IDENTIFICATION OF THE OPTIMUM PROTECTION CO-ORDINATION IN MEDIUM VOLTAGE DISTRIBUTION SYSTEM OF SRI LANKA

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DECLARATION

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Signature of the supervisor Date
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ABSTRACT

Majority of the faults in the transmission and distribution network are transient and these faults can be cleared with proper installation of protective devices with appropriate protection settings. It is important to clear the faults as soon as possible by keeping the healthy network undisturbed while avoiding damages to lives and instruments.

It was observed that applying protection settings to Medium Voltage network at Grid Substations and Medium Voltage distribution feeders are done by two separate parties without coordination between them. Monthly tripping summary of 33 kV feeders of Grid Substations of Ceylon Electricity Board revealed that some feeders getting disturbed abnormally. Further, it is observed that Auto Reclosers are installed in downstream of these 33 kV feeders to respond to the transient faults but they are not yielding expected results. Hence, applying most appropriate protection setting to these Auto Reclosers and relays are very much required for the higher reliability of the Medium Voltage network.

Two 33 kV feeders which were mostly disturbed were analyzed deeply and found that most of the feeder trippings are owing to Earth Fault. Further, with installation of temporary Digital Disturbance Recorder, it was observed that most of the faults have lasted less than 100 ms. Plotted Over Current and Earth Fault co-ordination curves for Medium Voltage distribution network disclose that requirement of revising the settings while identifying the most suitable way of applying Auto Reclosers to the 33 kV feeders.

Four scenarios were studied to identify the optimum way of installing Auto Reclosers and protection setting for this Medium Voltage network. Detailed analysis proved that 33 kV feeder with two downstream Auto Reclosers is the optimum solution. Then, the most suitable protection settings for the Medium Voltage network were derived for a typical Grid Substations. Furthermore, an algorithm was defined to find the optimum protection settings for any Grid Substations. Application of these setting to a selected 33 kV feeder viz Feeder 5 of Badulla Grid Substation, proved that the new settings are extremely effective.

Key Words: Medium Voltage distribution, Auto Recloser, Protection settings, Over Current, Earth Fault

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LIST OF ABBREVIATIONS

Abbreviation	**Description**
AR	Auto Recloser
CB	Circuit Breaker
CEB	Ceylon Electricity Board
CT	Current Transformer
DDR	Digital Disturbance Recorder
DEF	Directional Earth Fault
DOC	Directional Over Current
DT	Definite Time
EF	Earth Fault
EI	Extremely Inverse
F	Feeder
GSS	Grid Sub Stations
HV	High Voltage
IDMT	Inverse Definite Minimum Time
LECO	Lanka Electricity Company (pvt) Limited
LS	Load Shedding
LV	Low Voltage
MV	Medium Voltage
OC	Over Current
PS	Plug Setting
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SBEF	StandBy Earth Fault
SLD	Single Line Diagram
SI	Standard Inverse
TF	Transformer
TMS	Time Multiplier Setting
UF	Under Frequency
VI	Very Inverse

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Chapter 1

INTRODUCTION

1.1 Background

The main purpose of an electrical utility in a country is to supply an un-interrupted power to the end customers. Hence, transmission and distribution network ensure the transferring of the generated electrical power to end users. Power transmission is done in High Voltage (HV) while power distribution is done in Medium Voltage (MV) and Low Voltage (LV) levels. In various countries, these HV, MV and LV levels are defined in various limits but these are approximately same. In Sri Lanka, MV level is defined as 33 kV to 11 kV.

Overhead MV distribution system is subjected to various electrical faults. These faults are mainly categorized in to transient (temporary) faults and permanent faults, depending on the nature of the fault. Transient faults are faults which do not damage insulation permanently while allowing the circuit to safely re-energize after a short period. More than 80% of faults are transient [1] and usually these faults occur when phase conductors are electrically in contact with each other or ground momentary owing to lightning strikes, insulator flashovers, high winds, trees, birds or other animals and so on. On the other hand, permanent faults cause permanent damage to the insulation while damaging equipments which have to be repaired before restoration / re-energize.

Transient faults are cleared by a service interruption for defined small time duration to extinguish the power arc. For this purpose, protective relays having instantaneous or fast tripping and automatic reclosing are used to control the operation of Circuit Breaker (CB). The protective device co-ordination is the process of determining most appropriate timing of power system interruption during abnormal conditions in the power system [2]. Hence, most appropriate protection scheme is required for the power system mainly to minimize the fault duration and to minimize the number of customers affected. In addition to this, distribution protection system ensures the limitation of service outage to a smallest possible segment of the power network, protection of consumers' apparatus, disconnection of faulted lines, transformers and other apparatus as much as possible, minimization of service interruption and disturbance and elimination of safety hazards as fast as possible.

1.2 Identification of the Problem

There are about 60 numbers of Grid Sub Stations (GSSs) in power system network in Sri Lanka [3] to step down the transmitted electrical power from HV to MV. The MV system has been experiencing nuisance trippings for ages even though protection schemes are in place to isolate the faulty part of the distribution network. Main reasons for this nuisance trippings are incorrect selection of protective devices, lack of discrimination between protective devices and aging of electrical equipment in the system. Hence, proper selection of protective devices with proper protection co-ordination is required to maintain the power system reliability as well as to avoid damages to very costly equipment such as power transformers [4]. The correct operation of protective relays and auto-reclosers (ARs) during transient faults will minimize permanent trippings of the distribution network. Therefore, co-ordination of protective relays at GSS and downstream ARs are very much essential to maintain the high reliability in MV distribution network.

1.3 Objective of the Research

The objective of the study is to determine the optimum protection co-ordination of MV system of Sri Lankan power system by analyzing the existing protection settings and behavior of MV network. Protection settings of relays at GSS and downstream ARs of selected GSS will be analyzed with the standards to determine the optimum co-ordination in MV level. This study will present the optimum protection settings for the MV system of Sri Lankan power system.

1.4 Importance of the Research

A comprehensive study of MV system protection co-ordination of Sri Lankan power system has not been carried out in recent time. There has been a requirement of revising the existing protection settings of MV level, with the rapid development of distribution network. Since, there has been nuisance trippings in MV network at several MV feeders, the existing coordination between upper-stream relays and down-stream ARs may have a problem. Further, positioning of ARs also may have an issue on this nuisance trippings.

1.5 Research Methodology

By investigating the historical records of National Control Centre, 33 kV feeders which have been experiencing nuisance trippings have to be identified. Then the existing protection settings of protection relays and ARs have to be collected by logging to these protective devices. Appropriateness of this protection settings of above GSSs for the new fault levels should be analyzed by plotting co-ordination curves for MV system. After that, the optimum protection co-ordination for MV system should be defined by analyzing these data and the network requirement.

Chapter 2

MEDIUM VOLTAGE SYSTEM PROTECTION

2.1 Electrical Protection for Power Systems

Equipments involved with power system may damage during the operation owing to abnormal conditions and faults. Therefore, to limit the further damage to equipment and to restrict the danger to human life, it is required to apply fast electrical protection. Protective devices play vital role in this purpose as they operate to isolate the faulty part of the network by limiting the propagation of the system disturbance. Power system protection has following five main functions as its level of discipline and functionality shown in the order of priority [5].

1. To ensure safety of personnel
2. To safeguard the entire system
3. To ensure continuity of supply
4. To minimize damage
5. To reduce resultant repair cost

To ensure these requirements, it is required to detect the fault early, localize it and isolate it rapidly. Power system protection should have following requirements, in order to satisfy above functions [5].

1. Reliability – to operate in a pre-determined manner when an electrical fault is detected
2. Selectivity / Discrimination – to detect and safely isolate only the faulty item(s)
3. Stability / Security – to leave all healthy circuits intact and undisturbed and to ensure continuity of supply
4. Sensitivity – to detect even the smallest values of fault current or system abnormalities and operate correctly at its pre-set settings

5. Speed – to operate speedily when it is required thereby minimizing damage and ensuring safety to personnel

2.2 Medium Voltage System Protection

The MV network (primary distribution) is the portion of power delivery network that transmits the electricity from HV transmission network to consumer centers. As per IEEE standards, MV level is between 600 V to 35 kV. In Sri Lankan power System, MV levels are 33 kV and 11 kV. At a GSS, a power transformer steps down the voltage from 220 kV or 132 kV to 33 kV level and distributes via distribution lines. This MV system will supply power to large industrial consumers at the same voltage level or to household consumers after converting to LV level with the use of distribution transformers. The power network from LV side of the power transformer at GSS to distribution transformers at load centers belongs to MV network. Figure 2.1 shows the overview of the typical electricity infrastructure with voltage levels.

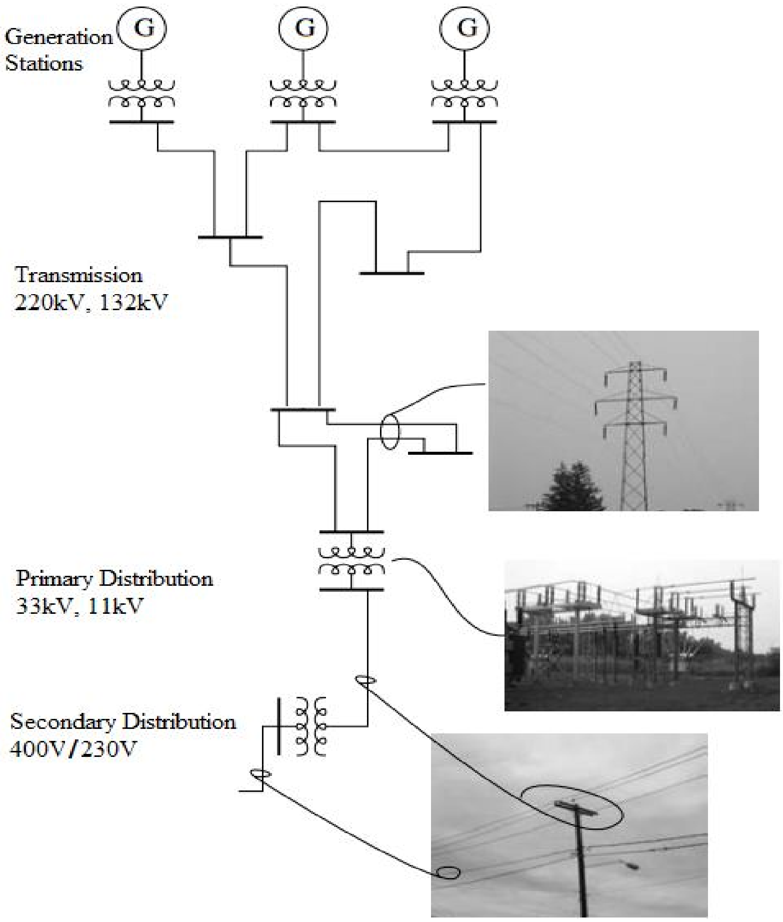


Figure 2.1: Overview of the Typical Electricity Infrastructure [6]

MV protection system consists of protection devices of power transformers and MV distribution lines.

Power transformers in the GSS are protected by CBs, surge arresters and any other protective devices. Differential protection and Restricted Earth Fault protection are the main protection schemes which protect the power transformer from the internal faults. Other than this, there are backup protection schemes to protect the transformer against external faults. These are;

- Over Current (OC) protection
- Earth Fault (EF) protection
- Directional Over Current (DOC) protection
- Directional Earth Fault (DEF) protection
- Stand By Earth Fault (SBEF) protection

Distribution line conductors are protected by CBs, surge arresters, other protective devices and sectionalizers. Mainly, distribution lines are protected by OC protection and EF protection because they do not need any backup protection. Most often, distribution protection has standardized settings, standardized equipment and standardized procedures. Standardization makes designing, operation and protection coordination easy and reduces engineering efforts [6].

2.3 Protection Using Relays

Current Transformers (CTs) are installed in the transmission and distribution lines to measure the current and provide the measured values into relays. When the measured current exceeds the preset value, the relay will operate at a time determined by the relay characteristics to trip the relevant CB. Relays are applied in the power network by considering the over current grading and fault discrimination.

The basic rules for correct relay co-ordination can generally be stated as follows [7];

- Whenever possible, use relays with the same operating characteristic in series with each other.
- Make sure that the relay farthest from the source has current settings equal to or less than the relay behind it.

2.4 Grading of Relays

Grading of relays is the adjustment of settings of the relays to ensure discrimination and selectivity. When a fault occurs in power network, the protection relay closest to the fault should operate by leaving the healthy network undisturbed. This is called grading. The grading of relays can be achieved by using of following methods [7, 8].

1. Current grading
2. Time grading
3. Current and time grading

2.4.1 Discrimination by Time

In this method, an appropriate time interval is set between each of the relays by controlling the CBs in a power system to ensure that the breaker nearest to the fault opens first [7, 8]. A sample radial distribution is shown in Figure 2.2, which illustrate the above principal.

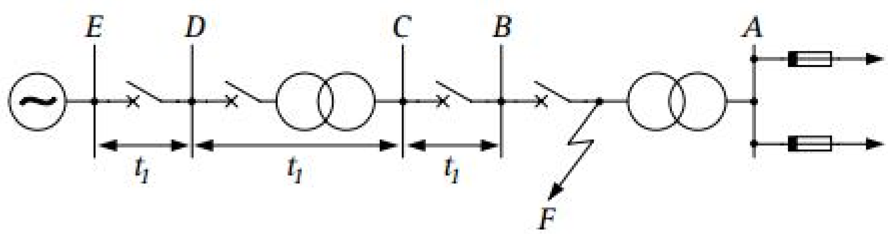


Figure 2.2: Radial System With Time Discrimination [8]

OC protection (or EF protection) is provided at in feed end of each section of the power system named as B, C, D and E. Each protection devices located in these positions has a defined constant time delay (t_1) between nearest relays. The operating time set for relay at B has lowest possible operating time while operating time of relays towards upstream increases. If a fault occurs at F, the relay at B will operate first by causing to operate the relevant CB. This CB isolates the faulty section of the network by keeping CBs at C, D and E in safe operation. The time interval t_1 between each relay operating time should be long enough to ensure the safe operation of upstream relays while relay nearest the fault operate and trip the faulty network to clear the fault.

The disadvantages of this method of discrimination is that the longest fault clearance time occurs or the fault closer to the source, where the fault level is highest [7, 8].

2.4.2 Discrimination by Current

Discrimination by current based on the fact that the current varies with the position of the fault, since the difference in impedances between source and the fault [7, 8]. The relays at different locations have different current settings in order to operate only the relay nearest to the fault. A sample radial distribution shown in Figure 2.3, illustrate the above principal.

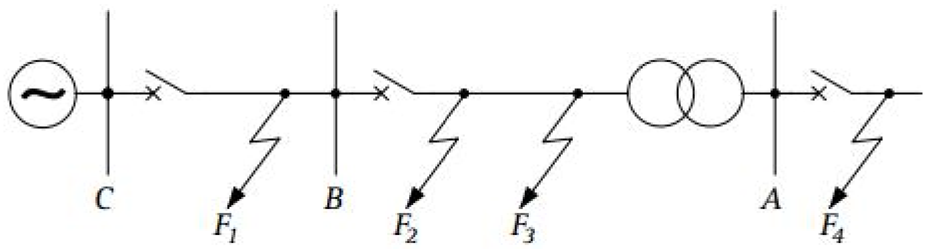


Figure 2.3: Radial System With Current Discrimination [8]

Fault level is increasing towards the source. Hence, fault current F_4 is lesser than fault current F_3, F_2 and F_1. Therefore, current setting of downstream relays should be lesser than upstream relays. When a fault occurs at F_4, relay at position A of the network should operate and trip the relevant CB without disturbing the upstream network. Current settings of relays at B and C may be very much closer, since only the conductor impedance effects for the fault level.

The disadvantage of current discrimination is that difficulty of achieving significant difference in setting if the length of the overhead line between two relays is not enough [7].

2.4.3 Discrimination by Both Time and Current

Each of the two methods described has a fundamental disadvantage. Because of this, an inverse time relay characteristic has been developed. With this characteristic, the time of operation is inversely proportional to the fault current level and the actual characteristic is a function of both "time" and "current" settings [7, 8]. Figure 2.4 illustrate the use of inverse time relay characteristic for time discrimination.

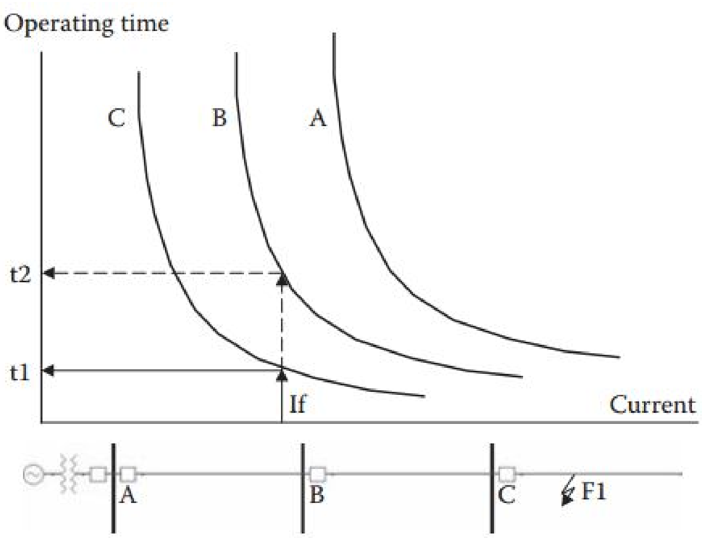


Figure 2.4: Use of Inverse Time Relay Characteristic for Time Discrimination [7]

According to the Figure 2.4, fault current of I_f occurs at the fault F_1. For this I_f current, operating time of relay at C and B are t_1 and t_2 respectively. Since, t_1 is less than t_2, relay at C operate before relay at B.

Protection settings for relays in series should be calculated very carefully by allowing the fault to be cleared from other relay by slightly delayed time, if the nearest relay is not operated properly. This delay should not be very much higher to limit the flowing of fault current to healthy network [7].

2.4.4 Grading Margin

The grading margin is the time interval between operating times of two adjacent protective relays [8, 9]. Sufficient grading margin should be set between relays to avoid unnecessary operation of relays. The grading margin depends on number of factors [8, 9];

- The CB fault interruption time (typically 2 - 8 cycles)
- The overshoot time of relay
- Safety margin for errors such as relay timing errors and CT errors

The grading margin used for electromechanical and static relays are 0.4 s and 0.35 s respectively [8]. With the advancement of technology, overshoot time for digital and numerical relays are lower and hence grading margin of 0.3 s is used [8, 9, 10]. When designing MV network, minimum number of grading levels should be used [10].

2.5 Protection Philosophies used in MV network

Widely used protection functions for MV network are OC protection and EF protection. The relays having OC and EF protection functions perform on different philosophies as mentioned below.

