Figure 3.7 shows bar chart presentation of reclosing of each feeder at Dickwella Gantrty.

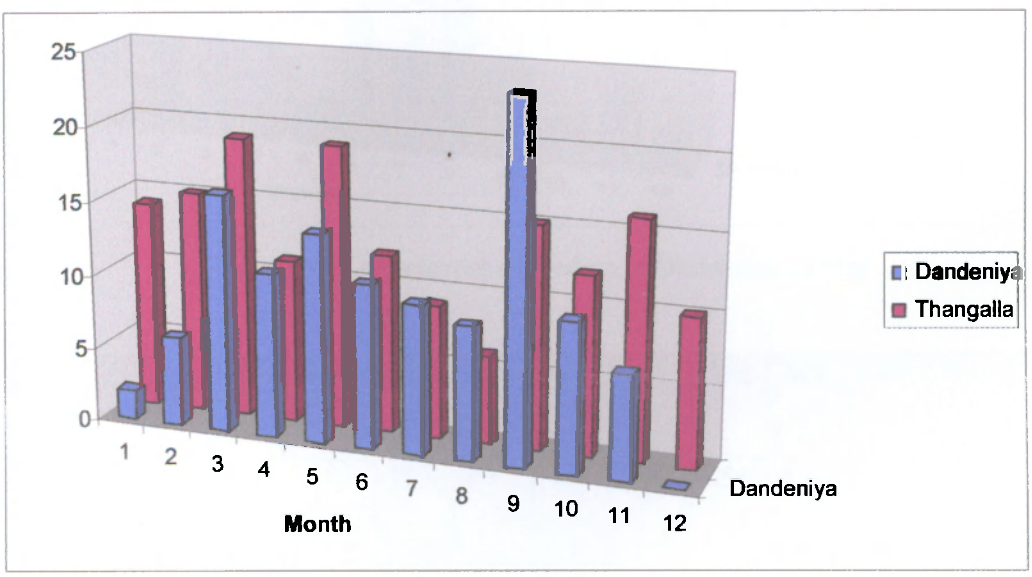

Figure 3.7- Reclosing of feeders at Dickwella Gantry

Figure 3.8 shows bar chart presentation of eartfault of each feeder at Dickwella Gantry.

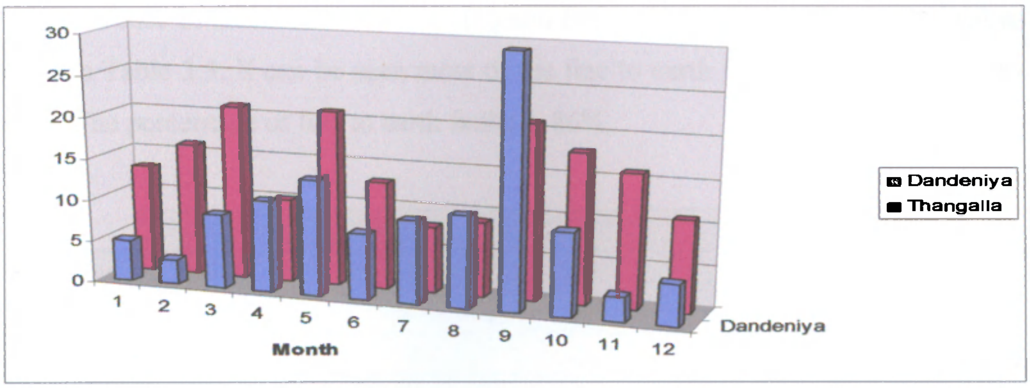

Figure 3.8- Earthfault of feeders at Dickwella Gantry

Figure 3.9 shows bar chart presentation of overcurrent of each feeder at Dickwella Gantry.

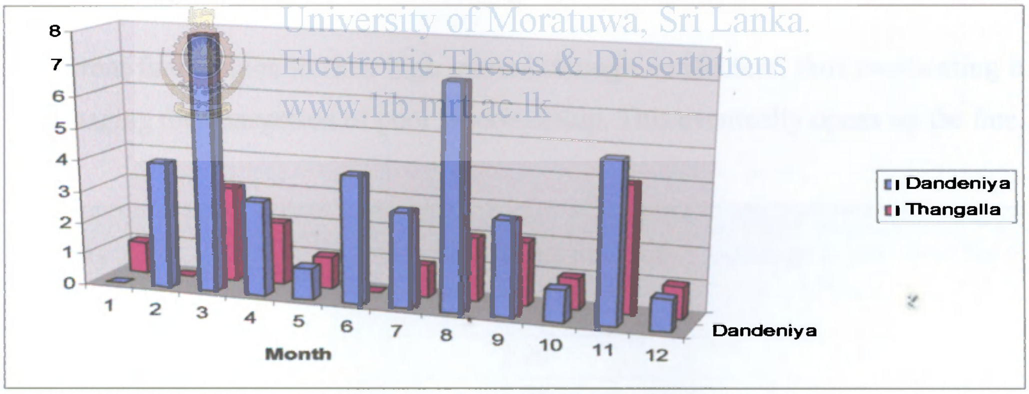

Figure 3.9- Overcurrent of feeders at Dickwella Gantry

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rain fall in mm	21	23	26	153	67	111	108	456	569	370	79	36

Table 3.2 – Rainfall data at Dickwella area

It can be seen that outage time and faults are high for two gantries during both monsoon periods.

The occurrence of faults between lines (L) and line to earth (E) can be categorized as shown in Table 3.3. It can be seen most of the line to earth faults are caused by way leaves. The percentage of line to earth faults is 86%.

	LE	LLE	LLLE	LL	LLL
Pellawatta	168	23	6	14	9
Sirikadura	45	5	2	7	4
Kalumale	96	10	4	5	3
Dandeniya	106	7	3	40	0
Thangalla	146	23	8	13	5

Table 3.3 – The occurrence of faults between lines and lines to earth

The average repair time for overcurrent and earthfault are given in Table 3.4. More time is required for repairing overcurrent faults.

Overcurrent fault causes to flow high current through conductors, thus overheating it and damaging the connection of poor workmanship. This eventually opens up the line.

Gantry name	Feeder Name	Average repair time for OC fault(hour)	Average repair time for EF(hour)
Dickwella	Thangalla	3.20	2.74
	Dandeniya	5.28	3.29
Kithulgoda	Pellawatta	4.45	1.27
	Sirikadura	5.23	4.81
	Kalumale	2.08	2.17

Table 3.4 – Average repair time of feeders

3.2. Type of faults

Maximum service reliability is achieved when the distribution system is designed and operated to minimize the effect of any fault that may occur. Two types of faults are encountered on the above overhead network and can be categorized as transient and permanent.

3.2.1. Transient faults

A transient fault is one that does not require corrective action to remove the fault from the system. If the arc can be cleared quickly, before burning into a permanent fault, the cause of the fault is gone. Since no equipment damage has occurred, the circuit can be re-energized immediately and supply reinstated. A transient fault would result from occurrences such as lightning, an arc caused by an animal or tree branch that then falls clear or the wind momentary blowing two conductors closer. The analyzed recloser attempts in each feeder are shown in Table 3.5. It can be seen that 67% of faults are in transient nature. The internationally proved level of transient faults in distribution system is between 60-80% [13].

	1st Attempt	2nd Attempt	3rd Attempt	Lockout
Pellawatta	170	17	33	33
Sirikadura	41	7	15	15
Kalumale	94	3	21	21
Dandeniya	110	10	36	36
Thangalla	149	9	37	37

Table 3.5 – Reloser attempts of feeders

3.2.2. Permanent faults

A permanent fault is one in which permanent damage has resulted from the cause of the fault. A permanent fault usually requires some form of repair before power can be stored (Examples; a broken insulator, a broken conductor or an automobile knocking a pole down). It also includes faults that are initially transient in nature but result in permanent damage to the system. In such a situation, the line must be de-energized, a line crew brought to the site, and repairs made.

The type of permanent faults occurred in the selected Gantries during 2007 year were grouped by comparing breakdown reports of Consumer Service Centre and the correspondence event log of reclosers. The failure records obtained from the breakdown register is validated after the discussion with the Electrical Superintend and his work gang. The type of faults of Kithulgoda Gantry is shown in Table 3.6 and that of Dikwella Gantry in Table 3.7.

	Pellawatta	Sirikadura	Kalumale	Total
Jumper broken	5	3	3	11
Tree branches fallen	17	6	7	30
Tree fallen	2	1	2	5
Lightning	0	0	0	0
Animals	0	0	0	0
Vehicles	0	1	0	1
Intermittent	8	2	7	17
Bird	0	0	0	0
Earth broke	0	0	0	0
Conductor broken	1	2	0	3
Wind	0	0	0	0
Insulators	0	1	2	3

Table 3.6- Type of faults at Kithulgoda Gantry.

	Thangalla	Dandeniya	Total
Jumper broken	5	3	8
Tree branches fallen	13	19	32
Tree fallen	2	1	3
Lightning	0	0	0
Animals	0	0	0
Vehicles	0	0	0
Intermittent	6	7	13
Bird	0	0	0
Earth broke	2	1	3
Conductor broken	4	3	7
Wind	0	0	0
Insulators	5	2	7

Table 3.7- Type of faults at Dickwella Gantry.

It can be seen from above tables tree branches fallen to line is common to all feeders and most of them occur in monsoon periods. More insulators have damaged in Tangalla Feeder, which is near to coastal zone. The spread of salt is mainly responsible for this type of faults. The non identified faults are categorized as intermittent faults. They are normally caused by way leaves or wind.

3.3. Outage reduction methods

There are several methods to reduce outage time and discussed in next section.

3.3.1 Reduce faults in the network

The two rainy seasons and fast growing thick vegetation surrounding medium voltage lines are responsible for many faults due to fall of trees and distance tree branches during windy and rainy days. These faults can be eliminated by carrying out way leaves programs before and after rainy seasons. Adequate clearance shall be maintained. The other suitable solution to minimize the effect will be the introduction of partially insulated Aluminum conductors for medium voltage line construction.

The problem of salt formation over the line insulators and flashover gives enormous problems to system reliability. The insulation paint can be applied over the insulators or composite type insulators can be used.

Re-stringing of conductors and adjustment of clearance of T-off should be carried out to overcome faults by way leaves and wind.

Compression type H connectors should be introduced for jumper connection at tension points or angle points and spur points to overcome opening during heavy fault current.

The compression type midspan joints should be used to connect damaged conductors.

3.3.2 Installation of remote fault indicators

The power supply of healthy section can be reinstated with the least possible delay after isolating the faulty section. Fault indicators can be used to detect faulty section. Its fault indication can be used to send remote signal to control centre. Then it can be given fast instruction to isolate faulty section. Then fault location of difficult areas will become easy and the outage time of such areas can be minimized. Recommended location of fault indicators;

i. Easy to access line points for immediate monitoring
ii. Next to the spur line
iii. After switch (Air Break Switch or Load Break Switch)
iv. Before and after the points that is difficult to reach such as forest or mountain.

3.3.3 Remote operation of reclosers

Modern Reclosers used in C.E.B can be remote operated by control centre. All the fault events can be reviewed. Therefore operation time of recloser can be minimized by remote operation. Then outage time of network can be reduced. It can be seen more intermittent faults occur in two Gantries (Table 3.6 and 3.7). The recloser can be operated from control centre without physically attending to the site. Hence it reduces outage time of network and also traveling and labour cost.

3.3.4 Using line sectionalize devices

For faults on the main feeder line, a line sectionalizing device (recloser or sectioalizer) can be used to divide the feeder into smaller line segments. All taps should have a protective device (fuses for small taps, a recloser or sectionalizer for large taps) where they connect to the main feeder. Even on very small taps, a fuse should be used. The justification is that although this type of tap fuse does not protect the tap; it protects the remainder of the distribution feeder from a fault on the tap.

The extent of the outage can be minimized by limiting the size and length of the affected line. The shorter line segment minimizes the number of customers affected and minimizes the time required to patrol the line and locate the fault.

3.4. Development of a model for reliability evaluation

A feeder can be represented by a single line diagram as follows.

a) Spur lines (lateral) connected to feeder directly is shown in Figure 3.10.
b) Spur lines protected by fuse link and sections separated by isolators are shown in Figure 3.11.

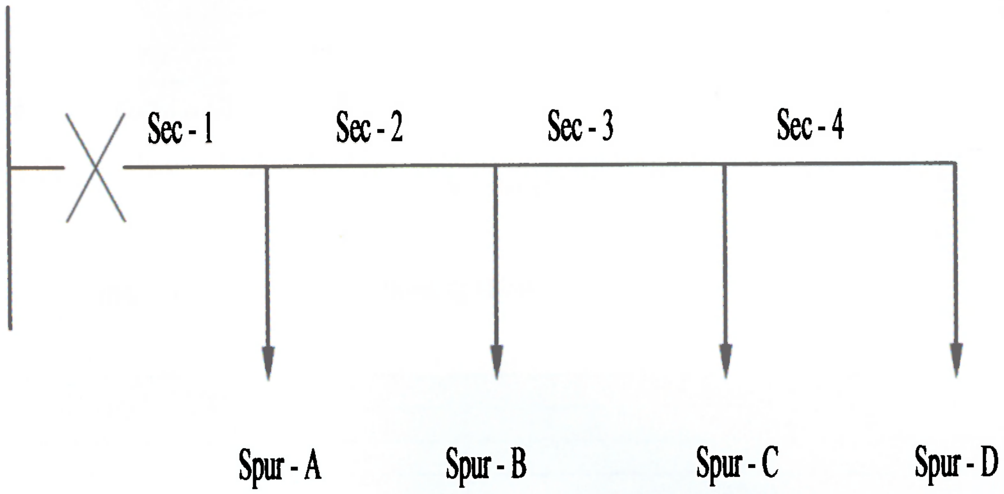

Figure 3.10 Spur lines connected directly to sections

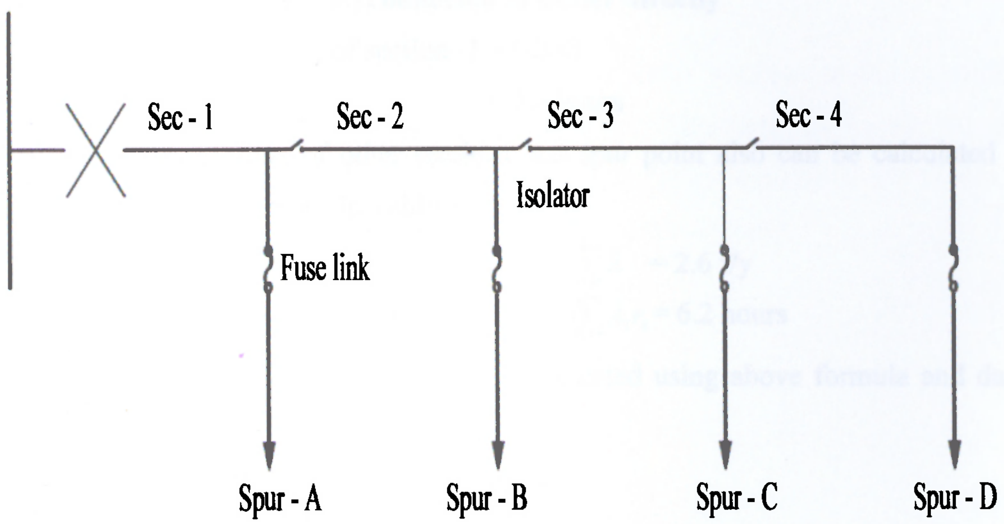

Figure 3.11 – Spur lines connected across fuse with sections

The assumed failure rates of sections and spurs are as shown in Table 3.8.

Item	Length (Km)	No. of failures/year (λ)	Repair time-r (hour)
Section – 1	2	0.2	3
Section – 2	3	0.3	3
Section – 3	3	0.3	3
Section – 4	2	0.2	3
Spur – A	2	0.4	2
Spur – B	3	0.6	2
Spur – C	1	0.2	2
Spur – D	2	0.4	2

Table 3.8- Assumed failure rates of feeder

The assumed customers are available is shown in Table 3.9.

Load point	No. of customers
A	1000
B	2000
C	4000
D	3000

Table 3.9 – Assumed customers of feeder

Effect of Spur lines (Lateral) connected to feeder directly

The annual outage time (U) of section -1 = 0.2×3

= 0.6 hours

The annual outage time of other sections and spur point also can be calculated as above and results are shown in Table 3.10.

The total failures (λ_s) $= \sum \lambda = 2.6$ f/y

Average Annual outage time (U_s) $= \sum_i \lambda_i r_i = 6.2$ hours

The customer orientated indices could be calculated using above formula and data, and the results are given bellow.