- Instantaneous
- Definite Time (DT)
- Inverse Definite Minimum Time (IDMT)
- Directional

With the invention of new technologies, relays with one or more philosophies of above are available for the application of the network according to the requirement.

2.5.1 Instantaneous Relay

Instantaneous relay operate when the current reaches a predetermined value. Its operating criteria is only current magnitude. The magnitude is defined based on the position by considering the fault level. Operating time is constant for this type of relay and it is about 0.1 s or less. There is no any time delay defined for instantaneous relay. Figure 2.5 shows the time – current characteristic for instantaneous relay.

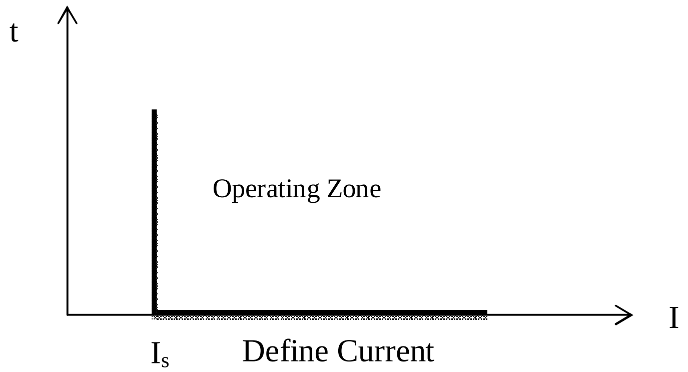


Figure 2.5: Instantaneous Relay Characteristic

2.5.2 Definite Time Relay

The DT relay operates when the current rises above the preset current magnitude and the time delay. Modern relays contain more than one stage of protection with independent settings. The time – current characteristic for DT relays with 0.5 s grading margin applied to a network is shown in Figure 2.6.

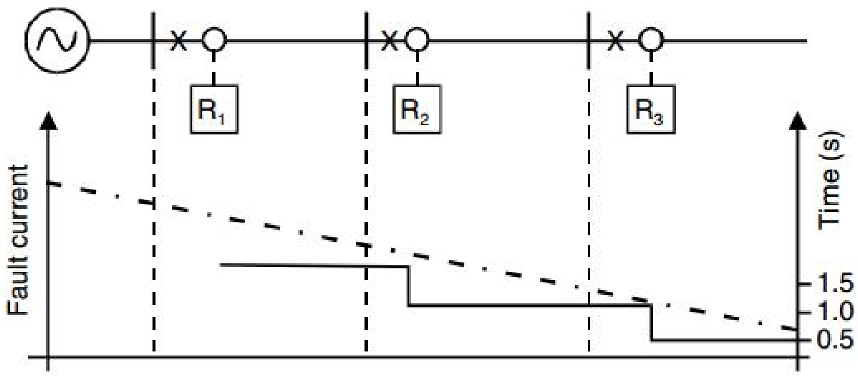


Figure 2.6: DT Relay Characteristic [10]

2.5.3 Inverse Definite Minimum Time Relay

In this relay, operating time is inversely proportional to current and hence the relay operates faster at higher fault current and slower at the lower fault current. The IDMT philosophy is the standard practice in use many countries. Application of IDMT relay for the network defined in chapter 2.5.2 is shown in Figure 2.7.

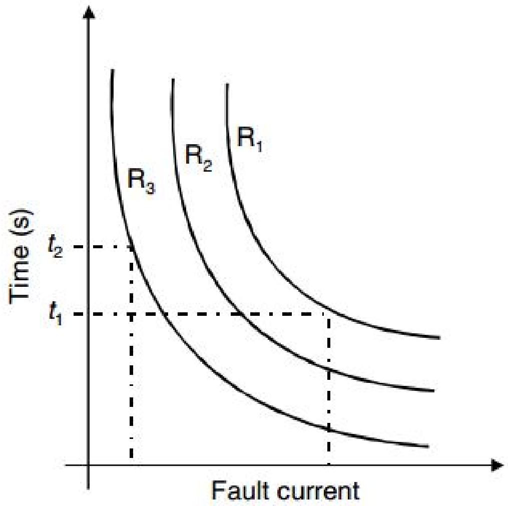


Figure 2.7: IDMT Relay Characteristic [10]

IEC 60255 defines a number of standard characteristic for IDMT relay (Figure 2.8), namely, Standard Inverse (SI), Very Inverse (VI), Extremely Inverse (EI) and long-time inverse. Each characteristic can be calculated from the equation in Table 2.1.

Table 2.1: IDMT Relay Characteristic to IEC 60255 [8]

Relay Characteristic	Equation (IEC 60255)
Standard Inverse (SI)	$t = TMS \times \frac{0.14}{I_r^{0.02} - 1}$
Very Inverse (VI)	$t = TMS \times \frac{13.5}{I_r - 1}$
Extremely Inverse (EI)	$t = TMS \times \frac{80}{I_r^2 - 1}$
Long time standard earth fault	$t = TMS \times \frac{120}{I_r - 1}$

$I_r = (I/I_S)$, where I_S = relay setting current
TMS = Time multiplier Setting

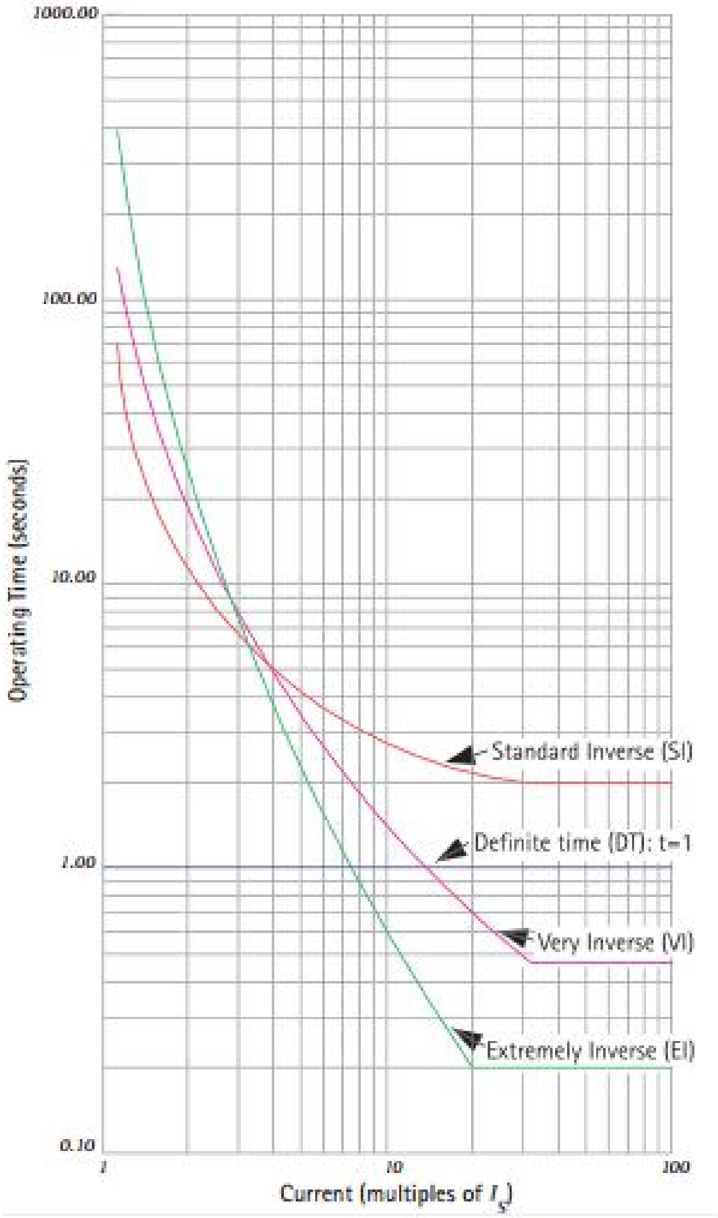


Figure 2.8: IEC 60255 Characteristic TMS = 1.0 [8]

2.5.4 Directional Relay

Directional control facility is used, when current flow in both directions through relay location and there is a requirement to define the relay operating direction. In this situation, additional voltage input is required to measure the direction. Current magnitude, time delay and direction should be satisfied to operate the relay.

2.6 Transformer Backup Protection (LV Side)

If a fault is not cleared promptly, a fault external to the transformer (through faults) can damage the transformer causing severe overheating. Phase or Ground fault OC relays can be used to clear the transformer from the fault bus or line before the transformer is damaged.

Power transformer protection for through faults should be limited to 2 s [9], according to ANSI Standard C37.91, Guide for Protective Relay Applications to Power Transformers.

2.6.1 IDMT Over Current Protection

When setting pickup value for IDMT over current relays, overload capabilities of the transformer and the energizing inrush current should be considered. Since transformer relay should coordinate with load-side protection, reclosing cycles and service restoration inrush, fast operating time is not possible. By considering the operation requirement and protection of transformer, a setting of 120% - 150% of transformer rated current is used as IDMT OC setting [11]. The time setting should be coordinated with downstream protective devices.

2.6.2 Instantaneous / DT Over Current Protection

Instantaneous OC setting is used to clear severe internal fault of the transformer. Pickup value for this should be higher than maximum asymmetrical through-fault current. The setting should be above the transformer inrush currents to avoid nuisance trippings. A pickup of 125% - 200% of calculated maximum low-side three-phase symmetrical fault current is used. Sometimes, Instantaneous relay cannot be used because of the actual fault current is smaller than the necessary setting [11, 12].

2.6.3 IDMT Earth Fault Protection

In Sri Lankan Power network, LV winding of power transformer has a delta connection. Therefore, the MV earthing system is obtained by connecting zigzag earthing transformer to LV side of the power transformer. Hence, EF protection is required for the protection against zero sequence current. Generally, pickup setting for EF relays is 10% or lesser than the rated current of the earthing transformer [11].

2.6.4 Instantaneous / DT Earth Fault Protection

It is not possible to use Instantaneous EF relay, because it could result in incorrect operation owing to dissimilar CT saturation and magnetizing inrush. Hence, DT EF relays with a sensitive setting are used [11].

2.7 MV Distribution Line Protection

OC and EF protection are primary protection to MV distribution lines. The pickup value for a relay is selected by considering maximum loading and transient current withstand capability of next protective device location while TMS setting is selected considering the maximum fault current at the location of protective device installed. Primary protection should recover the line from the fault within 1 s duration [9].

2.7.1 IDMT Over Current Protection

Relay pickup must be selected that it should not operate on the largest transient and short time current that can be tolerated by the system [9]. Therefore, two factors such as “short time maximum load” and “transient currents caused by switching operations on the power system” should be considered when selecting settings. Hence, Pickup of 125% - 150% of the maximum short time load or greater will be required to avoid operation on short time transients with inverse relay characteristics [4, 9, 12].

2.7.2 IDMT Earth Fault Protection

EF relays for faults involving zero sequence quantities, mainly single-phase-to-ground faults and two-phase-to-ground faults. Setting for EF relay can be set independently of OC relays. Pickup of EF relay are set to 10% - 20% of the sensitivity of OC relays [12].

2.7.3 Instantaneous / DT Over Current and Earth Fault Protection

Instantaneous or DT relay should be selected that it should not overreach any other protective devices. When radial MV distribution lines are considered, for the selection of pickup setting, maximum fault current at the next device location is considered. Typically pickup value of 110% - 130% of the maximum fault current at next location is set for the relay [9, 12]. Instantaneous / DT relays provide high-speed relay operation for close-in faults.

Chapter 3

REVIEW OF EXISTING CO-ORDINATION IN MV NETWORK

3.1 MV Network Disturbances

Ceylon Electricity Board (CEB) is the main electricity utility in Sri Lanka. CEB maintains 132 kV and 220 kV HV transmission network and step down these voltages to 11 kV and 33 kV at GSS using power transformers. CEB maintains 33 kV distribution network while 11 kV network is maintained by a sub utility named as Lanka Electricity Company (pvt) Limited (LECO).

With increasing demand for the electricity, HV and MV networks of CEB are regularly under development and capacities of the GSS are in increase. Even though, CEB properly maintains the MV network, still there are nuisance trippings of distribution feeders from which not only the faulty section but also the healthy network gets disturbed.

System Control Center daily issues the incident report which shows the summary of trippings per day. Records of 33 kV feeder trippings for one week duration (From 03rd November 2014 to 9th November 2014) are attached as Appendix 1. 33 kV feeders, which had tripped more than 40 times per month were summarized by analyzing incident records for last two years and it is attached as Appendix 2. From that tripping summary, it was observed that more frequent trippings have happened with some 33 kV feeders.

For the protection of MV network, there are ARs which have been installed in downstream of some 33 kV feeders other than protective relays at GSS. Details of AR installation in 33 kV feeders were collected and attached as Appendix 3.

In this chapter, two GSSs which were subjected to frequent nuisance trippings will be analyzed to check the adequacy of existing protection setting co-ordination in MV network.

3.2 Case Study 1 - Seethawaka GSS

Seethawaka GSS is a 132 / 33 kV substation and it was constructed in 1998. Polpitiya – Athurugiriya 132 kV transmission line feeds electrical power to Seethawaka GSS. Initially there were two 31.5 MVA, 132 / 33 kV power transformers and now it has three since 2012. There are five outgoing 33 kV feeders, one 33 kV generator feeder and one 33 kV spare feeder. The existing Single Line Diagram (SLD) of Seethawaka GSS is shown in Figure 3.1.

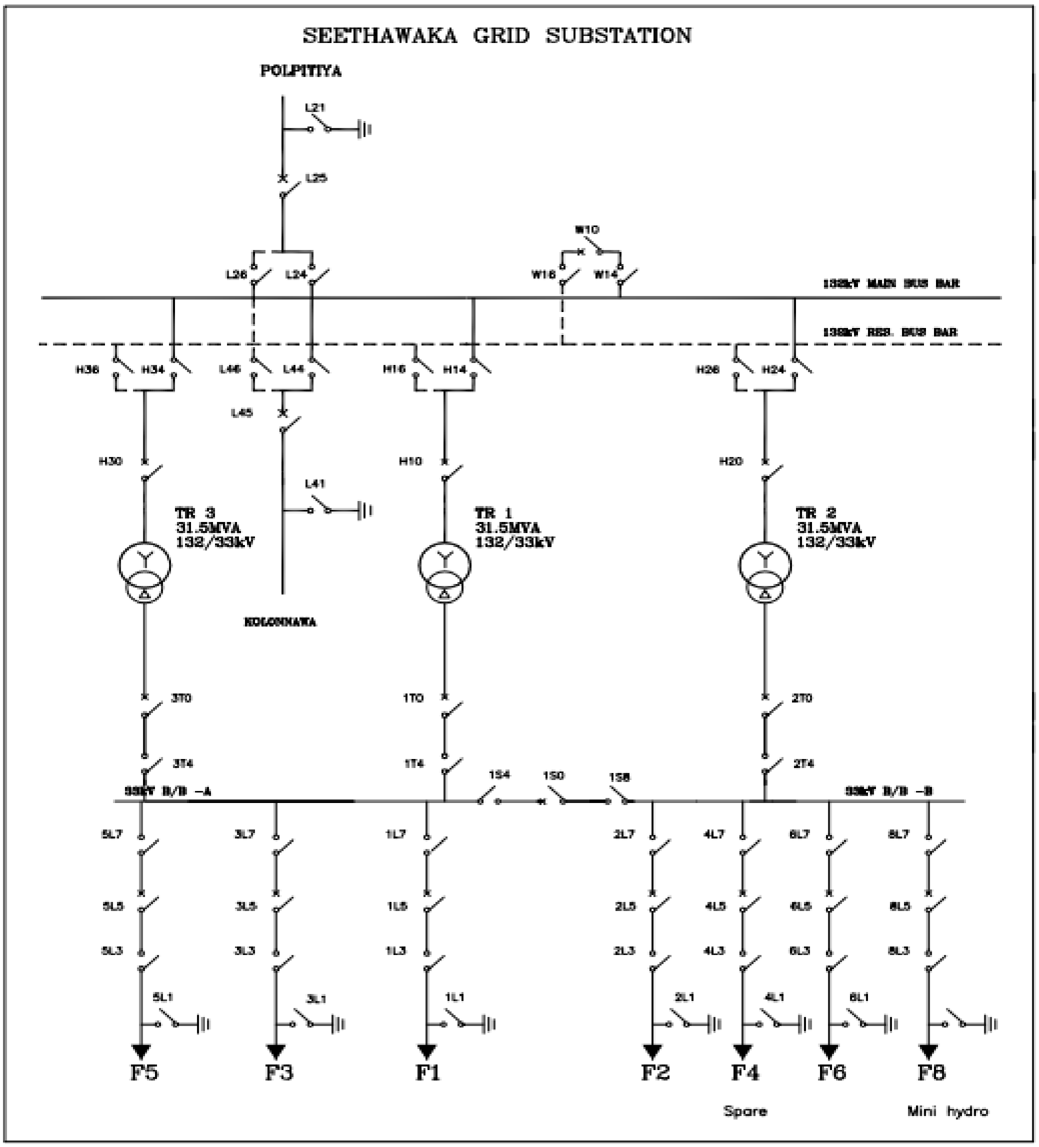


Figure 3.1: SLD of Seethawaka 132 / 33 kV GSS

3.2.1 Downstream AR Details of Seethawaka GSS

It was found that only Feeder 1 (F1), F2 and F8 have downstream ARs installed. Feeder number and the location of AR installation are tabulated in Table 3.1. According to the data, it was observed that four ARs have been installed in F1 while other two feeders have one AR in each. As per data, there is only one down stream AR in each feeder.

Table 3.1: Downstream AR Details of Seethawaka GSS

Feeder Number	Name / Location of the AR	Feeder Name	Distance from the GSS to the AR location
F1	Karawanella Gantry	Gonagaldeniya (Ruwanwella)	11.0 km
	Karawanella Gantry	Bogala (Yatiyantota)	11.0 km
	Karawanella Gantry	Deraniyagala (Dehiowita)	11.0 km
	Epalapitiya Gantry	Seethawaka	2.5 km
F2	Near Seethawaka GSS		
F8	Deraniyagala Gantry	Magalganga MHP	22.0 km

By analyzing tripping details of all 33 kV feeders, it was found that only F1 has large number of trippings per every month. Hence, F1 was considered for this analysis. The SLD of F1 is shown in Figure 3.2. Line lengths are not drawn to the scale.

All line conductors in F1 are Lynx. Normally, in MV distribution network of CEB, there are two types of line conductors, namely Lynx and Raccoon. Current carrying capacity of Lynx conductor is higher than Raccoon conductor.

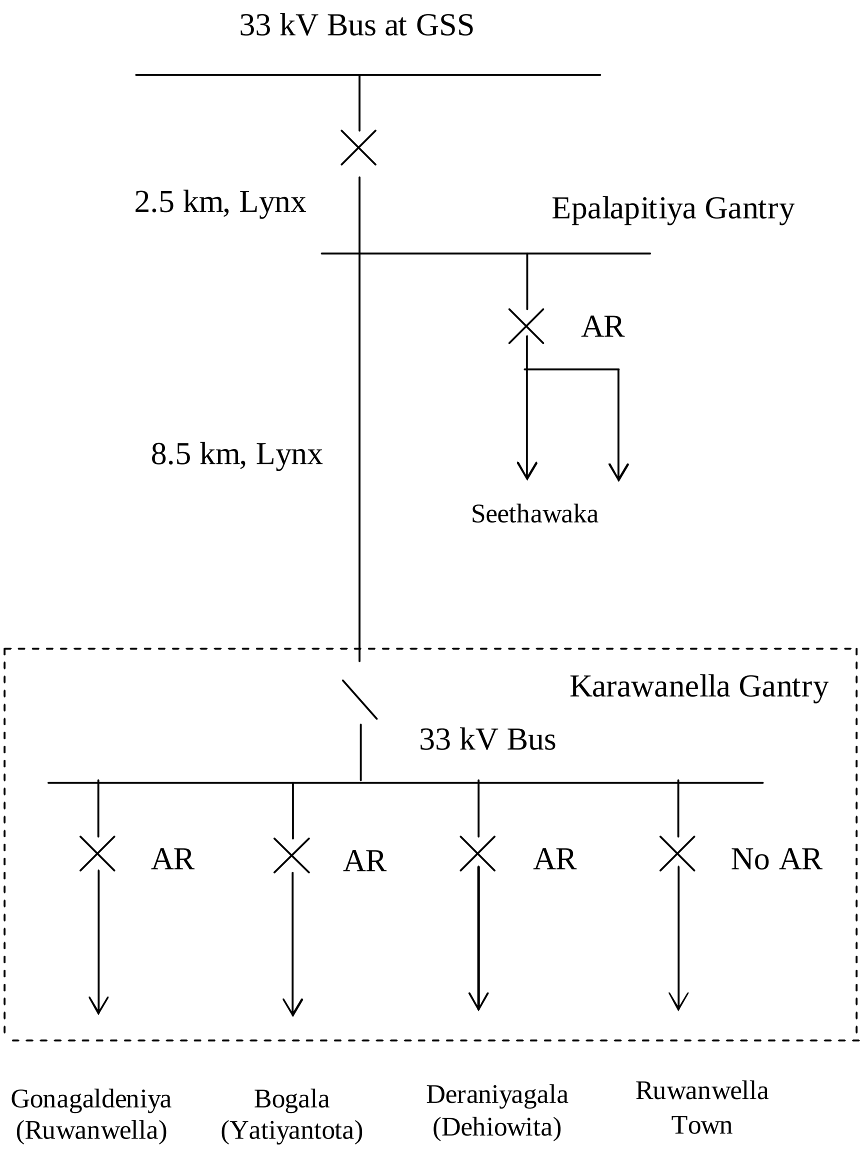


Figure 3.2: SLD of F1 of Seethawaka GSS

3.2.2 Trip Data of Seethawaka F1

As per the System Control Center data, F1 is the most disturbed 33 kV feeder compared to others. Comparison of feeder trippings in July 2014 is shown in Table 3.2. By analyzing the data in Appendix 2, a graph (Figure 3.3) is drawn for the tripping data of F1 for last two years. It is seen that, in most of the months, number of trippings per month in F1 are greater than 60.

Table 3.2: 33 kV Breakdown Summary of Seethawaka GSS in July 2014

GSS	Feeder	Number of Trippings									
		Auto						Manual			
	Number	EF	OC	OC + EF	Under Frequency (UF)	Others	Auto Total	Requested Trip	Load Shedding (LS)	Manual Total	TOTAL
Seethawaka	**F1**	59	2	1	-	-	62	2	-	2	**64**
	F2	12	-	-	-	-	12	1	-	1	**13**
	F3	-	-	-	-	-	-	-	-	-	**-**
	F4	-	-	-	-	-	-	-	-	-	**-**
	F5	9	-	2	-	-	11	2	-	2	**13**
	F6	2	-	-	-	-	2	3	-	3	**5**
	F7	-	-	-	-	-	-	-	-	-	**-**
	F8	21	1	-	-	4	26	-	-	0	**26**

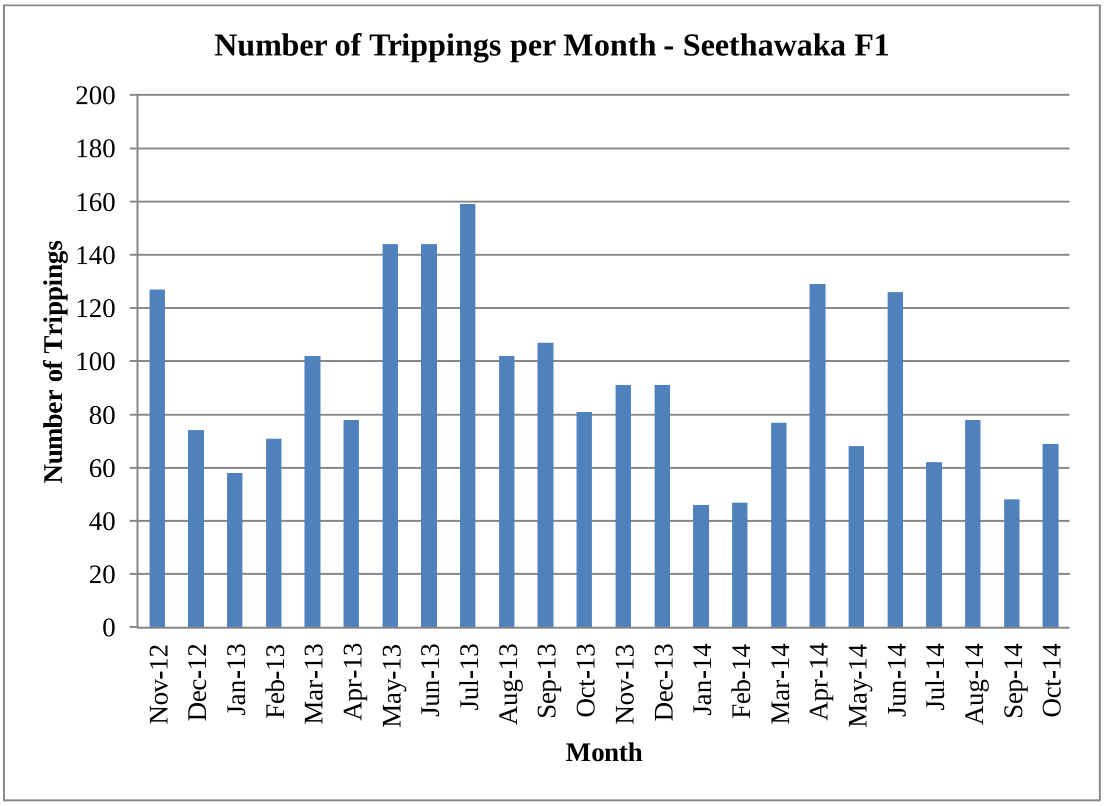


Figure 3.3: History of Trippings in F1 of Seethawaka GSS

Total trippings per month of F1 for three months were compared for auto and manual tripping as depicted in Figure 3.4. It is revealed that the majority of them are auto tripping scenarios.

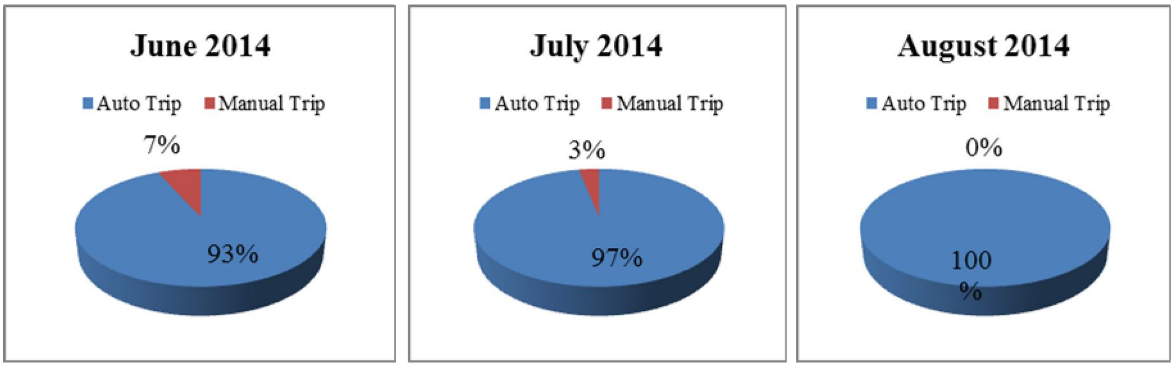


Figure 3.4: Comparison of Auto and Manual Trippings in F1

Then, auto trippings in F1 was compared for operated protection function. Figure 3.5 shows that majority of trippings is owing to operation of EF relay.

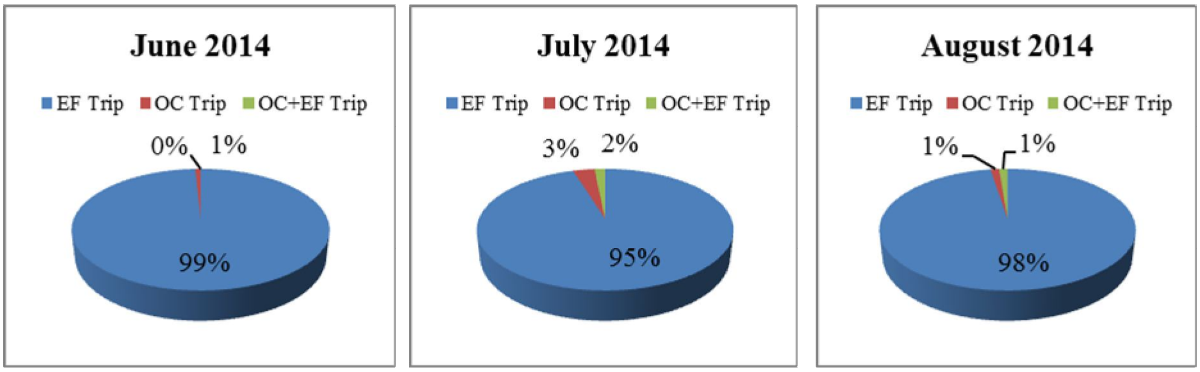


Figure 3.5: Comparison of Auto Trippings in F1 as per Cause

3.2.3 Digital Disturbance Records Analysis

Portable Digital Disturbance Recorder (DDR) was installed in to the F1 at Seethawaka GSS to study the behavior of F1. DDR records for ten days (From 29th July 2014 to 07th August 2014) were obtained for the analysis. Summary of analysis of DDR records during above 10 days are shown in Table 3.3.

Table 3.3: Summary of DDR Records Analysis for 10 Days of F1

Number	Date	Time of Interruption (hrs)	Maximum Fault Current - R Phase (kA)	Maximum Fault Current - Y Phase (kA)	Maximum Fault Current - B Phase (kA)	Maximum Fault Current - Earth (kA)	Fault Duration (ms)
1	29/07/2014	15.24	6.60		6.60	0.01	12.0
2	31/07/2014	11.14			1.07	1.07	68.4
3	01/08/2014	5.13	1.00			1.00	43.2
4		5.24	0.30	0.90	0.50	0.50	60.0
5		8.55			0.80	1.10	64.2
6	02/08/2014	13.56	0.35	0.35	0.80	0.50	200.8
7		13.59	0.53	0.30	0.95	0.55	199.2
8		20.06	0.50	0.90	0.50	0.55	194.4
9	03/08/2014	14.19	1.60			1.60	37.6
10		15.47	7.70		7.70	0.00	28.8
11		15.57	1.00			0.90	47.4
12		16.19	1.14			1.11	50.2
13		16.44	2.20			2.20	61.4
14		16.58	1.00			1.00	46.0
15		17.44	1.30			1.30	57.4
16	04/08/2014	5.04	7.50	7.50		0.00	10.6
17		19.48	0.90			0.90	18.2
18		23.29	0.90			1.05	19.0
19	05/08/2014	8.03			0.92	1.18	29.2
20		8.25	0.84			1.07	26.4
21		8.44			0.89	1.13	51.6
22		9.06	0.95			1.02	29.2
23		13.19	0.87			0.93	13.8
24		14.36	0.91			1.10	40.4
25		15.29			1.57	1.62	67.0
26	06/08/2014	0.40	1.43			1.60	69.8
27	07/08/2014	10.39			0.89	1.23	65.6

It can be seen that, F1 has tripped 27 times within these ten days, majority being due to EF. As per analysis, most of the faults have withstood less than 100 ms. EF current variation during each fault within these 10 days is shown in following graph (Figure 3.6).

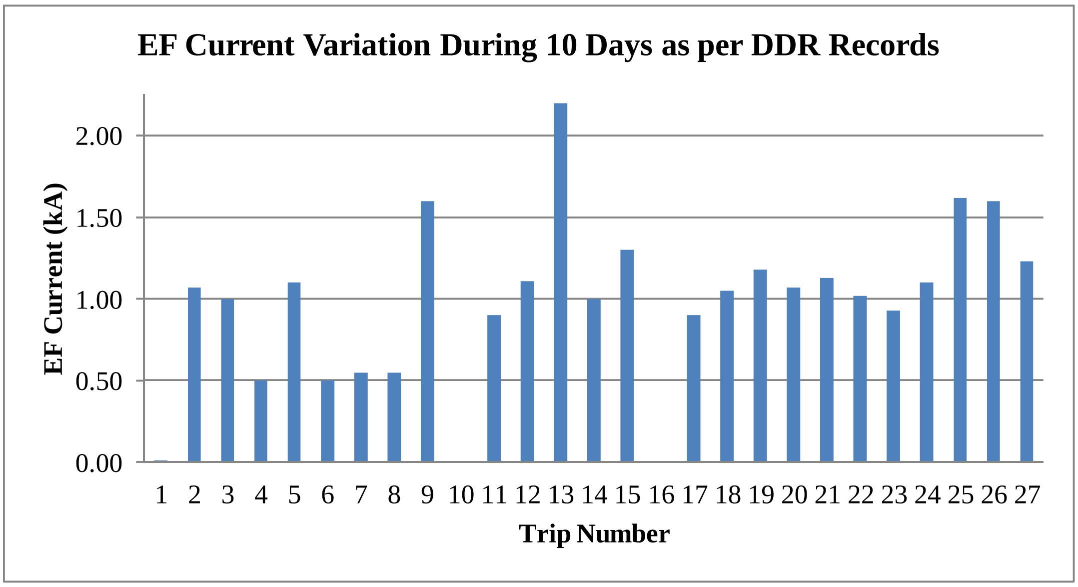


Figure 3.6: EF Current Variation of F1 during Faults as per DDR Records

F1 has tripped three times in 04th August 2014. The DDR has recorded seven other records in the same day. In depth analysis of the DDR records are given below. (There is two minutes of time different in DDR and GSS data.)

Analysis of F1 failure on 04th August 2014 at 05.05 hrs

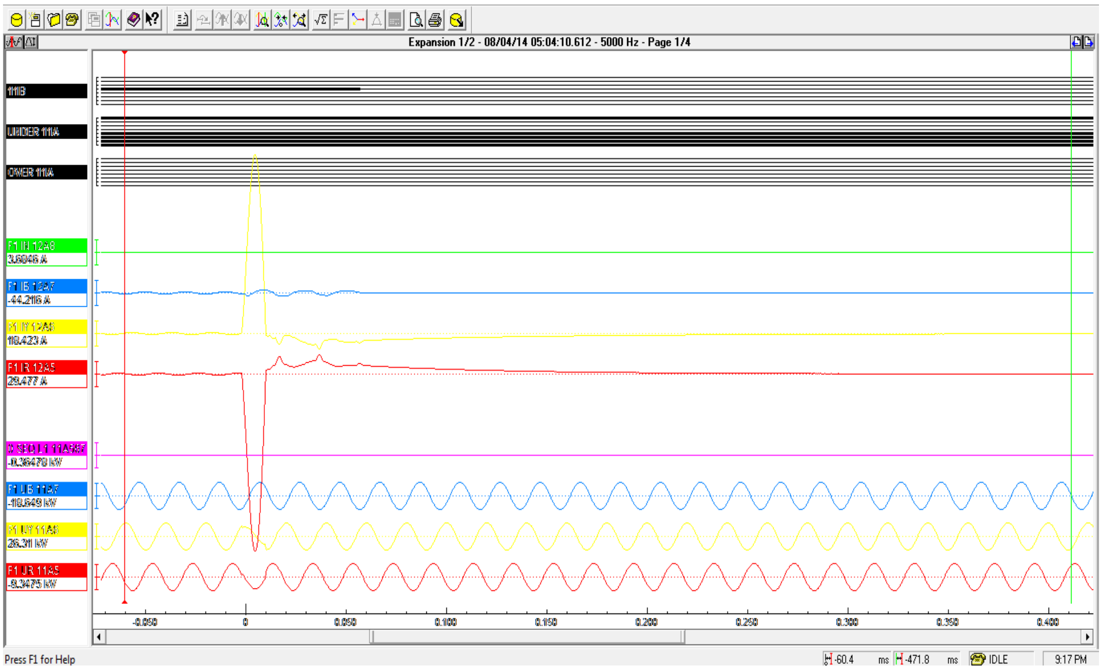


Figure 3.7: DDR Record at 05.05 hrs on 04th August 2014

F1 has tripped with the operation of OC relay at 05.05 hrs on 04th August 2014. According to the DDR record shown in Figure 3.7, there is a phase-phase fault in R and Y phases. Fault current of 7.5 kA has flown through these phase conductors for 10.6 ms and then fault current has suddenly decayed. CB has operated within 58.6 ms after detection of the fault.