SAIFI = 2.6 interruption / customer yr

SAIDI = 6.2 hours / customer yr

ASAI = 0.999292

	Customer A			Customer B			Customer C			Customer D		
Item	λ (f/y)	r (h)	U (h)	λ (f/y)	r (h)	U (h)	λ (f/y)	r (h)	U (h)	λ (f/y)	r (h)	U (h)
Section - 1	0.2	3	0.6	0.2	3	0.6	0.2	3	0.6	0.2	3	0.6
Section - 2	0.3	3	0.9	0.3	3	0.9	0.3	3	0.9	0.3	3	0.9
Section - 3	0.3	3	0.9	0.3	3	0.9	0.3	3	0.9	0.3	3	0.9
Section - 4	0.2	3	0.6	0.2	3	0.6	0.2	3	0.6	0.2	3	0.6
Spur - A	0.4	2	0.8	0.4	2	0.8	0.4	2	0.8	0.4	2	0.8
Spur - B	0.6	2	1.2	0.6	2	1.2	0.6	2	1.2	0.6	2	1.2
Spur - C	0.2	2	0.4	0.2	2	0.4	0.2	2	0.4	0.2	2	0.4
Spur - D	0.4	2	0.8	0.4	2	0.8	0.4	2	0.8	0.4	2	0.8
Total	2.6	2.4	6.2	2.6	2.4	6.2	2.6	2.4	6.2	2.6	2.4	6.2

Table 3.10 – Annual outage time when spur connected directly to section

Effect of Spur lines protected by fuse link

The effects of protection failures and load transfer circuits are not considered in this evaluation due to non-availability of data.

It is assumed feeder sections are isolated manually and average time for manual isolation (i) is 1 hour. When the fault is in feeder section it is sectionalized manually as far as it is not in the mainstream of the fault current.

When faults occur in the spurs (lateral) the fuse links installed at the beginning operates and isolates the spur from the main feeder. This happens for all the spur points. The annual outage time of sections and spur points calculated are shown in Table 3.11. The improved reliability indices are evaluated bellow.

SAIFI = 1.4 interruption / customer yr

SAIDI = 3.2 hours / customer yr

ASAI = 0.999635

	Customer A				Customer B				Customer C				Customer D			
Item	λ f/y	r (h)	i(h)	U (h)	λ f/y	r (h)	i(h)	U (h)	λ f/y	r (h)	i(h)	U (h)	λ f/y	r (h)	i(h)	U (h)
Section – 1	0.2	3		0.6	0.2	3		0.6	0.2	3		0.6	0.2	3		0.6
Section – 2	0.3		1	0.3	0.3	3		0.9	0.3	3		0.9	0.3	3		0.9
Section – 3	0.3		1	0.3	0.3		1	0.3	0.3	3		0.9	0.3	3		0.9
Section – 4	0.2		1	0.2	0.2		1	0.2	0.2		1	0.2	0.2	3		0.6
Spur – A	0.4	2		0.8												
Spur – B					0.6	2		1.2								
Spur – C									0.2	2		0.4				
Spur – D													0.4	2		0.8
Total	1.4	1.6		2.2	1.6	2		3.2	1.2	2.5		3	1.4	2.7		3.8

Table 3.11 –Annual outage time when spur equipped with fuses and manual isolation

The isolating time of isolator can be assumed as zero if isolator is replaced with sectionalizer. The annual outage time of sections and spur points calculated are shown in Table 3.12. Then improved reliability indices are evaluated below;

SAIFI = 1.4 interruption / customer yr
SAIDI = 2.9 hours / customer yr
ASAI = 0.999664

	Customer A			Customer B			Customer C			Customer D		
Item	λ f/y	r (h)	U (h)	λ f/y	r (h)	U (h)	λ f/y	r (h)	U (h)	λ f/y	r (h)	U (h)
Section – 1	0.2	3	0.6	0.2	3	0.6	0.2	3	0.6	0.2	3	0.6
Section – 2	0.3			0.3	3	0.9	0.3	3	0.9	0.3	3	0.9
Section – 3	0.3			0.3			0.3	3	0.9	0.3	3	0.9
Section – 4	0.2			0.2			0.2			0.2	3	0.6
Spur – A	0.4	2	0.8									
Spur – B				0.6	2	1.2						
Spur – C							0.2	2	0.4			
Spur – D										0.4	2	0.8
Total	1.4	1	1.4	1.6	1.7	2.7	1.2	2.3	2.8	1.4	2.7	3.8

Table 3.12 – Annual outage time when spur equipped with fuses and sectionalizers

It can be seen from above analysis that reliability improvements can be achieved by proposed replacement of protection devices in spurs and sections.

Chapter 4

An effective protection scheme to reduce outage rate

4.1. Protection scheme of C.E.B 33kV network

As a case study protection scheme developed from Mathugama gantry to Kithulgoda Gantry shown in Figure 4.1 is selected for analysis. The overcurrent and earthfault settings of circuit breakers at Mathugama GSS and reclosers at Kithulgoda gantry are shown in Figure 4.1. The protection curves drawn by SynerGEE Electric Program are shown in Figure 4.2 [4]. This protection scheme was issued by Distribution Planning Branch-C.E.B and is common for all gantries in Medium Voltage Network of C.E.B [2].

CT: 400: 1
O/C
PMS=1 (400A)
TMS=0.1
Inst=8
Curve: SI
E/F
PMS=0.1 40A)
TMS=0.1
Inst=8
Curve: SI

Phase Trip =200A (O/C)
Time Mult. = 0.1
Inst. Mult. = 8
Curve: VI
Earth Trip = 20 A (E/F)
Time Mult. = 0.1
Inst Mult = 8
Curve: VI

Figure 4.1-Protection scheme between GSS CB and Gantry recloser

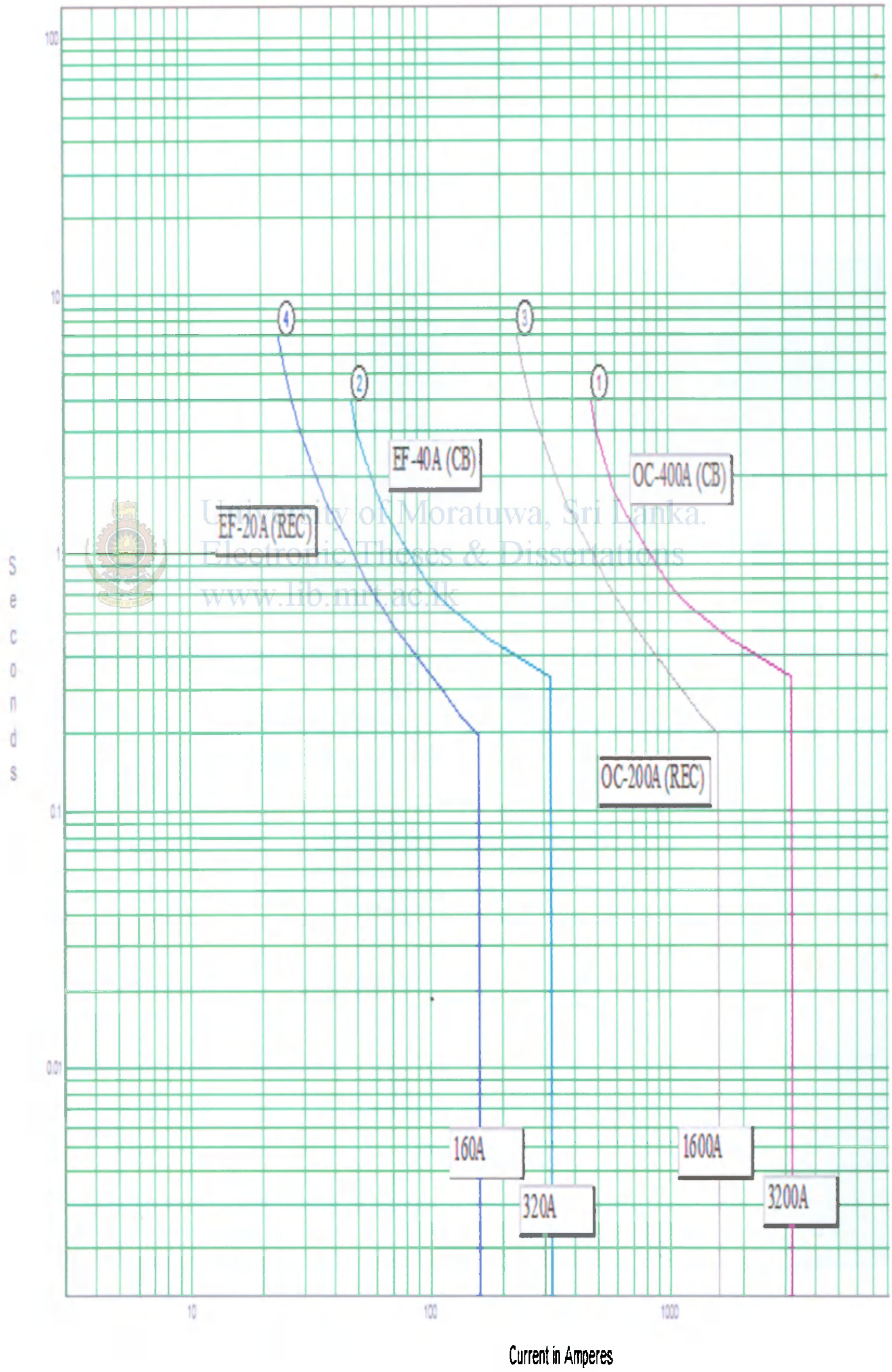

Figure 4.2-Protection curves between GSS CB and Gantry Recloser

4.1.1. Downstream protection scheme

The downstream protection devices of Kalumale feeder of Kithulgoda gantry is selected for analysis. Feeder arrangement of Kalumale feeder is attached in Appendix -1. There are 7 Spur points numbered 1, 2, 3 etc. The connected fuse links for Transformers and Spurs are listed in Table 4.1 [11].

Spur Point	Sin No	Transformer-Capacity (kVA)	Recommended fuse link connected to Transformer (A)	Present Connected Fuse link in spurs
1	A12	250	8	40
	A71	160	6	
	A11	160	6	
	A90	1000	20	
2	A50	100	3	15
	A60	100	3	
	A80	100	3	
	A68	100	3	
3	A59	100	3	15
	A13	160	6	
	A73	100	3	
4	A16	100	3	20
	A46	160	6	
	A17	250	8	
	A28	100	3	
5	A19	250	8	15
	A20	160	6	
6	A64	160	6	10
7	A24	100	3	10
	A44	100	3	

Table 4.1 Connected fuse links at Kalumale feeder

The spur lines are protected by 10A, 15A, 20A and 40A fuse links. A 'K' type (fast type – low speed ratio) fuses are used by C.E.B. The downstream protection scheme is analyzed by drawing fuse curves with upper stream protection scheme. These curves are drawn by SynerGEE Electric Program.

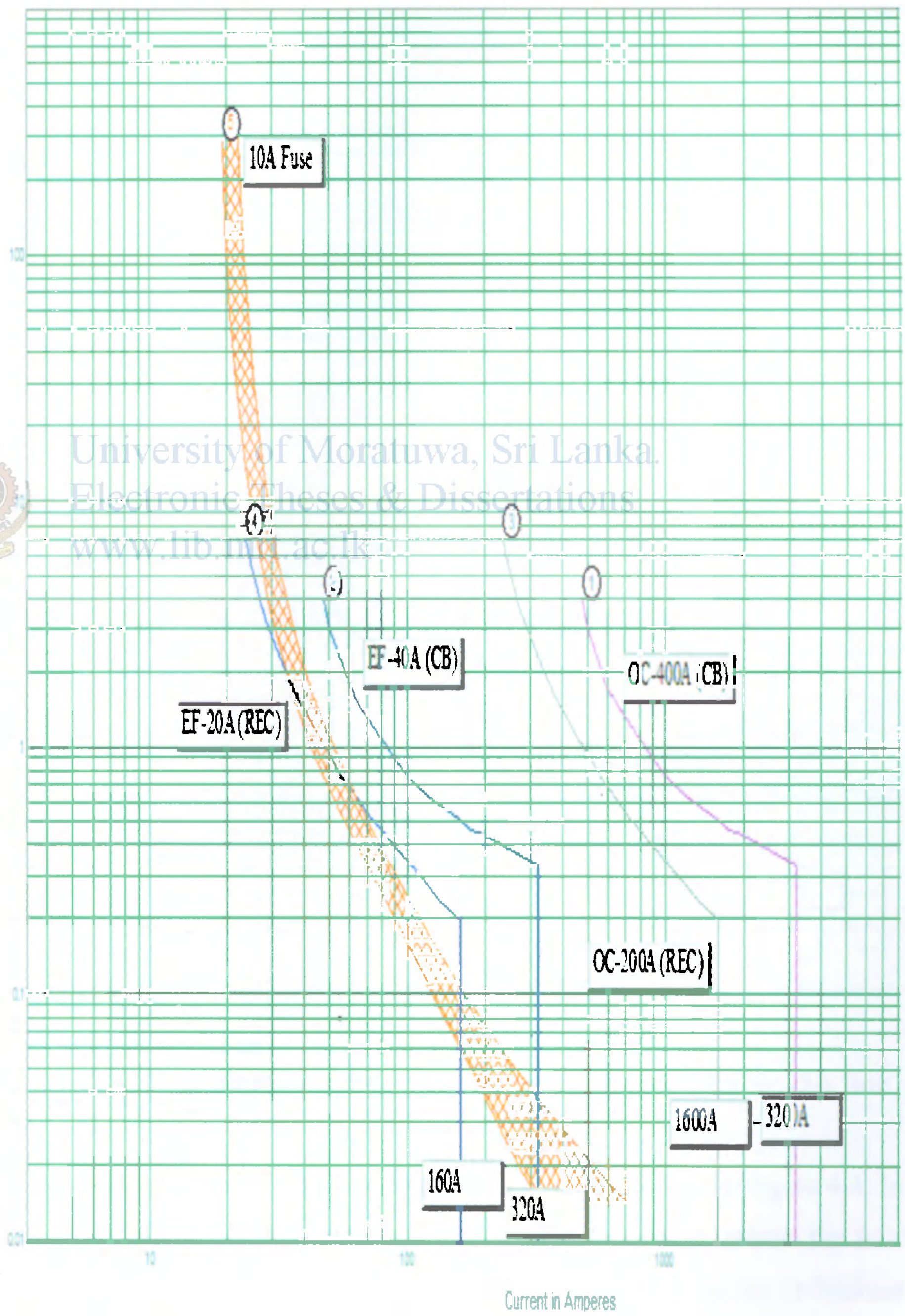

Figure 4.3 –Protection curves when a spur line is protected by 10A fuse

The protection scenario of a spur line protected by 10A fuse is shown in Figure 4.3. In this scheme all transient and permanent faults between 70A to 160A cause to operate fuse link. But the desired operation is to clear transient faults by the recloser and permanent faults by the fuse. Therefore, existing protection scheme does not serve the purpose by isolating the faulty section only, but trips the spur line affecting all the consumers on that spur unnecessarily.