Analysis of F1 failure on 04th August 2014 at 19.48 hrs

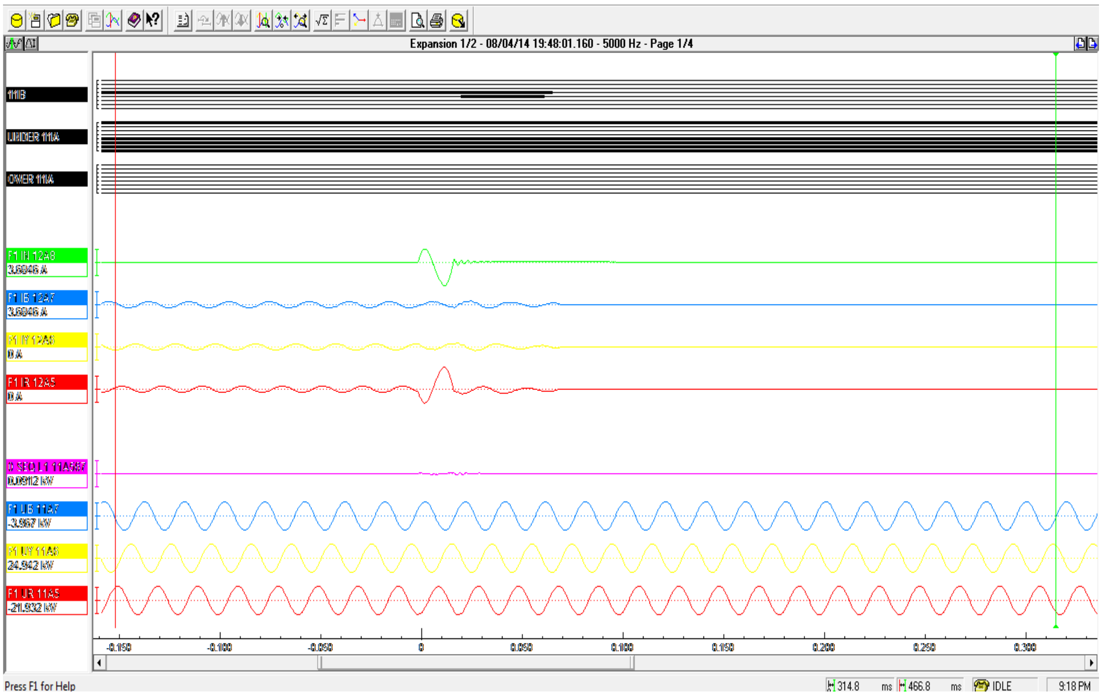


Figure 3.8: DDR Record at 19.48 hrs on 04th August 2014

As per the DDR record shown in Figure 3.8, phase-earth fault has occurred in F1 at 19.48 hrs on 04th August 2014. Maximum fault current (Peak) of 921 A and 884 A are shown in Ground and R phase conductors respectively in the record. The fault has withstood only for 18.2 ms. Instantaneous EF function of the protection relay has operated and has sent the signal to the CB within 41.2 ms. From the analysis, it is found that, time between the fault initiation and the CB open operation is 66.4 ms.

Analysis of F1 failure on 04th August 2014 at 23.29 hrs

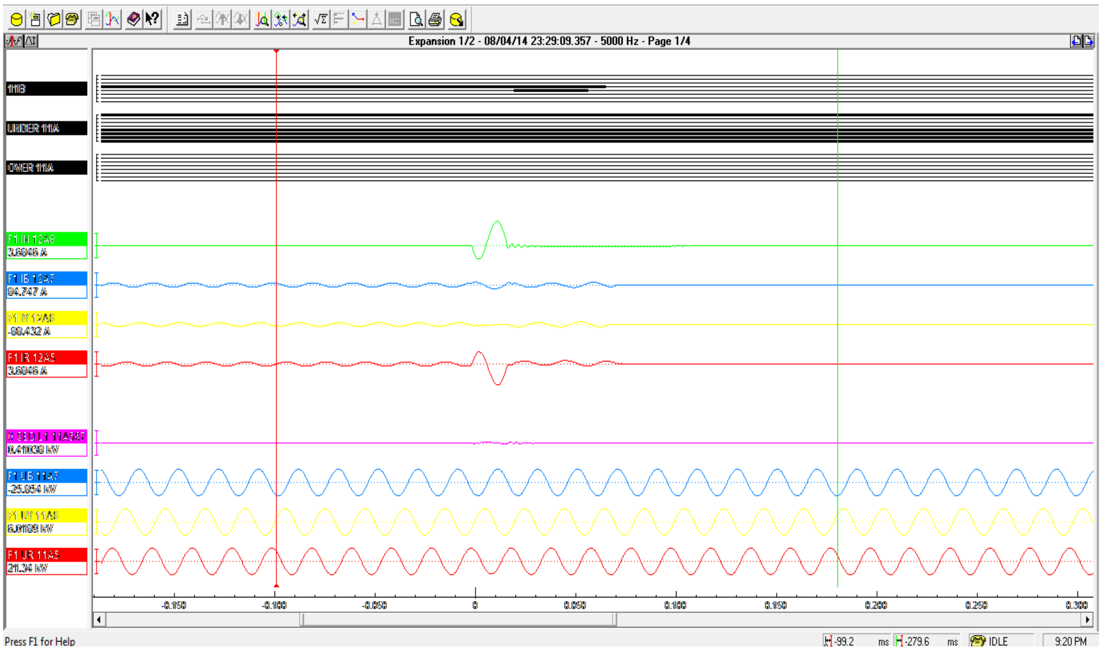


Figure 3.9: DDR Record at 23.29 hrs on 04th August 2014

Third tripping of F1 on the same day has happened at 23.29 hrs owing to an EF. Instantaneous EF element of the protection relay has detected a fault current of 899 A and 1,053 A in R phase and ground. The fault duration is only 19 ms and the fault has cleared within 67.2 ms.

Analysis of DDR record on 04th August 2014 at 05.30 hrs

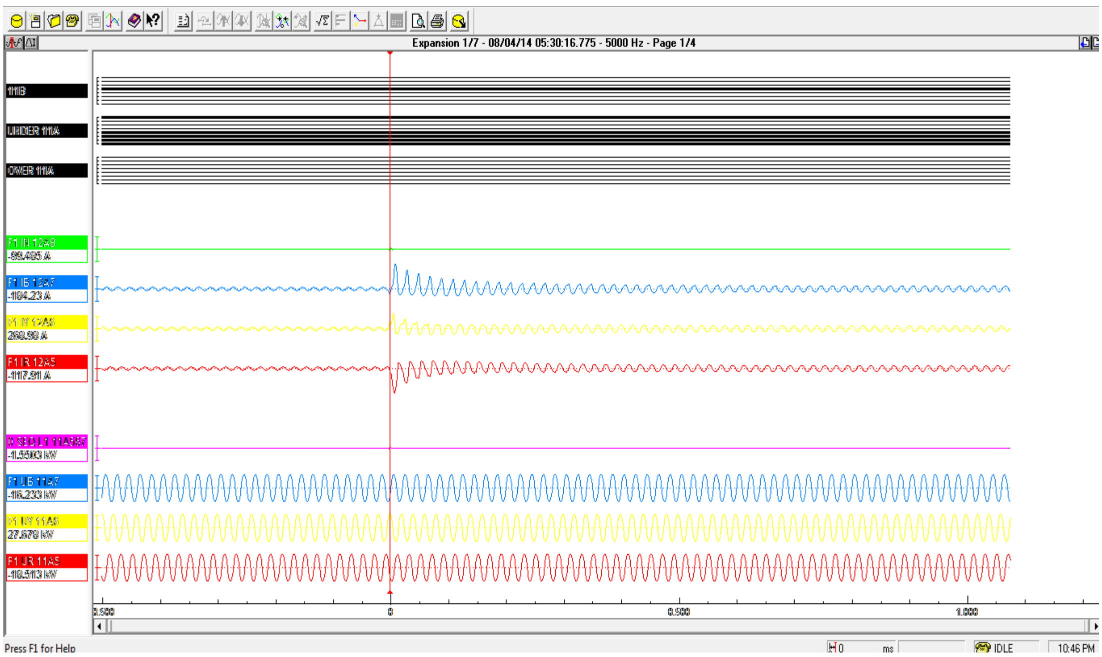


Figure 3.10: DDR Record at 05.30 hrs on 04th August 2014

DDR has recorded disturbance of three phases at 05.30 hrs on the same day. Maximum fault currents of 1,035 A, 641 A and 1,068 A are shown in R, Y and B phases respectively (Figure 3.10). This faulty condition has withstood for more than 1 s and has not caused tripping of the CB. Hence the F1 was healthy during this fault.

Analysis of DDR record on 04th August 2014 at 12.52 hrs

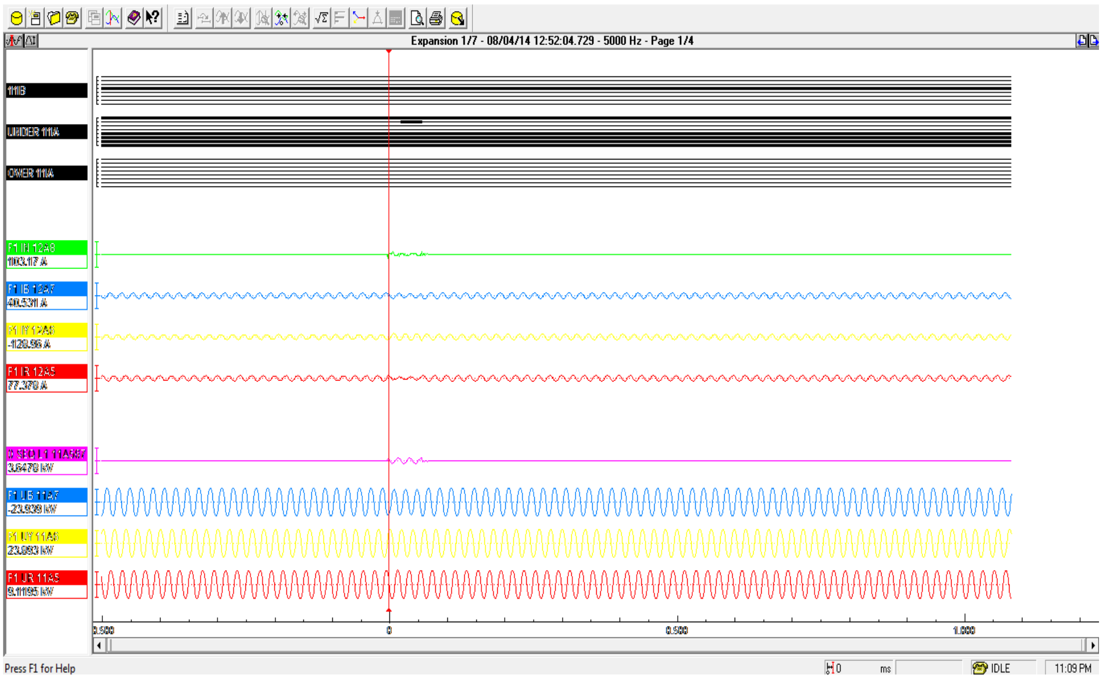


Figure 3.11: DDR Record at 12.52 hrs on 04th August 2014

Faulty condition of F1 has detected at 15.52 hrs on the same day. As per the DDR record (Figure 3.11), Maximum fault current which has flown through the ground conductor is 147 A. This fault incident has not caused tripping of F1.

Summary of DDR records on 04th August 2014

Summary of analysis of all DDR records pertaining to the 04th August 2014 and EF current variation during the day are given in Table 3.4 and Figure 3.12 respectively.

Table 3.4: Analysis of DDR Records of F1 on 04th August 2014

DDR Time	Maximum Fault Current - R Phase (A)	Maximum Fault Current - Y Phase (A)	Maximum Fault Current - B Phase (A)	Maximum Fault Current - Ground (A)	Fault Duration (ms)	Remarks
5:04:10	7443	7513	136	3	10.6	Trip
5:04:29	1448	1020	1385	66		Line Restore
5:30:16	1035	641	1068	99		Not Trip
9:18:59	888	405	895	3		Not Trip
11:37:38	114	110	125	99		Not Trip
12:00:02	125	143	125	84		Not Trip
12:05:22	70	95	84	77		Not Trip
12:15:03	95	99	95	84		Not Trip
12:52:04	70	154	132	147		Not Trip
19:48:01	884	125	114	921	18.2	Trip
19:48:25	1916	1068	1956	25		Line Restore
23:29:09	158	121	899	1053	19.0	Trip
23:29:38	1706	1507	840	51		Line Restore

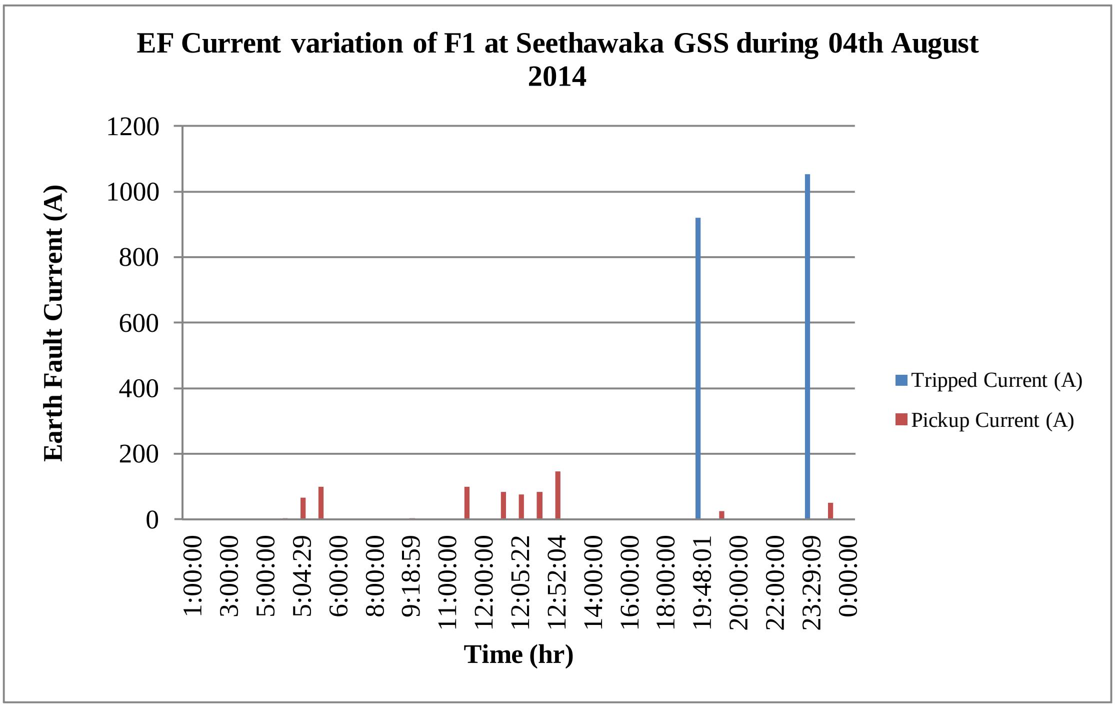


Figure 3.12: EF Current Variation of F1 on 04th August 2014 as per DDR Records

3.2.4 Auto Recloser Events Analysis

There are four downstream ARs installed for F1 of Seethawaka GSS. The time of AR at Epalapitiya sub-feeder is not updated and hence, AR events of this sub-feeder were not considered for the analysis. Therefore, only analysis of AR events of Dehiowita, Ruwanwella and Yatiyantota sub-feeders were given in Table 3.5, 3.6 and 3.7 to compare the DDR analysis on 04th August 2014.

AR events analysis - Dehiowita sub-feeder

As per the AR records given in Table 3.5, Dehiowita sub-feeder had no faults during the day. Tripping of the entire F1 at 05.05 hrs, 19.48 hrs and 23.29 hrs are recorded in AR events at slightly difference times as there is a small difference in the time set at both locations.

Table 3.5: Analysis of AR Events of Dehiowita Sub-feeder

Date	Time	Event Text	Remarks
04/08/2014	23:29:07	Aux Supply Normal	Trip from GSS
04/08/2014	23:29:06	Load Supply ON	
04/08/2014	23:29:06	Source Supply ON	
04/08/2014	23:28:38	Aux Supply Fail	
04/08/2014	23:28:38	Source Supply OFF	
04/08/2014	23:28:38	Load Supply OFF	
04/08/2014	19:47:54	Aux Supply Normal	Trip from GSS
04/08/2014	19:47:53	Load Supply ON	
04/08/2014	19:47:53	Source Supply ON	
04/08/2014	19:47:31	Aux Supply Fail	
04/08/2014	19:47:30	Load Supply OFF	
04/08/2014	19:47:30	Source Supply OFF	
04/08/2014	18:48:03	Modem Auto PwrCyc.	
04/08/2014	05:03:59	Aux Supply Normal	Trip from GSS
04/08/2014	05:03:58	Load Supply ON	
04/08/2014	05:03:58	Source Supply ON	
04/08/2014	05:03:41	Aux Supply Fail	
04/08/2014	05:03:40	Load Supply OFF	
04/08/2014	05:03:40	Source Supply OFF	

AR events analysis- Ruwanwella sub-feeder

Table 3.6: Analysis of AR Events of Ruwanwella Sub-feeder

Date	Time	Event Text	Remarks
04/08/2014	23:22:30	Sequence Reset	EF Trip
04/08/2014	23:22:18	Aux Supply Normal	
04/08/2014	23:22:17	Load Supply ON	
04/08/2014	23:22:17	Source Supply ON	
04/08/2014	23:21:59	Automatic Reclose	
04/08/2014	23:21:49	Aux Supply Fail	
04/08/2014	23:21:48	Source Supply OFF	
04/08/2014	23:21:48	Load Supply OFF	
04/08/2014	23:21:44	E Max 444 Amp	
04/08/2014	23:21:44	B Max 451 Amp	
04/08/2014	23:21:44	Prot Trip 1	
04/08/2014	23:21:44	Earth Prot Trip	
04/08/2014	23:21:44	Prot Group A Active	
04/08/2014	23:21:44	Pickup	
04/08/2014	19:46:18	Modem Auto PwrCyc.	
04/08/2014	19:41:22	Sequence Reset	EF Trip
04/08/2014	19:41:05	Aux Supply Normal	
04/08/2014	19:41:04	Load Supply ON	
04/08/2014	19:41:04	Source Supply ON	
04/08/2014	19:40:51	Automatic Reclose	
04/08/2014	19:40:41	Aux Supply Fail	
04/08/2014	19:40:41	Source Supply OFF	
04/08/2014	19:40:41	Load Supply OFF	
04/08/2014	19:40:36	E Max 418 Amp	
04/08/2014	19:40:36	Prot Trip 1	
04/08/2014	19:40:36	Earth Prot Trip	
04/08/2014	19:40:36	Prot Group A Active	
04/08/2014	19:40:36	Pickup	
04/08/2014	04:57:12	Aux Supply Normal	Trip from GSS
04/08/2014	04:57:11	Load Supply ON	
04/08/2014	04:57:11	Source Supply ON	
04/08/2014	04:56:54	Aux Supply Fail	
04/08/2014	04:56:53	Load Supply OFF	
04/08/2014	04:56:53	Source Supply OFF	

AR events with about eight minutes lagging behind GSS timing is given in Table 3.6. As per the AR events, two EF incidents have initiated in this feeder. Maximum EF current recorded at 19.40 hrs and 23.21 hrs are 418 A and 444 A respectively as per the AR time (Figure 3.13). AR has initiated auto reclosing during both incidents for the first attempt, but has not recovered the line since relay at GSS has also operated by tipping entire F1within 50 ms of pickup.

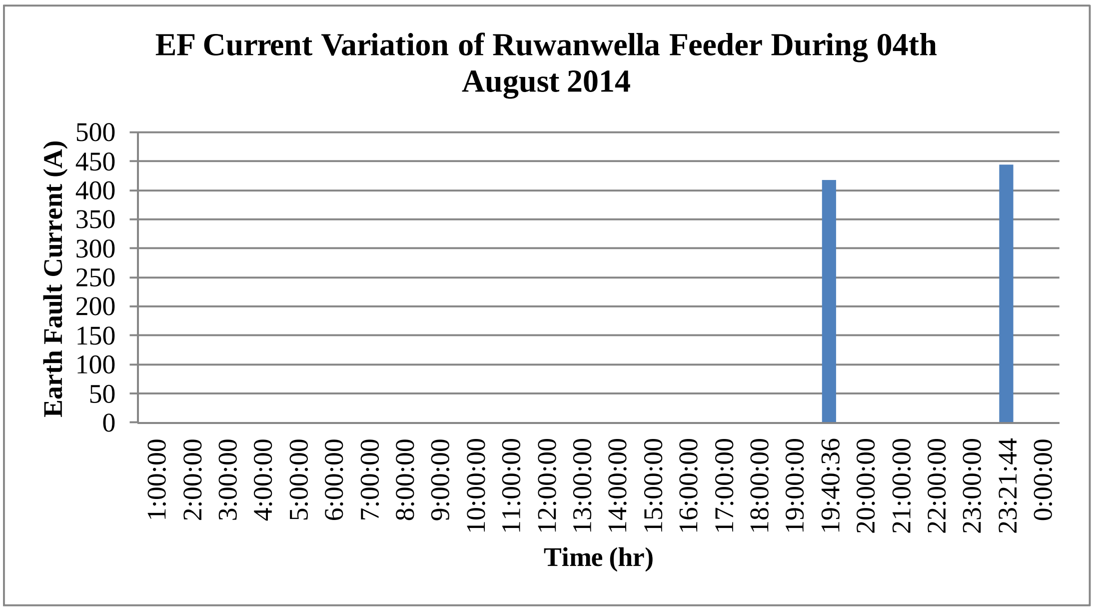


Figure 3.13: EF Current Variation of F1 on 04th August 2014 as per AR Events

AR events analysis – Yatiyantota sub-feeder

As per the AR events (Table 3.7), OC fault in the day has initiated from the Yatiyantota sub-feeder on 04th August 2014. Only B phase current of 201 A during the fault is observed in the events. Inrush current owing to distribution line restoration is also recorded at two occasions in these sample AR events at 05.05 hrs and 19.49 hrs.

There are fault incidents in the AR events after which the line has successfully auto reclosed without disturbing entire F1 in other days.

Table 3.7: Analysis of AR Events of Yatiyantota Sub-feeder

Date	Time	Event Text	Remarks
04/08/2014	23:30:43	Aux Supply Normal	Trip from GSS
04/08/2014	23:30:42	Load Supply ON	
04/08/2014	23:30:42	Source Supply ON	
04/08/2014	23:30:14	Aux Supply Fail	
04/08/2014	23:30:13	Load Supply OFF	
04/08/2014	23:30:13	Source Supply OFF	
04/08/2014	19:49:29	Aux Supply Normal	Pickup
04/08/2014	19:49:28	Load Supply ON	
04/08/2014	19:49:28	Source Supply ON	
04/08/2014	19:49:24	B Max 257 Amp	
04/08/2014	19:49:24	A Max 266 Amp	
04/08/2014	19:49:24	Pickup	
04/08/2014	19:49:05	Aux Supply Fail	Trip from GSS
04/08/2014	19:49:04	Load Supply OFF	
04/08/2014	19:49:04	Source Supply OFF	
04/08/2014	06:16:28	Modem Auto PwrCyc.	
04/08/2014	05:05:33	Aux Supply Normal	Pickup
04/08/2014	05:05:32	Load Supply ON	
04/08/2014	05:05:32	Source Supply ON	
04/08/2014	05:05:28	B Max 247 Amp	
04/08/2014	05:05:28	A Max 241 Amp	
04/08/2014	05:05:28	Pickup	
04/08/2014	05:05:14	Aux Supply Fail	OC Trip
04/08/2014	05:05:13	Load Supply OFF	
04/08/2014	05:05:13	Source Supply OFF	
04/08/2014	05:05:09	B Max 210 Amp	
04/08/2014	05:05:09	Pickup	

3.2.5 Existing Protection Settings of Seethawaka GSS

Existing OC and EF protection settings of power transformers and 33 kV feeders at Seethawaka GSS were collected by logging into relays. Relays installed for 33 kV feeders are digital type MCGG relays while backup protection relay of transformers are numerical type MICOM relays. OC and EF protection settings of MV system of Seethawaka GSS are given in Table 3.8 which depicts that sufficient grading margin between protective devices are available and revision of EF settings is required.

Table 3.8: Existing MV System Protection Settings of Seethawaka GSS

Bay	CT		Fault Current (A)	Relay	Protection Function	Existing Settings				
						DT Setting		IDMT Setting		
	Prim-ary	Seco-ndary				x In	Delay (s)	PS	TMS	Operating Time (s)
33 kV Transformer Feeder	800	1	3.27	MICOM P141	OC			0.8	0.235	0.99
	800	1	0.76		EF			0.1	0.175	0.53
	800	1	3.27		DOC			0.4	0.100	0.29
	800	1	0.76		DEF			0.1	0.100	0.30
	800	1	0.76	MICOM P120	SBEF-LV			0.1	0.300	0.91
33 kV Bus section (Single Transformer side)	1600	1	4.90	MCGG62	OC			0.75	0.100	0.49
33 kV BS (Two Transformer side)	1600	1	4.90		OC			0.75	0.100	0.49
33 kV Outgoing Feeders - F1, F2 (AR)	400	1	1.60	MCGG82	OC	4	0.0	1	0.100	0.50
	400	1	0.32		EF	8	0.0	0.1	0.100	0.33
33 kV Outgoing Feeders - F3, F4, F5, F6	400	1	1.60	MCGG82	OC	4	0.0	1	0.100	0.50
	400	1	0.16		EF	4	0.0	0.1	0.100	0.50
33 kV Outgoing Feeders - F8 (AR)	400	1	1.60	MICOM 127	OC	12.5	0.3	1	0.150	0.75
	400	1	1.60		DOC	4	0.1	1	0.100	0.50
	400	1	0.32		EF	8	0.1	0.1	0.100	0.33
	400	1	0.32		DEF	2.5	0.3	0.1	0.275	0.91

Existing protection settings of ARs installed in F1 were also found by logging to relays and it is tabulated in Table 3.9. It shows that EF settings have to be changed to avoid trippings of feeders as shown in chapter 3.2.3 and chapter 3.2.4.

Table 3.9: Existing AR Protection Settings of F1

Sub feeder	Reclose Time		EF Protection				OC Protection			
	Trip 1 (s)	Trip 2 (s)	EF Setting	Curve	TMS	EF Inst-antaneous Multiplier	OC Setting	Curve	TMS	OC Inst-antaneous Multiplier
Karawanella - Ruwanwella	15	15	20	NI	0.05	3	200	NI	0.05	3
Karawanella - Yatiyanthota	5	8	20	NI	0.05	3	200	NI	0.05	3
Karawanella - Dehiowita	5	10	20	NI	0.05	3	150	NI	0.05	3
Epalapitiya	10	15	30	NI	0.05	8	150	NI	0.05	8

3.2.6 Fault Level Calculation

When calculating operating times of protective devices, it is required to find the fault levels at the location of protective devices (relays and ARs). Fault levels at GSS are calculated using PSSE software and published in “Long Term Transmission Development Plan” annually by CEB. “Maximum Fault Levels” published in 2013 is attached in the Appendix 4.

33 kV fault level (Three phase) at GSS can be obtained from Appendix 4 (Table 3.10) and beyond that, fault levels can be calculated by using impedances of conductors.

Table 3.10: Fault Levels of Seethawaka GSS (Appendix 4)

Grid Substation	Voltage Level (kV)	Maximum Three Phase Fault Level					
		2013		2017		2022	
		kA	degree	kA	degree	kA	degree
Seethawaka	132	8.2	-71.7	5.5	-85.2	5.7	-85.2
	33	11.4	-84.2	9.8	-88	10	-88.1

132 / 33 kV power transformers used in GSS have YNd1 connection. Hence, LV side has a delta winding. Therefore, to detect EF, external source of zero sequence current is obtained by connecting earthing transformer as shown in Figure 3.14. Zero sequence impedance of these earthing transformers are in the range of 70 - 75 Ω.

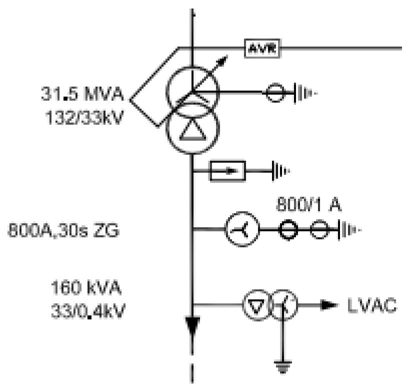


Figure 3.14: Power Transformer and Earthing Transformer Connection in a GSS

Hence,

Maximum EF current in 33 kV side of a power transformer $= \frac{33{,}000}{\sqrt{3}} \times \frac{1}{(75/3)}$ A

$= 762$ A

According to the number of transformers connected, EF level at GSS can vary.

Figure 3.15 shows the sub feeder arrangement of F1, F2 and F8 of GSS to calculate fault levels at location of ARs.

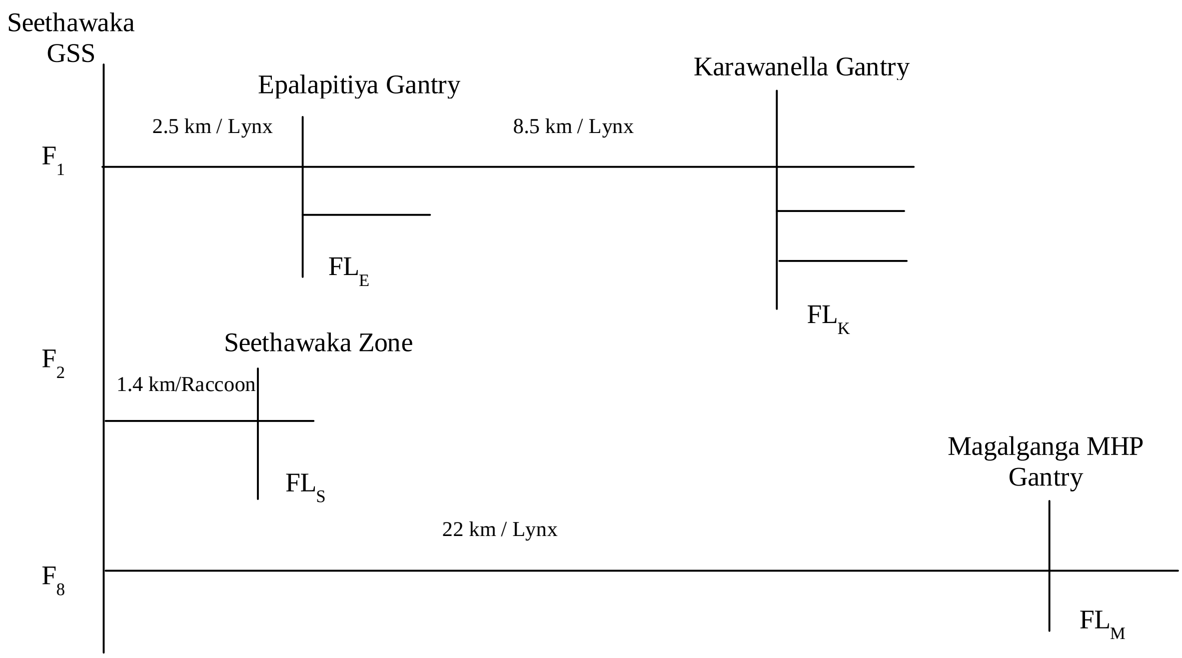


Figure 3.15: Sub-feeder Arrangement of F1, F2 and F8

Positive, negative and zero sequence impedances of conductors are used from the Table 3.11 for the calculation of fault levels.

Table 3.11: Conductor Impedances

Conductor	Positive Impedance Ω/km	Negative Impedance Ω/km	Zero Impedance Ω/km
Raccoon	0.431+0.3731 i	0.431+0.3731 i	0.580+1.651 i
Lynx	0.177+0.3723 i	0.177+0.3723 i	0.396+1.466 i

Following Base Values are considered for calculations;

S = 100 MVA

V = 33 kV

I = S / (√3 × V) = 100 / (√3 × 33) = 1.75 kA

Z = V / (√3 × I) = 33 / (√3 × 1.75) = 10.89 Ω

Per Unit (pu) values of three phase and ground fault levels at Seethawaka GSS are calculated below using the above data.

From Long Term Transmission Development Plan 2013 - 2022,

Three phase Fault Level of 33 kV bus at Seethawaka GSS = 9.8 kA

Three phase Fault Level of 33 kV bus at Seethawaka GSS in pu values =5.60 pu

Impedance up to the 33 kV bus at Seethawaka GSS in pu values (Z1) = 0.18 pu

= 0.18i pu

Since three transformers are connected in parallel,

Earth Fault Level of 33 kV bus at Seethawaka GSS =2.29 kA

Earth Fault Level of 33 kV bus at Seethawaka GSS in pu values =1.31 pu

Impedance up to the 33 kV bus at Seethawaka GSS in pu values (Z1E) =0.77 pu

=0.77 i pu

Per Unit values of line positive / negative and zero sequence impedances are calculated in Table 3.12 and 3.13.

Table 3.12: Line Positive / Negative Sequence Impedances

Line	**Conductor Type**	**Length (km)**	**Impedance (per km)**	**Total Impedance (Ω)**	**Total Impedance (Z_1 and Z_2) (pu)**
Seethawaka – Karawanella	Lynx	11.0	0.177+0.3723i	1.947+4.0953i	0.178787878787879 +0.376060606060606i
Seethawaka – Epalapitiya	Lynx	2.5	0.177+0.3723i	0.4425+0.93075i	0.040633608815427 +0.0854683195592286i
Seethawaka - Seethawaka Zone	Raccoon	1.4	0.431+0.3731i	0.6034+0.52234i	0.0554086317722681 +0.0479651056014692i
Seethawaka - Magalganga MHP	Lynx	22.0	0.177+0.3723i	3.894+8.1906i	0.357575757575758 +0.752121212121212i

Table 3.13: Line Zero Sequence Impedances

Line	**Conductor Type**	**Length (km)**	**Impedance (per km)**	**Total Impedance (Ω)**	**Total Impedance (Z_0) (pu)**
Seethawaka - Karawanella	Lynx	11.0	0.396+1.466 i	4.356+16.126 i	0.4 +1.48080808080808 i
Seethawaka - Epalapitiya	Lynx	2.5	0.396+1.466 i	0.99+3.665 i	0.0909090909090909 +0.336547291092746 i
Seethawaka - Seethawaka Zone	Raccoon	1.4	0.58+1.651 i	0.812+2.3114 i	0.0745638200183655 +0.212249770431589 i
Seethawaka - Magalganga MHP	Lynx	22.0	0.396+1.466 i	8.712+32.252 i	0.8 +2.96161616161616 i

Following equations [13] are used for the calculation of three phase fault levels and line-ground fault levels at location of ARs.

$$I_{af} = \frac{V_f}{Z_1 + Z_f}$$

$$I_{af} = \frac{V_f}{Z_0 + Z_1 + Z_2 + 3Z_f}$$

Where; I_{af} = Fault Level at location of AR (pu)
V_f = Source Voltage (pu)
Z_0 = Line Zero Sequence Impedance (pu)
Z_1 = Line Positive Sequence Impedance (pu)
Z_2 = Line Negative Sequence Impedance (pu)
Z_f = Fault level at GSS (pu)

Calculated three phase fault levels and line-ground fault levels at location of ARs are given in Table 3.14 and Table 3.15 respectively.

Table 3.14: Three Phase Fault Levels at AR Locations

AR Location	**Fault path impedance ($Z_1 + Z_f$) (pu)**	**Magnitude of fault path impedance ($Z_1 + Z_f$) (pu)**	**Fault level (I_{af}) (pu)**	**Fault level (kA)**
Karawanella Gantry	0.178787878787879 +0.554585735680156i	0.582692409	1.716171318	**3.00**
Epalapitiya	0.040633608815427 +0.263993449178779i	0.267102286	3.743884089	**6.55**
Seethawaka Zone	0.0554086317722681 +0.226490235221019i	0.233169344	4.288728447	**7.50**
Magalganga MHP	0.357575757575758 +0.930646341740762i	0.996976948	1.003032218	**1.75**

Table 3.15: Line-Ground Fault Levels at AR Locations

AR Location	**Fault path impedance (Z_0 + Z_1 +Z_2 + 3Z_f) (pu)**	**Magnitude of fault path impedance (Z_0 + Z_1 +Z_2 + 3Z_f) (pu)**	**Fault level (I_{af}) (pu)**	**Fault level (kA)**
Karawanella Gantry	0.757575757575758 +4.52861340679523i	4.59154227	0.653375233	**1.14**
Epalapitiya	0.172176308539945 +2.80316804407714i	2.808450777	1.068204586	**1.87**
Seethawaka Zone	0.185381083562902 +2.60386409550046i	2.610454821	1.149225022	**2.01**
Magalganga MHP	1.51515151515152 +6.76154269972452i	6.929223896	0.43294892	**0.76**

3.2.7 Existing Co-ordination

Operating times for relays and ARs of Seethawaka GSS were calculated by applying the calculated fault levels and using the equation defined by IEC 60255 for NI curves (Table 3.16). Then co-ordinations curves for both OC and EF protection were plotted as given in Figure 3.16 and Figure 3.17.