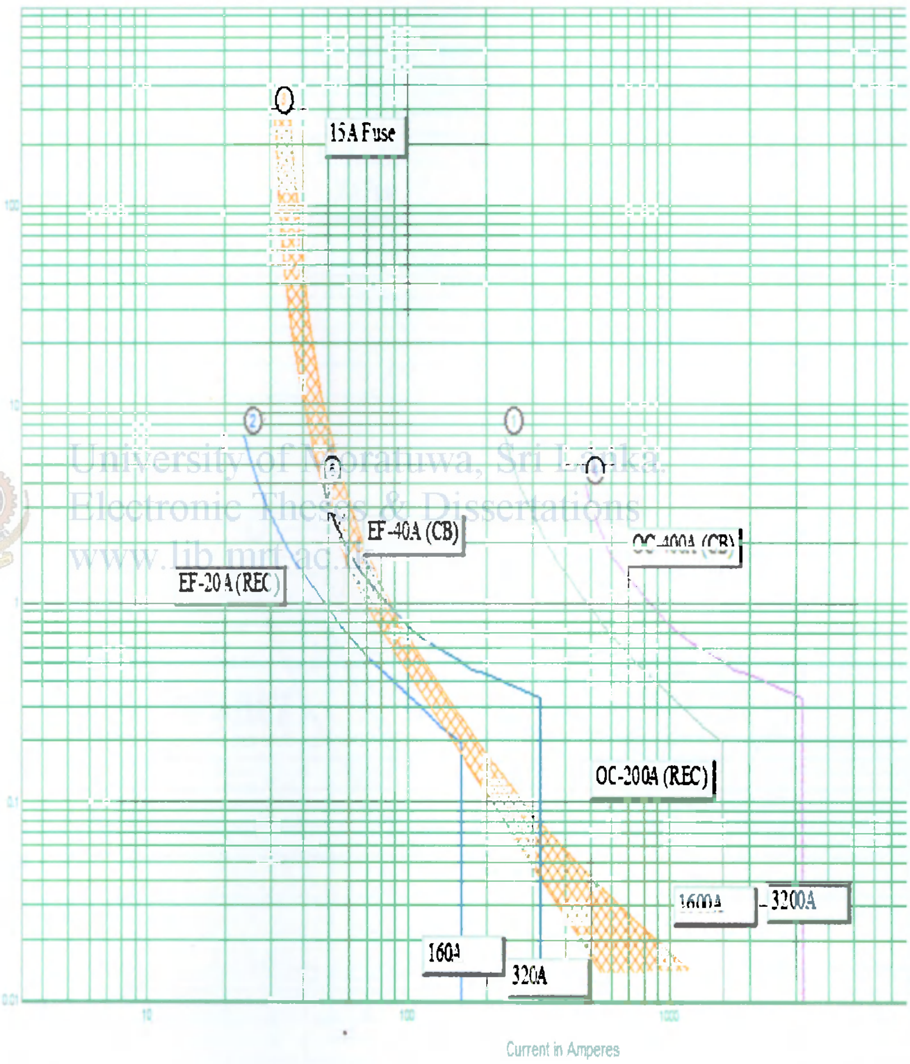

Figure 4.4 – Protection curves when a spur line is protected by 15A fuse

The protection scenario of a spur line protected by 15A fuse is shown in Figure 4.4. In this scheme all transient and permanent faults below 1600A cause to operate the fuse link. If a permanent earthfault (below 160A) occurs in spur line it causes to lockout recloser but not the spur line leading to supply outage to all customers in Feeder. Fuse is not actually an earthfault detection device, but at the time of the earthfault the earthfault current is equal to one of phase current in Feeder. It occurs 90% of the time during an earthfault situation as proven by the event log records of recloser, the equivalent of earth fault current and phase current at the time of earth fault is deducted in Chapter 3.1. The desired operation is by recloser for clear transient faults and by fuse for permanent faults. Therefore existing protection scheme does not serve the purpose by isolating the faulty section.

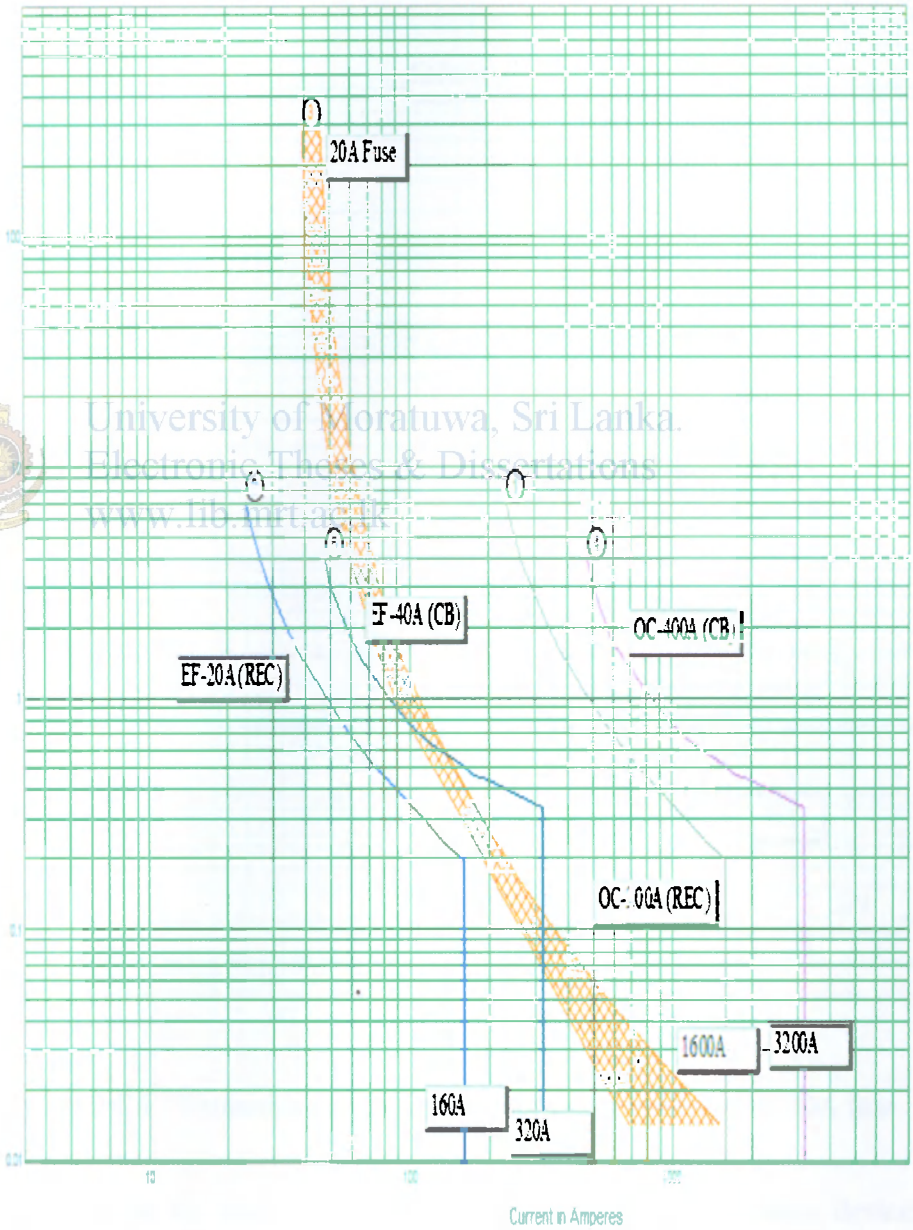

Figure 4.5 – Protection curves when a spur line is protected by 20A fuse

The above behavior is applicable also for spur line protected by 20A (see Figure 4.5) and 40A (see Figure 4.6)

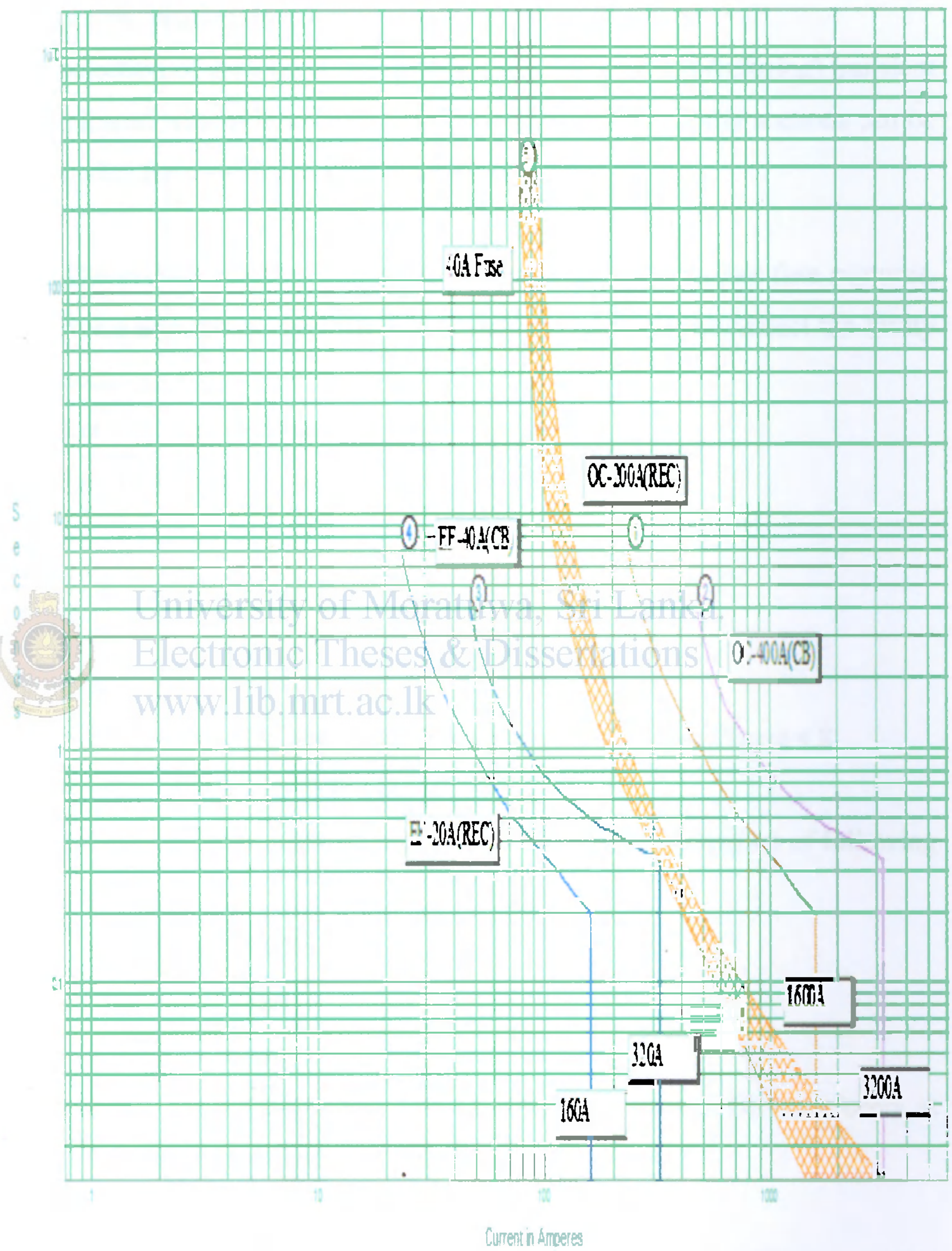

Figure 4.6 – Protection curves when a spur line is protected by 40A fuse

It is understood from the above analysis that the down stream protective devices beyond the recloser do not distinguish permanent and transient faults in the spurs of the network. It can be seen that nuisance fuse blowings in spurs as well as nuisance recloser lockouts occur affecting all customers in the Feeder.

Therefore there are possibilities of improving reliability of network by considering downstream protective devices and minimizing unnecessary fuse blowings.

4.2. Design new protection scheme

With proper selection of protection devices (fast tripping and fast reclosing) transient faults can be cleared without a sustained outage and permanent faulty sections can be isolated. Following three operations are available [2];

I. The main protection should clear a temporary fault before fuse ruptures. For a permanent fault the fuse should rupture and disconnect the faulty section.

II. Let the fuse blow even for temporary faults.

III. Let the fuse not blow at all.

The criteria '1' is selected for design of the new protection scheme.

4.2.1. Design algorithm

The algorithm for design of the new protection scheme is shown in Figure 4.8.

The design algorithm comprises following steps.

1. The applied algorithm network is shown in Figure 4.7. Collection of following network data;
    - Fault levels at GSS
    - Line impedances
    - Transformer data
2. Collection of the functions and data of circuit breakers at GSS, reclosers at Gantries, fuses at spurs and transformers.
3. Calculate fault level in network.
4. Select the devices to check coordination by considering continuous current ratings of equipment.

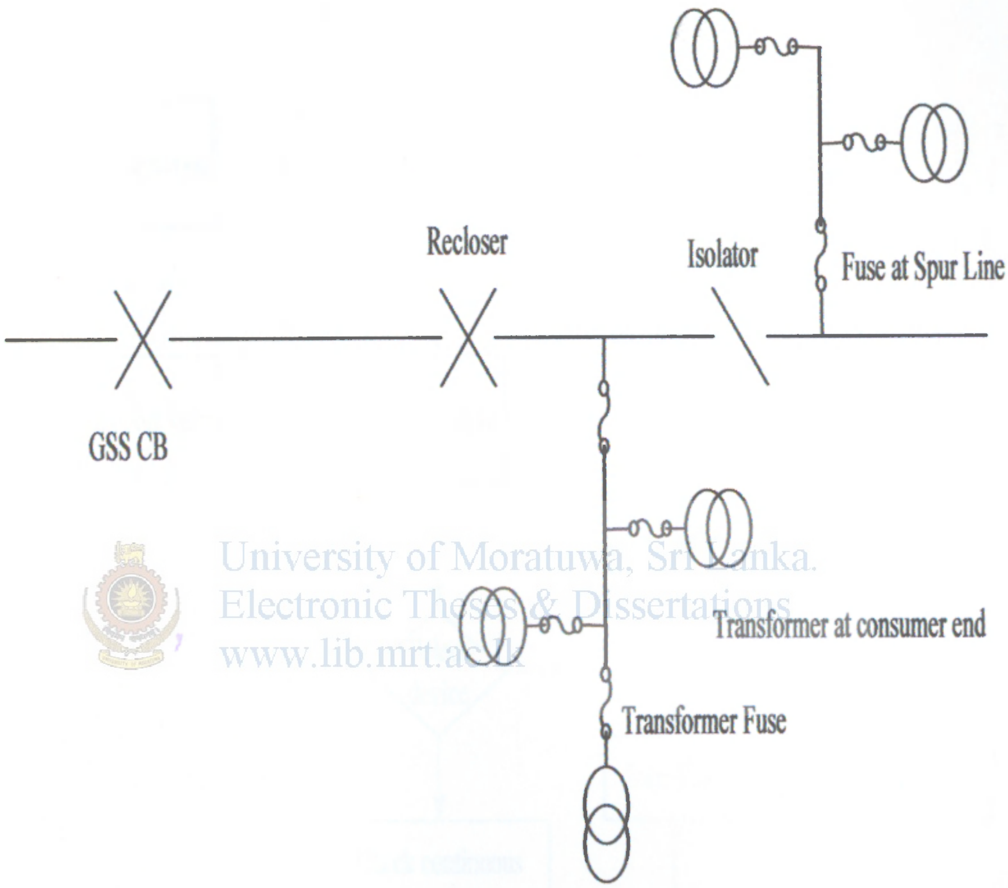

Figure 4.7 - Network diagram

5. If the coordination between devices is success, new protection scheme could be adopted.
6. If there is a miscoordination between protective devices, It should be classified recloser to fuse, fuse to fuse and relay to relay as follows;