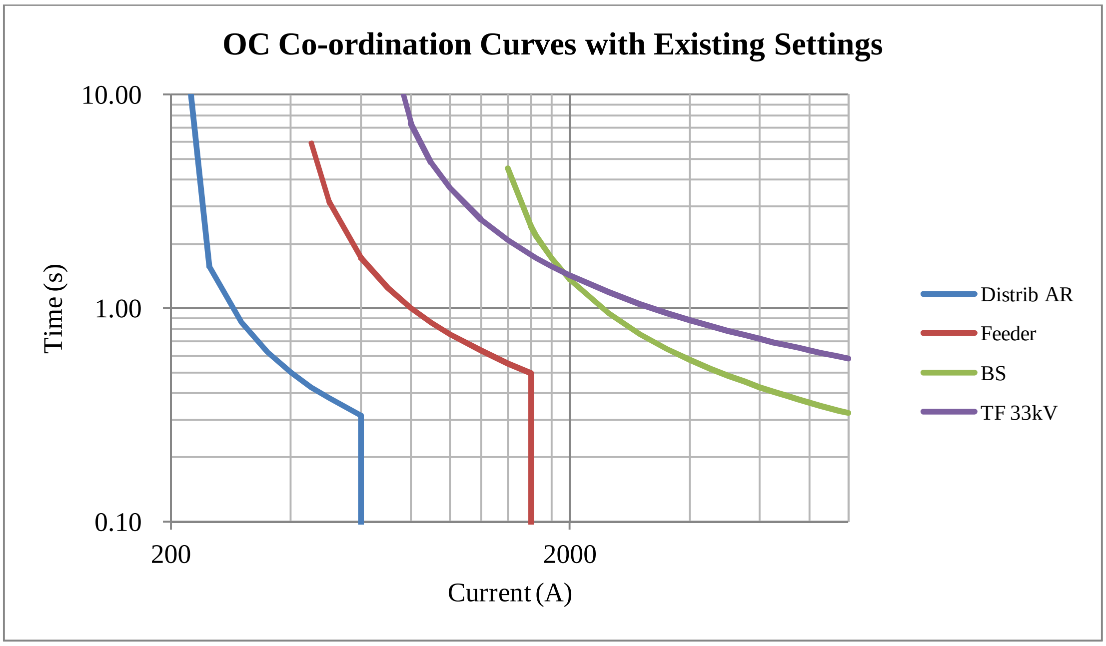


Figure 3.16: OC Co-ordination Curves for Existing Settings

Table 3.16: Operating Times of OC and EF protection Relays With Existing Settings

Bay	Fault Current	Relay	Protection Function	Existing Settings				
				DT Settings		IDMT Setting		
				x In	Delay (s)	PS	TMS	Operating Time (s)
33 kV Transformer Feeder	3.27	MICOM P141	OC			0.80	0.235	0.99
	0.76	MICOM P141	EF			0.10	0.175	0.53
	3.27	MICOM P141	DOC			0.40	0.100	0.29
	0.76	MICOM P141	DEF			0.10	0.100	0.30
	0.76	MICOM P120	SBEF-LV			0.10	0.300	0.91
33 kV BS (Single Transformer side)	4.90	MCGG62	OC			0.75	0.100	0.49
33 kV BS (Two Transformer side)	6.53	MCGG62	OC			0.75	0.100	0.41
33 kV BS	2.29	MCGG62	EF					
33 kV Outgoing Feeders F1, F2	9.80	MCGG82	OC	4.0	0.0	1.00	0.100	0.23
	2.29	MCGG82	EF	8.0	0.0	0.10	0.100	0.23
33 kV Outgoing Feeders F3, F4, F5, F6	9.80	MCGG82	OC	4.0	0.0	1.00	0.100	0.23
	2.29	MCGG82	EF	4.0	0.0	0.10	0.100	0.23
33 kV Outgoing Feeders F8	9.80	MICOM 127	OC	12.5	0.3	1.00	0.150	0.34
	9.80	MICOM 127	DOC	4.0	0.1	1.00	0.100	0.23
	2.29	MICOM 127	EF	8.0	0.1	0.10	0.100	0.23
	2.29	MICOM 127	DEF	2.5	0.3	0.10	0.275	0.62
Seethawaka Zone	7.50	NEWLEC	OC	3.0	0.0	0.50	0.050	0.11
	2.01	NEWLEC	EF	3.0	0.0	0.05	0.050	0.11
Epalapitiya Gantry	6.55	NEWLEC	OC	3.0	0.0	0.50	0.050	0.11
	1.87	NEWLEC	EF	3.0	0.0	0.05	0.050	0.11
Karawanella Gantry	3.00	NEWLEC	OC	3.0	0.0	0.50	0.050	0.13
	1.14	NEWLEC	EF	3.0	0.0	0.05	0.050	0.11
Magalganga MHP	1.75	NEWLEC	OC	3.0	0.0	0.50	0.050	0.16
	0.76	NEWLEC	EF	3.0	0.0	0.05	0.050	0.11

It is found that both IDMT and DT, existing EF setting of ARs are very sensitive. There is a requirement to change the existing protection settings of ARs and then in relays accordingly.

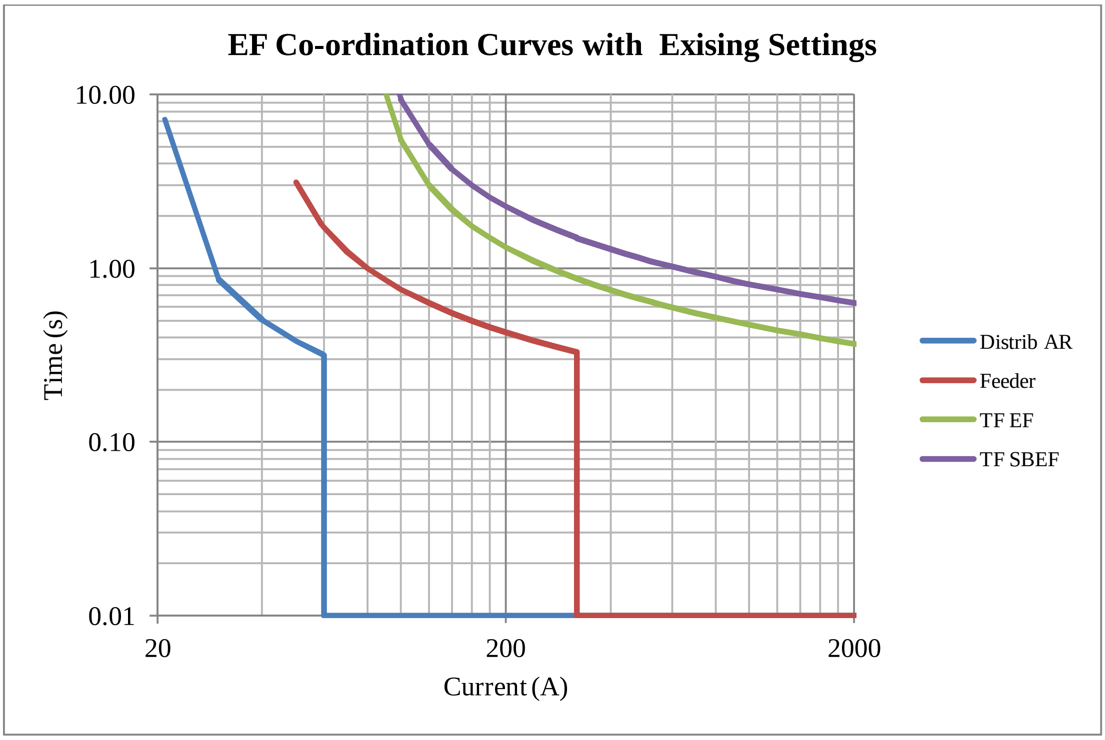


Figure 3.17: EF Co-ordination Curves for Existing Settings

3.2.8 Outcome of Case Study 1

From the trip details, it is found that majority (more than 90%) of trippings are owing to EF.

DDR records show that most of the faults have persisted less than 100 ms (5 cycles).

EF settings of AR are very sensitive and always tend to trip the F1 definitively without auto reclosing the line. Hence revision of AR settings is required with suitable settings to relays for better coordination.

To obtain better operating times, it is required to check whether application of VI or EI curves are more suitable instead of NI curves.

3.3 Case Study 2 – Badulla GSS

Badulla GSS is a 132 / 33 kV substation which was initially constructed in 1983 and refurbished both in 1994 and in 2014. Following SLD (Figure 3.18) shows the arrangement of the GSS which includes 132 kV transmission lines, 31.5 MVA, 132 / 33 kV power transformers and 33 kV feeders.

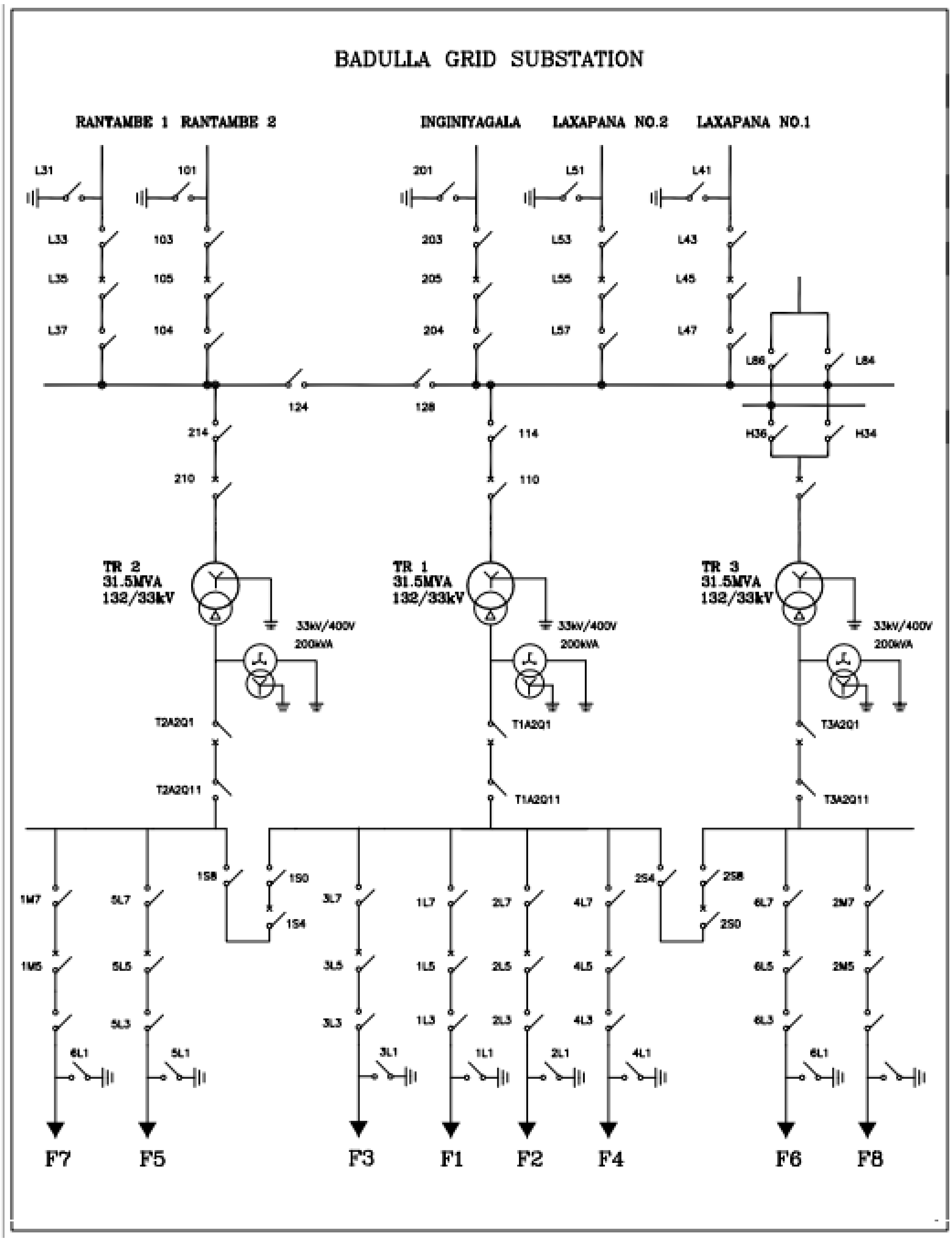


Figure 3.18: SLD of Badulla 132 / 33 kV GSS

3.3.1 Downstream AR Details of Badulla GSS

Out of all feeders F3, F4, F5, F6 and F8 have downstream ARs installed. Since frequency of tripping of F5 is comparably high, only details of F5 were collected for the analysis. The SLD of F5 is shown in Figure 3.19 and AR installation data are tabulated in Table 3.17. There are sub-feeders which have ARs connected in series.

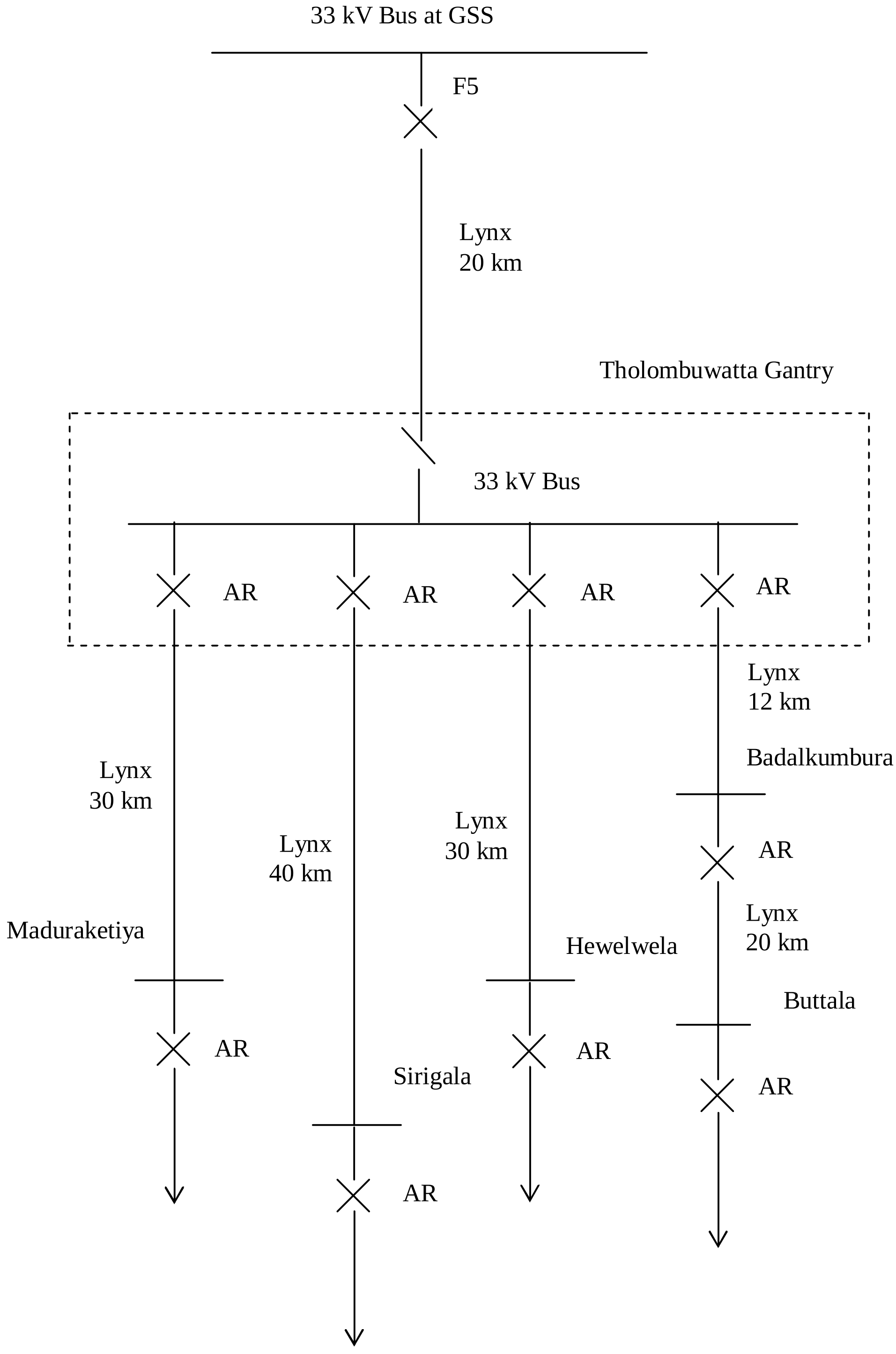


Figure 3.19: SLD of F5 of Badulla GSS

Table 3.17: Downstream AR Details of Badulla GSS

Feeder Number	Feeder name – AR 1	Distance from the GSS to the AR location	Feeder name – AR 2	Distance from 1st AR to 2nd AR location	Feeder name – AR 3	Distance from 2nd AR to 3rd AR location
F5	Tholombuwatta Gantry (04 AR)	20.0 km	Maduraketiya (01 AR)	30.0 km		
			Sirigala (01 AR)	40.0 km		
			Hewelwela (01 AR)	30.0 km		
			Badalkumbura (01 AR)	12.0 km	Buttala (01 AR)	20.0 km

3.3.2 Trip Data of Badulla F5

F5 is the most disturbed feeder in Badulla GSS, as per the System Control Center data. Table 3.18 gives the comparison of feeder trippings in July 2014. F2 is a spare feeder.

Table 3.18: 33 kV Breakdown Summary of Badulla GSS in July 2014

GSS	Feeder	Number of Trippings									
		Auto						Manual			
	Number	EF	OC	OC+EF	UF	Others	Auto Total	Requested Trip	LS	Manual Total	TOTAL
Badulla	**F1**	1	-	-	-	-	1	2	-	2	**3**
	F2	-	-	-	-	-	0	-	-	0	**0**
	F3	2	-	-	-	-	2	4	-	4	**6**
	F4	5	-	-	-	-	5	3	-	3	**8**
	F5	57	-	-	-	-	57	7	-	7	**64**
	F6	12	-	-	-	-	12	4	-	4	**16**
	F7	17	-	-	-	-	17	10	-	10	**27**
	F8	2	1	1	-	-	4	4	-	4	**8**

From the data in Appendix 2, the tripping data of F5 for last two years were analyzed and plotted in a graph (Figure 3.20). Data proves that, the frequency of tripping in F5 is more than 40 per month.

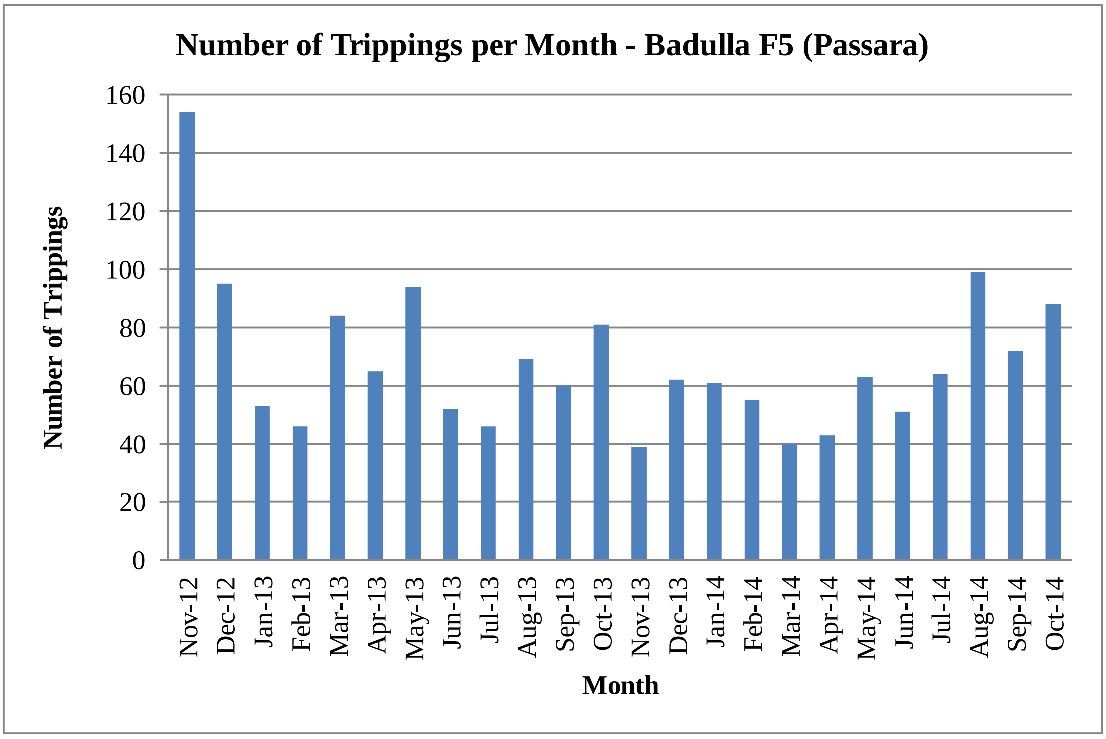


Figure 3.20: History of Trippings in F5 of Badulla GSS

Figure 3.21 shows the comparison of total trippings between auto and manual tipping per month of F5 for three months. Similar to Case Study 1, auto trippings are the highest.

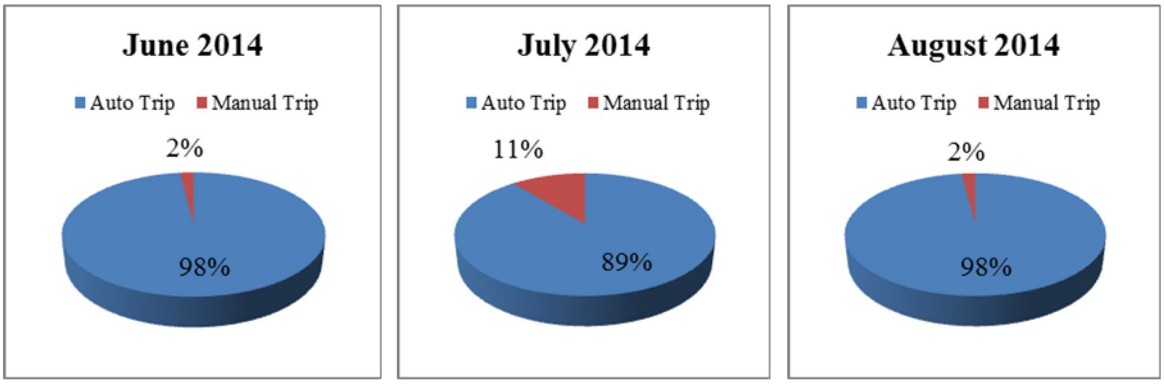


Figure 3.21: Comparison of Auto and Manual Trippings in F5

Comparison among operated protection functions (Figure 3.22) show that the trippings owing to EF is comparably high in F5.

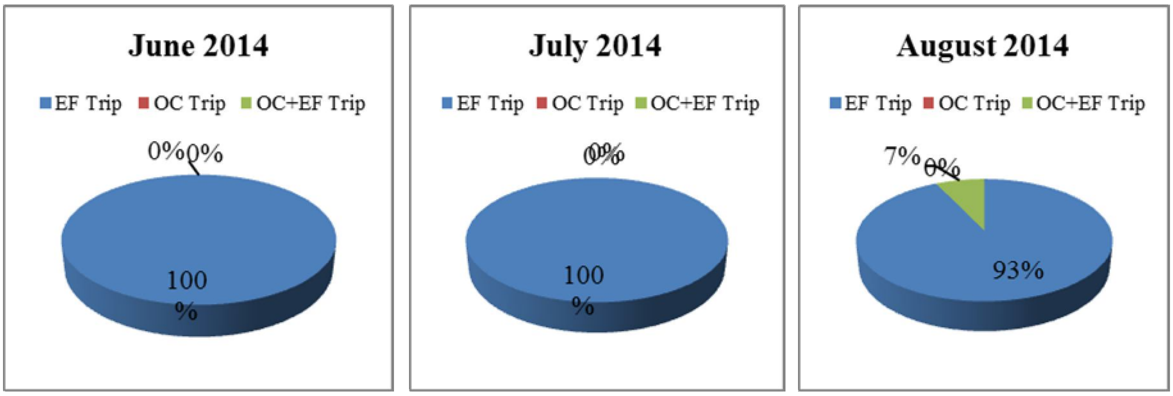


Figure 3.22: Comparison of Auto Trippings in F5 as per Cause

3.3.3 Auto Recloser Events Analysis

Trip data gathered from the GSS for six days from 11th November 2014 to 16th November 2014 were considered for this analysis. There were 22 number of line interruptions during the period considered. Tripping data including EF current recorded in AR for six days are shown in Table 3.19. According to the records, all are auto trippings owing to operation of EF relay. EF current recorded during these line interruptions were plotted in Figure 3.23.

As per the data, there are nine downstream ARs installed in F5 of Badulla GSS. These ARs are two types such as NEWLEC and NTEC. AR data can be downloaded only from NEWLEC type. During the line interruption, all downstream ARs affected. Hence, event records from AR at Hewalwela were downloaded for this analysis.

Table 3.19: 33 kV Feeder 5 Tripping Detail During Six Days of Badulla GSS

Number	Date	Time of Interruption (hrs)	Time of Restoration (hrs)	Indications	Type of Failure	Fault Current (A)
1	11/11/2014	2.02	2.04	EF	Auto	302
2		9.32	9.35	EF	Auto	80
3		11.16	11.17	EF	Auto	337
4		13.05	13.07	EF	Auto	568
5		19.27	19.28	EF	Auto	51
6	12/11/2014	21.06	21.08	EF	Auto	317
7		22.12	22.13	EF	Auto	331
8		23.27	23.28	EF	Auto	56
9	13/11/2014	11.38	11.39	EF	Auto	42
10		12.21	12.22	EF	Auto	321
11	14/11/2014	17.02	17.04	EF	Auto	342
12		17.48	17.52	EF	Auto	276
13		22.47	22.51	EF	Auto	51
14	15/11/2014	5.03	5.04	EF	Auto	291
15		5.58	5.59	EF	Auto	488
16		12.38	12.39	EF	Auto	362
17	16/11/2014	1.08	1.1	EF	Auto	329
18		4.35	4.36	EF	Auto	247
19		5.46	5.47	EF	Auto	53
20		12.1	12.12	EF	Auto	519
21		15.13	15.14	EF	Auto	629
22		16.08	16.09	EF	Auto	567

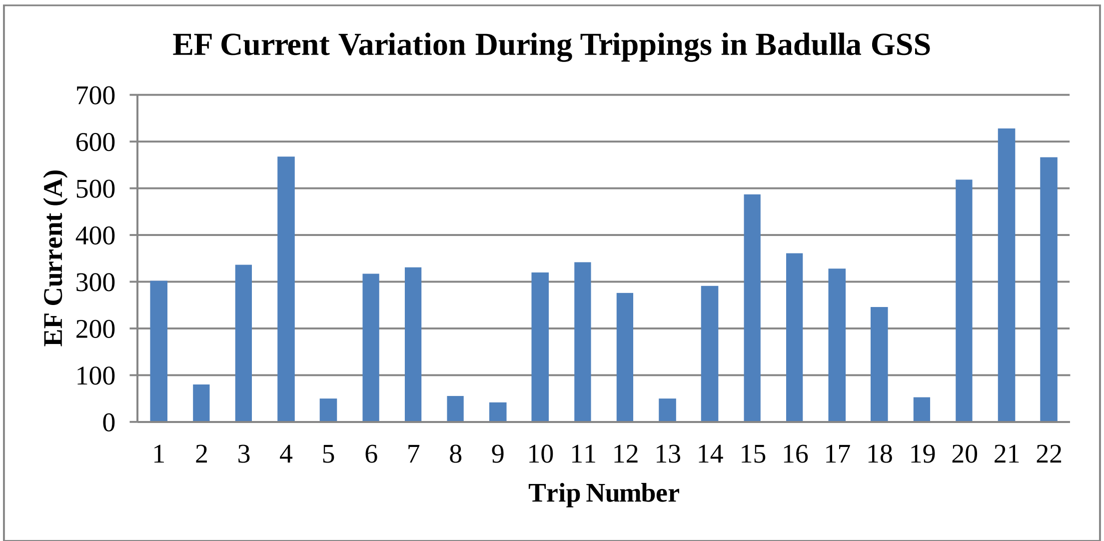


Figure 3.23: EF Current Variation of F5 Within Six Days as per AR Events

From the detailed analysis of AR events for 16th November 2014, EF current variation was plotted as Figure 3.24. F5 has interrupted five times in this day and line has recovered without tripping at seven times with successful auto reclosing.

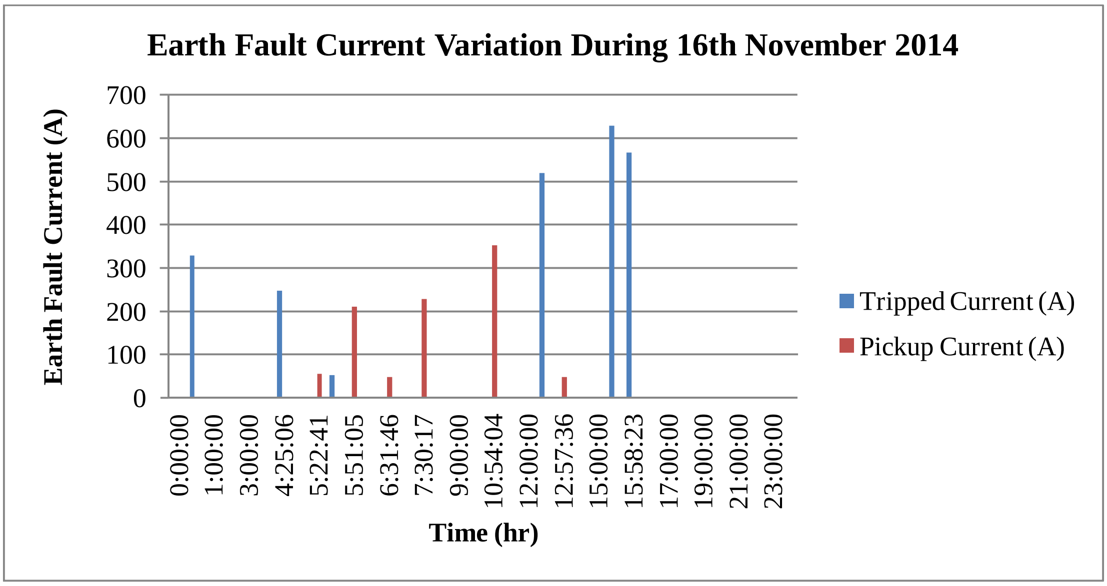


Figure 3.24: EF Current Variation of F5 on 16thNovember 2014 as per AR Events

Above graph reveals that in some cases the feeder has tripped owing to small EF current (about 50 A), while feeders have recovered sometimes with EF current higher than that value.

3.3.4 Existing Protection Settings of Badulla GSS

Existing OC and EF protection settings of power transformers, 33 kV bus section and 33 kV feeders at Badulla are tabulated in Table 3.20. All relays at GSS are numerical type. Primary protection relay of 33 kV feeders and 33 kV bus section is REF 630. Backup protection relay of transformers is also REF 630 and SBEF function is in primary protection relay; T60. These relays were manufactured by GE.

Existing protection settings of ARs installed in F5 is also given in Table 3.21.

Table 3.20: Existing MV System Protection Settings of Badulla GSS

Bay	CT		Fault Current	Relay	Protection Function	Protection Settings				
						DT Settings		IDMT Setting		
	Prim-ary	Seco-ndary				x In	Delay (s)	PS	TMS	Operating Time (s)
33 kV Transformer Feeder	800	1	0.76	T60	SBEF-LV			0.125	0.33	1.11
	800	1	4.00	REF 630	OC			0.75	0.23	0.83
	800	1	0.76		EF			0.1	0.26	0.79
33 kV Bus Section	2000	1	8.00	REF 630	OC	0.83	0.4	0.6	0.13	0.47
	2000	1	1.52		EF	0.18	0.4	0.05	0.16	0.40
33 kV Feeder 1, 2, 3, 4 & 6	400	1	1.60	REF 630	OC	4	0.10	1	0.08	0.40
	400	1	0.16		EF	4	0.10	0.1	0.11	0.55
33 kV Feeder 5	400	1	1.60	REF 630	OC	4	0.10	1	0.08	0.40
	400	1	0.32		EF	0.8	0.10	0.1	0.11	0.36
33 kV Feeder 7 & 8	400	1	1.60	REF 630	OC	4	0.10	1	0.08	0.40
	400	1	0.16		EF	0.4	0.10	0.1	0.1	0.50
	400	1	1.60		DOC	4	0.10	1	0.1	0.50
	400	1	0.16		DEF	0.4	0.10	0.1	0.1	0.50

Table 3.21: Existing AR Protection Settings of F5

			Reclose Time		Earth Protection			Phase Protection		
ARC Location	Earth Trip Current	Phase Trip Current	Trip 1 (s)	Trip 2 (s)	Curve	Earth Time Multi-plier	Earth Instant-antaneous Multi-plier	Curve	Phase Time Multi-plier.	Phase Instant. antaneous Multi-Plier
Tholombuwatta Gantry	30	200	15	15	NI	0.08	5	NI	0.10	8
Badalkumbura Gantry	20	200	15	15	NI	0.05	4	NI	0.05	3
Buttala Gantry	20	200	15	15	NI	0.01	4	NI	0.01	3
Hewelwela Gantry	20	200	15	15	NI	0.05	4	NI	0.05	3
Sirigala Gantry	20	200	15	15	NI	0.05	4	NI	0.05	3
Maduraketiya Gantry	20	200	15	15	NI	0.05	4	NI	0.05	3

3.3.5 Fault Level Calculation

33 kV fault level (Three phase) at Badulla GSS was obtained from Appendix 4 and is given in Table 3.22. Then fault levels (three phase) at locations of ARs were calculated using conductor impedances given in Table 3.11 in chapter 3.2.6. Calculation of EF levels at GSS is as in chapter 3.2.6.

Table 3.22: Fault Levels of Badulla GSS (Appendix 4)

Grid Substation	Voltage Level (kV)	Maximum Three Phase Fault Level					
		2013		2017		2022	
		kA	deg.	kA	deg.	kA	deg.
Badulla	132	6.9	-76.1	10.1	-78.9	10.5	-78.6
	33	10.5	-85.0	12.0	-86.9	12.2	-87.0

Figure 3.25 shows the sub feeder arrangement of F5 of Badulla GSS to calculate fault levels at location of ARs.

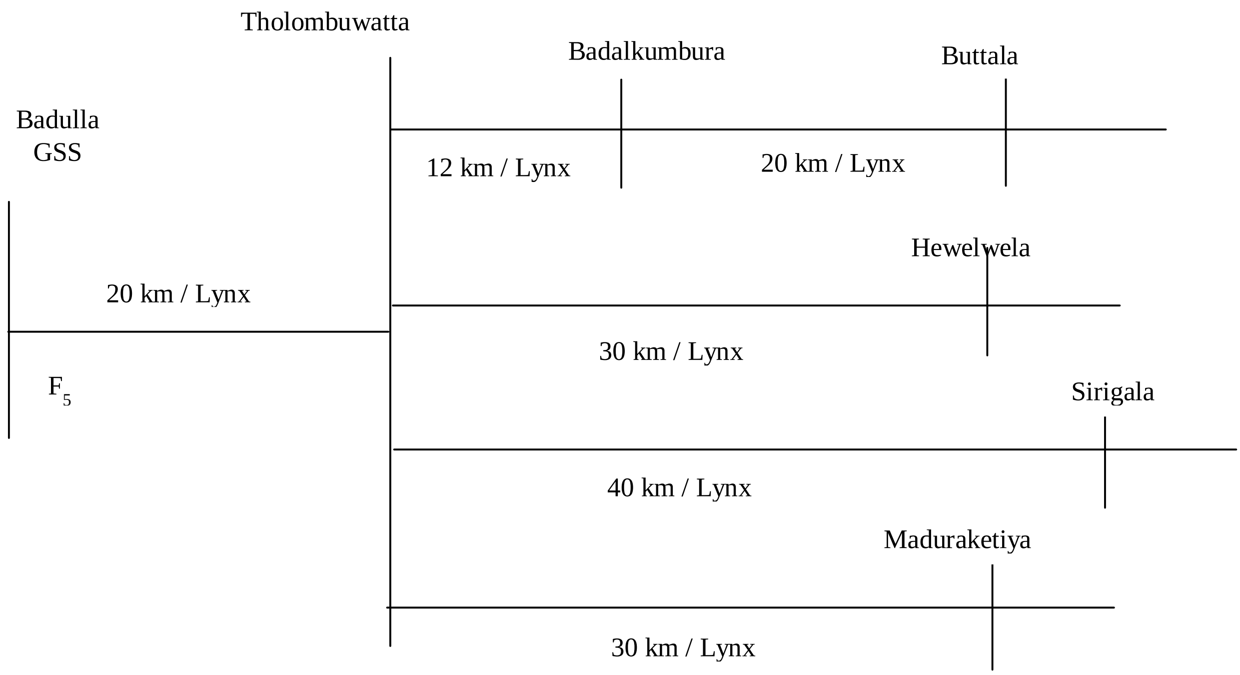


Figure 3.25: Sub-feeder Arrangement of F5

Using the Base Values defined in chapter 3.2.6, Per Unit values of three phase and ground fault levels at Badulla GSS are calculated below with gathered data.

From Long Term Transmission Development Plan 2013-2022,

Three phase Fault Level of 33 kV bus at Badulla GSS	= 12 kA
Three phase Fault Level of 33 kV bus at Badulla GSS in pu values	= 6.86 pu
Impedance up to the 33 kV bus at Badulla GSS in pu values (Z1)	= 0.15 pu
	= 0.15i pu

Since three transformers are connected in parallel,

Earth Fault Level of 33 kV bus at Badulla GSS	= 2.29 kA
Earth Fault Level of 33 kV bus at Badulla GSS in pu values	= 1.31 pu
Impedance up to the 33 kV bus at Badulla GSS in pu values (Z1E)	= 0.77 pu
	= 0.77i pu

Then, similar to the calculations done in chapter 3.2.6, fault levels for three phase faults and ground fault were calculated. Values are given in Table 3.23.