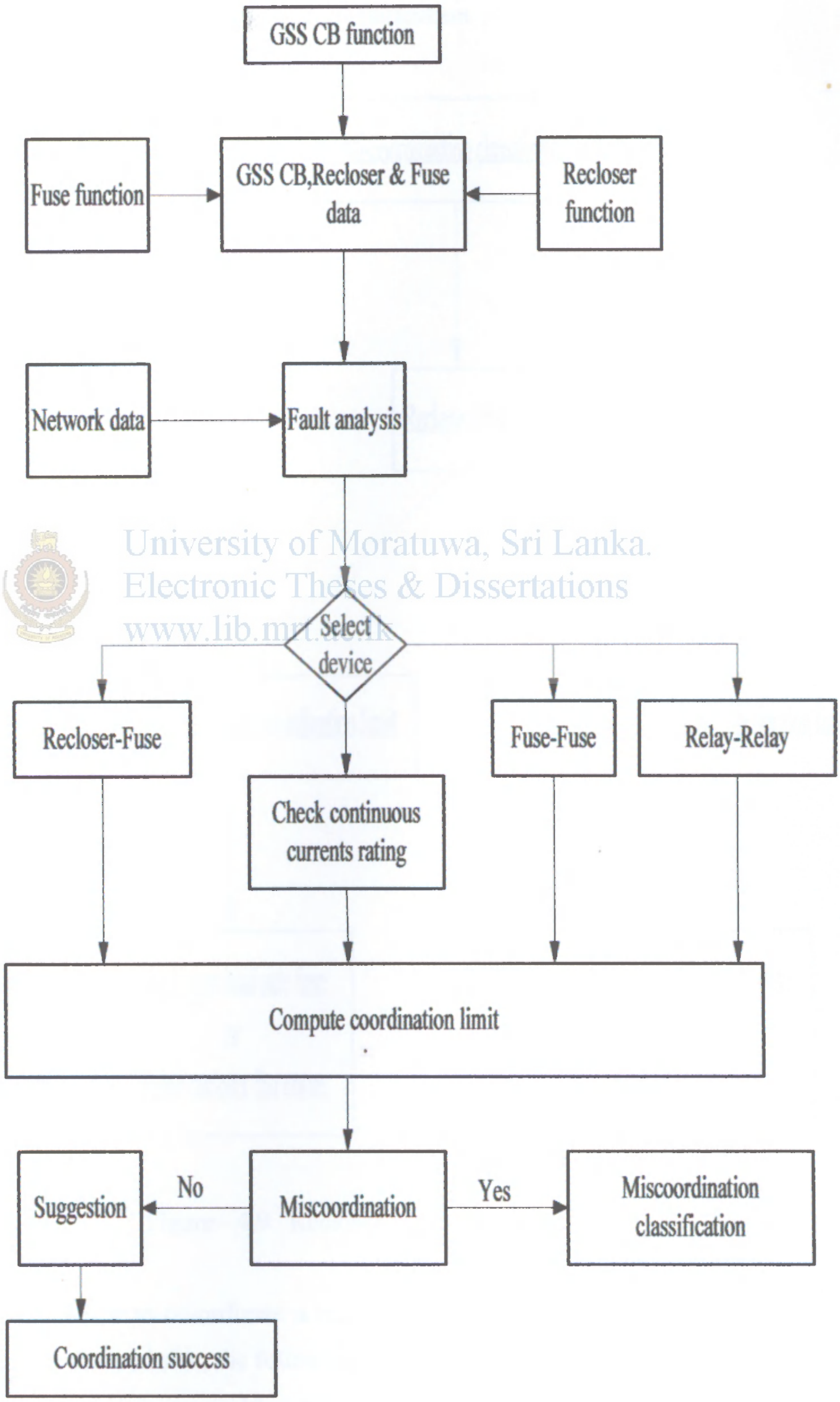

Figure 4.8- Algorithm for the new protection scheme design

Recloser – fuse miscoordination classification

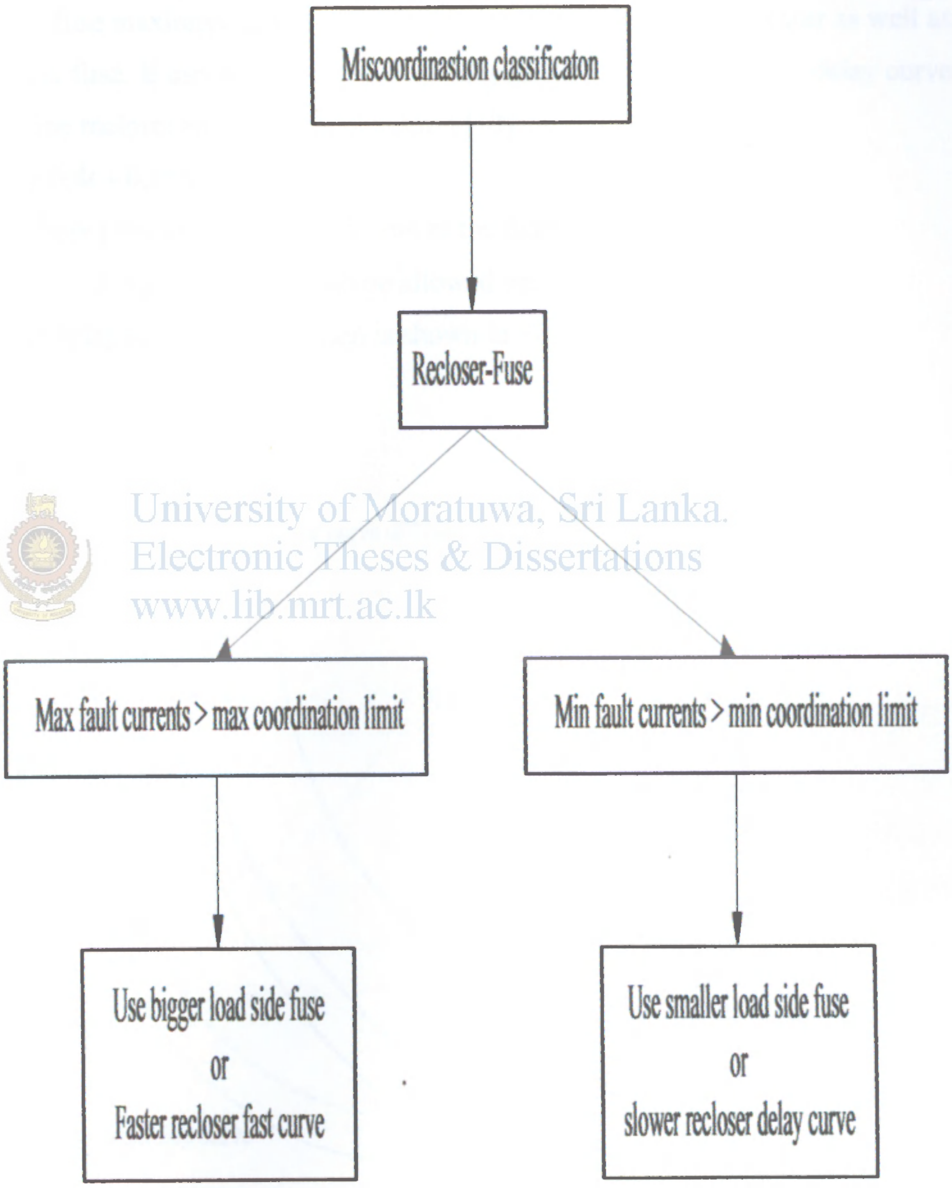

Figure - 4.9 Recloser to fuse miscoordination classification

The procedure to co-ordinate a reloser and a fuse is shown in Figure 4.9, when the fuse is at the load side, the following rules is applied [6]:

- The minimum melting time of the fuse must be greater than the fast curve of the recloser times the multiplying factor (k), given in Table 4.2. The recloser to fuse coordination curves are shown in Figure 4.10.

- The maximum clearing time of the fuse must be smaller than the delay curve of the recloser without any multiplying factor. If the delay curve of recloser and fuse maximum clearing curve coincide, it causes to trip recloser as well as blow fuse. It can be overcome by giving grading margin between delay curve of the recloser and the fuse as follows [13].

  $t' = 0.4t + 0.15 Seconds$

  Where t = nominal operating time of the fuse

  t' = grading margin to be allowed between the relay and the fuse

  The relay to fuse coordination is shown in Figure 4.11

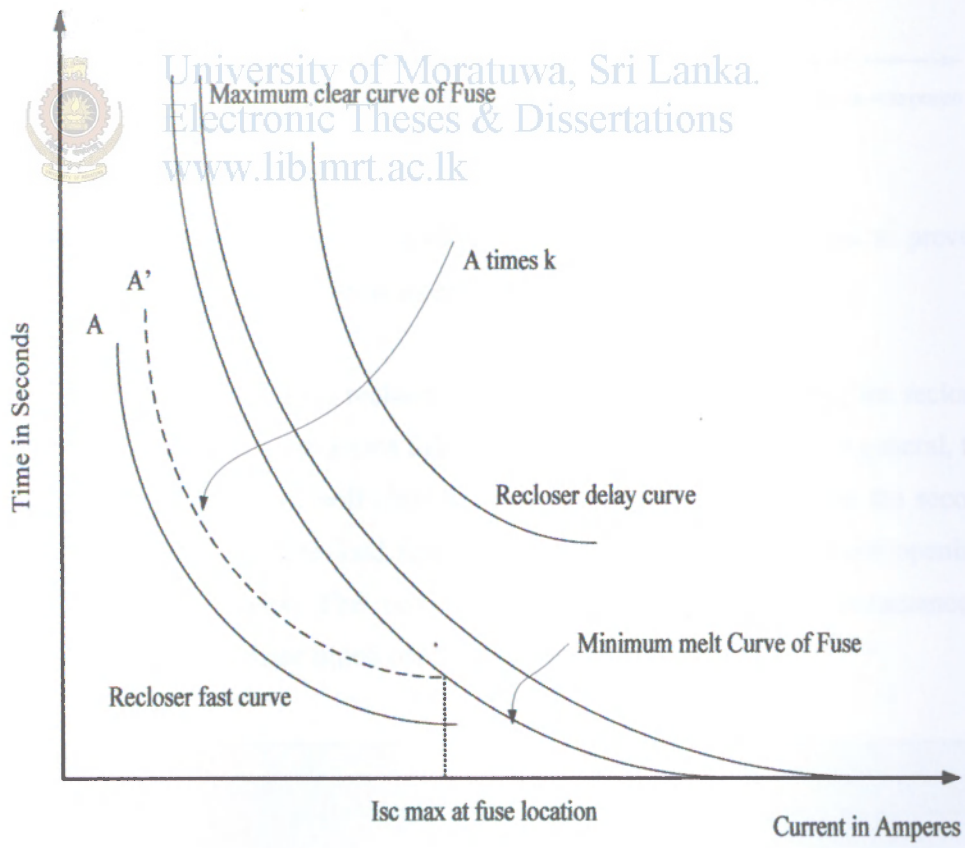

Figure 4.10 – Recloser to fuse coordination curves

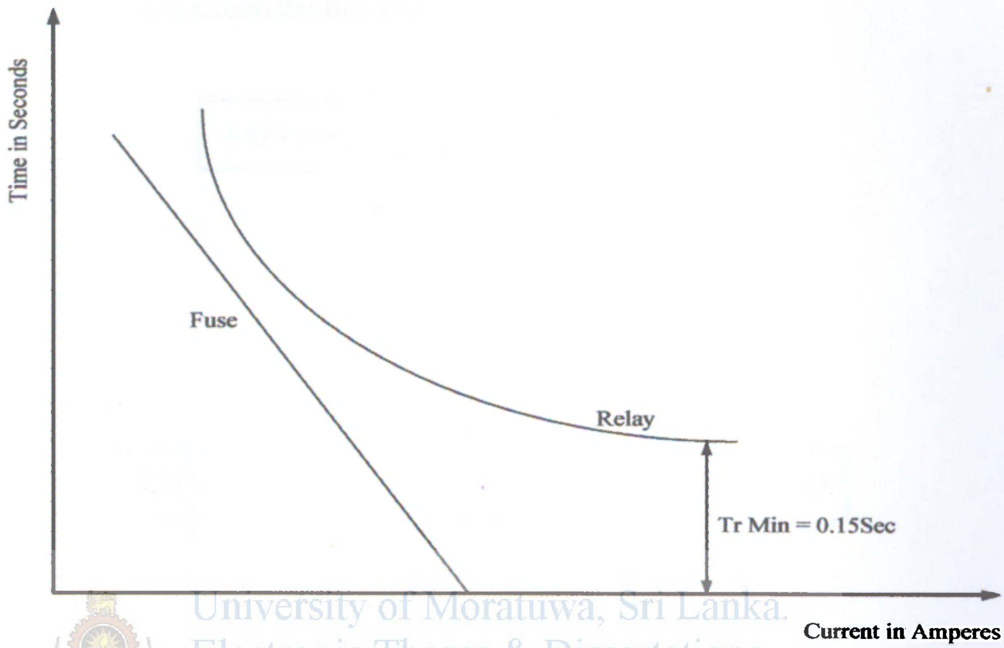

Figure 4.11 - Relay to fuse coordination curves

- The recloser should have at least two or more delayed operations to prevent loss of service in case the recloser trips when the fuse operates.

Better co-ordination between a recloser and a fuse is obtained by setting the recloser to give two instantaneous operations followed by two timed operations. In general, the first opening of the recloser will clear 80% of the temporary faults, and the second will clear a further 10%. The load fuses are set to operate before the third opening, clearing permanent faults. The co-ordination obtained using one instantaneous operations followed by three timed operations is less effective.

Reclosing time in cycle	Multipliers for	
	one fast operation	two fast operation
25-30	1.25	1.80
60	1.25	1.35
90	1.25	1.35
120	1.25	1.35

Table 4.2- Multiplying factor (k) for recloser curve

Fuse to fuse miscoordination classification

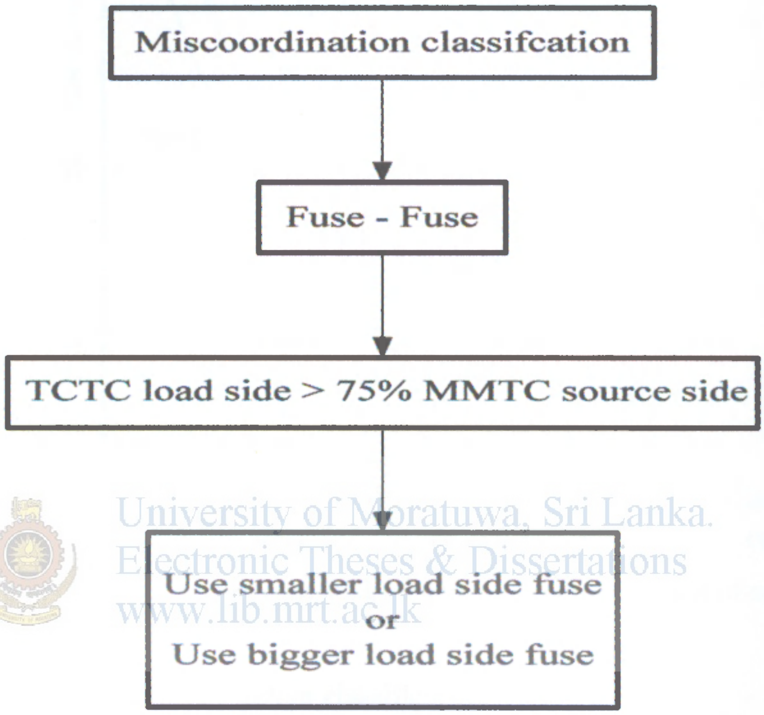

Figure 4.12 – Fuse to fuse miscoordination classification

The fuse to fuse coordination criteria is shown in Figure 4.12. The essential criterion when using fuses is that the maximum clearance time for a main fuse should not exceed 75% of the minimum melting time of the back-upfuse. ($T1<0.75\times T2$) [13]. The fuse to fuse coordination of curves is shown in Figure 4.13.

Simple 'RULE OF THUMB' for grading

Choose $I_{FA} \approx 2\times I_{FB}$ Where; I_{FA} = Fuse current rating at source side

I_{FB} = Fuse current rating at load side

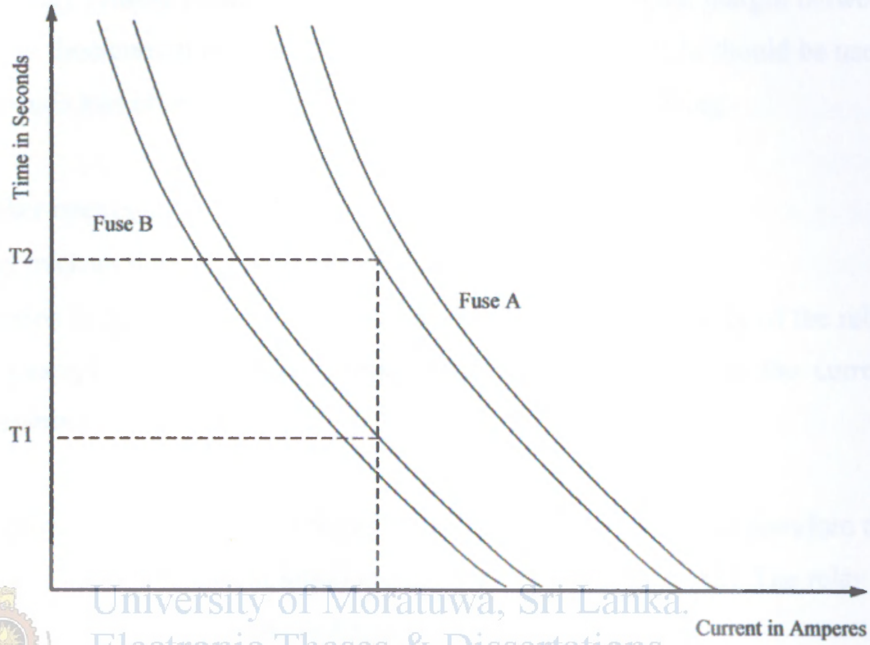

Figure 4.13 – Fuse to fuse coordination of curves

Relay to Relay miscoordination classification

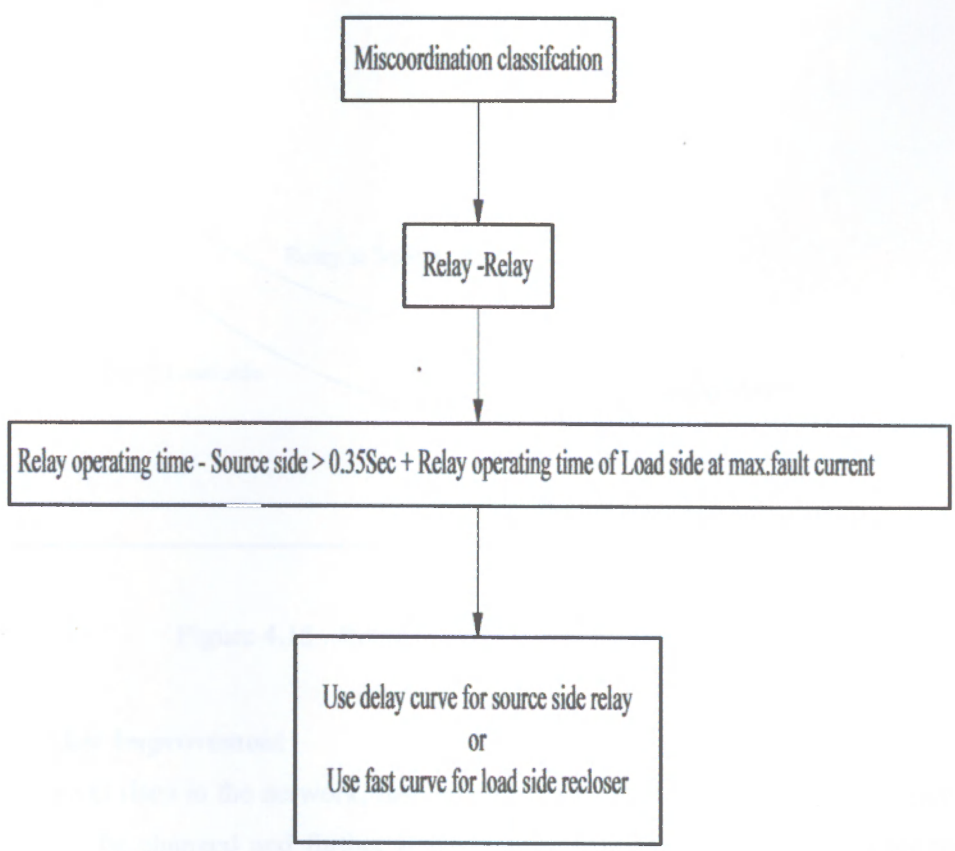

Figure 4.14 – Relay to relay miscoordination classification

The relay to relay criteria is shown in Figure 4.14. A discrimination margin between two successive time/current characteristics of the order of 0.3s to 0.5s should be used. This value avoids loss of selectivity due to one or more of the following:

- Breaker opening time.
- Relay overrun time after the fault has been cleared.
- Variation in fault levels deviations from the characteristics curves of the relay (for example, due to manufacturing tolerances), and errors in the current transformers.

In modern relays the overrun time is negligible, or even nonexistent, and therefore the margin could be chosen at the minimum indicated above, i.e. 0.35S [13]. The relay to relay coordination curves are shown in Figure 4.15.

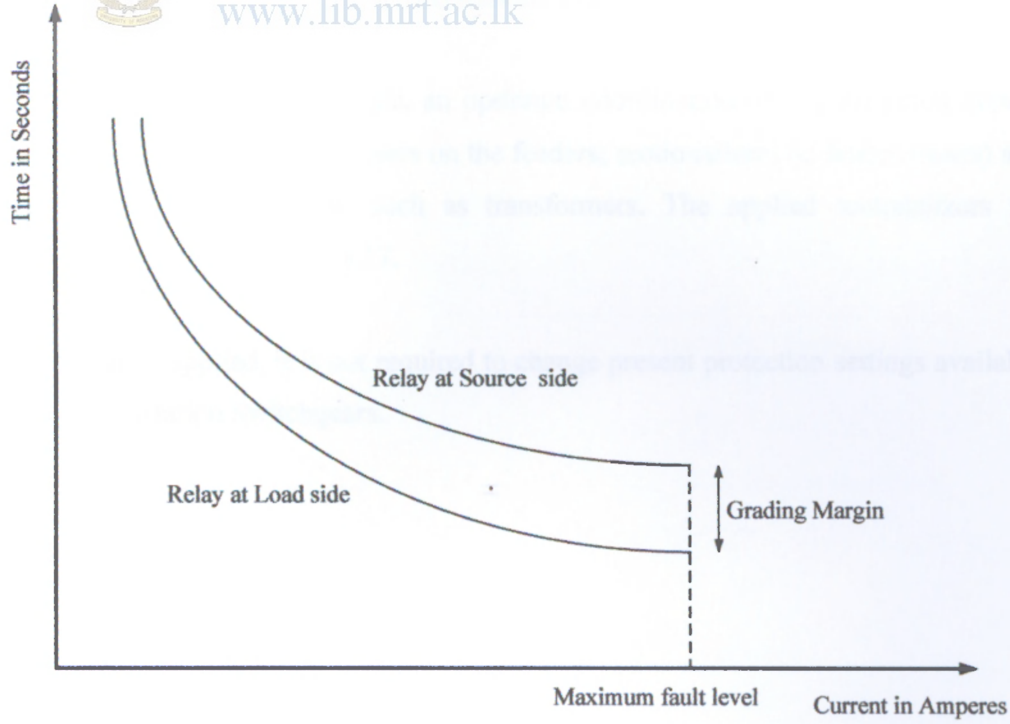

Figure 4.15– Relay to relay coordination curves

4.2.2. Further improvement

If the fault level rises in the network, fuse ratings and protection settings of upstream devices are to be changed and further if the fault persist in the section it causes to lockout recloser affecting all customers in the feeder.

The above problems can be avoided by the advent of an automatic sectionalizer which can be used directly in place of 33kV fuses. It is shown in Figure 4.16. A sectionalizer is a protective device which has no time-current characteristics and does not interrupt fault. When subjected to an overcurrent followed by a current below its minimum threshold, it merely counts backup recloser operations. After predetermined number of such operations, it isolates the circuit while the backup recloser is in the open position. The recloser is then allowed to close, restoring the service to unaffected sections of the system. If the fault is temporary and is cleared before the sectionalizer count reaches the predetermined number, the sectionalizer remains closed and resets to its original state after a predetermined time.

With no fuse curve to intersect recloser time-current characteristics, the coordination range is extended to the system maximum available short-circuit current. As an added benefit, the transformer fuse link becomes an independent entity.

Based on the foregoing analysis, an optimum coordination of a distribution system can be achieved by using reclosers on the feeders; sectionalizers on lateral (spurs) and fuses to protect equipment such as transformers. The applied sectonalizers for network is shown in Figure 4.17.

If this can be applied, it is not required to change present protection settings available in Grid Substation Switchgears.

Figure 4.16 – Sectionalizer device

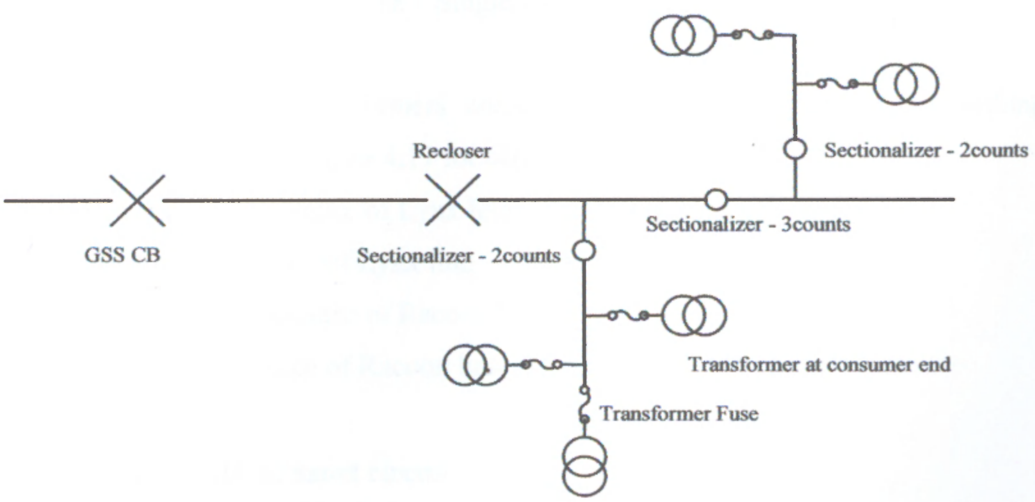

Figure 4.17 - Sectionalizers in 33kV network

Most of switching gantries are situated in rural areas (low load currents) and single phasing can be permitted. Therefore single phase sectionalizers can be used for spurs. A three phase sectionalizers can be used for industrial consumers and heavy load currents lines.

4.3. Sample design: Kalumale Feeder

The single circuit diagram of Kalumale Feeder from Matuama GSS is shown in Figure 4.18. The above algorithm model described in section 4.4 is used to design new protection scheme for Kalumale feeder.

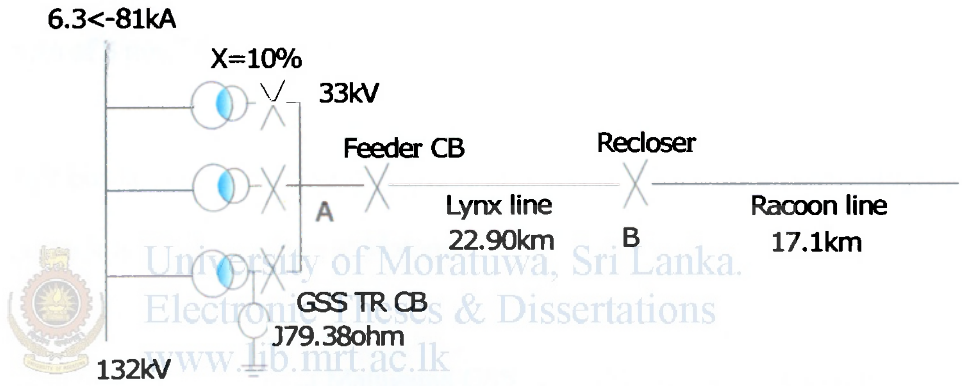

Figure 4.18 – Single line diagram of Kalumle Feeder

There are 3 earthing transformers connected to each Transformer one earthing transformer is shown in Figure 4.17 for clarity.

Positive sequence impedance of Lynx line = 0.177+j0.335 Ω/km

Zero sequence impedance of Lynx line = 0.325+j1.0239 Ω/km

Positive sequence impedance of Racoon line= 0.431+j0.375 Ω/km

Zero sequence impedance of Racoon line = 0.579+j1.1123 Ω/km

4.3.1. Calculation of short circuit current

Kalumale feeder of Kithulgoda Gantry is selected for short-circuit calculation. Kithulgoda gantry is fed by Matugama Grid substation.

The Fault level at 132kV bus at Matugama GSS = $6.3\angle -81$

Fault level in MVA at Matugama GSS = $\sqrt{3} \times 132 \times 6.3$ MVA

= 1440.33 MVA

Assume 100MVA base

Z_{pu} at 132kV bus $= \dfrac{MVAbase}{\sqrt{3} \times kVbase \times Ifault}$

$$Z_{pu} = \frac{100}{\sqrt{3} \times 132 \times 6.3\angle -81}$$

$$Z_{pu} = 0.0108 + j\ 0.0686$$

Impedances of Transformers at Matugama GSS = 10% at 31.5MVA

Impedances of 3 nos.T/F at Matugama GSS $= \dfrac{100 \times 10}{31.5 \times 100} \times \dfrac{1}{3}$

$= j\ 0.1058$

Z_{pu} at 33kV bus at Matugama GSS $= 0.0108 + j0.1744$ - - - (a)

Hence, pu fault level of 33kV bus at Matugama GSS $= \dfrac{1}{0.0108 + j0.1744}$

$= 5.72kA$

Actual, fault level at 33kV bus at Matugama GSS = (MVA) base× (pu fault level)

= 100×5.72 = 572 MVA

Maximum 3-phase fault current of 33kV at Matugama GSS

$$= \frac{MVAbase}{\sqrt{3} \times kVbase}$$

$$= \frac{572}{\sqrt{3} \times 33} = 10\ kA$$

Impedance of double circuit LYNX line = 0.177 + j0.335 Ω/km

Distance from Matugama GSS to Kitugoda Gantry = 22.90 km

Impedance of Lynx line from Matugama·GSS to Kithulgoda Gantry

= 22.90× (0.177 + j0.335)

= 4.0533+j 7.6715 Ω

$$Z_{base} = \frac{kVb^2}{MVAbase} = \frac{33^2}{100} = 10.89$$

Z_{pu} of Lynx line $= \dfrac{4.0533 + j7.6715}{10.89}$

$= 0.3722 + j0.7045$ - - - (b)

Total Z_{pu} from GSS to Switching Gantry $= 0.383 + j0.8789$ - - - (a+b)

Hence pu fault level at Switching gantry $= \dfrac{1}{|0.383 + j0.8789|} = 1.04$

Actual fault level at Switching gantry $= 100 \times 1.04 = 104$ MVA

Maximum 3-Phase fault current at switching gantry $= \dfrac{104}{33 \times \sqrt{3}} = 1.820$ kA

The longest distance of Kalumale feeder from switching gantry

$= 17.1$ Km

The impedance of Kalumale feeder (Racoon line) $= 0.431 + j0.375\ \Omega/\text{km}$

Total impedance o Kalumale feeder $= 17.1 \times (0.431 + j0.375)$

$= 7.3701 + j6.4125\ \Omega$

Z_{pu} of Racoon line $= \dfrac{7.3701 + j6.4125}{10.89}$

$= 0.6768 + j0.5888$ - - - (c)

Total Zpu from GSS to longest feeder of Kalumale $= 1.0598 + j1.4677$ -(a+b+c)

Actual pu fault level at longest point of

Kalumale feeder $= \dfrac{1}{|1.0598 + j1.4677|} = 0.552$

Actual fault level at longest point of Kalumale feeder $= 100 \times 0.552 = 55.2$ MVA

Maximum 3-Phase fault current at longest point of Kalumale feeder

$= \dfrac{55.2}{33 \times \sqrt{3}} = 0.966$kA

4.3.2. Calculation of earthfault current

The zero sequence impedances of Transformers at

Matugama GSS $= j79.38\Omega$

Per unit zero sequence impedance at 33kV bus at

Matugama GSS $= \dfrac{100 \times 79.38}{33^2 \times 3} = j2.4298$

Assume fault resistance $= 40\Omega$

Per unit impedance of fault resistance $= \dfrac{40}{10.89} = 3.6731$

Positive sequence impedance at 33kV bus at

Matugama GSS $= 0.0108 + j0.1744$ ---- (a)

The per unit earthfault current of 3-Phase system is given by following equation.

$$If = \frac{3}{|Z1 + Z2 + Z0 + 3 \times Zf)|}$$

Where; Z1=Positive sequence impedance

Z2=Negative sequence impedance

Z0=Zero sequence impedance

Zf=Fault impedance

The earth fault currents are calculated for two different fault impedance values 0 Ω & 40Ω.

Assume positive and negative sequence impedances are equal (Z1=Z2).

When fault impedance is zero, per unit earthfault current at 33kV bus at Matugama

$$If = \frac{3}{|2(0.0108 + j0.1744) + j2.4298|}$$

$$= 1.08$$

Actual earthfault current at 33kV bus at Matugama $= \frac{1.08 \times 100}{\sqrt{3} \times 33} = 1.890\text{kA}$

$$= 1890\text{A}$$

When fault impedance is 40Ω, per unit earthfault current at 33kV bus at Matugama

$$If = \frac{3}{|2(0.0108 + j0.1744) + j2.4298 + 3 \times 3.6731|}$$

$$= 0.2635$$

Actual earthfault current at 33kV bus at

Matugama GSS $= \frac{0.2635 \times 100}{\sqrt{3} \times 33} = 0.461\text{`kA}$

$$= 461\text{A}$$

Zero sequence impedance of Lynx line = 0.325+j1.0239 Ω/km

Total zero sequence impedance from GSS to

Kithulgoda Gantry = (0.325+j1.0239) ×22.9

= 7.4425+j23.4473 Ω

Per unit impedance of Lynx line $= \frac{7.4425 + j23.4473}{10.89}$

= 0.6834+j2.1531- - - (d)

Positive sequence impedance from GSS to

Kithulgoda Gantry = 0.383+j0.8789 - - - (a+b)

When fault impedance is zero per unit earthfault current at Kithulgoda Gantry

$$If = \frac{3}{|2(0.383 + j0.8789) + 0.6834 + j2.1531 + j2.4298|}$$

$$= \frac{3}{|1.4494 + j6.3407|} = 0.461$$

Actual earthfault current at Kithulgoda Gantry $= \dfrac{0.461 \times 100}{\sqrt{3} \times 33} = 0.807\text{kA}$

$= 807\text{A}$

When fault impedance is 40Ω, per unit earthfault current at Kithulgoda Gantry

$$If = \frac{3}{|2(0.383 + j0.8789) + 0.6834 + j2.1531 + j2.4298 + 3 \times 3.6731|}$$

$$= \frac{3}{|12.4687 + j6.3407|} = 0.214$$

Actual earthfault current at Kithulgoda Gantry $= \dfrac{0.214 \times 100}{\sqrt{3} \times 33} = 0.374\text{ kA}$

$= 374\text{A}$

Zero sequence impedance of Racoon line = 0.579+j1.1123 Ω/km

Total zerosequense impedance from Kithulgoda Gantry

to longest feeder of Kalumale Feeder = (0.579+j1.1123)×17.1

= 9.9009+j19.0203 Ω

Per unit impedance of line $= \dfrac{9.9009 + j19.0203}{10.89}$

= 0.9092+j1.7466 - - - (e)

Total zero sequence impedance of

Lynx & Racoon line = 1.5926+j3.8997 - - - (d+e)

The positive sequence impedance from GSS to longest point of

Kalumale Feeder = 1.0598+j1.4677 (a+b+c)

When fault impedance is zero, per unit earthfault current longest point of Kalumale Feeder

$$If = \frac{3}{|2(1.0598 + j1.4677) + 1.5926 + j3.8997 + j2.4298|}$$

$$= \frac{3}{|3.7122 + j9.2649|} = 0.301$$

Actual earthfault current at longest point of

$$\text{Kalumale Feeder} = \frac{0.301 \times 100}{\sqrt{3} \times 33} = 0.527\text{kA}$$

$$= 527\text{A}$$

When fault impedance is 40Ω, per unit earthfault current longest point of

$$\text{Kalumale Feeder } If = \frac{3}{|2(1.0598 + j1.4677) + 1.5926 + j3.8997 + j2.4298 + 3 \times 3.6731|}$$

$$= \frac{3}{|14.7315 + j9.2649|} = 0.172$$

Actual earthfault current at longest point of

$$\text{Kalumale Feeder} = \frac{0.172 \times 100}{\sqrt{3} \times 33} = 0.301\text{kA}$$

$$= 301\text{A}$$

4.3.3. Selection of the number of recloser attempts

A present recloser attempt to lockout is 3. Most of the temporary faults are cleared by fist attempt. Analysis data of Gantry feeders shows that first opening of the recloser clear 62% of the temporary faults and second opening clear a further 5% (see Table 3.5).

Better coordination between the recloser and the fuse is obtained by setting the recloser to give two instantaneous operations followed by two timed operations. First dead time is selected as 0.5S and others as 2S.

4.3.4. Selection protection setting

Current rating of Racoon line of Kaumale Feeder = 200A

Therefore selected over current setting of recloser = 200A

The maximum short-circuit current of Kalumale Feeder = 1820A

Therefore Instantaneous current setting = Current transformer ratio × Plug setting multiplier of relay

=200×6= 1200A

(Instantaneous setting = 50% of the maximum short-circuit current at the point of connection of the relay or between six to ten times of maximum circuit current [6])

The opening time of the recloser at above 1200A (phase current) =0.04 S

The minimum time to prevent hot the fuse at Max.fault current = 1.8×0.04

(Select maximum multiplying factor as 1.8 from Table 4.2) = 0.072 S

3 -Phase fault current at Spur Point '1' = 1506A

(Calculated as earlier- 4.2km from Switching Gantry to spur point '1')

It can be selected 50A fuse - T type (slow type – high speed ratio) for coordination with reclosers for matching maximum short circuit current capacity at Spur Point -1.

The minimum time to prevent hot the50A fuse at maximum

fault Current (1506A) = 0.077S

The fuse minimum melting time (0.077S) is above the recloser times the multiplying factor. (Time with multiplying factor = 0.072S)

Therefore fuse will be protected by preheating.

The selected fast overcurrent tripping

curve of recloser [5] = 162

(Curve-162-Specified curve for Nulec reclosers)

TMS of fast tripping Curve = 0.05

(Above curve and TMS is selected to operate recloser at minimum time & to match Fuse Curve).

Then it can be found delay tripping curve for overcurrent settings of recloser.

Relay operating time at the maximum fault current- t = 0.4t'+0.15S (t'=Nominal operating time of fuse)

Therefore recloser operating time at the Maximum short circuit

fault current at Spur point -1 $= 0.4\times0.13 + 0.15$

$= 0.202$ S

Select delay operating time of recloser as extremely inverse to better coordination of fuse

Operating time of extremely inverse curve $= \dfrac{80TMS}{\left(\dfrac{I}{Is}\right)^2 - 1}$

Where; TMS – Time Multiplier second

I – Operating current

Is – Current transformer ratio

Therefore suitable TMS value for recoser delay curve $= 0.202\dfrac{\left(\dfrac{1506}{200}\right)^2 - 1}{80}$

$= 0.14$

Therefore TMS value can be selected for recloser delay curve above 0.14.

Then above curves are drawn in SynerGEE Electric Program and it is selected TMS value of delay curve of reloser as a 0.25.

Then it should be find protection settings of Feeder GSS circuit breaker because present setting is not coordinate with recloser.

Maximum short circuit current at Gantry $= 1820A$

Operating time of recloser at this short circuit current at Gantry

$$= \frac{80 \times 0.25}{\left(\frac{1820}{200}\right)^2 - 1}$$

$$= 0.24\ S$$

The usually better margin for relay to relay $= 0.35\ S$

Operating time of the GSS CB a fault current of 2782A $= 0.24+0.35$

$$= 0.59\ S$$

The selected curve of GSS CB is Very inverse Inverse

Operating time of Very inverse curve

$$= \frac{13.5TMS}{\left(\frac{I}{Is}\right) - 1}$$

TMS of GSS

$$= 0.59 \frac{\left(\frac{1820}{400}\right) - 1}{13.5}$$

$$= 0.16$$

Therefore TMS value can be selected for GSS CB delay curve is selected as above 0.16. Then above curves are dawn in SynerGEE Electric Program. It is found better TMS value is 0.20.

The maximum short circuit current at Kaumale Feeder $= 1820A$

Suitable Instantaneous value to prevent operate relay for outside faults $= 1820 \times 1.2 = 2184A$

The application of an instantaneous unit makes possible a reduction in the tripping time at high fault levels and also allows the discriminating curves behind the high set unit to be lowered thereby improving overall system grading.

When using high set units it is important to ensure that the relay does not operate for faults outside the protected section. The relays are normally set at 1.2-1.3 times the maximum fault level at the remote end of the protected section [13].

The selected Instantaneous value of GSS Feeder CB $= 400\times6=2400A>2184A$

Now it should be checked whether the new protection settings of GSS CB is matched with GSS T/F CB.

GSS T/F Protection settings:

Current transformer ratio = 600/5A

PSM = 5A

TMS = 0.325

Curve = Standard Inverse

Operating time of standard inverse curve $$= \frac{0.14TMS}{\left(\frac{I}{Is}\right)^{0.02} - 1}$$

Maximum short circuit current at GSS Bus $= 10000A$

Operating time of GSS Feeder CB $$= \frac{13.5\times0.20}{\left(\frac{10000}{400}\right) - 1}$$

$= 0.11$ Sec

Operating time of T/F GSS CB $$= \frac{0.14\times0.325}{\left(\frac{10000}{600}\right)^{0.02} - 1}$$

$= 0.78$ S

Time margin of at maximum short circuit current $= 0.78-0.11=0.67S$

Time margin is above 0.35 S.Therefore existing protection setting of GSS TR CB is enough. The overcurrent setting of protective devices with 50A fuse is shown in Figure 4.19.

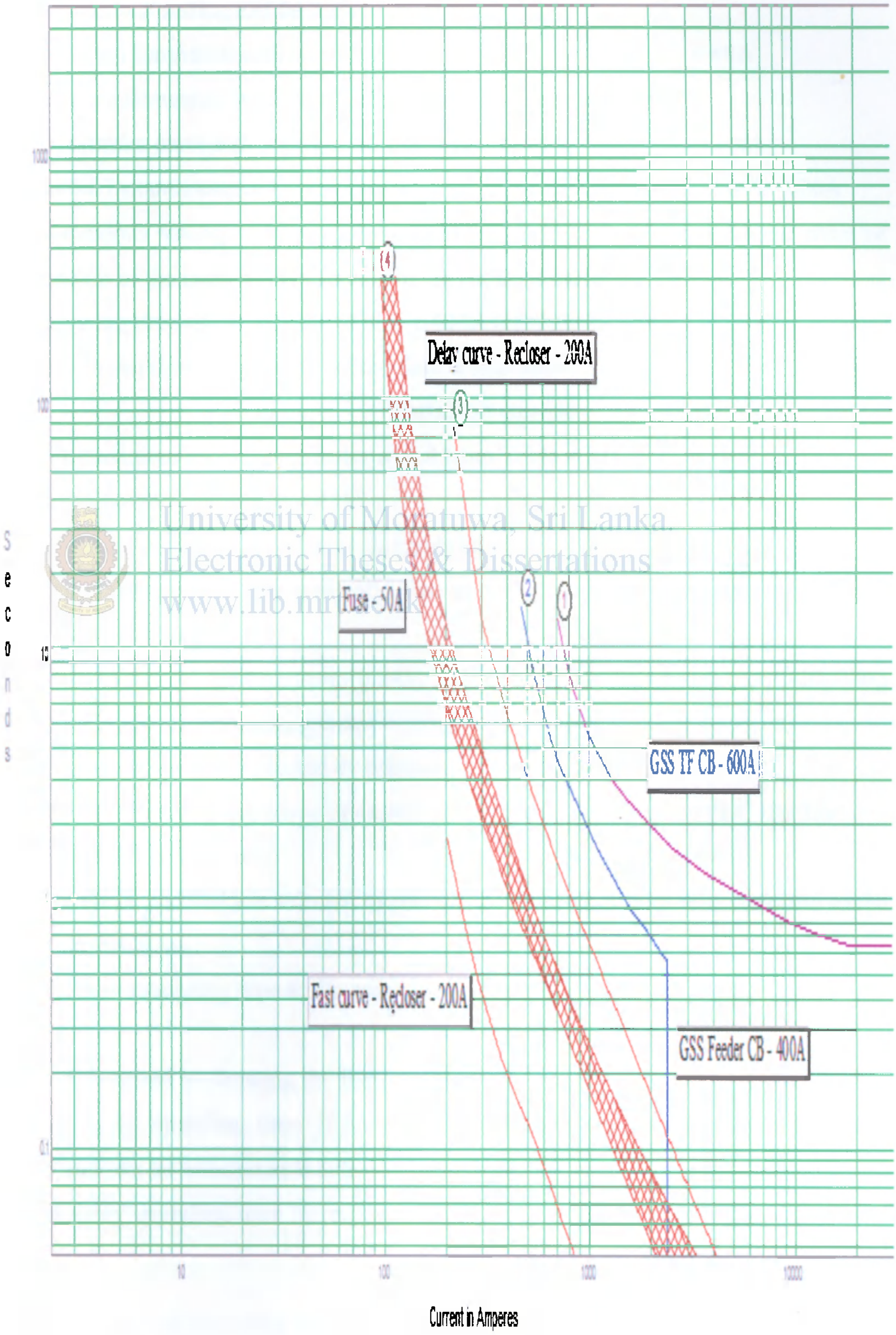

Figure 4.19 – Overcurrent settings of protective devices with 50A fuse

Then earthfault setting can be found.

The selected Earthfault setting of recloser = 60A

(Unbalance allowance is taken as 30% from overcurrent setting [6])

The maximum earthfault current of Kalumale Feeder = 808A

Therefore Instantaneous current setting = 60×7= 420A

(Instantaneous setting = 50% of the maximum short-circuit current at the point of connection of the relay or between six to ten times of earthfault setting)

The opening time of the recloser at above 420A (earthfault current)=0.04 S

The minimum times to prevent hot the fuse at maximum

earthfault current = 1.8×0.04

(Select maximum multiplying factor as 1.8 from Table 4.2) = 0.072 S

Earth fault current at Spur Point '1' = 715A

(Calculated as earlier-4.2km from Switching Gantry)

The minimum melting time of the 50A fuse at maximum

fault Current (715A) = 0.34S

The fuse minimum melting time (0.34S) is above the recloser times the multiplying factor. (Time with multiplying factor = 0.072S)

Therefore fuse will be protected by preheating.

The selected fast tripping curve of earthfault recloser = IEC Ext Inv

TMS of fast tripping Curve = 0.05

(Above curve and TMS is selected to operate the recloser at minimum time and to the match Fuse Curve.)

The recloser operating time at the maximum earthfault

fault current at Spur point -1=0.49S

(Time is selected by drawing the fuse curve)

Therefore the operating time of the recloser earthfault delay curve should be above 0.49S and can be selected as 0.50S.

Select delay operating time of recloser as extremely inverse to better coordination of fuse

Operating time of extremely inverse $= \dfrac{80TMS}{\left(\dfrac{I}{Is}\right)^2 - 1}$

Therefore suitable TMS value for recoser delay curve $= 0.50\dfrac{\left(\dfrac{715}{60}\right)^2 - 1}{80}$

$= 0.88$

Therefore TMS value can be selected for recloser delay curve above 0.88.

Above curves are drawn in SynerGEE Electric Program and TMS value of delay curve of reloser is selected as 2.0 in order to overcome minimized the intersect delay curve of recloser and the 50A fuse. (The maximum TMS setting for the recloser is 2.0)

Then protection settings of GSS Feeder Circuit breaker should be found because the present setting does not coordinate with the recloser.

Maximum eartfault current at Gantry $= 808A$

Operating time of recloser at this short circuit current at Gantry $= \dfrac{80 \times 2.0}{\left(\dfrac{808}{60}\right)^2 - 1}$

$= 0.89$ S

The usually better margin for relay to relay $= 0.35$ S

Operating time of the GSS CB a fault current of 776A $= 0.89+0.35$

$= 1.24$ S

The selected earthfault current setting of GSS Feeder CB $= 100A$

(Unbalance allowance is taken as 25% from overcurrent setting)

The selected curve of GSS CB is Extremely Inverse

TMS of GSS CB $=1.24\dfrac{\left(\dfrac{808}{100}\right)^2 - 1}{80}$

$= 1.0$

Therefore TMS value can be selected for GSS CB delay curve is selected as 1.0 by drawing above curves in SynerGEE Electric program.

The maximum earthfault current at Kalumale Feeder $= 808A$

Suitable instantaneous value to prevent relay operation for outside faults $= 808 \times 1.2 = 970A$

The selected instantaneous value of GSS Feeder CB $= 100 \times 10 = 1000A > 970A$

Now it should be checked whether the new protection settings of GSS CB is matched with GSS T/F CB.

GSS T/F Protection settings:

Current transformer ratio = 600/5A

Earth fault settings

PSM	= 0.65A
TMS	= 0.325
Curve	= Standard Inverse
Maximum earthfault current at GSS Bus	= 1890A
Operating time of GSS Feeder CB	= 0.04S

Operating time of T/F GSS CB

$$= \frac{0.14 \times 0.325}{\left(\frac{1890}{78}\right)^{0.02} - 1}$$

$$= 0.69 \text{ S}$$

Time margin at maximum short circuit current = 0.69-0.04

=0.65S

Time margin is above 0.35S. The margin is sufficient, but it can be seen curves of GSS CB and GSS Transformer intersect at lower current values Earth fault setting of GSS CB is 100A and GSS Transformer CB is 78A. Therefore new protection setting should be applied to GSS Transformer CB.

As earlier calculations and by drawing curves in SynerGEE Electric program following settings is selected.

Earth fault settings of GSS Transformer CB	= 150A
Curve	= IEC Very inv
TMS	=1.0

The stand by earth fault setting can also be set of the same values. The earth fault settngs of protective devices with 50A fuse is shown in Figure 4.20.

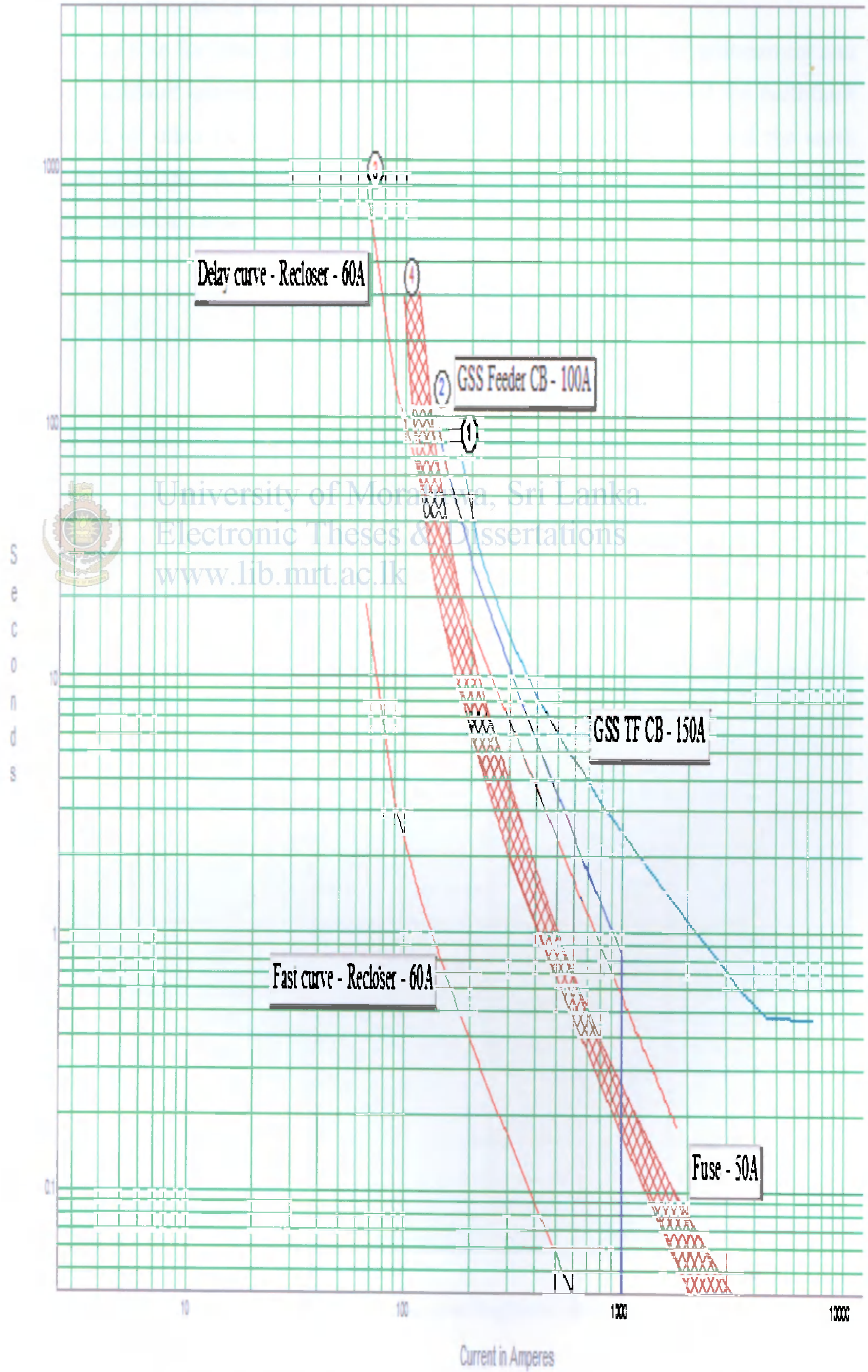

Figure 4.20 – Earthfault settings of protective devices with 50A fuse

4.3.5. Selection fuses for spurs at Kalumale Feeder.

The selected fuse for spur point '1' is 50A. It is the maximum short circuit current and also the earthfault current point of spurs. The short circuit current and the earthfault currents of all other points are below maximum short-circuit current and the earth fault current at spur point '1'. Therefore 50A fuse can be selected for other points also. The connected fuse links for Transformers and Spurs are listed in Table 4.3.

Spur Point	Sin No	Transformer-Capacity (kVA)	Recommended fuse link connected to Transformer (A)	Present Connected Fuse Capacity	Selected Fuse Capacity (A)
1	A12	250	8	40	50
	A71	160	6		
	A11	160	6		
	A90	1000	20		
2	A50	100	3	15	50
	A60	100	3		
	A80	100	3		
	A68	100	3		
3	A59	100	3	15	50
	A13	160	6		
	A73	100	3		
4	A16	100	3	20	50
	A46	160	6		
	A17	250	8		
	A28	100	3		
5	A19	250	8	15	50
	A20	160	6		
6	A64	160	6	10	50
7	A24	100	3	10	50
	A44	100	3		

Table 4.3 Connected fuse links in Kalumale feeder with new protection scheme

There are fuses at spurs for transformer protection. It should be checked whether the 50A fuse is properly coordinated with them. Following fuse coordination should be checked.

1. 50A (T type) fuse to 20A (K type) fuse
2. 50 A (T type) fuse to 8A (K type) fuse
3. 50 A (T type) fuse to 6A (K type) fuse
4. 50 A (T type) fuse to 3A (K type) fuse

The fuse coordination between 50A (T type) fuse to 20A (K type) fuse should be matched because 50A fuse is 2.5 times 20A fuse. The 20A fuse is protected by 1000kVA Transformer and situated in Spur Point-1 with a distance from point-1 of 1.1km. The total clearing time of maximum short circuit current (1439A) of 20A (K type) fuse is 0.016S and the minimum melting time of that current for the 50A (T type) fuse is 0.080S. Therefore, the maximum clearance time for the main fuse does not exceed 75% of the minimum melting time of the back-up fuse. The Figure 4.21 shows coordination between 50A and 20A fuses. Other fuse coordination should also be matched similarly.

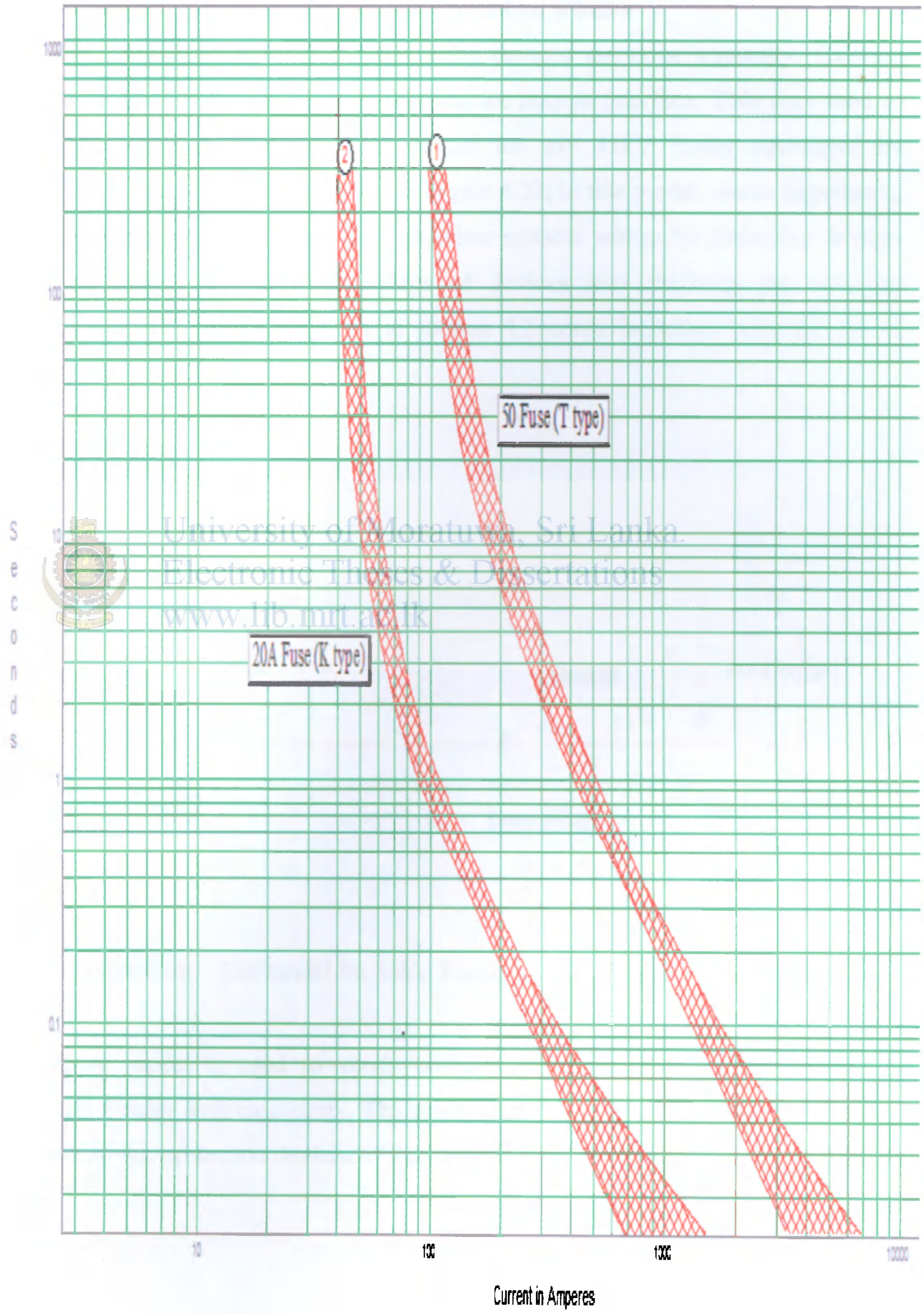

Figure 4.21 – Coordination of 50A (T type) fuse and 20A (K type) fuse

4.4. Computer based model for new protection scheme

Normally, coordination between protections devices are done manually. Existing practice is based upon set of rules that require human interface. This may lead to errors and incorrect operation. The model for any 33kV feeder developed by SynerGEE Electric program is shown in Figure 4.22. In this model source impedance, line length and impedances could be set. Then suitable values for protective devices could be found by changing settings of devices and checking the achieved coordination. The algorithm given in section 4.2 could be tested with the aid of network computer model.

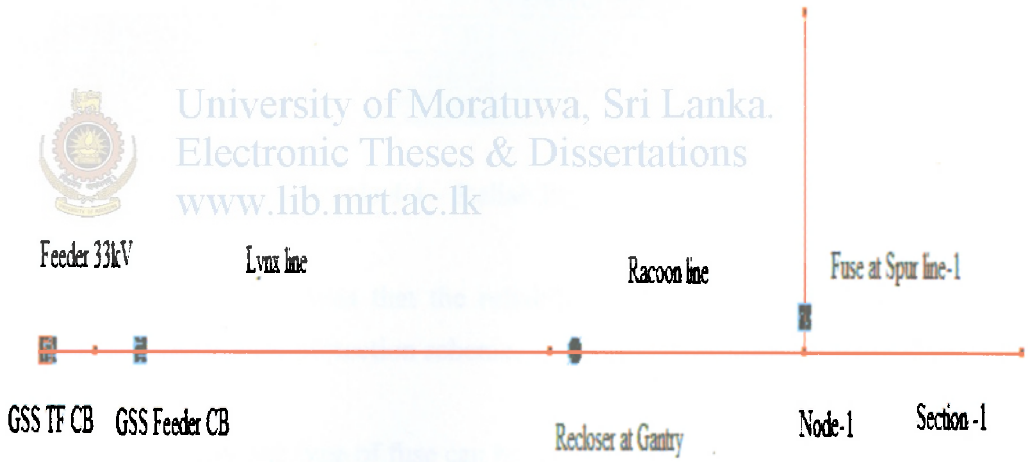

Figure 4.22 – The model for 33kV Feeder to analyze protection coordination

The above model is used to verify coordination between protective devices of Kalumale Feeder as a case study. The summarized fault report and the coordination results between protection devices of Kalumale Feeder are given in Appendix II & III.

4.5. Advantages using new protection scheme.

i. The new reliability indices for Kalumale Feeder if above protection scheme is adopted are shown in Table 4.4. These values are evaluated based on the model developed in Chapter 3.4.

	With old protection scheme	With new protection scheme(Insert 50A Fuse for Spurs)	With new protection scheme (Insert 50A Fuse for Spurs & Sectionalizers for Isolators)
SAIFI(int/yr)	5.6	3.5	3.5
SAIDI(h/yr)	67.5	39.3	35.6
ASAI	0.992295	0.995514	0.995936

Table 4.4 – Reliability indices of Kalumale Feeder

It can be seen that the reliability indices are significantly improved with new protection scheme.

ii. Only one type of fuse can be selected for all spurs. This reduces human errors, and also the number of different types of fuses to be stocked. The annual requirement of fuses used with old protection scheme in C.E.B is shown in Table 4.5 [15]. The old protection scheme causes nuisance fuse blowing. It saves 67% (Transient faults) of fuse requirement with new protection scheme and the saving financial is estimated to be Rs. 14,173,850.00.

Fuse type	Unit price (Rs)	Quantity	Cost (Rs)
10A	121.00	45000	5,445,000.00
15A	161.00	30000	4,830,000.00
20A	163.00	35000	5,705,000.00
40A	207.00	25000	5,175,000.00
Total cost			21,155,000.00

Table 4.5 – Annual requirement of fuse types of C.E.B

iii. The traveling time to find the fault is reduced because only faulty line is isolated by new protection scheme. (Consumers at faulty section will inform about supply outage to Consumer Service Centre). When we consider Kalumale Feeder with old protection scheme, the average fault finding distance is about 20km and average fault repairing time is 2hours.

Chapter 5

Conclusion & Recommendation

5.1. Improvement of reliability

The objective of this study is to improve reliability of 33kV network of C.E.B using effective fault isolating methodologies. The results of the study show that reliability of 33kV network is very poor compared to international level.

The reliability of 33kV network is directly related to the faults in the network. Most of the faults in the network are during the two rainy periods of the year.

There is no proper protection scheme to isolate the faulty sections of the network. As the faulty section cannot be identified at the very beginning of the incident, the repairing time and labour involvement is high. The situation is more severe in rural areas.

5.2. Recommendation

In order to overcome this problem and to increase the reliability of 33kV network of C.E.B some recommendations are given below:

5.2.1. Using event log of recloser

It is recommended to analyze event log of reclosers. Following benefits can be obtained:

a. Predominant causes of faults in the network can be identified. The maintenance schedules such as way leaves program can be better planned.
b. The faults can be categorized as overcurrent and earthfaults. More repair time is required to repair overcurrent faults caused by loose jumper connections and damaged conductors in the line.
c. The momentary interruption of duration (below '1'min) can be analyzed. If the momentary interruption is higher for a certain period, it can be predicted that tree branches are close to line. Then immediate way leaves clearing program can be arranged after line inspection.

5.2.2. Reduce outages in the network

Faults in the network highly affect the reliability of the network. Faults are higher in the period of two rainy seasons. These faults can be eliminated by carrying out way leaves programs before and after rainy seasons. Predefined clearance should be strictly maintained.

Re-stringing of conductors and adjustment of clearance of T-off should be carried out to overcome faults by way leaves and wind.

Compression type of H connectors for jumper connections should be introduced at tension points, angle points and spur points to overcome open circuit under heavy fault current.

The compression type midspan joints should be used to connect damaged conductors.

The outage time of the network can be reduced by a considerable amount by installing fault indicators because it reduces fault finding time and gives a remote indication to the control centre. Recommended location of fault indicators are given below;

i. Easy to access line points for immediate monitoring
ii. Next to the spur line
iii. After switch (Air Break Switch or Load Break Switch)
iv. Before and after the points that is difficult to reach such as forest or mountain.

Reclosers used in C.E.B can be operated by remotely. This function is still not initiated by C.E.B. The outage time can be reduced by using remote operation. Thereby it improves reliability of the network.

A line sectionalizing device shall be used to divide the feeder in to smaller line segments. All taps should have protective devices such as reclosers or sectionalizers for large taps and fuses for all taps. Fuses shall be used even for small taps.

The outage time can be minimized by limiting the size and length of the affected line. Therefore the locating time of the fault can be minimized.

5.2.3. Isolating faulty line from the feeder.

The recloser to fuse protection coordination should be designed to clear transient faults by the recloser and the permanent faults by fuse. The faulty section can be isolated more effectively with this protection scheme.

The nuisance fuse blows can be reduced with this protection scheme. Thereby a stock of fuses for spurs can be reduced by 67%. It is recommended to use fuses of same rating for all spurs.

The sectionalizers can be used for spurs and sections when rising fault level in the network because it has no time-current characteristics. This does not require changing of GSS protection setting.

A single phase sectionalizer can be used for spurs in rural areas. A three phase sectionalizers can be used for industrial consumers and heavy load current lines.

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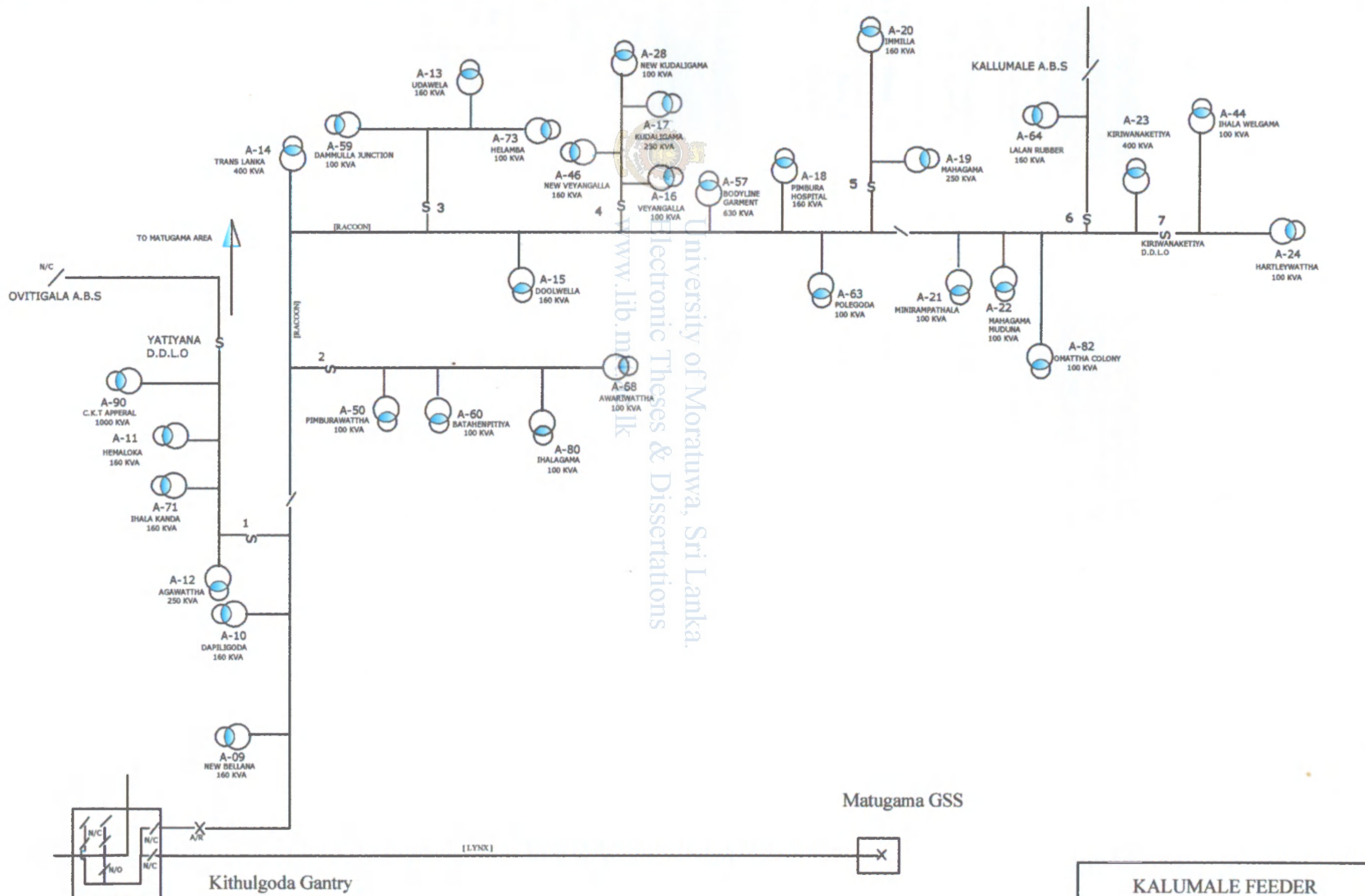
KALUMALE FEEDER
Appendix I



Fault Report for Feeder at Kalumale Feeder

Section Fault Summary for Kalumale Feeder

Section Id	Fit Loc	Phase Conductor	Dist kM	Phs Cfg	Cuml. Impedance R1	X1	R0	X0	Nominal kV	Symmetrical Amps Min G	Max G	L-L	L-L-G	3 Ph
Feeder Kalumale Feeder				ABCN	0.118	1.899	-0.000	26.460	33.0	461	1889	8672	8688	10014
33kV Bus	33kV Bus	1 CU	0.0	ABCN	0.118	1.899	0.000	26.460	33.0	461	1889	8670	8686	10012
Mathugama GSS to Kithulgoda Gant	Kithulgoda Gantry	1431ACSR	22.9	ABCN	4.172	9.571	7.443	49.908	33.0	375	807	1580	1600	1825
Kithulgoda Gantry to Node - 1	Node - 1	1/0 ACSR	27.1	ABCN	5.982	11.146	9.874	54.579	33.0	354	715	1304	1323	1506
Spur-1	Spur-1	1/0 ACSR	28.1	ABCN	6.413	11.521	10.453	55.692	33.0	350	696	1251	1270	1445
Section-1	Section-1	1/0 ACSR	40.0	ABCN	11.542	15.983	17.343	68.928	33.0	302	526	837	854	966

Device Name	Device Category	Device Type	Fault Values LG	LL	LLG	3Ph	Interrupt Rating	Percent Interrupt LG	LL	LLG	3Ph	Dwn Stream Min. LG Section	Amps	Dwn Stream Min. 3Ph Section	Amps
Matugama GSS TF OG CB	Brkr	GEC, MCGG	1889	8672	8688	10014	25000	8	35	35	40	33kV Bus	461.0	33kV Bus	10011.6
Matugama GSS Feeder CB	Brkr	GEC, MCGG	1889	8670	8686	10012	25000	8	35	35	40	Mathugama GSS to Kithulgoda Gant	375.2	Mathugama GSS to Kithulgoda Gant	1824.9
Recloser - Kaiumle Feeder	Recl	Nu-Lec, N series	807	1580	1600	1825	16000	5	10	10	11	Section-1	301.6	Section-1	966.4
Fuse Spur - 1	Fuse	Chance, T	715	1304	1323	1506	---	---	---	---	---	Spur-1	349.6	Spur-1	1445.0

Check Coordination at Kalumale Feeder

Project :			
Licensee :	SAI In house (Carlisle)		
Analysis :	Check Coordination	***Run :***	*06:12PM on January 06, 2009*

SynerGEE Electric 3.5 ***(Oct 21 2002)***
Stoner Associates, Inc. © *2001*

Check Summary

Feeder	Number Checks	Failed Checks	Passed Checks
Kalumale Feeder	39	0	39

Margin Summary

Category	Margin
Relay Protecting Fuse (pct)	100.0 %
Relay Protecting Fuse (sec)	0.3 Sec
Fuse Protecting Relay (sec)	0.3 Sec
Fuse Protecting Fuse (pct)	75.0 %
Recloser Protecting Fuse (pct)	90.0 %
Fuse Protecting Recloser (pct)	95.0 %
Relay Protecting Relay (pct)	75.0 %
Relay Protecting Relay (sec)	0.3 Sec
Recloser Protecting Transformer (pct)	75.0 %
Relay Protecting Transformer (pct)	75.0 %
Fuse Protecting Transformer (pct)	75.0 %
Recloser Protecting Recloser (pct)	75.0 %
Recloser Protecting Relay (pct)	75.0 %
Relay Protecting Recloser (pct)	70.0 %
Fuse - Transformer Inrush (pct)	75.0 %
Recloser - Transformer Inrush (pct)	75.0 %
Relay - Transformer Inrush (pct)	75.0 %
Fuse Minimum Fault Margin (pct)	220.0 %
Fuse Load Current Margin (pct)	90.0 %
Recloser Protecting Recloser (sec)	0.2 Sec

	Protecting Device (A)			Protected Device (B)			Protecting Phase Amps					Protecting Ground Amps			
Pair	(Downstream)			(Upstream)			Min		Max	Load	Shift	Min		Max	Shift
#	Type	Name	Sect	Type	Name	Sect	Flt	At	Flt	Amps	B -> A	Flt	At	Flt	B -> A
Feeder Kalumale Feeder															
1	Brkr	Matugama GSS TF OG CB	33kV Bus	—	—	—	756	33kV Bus	10014	0	—	756	33kV Bus	1889	—
2	Brkr	Matugama GSS Feeder CB	Mathugama GSS to Kithulgoda Gantry	—	—	—	323	Mathugama GSS to Kithulgoda Gantry	10012	0	—	323	Mathugama GSS to Kithulgoda Gantry	1889	—
3	Recl	Recloser - Kalumle Feeder	Kithulgoda Gantry to Node - 1	—	—	—	210	Section-1	1825	0	—	210	Section-1	807	—
4	Fuse	Fuse Spur - 1	Spur-1	—	—	—	278	Spur-1	1506	0	—	278	Spur-1	715	—
5	Brkr	Matugama GSS Feeder CB	Mathugama GSS to Kithulgoda Gantry	Brkr	Matugama GSS TF OG CB	33kV Bus	323	Mathugama GSS to Kithulgoda Gantry	10012	0	None	323	Mathugama GSS to Kithulgoda Gantry	1889	None
6	Recl	Recloser - Kalumle Feeder	Kithulgoda Gantry to Node - 1	Brkr	Matugama GSS Feeder CB	Mathugama GSS to Kithulgoda Gantry	210	Section-1	1825	0	None	210	Section-1	807	None
7	Recl	Recloser - Kalumle Feeder	Kithulgoda Gantry to Node - 1	Brkr	Matugama GSS TF OG CB	33kV Bus	210	Section-1	1825	0	None	210	Section-1	807	None
8	Fuse	Fuse Spur - 1	Spur-1	Recl	Recloser - Kalumle Feeder	Kithulgoda Gantry to Node - 1	278	Spur-1	1506	0	None	278	Spur-1	715	None
9	Fuse	Fuse Spur - 1	Spur-1	Brkr	Matugama GSS Feeder CB	Mathugama GSS to Kithulgoda Gantry	278	Spur-1	1506	0	None	278	Spur-1	715	None
10	Fuse	Fuse Spur - 1	Spur-1	Brkr	Matugama GSS TF OG CB	33kV Bus	278	Spur-1	1506	0	None	278	Spur-1	715	None

Fuse Checks						
4	Pass	Fuse Spur - 1	10-02	220%	278 A -	Minimum phase fault of 278A should exceed 220% of fuse 50 amp rating
4	Pass	Fuse Spur - 1	10-03	220%	278 A -	Minimum ground fault of 278A should exceed 220% of fuse 50 amp rating
4	Pass	Fuse Spur - 1	10-05	---	---	Fuse has valid min-melt (34581) and max-clear (34583) curves

Check Coordination

Fuse Protecting Recloser Checks.

8	Pass	Fuse Spur - 1 / Recloser - Kalumle Feeder	12-01	95%	278 - 1508 A	Recloser fast phase curve (K Factor = 1.8) should lie below fuse min. melt curve
8	Pass	Fuse Spur - 1 / Recloser - Kalumle Feeder	12-02	95%	278 - 715 A	Recloser fast ground curve (K Factor = 1.8) should lie below fuse min. melt curve.
8	Pass	Fuse Spur - 1 / Recloser - Kalumle Feeder	12-03	95%	278 - 1508 A	Recloser slow phase curve should lie above the fuse max. clear curve
8	Pass	Fuse Spur - 1 / Recloser - Kalumle Feeder	12-04	95%	278 - 715 A	Recloser slow ground curve should lie above the fuse max. clear curve.

Fuse Protecting Relay Checks.

10	Pass	Fuse Spur - 1 / Matugama GSS TF OG CB	13-01	0.30 sec	278 - 1508 A	The fuse max clear curve should lie below the relay phase curve.
9	Pass	Fuse Spur - 1 / Matugama GSS Feeder CB	13-01	0.30 sec	278 - 1508 A	The fuse max clear curve should lie below the relay phase curve.

Recloser Checks.						
3	Pass	Recloser - Kalumle Feeder	20-01	—	—	1825A phase fault current should not exceed recloser 16000 amp interrupt rating
3	Pass	Recloser - Kalumle Feeder	20-02	—	—	807A ground fault current should not exceed recloser 16000 amp interrupt rating
3	Pass	Recloser - Kalumle Feeder	20-03	—	—	Recloser should pickup minimum phase fault current of 210A
3	Pass	Recloser - Kalumle Feeder	20-04	—	—	Recloser should pickup minimum ground fault current of 210A.
3	Pass	Recloser - Kalumle Feeder	20-05	—	—	Recloser fast ground curve should lie below its slow curve.
3	Pass	Recloser - Kalumle Feeder	20-05	—	—	Recloser fast phase curve should lie below its slow curve.
3	Pass	Recloser - Kalumle Feeder	20-06	—	—	Recloser should have at least one fast or one time-delay ground operation.
3	Pass	Recloser - Kalumle Feeder	20-06	—	—	Recloser should have at least one fast or one time-delay phase operation.
3	Pass	Recloser - Kalumle Feeder	20-07	—	210 - 1825 A	Recloser fast and slow phase operation curves should extend past 210A minimum fault level.
3	Pass	Recloser - Kalumle Feeder	20-08	—	210 - 807 A	Recloser fast and slow ground operation curves should extend past 210A minimum fault level
3	Pass	Recloser - Kalumle Feeder	20-09	—	210 - 1825 A	Recloser fast and slow phase operation curves should pickup below 1825 maximum fault amps
3	Pass	Recloser - Kalumle Feeder	20-10	—	210 - 807 A	Recloser fast and slow Ground operation curves should pickup below 807 maximum fault amps.
3	Pass	Recloser - Kalumle Feeder	20-12	—	210 - 807 A	Maximum fault current of 807A should not exceed either of the recloser ground operation curves
3	Pass	Recloser - Kalumle Feeder	20-13	—	—	Recloser should have phase or ground curves
Recloser Protecting Relay Checks.						
7	Pass	Recloser - Kalumle Feeder / Matugama GSS TF OG CB	23-01	75%	210 - 1825 A	Recloser phase t.d. curve should lie below relay phase curve
6	Pass	Recloser - Kalumle Feeder / Matugama GSS Feeder CB	23-01	75%	210 - 1825 A	Recloser phase t.d. curve should lie below relay phase curve
7	Pass	Recloser - Kalumle Feeder / Matugama GSS TF OG CB	23-02	75%	210 - 807 A	Recloser ground t.d. curve should lie below relay ground curve
6	Pass	Recloser - Kalumle Feeder / Matugama GSS Feeder CB	23-02	75%	210 - 807 A	Recloser ground t.d. curve should lie below relay ground curve.
Relay Checks.						
2	Pass	Matugama GSS Feeder CB	30-01	—	—	10012A phase fault current should not exceed breaker's 25000 amp interrupt rating

Check Coordination

Relay Checks.

2	Pass	Matugama GSS Feeder CB	30-01	---	---	10012A phase fault current should not exceed breaker's 25000 amp interrupt rating
1	Pass	Matugama GSS TF OG CB	30-01	---	---	10014A phase fault current should not exceed breaker's 25000 amp interrupt rating
2	Pass	Matugama GSS Feeder CB	30-02	---	---	1889A ground fault current should not exceed breaker's 25000 amp interrupt rating
1	Pass	Matugama GSS TF OG CB	30-02	---	---	1889A ground fault current should not exceed breaker's 25000 amp interrupt rating
1	Pass	Matugama GSS TF OG CB	30-04	---	---	Relay Ground curve (pickup = 150) should pickup minimum fault current of 756A.
2	Pass	Matugama GSS Feeder CB	30-04	---	---	Relay Ground curve (pickup = 100) should pickup minimum fault current of 323A.
1	Pass	Matugama GSS TF OG CB	30-09	---	---	Breaker should have phase or ground relay curves.
2	Pass	Matugama GSS Feeder CB	30-09	---	---	Breaker should have phase or ground relay curves.

Relay Protecting Relay Checks.

5	Pass	Matugama GSS Feeder CB / Matugama GSS TF OG CB	33-01	75%	323 - 10012 A	Protecting phase relay curve should lie below protected relayphase curve.
5	Pass	Matugama GSS Feeder CB / Matugama GSS TF OG CB	33-02	75%	323 - 1889 A	Protecting ground relay curve should lie below protected relayground curve
5	Pass	Matugama GSS Feeder CB / Matugama GSS TF OG CB	33-03	0.35 sec	323 - 10012 A	Protecting phase relay curve should lie below protected relayphase curve.
5	Pass	Matugama GSS Feeder CB / Matugama GSS TF OG CB	33-04	0.35 sec	323 - 1889 A	Protecting ground relay curve should lie below protected relayground curve

Check Coordination