Table 3.23: Three Phase and Line-Ground Fault Levels at AR Locations

AR Location	**Three phase fault level (kA)**	**Line-ground fault level (kA)**
Badulla GSS	12.00	2.29
Tholombuwatta	1.96	0.81
Badalkumbura	1.30	0.58
Buttala	0.83	0.39
Hewelwela	0.86	0.41
Sirigala	0.73	0.35
Maduraketiya	0.86	0.41

3.3.6 Existing Co-ordination

Calculated fault levels were used to find the existing operating times of protective devices of Badulla GSS and F5 and values are given below.

Table 3.24: Operating Times of OC and EF protection Relays With Existing Settings

Bay	CT		Fault Current (kA)	Relay	Protection Function	Protection Settings				
						DT Setting		IDMT Setting		
	Prim -ary	Seco-nadry				x In	Delay(s)	PS	TMS	Operating Time(s)
33 kV Transformer Feeder	800	1	0.76	T60	SBEF-LV			0.125	0.33	1.11
	800	1	4.00	REF 630	OC			0.75	0.23	0.83
	800	1	0.76		EF			0.1	0.26	0.79
33 kV Bus Section	2000	1	6.00	REF 630	OC	0.83	0.4	0.6	0.13	0.56
	2000	1	1.14		EF	0.18	0.4	0.05	0.16	0.45
33 kV Feeder 1, 2	400	1	12.00	REF 630	OC	4	0.10	1	0.08	0.18
	400	1	2.29		EF	4	0.10	0.1	0.11	0.25
33 kV Feeder 3, 4, 5 & 6	400	1	12.00	REF 630	OC	4	0.10	1	0.08	0.18
	400	1	2.29		EF	8	0.10	0.1	0.11	0.25
33 kV Feeder 7 & 8	400	1	12.00	REF 630	OC	4	0.10	1	0.08	0.18
	400	1	2.29		EF	4	0.10	0.1	0.1	0.23
	400	1	12.00		DOC	4	0.10	1	0.1	0.23
	400	1	2.29		DEF	4	0.10	0.1	0.1	0.23
Tholombuwatta Gantry	400	1	1.96	AR	OC	4	0.00	0.5	0.1	0.30
	400	1	0.81		EF	4	0.00	0.075	0.08	0.18
Badalkumbura Gantry	400	1	1.30	AR	OC	1.5	0.00	0.5	0.05	0.18
	400	1	0.58		EF	0.2	0.00	0.05	0.05	0.11
Hewelwela Gantry	400	1	86.00	AR	OC	1.5	0.00	0.5	0.05	0.11
	400	1	0.41		EF	0.2	0.00	0.05	0.05	0.11
Sirigala Gantry	400	1	0.73	AR	OC	1.5	0.00	0.5	0.05	0.27
	400	1	0.35		EF	0.2	0.00	0.05	0.05	0.12
Maduraketiya Gantry	400	1	0.86	AR	OC	1.5	0.00	0.5	0.05	0.24
	400	1	0.41		EF	0.2	0.00	0.05	0.05	0.11
Buttala Gantry	400	1	0.83	AR	OC	1.5	0.00	0.5	0.01	0.05
	400	1	0.39		EF	0.2	0.00	0.05	0.01	0.02

Calculated values reveal that there is no sufficient grading margin between ARs and AR and relays at GSS. The OC and EF settings of ARs are very low and therefore nuisance trippings can happen causing improper operation of protective devices.

Then co-ordinations curves for both OC and EF protection were plotted as given in Figure 3.26 and Figure 3.27. These curves show that EF settings are very sensitive and sufficient grading margin is not available between some protective devices.

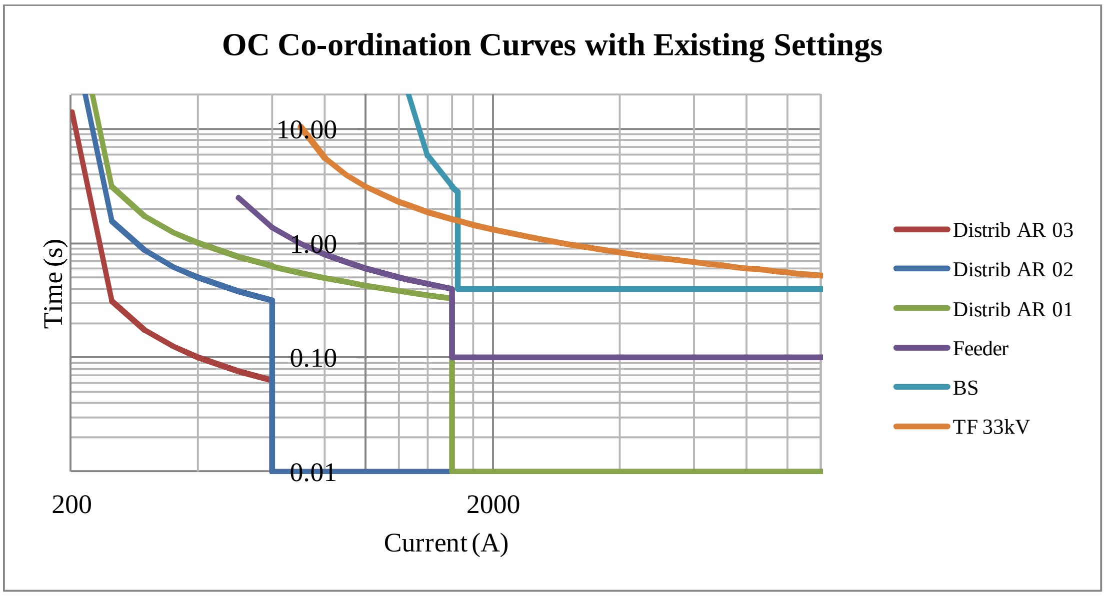


Figure 3.26: OC Co-ordination Curves for Existing Settings

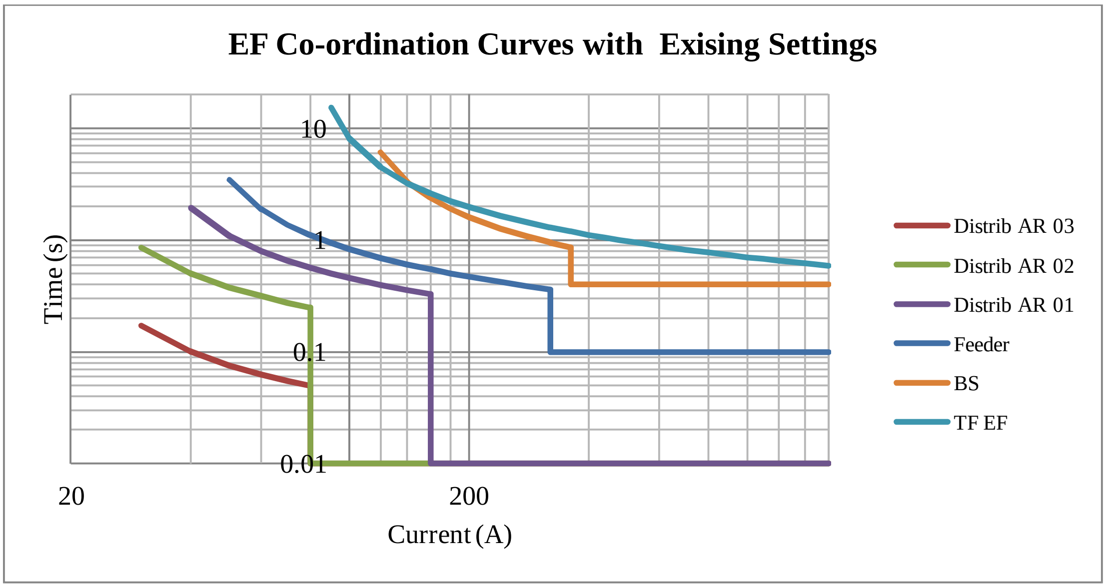


Figure 3.27: EF Co-ordination Curves for Existing Settings

3.3.7 Outcome of Case Study 2

From the trip details, it is found that majority (more than 90%) of trippings are owing to EF.

EF settings of AR are very sensitive and always tend to trip the F5 definitively without auto reclosing the line. Hence revision of settings of downstream ARs is required for better coordination with upstream relays.

To obtain better operating times, it is required to check whether application of VI or EI curves instead of NI curves for IDMT relays.

Optimum number of ARs that can be installed in series downstream of the GSS has to be determined.

Chapter 4

SELECTION OF PROTECTION SETTINGS FOR MEDIUM VOLTAGE NETWORK

4.1 Introduction

This chapter will discuss the selection of optimum protection settings for MV distribution lines and MV system of GSS. As stated earlier, only some 33 kV feeders have had trippings more frequently (more than 3 times per day). Majority of these feeders have downstream ARs installed. Hence, it is required to find the optimum protection settings and co-ordination for relays and ARs at MV network to avoid frequent trippings of 33 kV feeders and to increase the reliability of the MV system.

There have been several studies done worldwide to find the optimum allocation of ARs in distribution network. Some studies [14, 15, 16, 17] have focused on finding optimum co-ordination while using reliability indices such as SAIFI (System Average Interruption Frequency Index) and SAIDI (System Average Interruption Duration Index). These researches have taken both radial and loop network examples into consideration and the solutions were relevant only to the discussed cases separately. Newly defined characteristic curves have been used in some studies [18] to propose their solutions. As per these researches, it is revealed that optimum allocation of ARs depends on the network considered and the method of study.

There are 33 kV feeders in the CEB network which have one, two or three downstream ARs installed. Better co-ordination between these ARs and relays will improve the power system reliability because improper co-ordination will lead to nuisance trippings of the network. Hence, optimum protection co-ordination for CEB MV network will be determined in this chapter by considering several scenarios that conform with standards and best practices. Typical 33 kV feeders each of which has none, one, two and three downstream ARs were considered for these scenarios.

Since, general guidelines are to be proposed in this study, maximum loading of MV distribution lines having Lynx and Raccoon conductors of several GSS were studied and following values were obtained.

MV distribution line (Lynx conductor) : 275 A

MV distribution line (Raccoon conductor) : 150 A

Conductor impedances given in Table 3.11, 2.29 kA of maximum phase-ground fault level at GSS (derived in chapter 3.3.5) and 12 kA of maximum three phase fault level at selected GSS were used for further calculations.

4.2 Scenario 1 – No Downstream AR

Parallel connected 31.5 MVA, 132 / 33 kV three power transformers, three 33 kV bus sections, and 33 kV feeders having no downstream ARs connected are considered in this scenario. Following SLD (Figure 4.1) shows the arrangement of the MV network. Power transformers have delta winding in LV side and hence system ground has been obtained by shunt connected earthing transformer having zero sequence impedance of 75 Ω. Assume MV distribution feeders have both Lynx and Raccoon conductors of 20 km length.

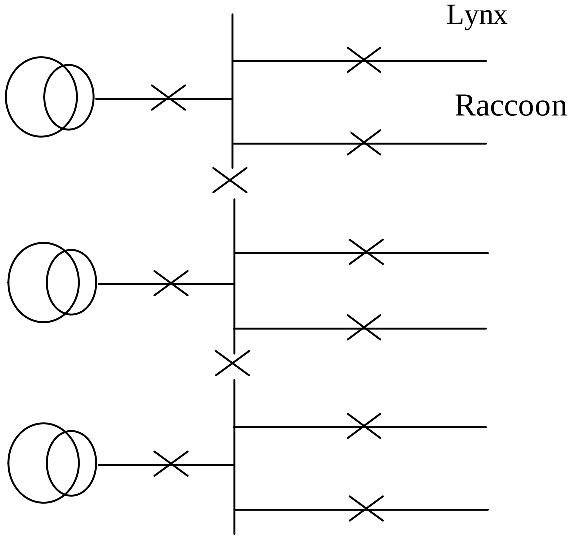


Figure 4.1: SLD of Scenario 1

Table 4.1: Fault Levels used for Scenario 1

Location	**Three phase fault level (kA)**	**Phase-to-earth fault level (kA)**
GSS	12.00	2.29
Line end (lynx)	1.96	0.81
Line end (Raccoon)	1.52	0.73

Calculated fault levels given in Table 4.1 were used for selection of settings. Then pickup settings were selected based on the theory discussed in chapter 2.6 and 2.7 and were given in Table 4.2.

Table 4.2: OC and EF Settings of MV System

Feeder	**Protection Function**	**Criteria used for selecting Pickup setting**	**Selected Pickup Setting (A)**
33 kV Distribution Feeder (Lynx)	IDMT OC	125% - 150% of maximum short time load	400
	IDMT EF	10% - 20% of IDMT OC setting	40
	DT OC	110% - 130% of FL at line end	2200
	DT EF	110% - 130% of FL at line end	900
33 kV Distribution Feeder (Raccoon)	IDMT OC	125% - 150% of maximum short time load	200
	IDMT EF	10% - 20% of IDMT OC setting	20
	DT OC	110% - 130% of FL at line end	1600
	DT EF	110% - 130% of FL at line end	900
33 kV Bus Section	IDMT OC	100% - 120% of Transformer rated current (when two transformers are parallel)	1200
	IDMT EF	10% or lesser than the Transformer rated current (when two transformers are parallel)	100
Transformer 33 kV Feeder	IDMT OC	120% - 150% of transformer rated current	660
	IDMT EF	10% or lesser than the rated load current of the transformer	60
	SBEF	10% or lesser than the rated load current of the earthing transformer	80

Time Multiplier Setting (TMS) of above protective devices were calculated by maintaining 0.3 s grading margin between operating times of these devices. NI standard characteristic curve defined by IEC 60255 were applied for these IDMT relays. Following table (Table 4.3) shows the selected Pickup Setting, TMS and operating times of the MV system considered.

Table 4.3: OC and EF Settings of MV System – Scenario 1

Bay	**Fault Current (kA)**	**Protection Function**	**Protection Settings**				
			Instantaneous Setting		**IDMT Setting**		
			I (A)	**Delay (s)**	**I (A)**	**TMS**	**Operating Time (s)**
Transformer 33 kV Feeder	4.00	SBEF			80	0.45	1.02
	4.00	OC			660	0.19	0.72
	0.76	EF			60	0.27	0.72
33 kV Bus Section	6.00	OC			1200	0.1	0.43
	1.15	EF			100	0.15	0.42
33 kV Distribution Feeder (Lynx)	12.00	OC	2200	0.0	400	0.05	0.11
	2.29	EF	900	0.0	40	0.05	0.11
33 kV Distribution Feeder (Raccoon)	12.00	OC	1600	0.0	400	0.05	0.11
	2.29	EF	900	0.0	20	0.05	0.11

As per the DDR record analyzed in chapter 3.2, most of the faults have withstood only less than 100 ms. Hence, operating time of IDMT protection was selected as 100 ms to avoid the tripping of the feeder during transient faults. To operate relays during high fault current incidents, Instantaneous settings were used for feeder.

As per the above protection settings, primary protection clears fault within 0.43 s and it is in the satisfactory range. Backup protection operates within 1.02 s and it is also less than 2 s of recommended range.

4.3 Scenario 2 – One Downstream AR in Series

33 kV feeder having one downstream AR installed was considered in the second scenario. Length of the 33 kV feeder was taken as 40 km while assuming the AR is installed at 20 km distance from the GSS. These lengths were selected by assuming

the ARs are installing on feeders with the increase of the length of distribution line. The capacity of GSS was considered similar to the previous scenario. The SLD of the considered MV network, calculated fault levels, OC & EF setting selection and OC & EF settings of MV network are given in Figure 4.2, Table 4.4, Table 4.5 and Table 4.6 respectively.

Maximum short time loading of MV lines was considered similar to chapter 4.1 and maximum short time loading at location of AR was taken as follows;

At location AR 1(Lynx conductor) : 225 A

At location AR 1 (Raccoon conductor) : 125 A

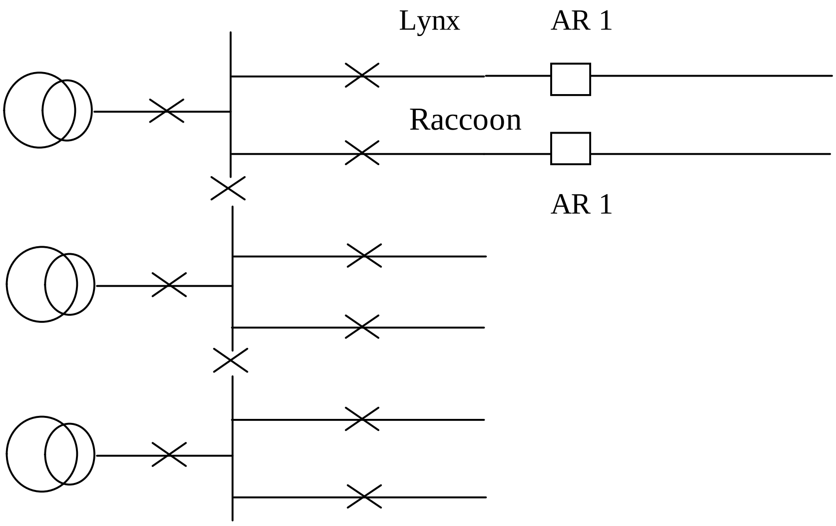


Figure 4.2: SLD of Scenario 2

Table 4.4: Fault Levels used for Scenario 2

Location	Three phase fault level (kA)	Phase-to-earth fault level (kA)
GSS	12.00	2.29
AR 1 (Lynx)	1.96	0.81
AR 1 (Raccoon)	1.52	0.73
Line end (Lynx)	1.06	0.49
Line end (Raccoon)	0.80	0.43

Table 4.5: OC and EF Settings of MV System

Feeder	**Protection Function**	**Criteria used for selecting Pickup setting**	**Selected Pickup Setting (A)**
Downstream AR 1 (Lynx line)	IDMT OC	125% - 150% of maximum short time load	300
	IDMT EF	10% - 20% of IDMT OC setting	30
	DT OC	110% - 130% of FL at line end	1200
	DT EF	110% - 130% of FL at line end	600
Downstream AR 1 (Raccoon line)	IDMT OC	125% - 150% of maximum short time load	160
	IDMT EF	10% - 20% of IDMT OC setting	16
	DT OC	110% - 130% of FL at line end	1000
	DT EF	110% - 130% of FL at line end	500
33 kV Distribution Feeder (Lynx)	IDMT OC	125% - 150% of maximum short time load	400
	IDMT EF	10% - 20% of IDMT OC setting	40
	DT OC	110% - 130% of FL at AR 1	2200
	DT EF	110% - 130% of FL at AR 1	900
33 kV Distribution Feeder (Raccoon)	IDMT OC	125% - 150% of maximum short time load	200
	IDMT EF	10% - 20% of IDMT OC setting	20
	DT OC	110% - 130% of FL at AR 1	1600
	DT EF	110% - 130% of FL at AR 1	900
33 kV Bus Section	IDMT OC	100% - 120% of Transformer rated current (when two transformers are parallel)	1200
	IDMT EF	10% or lesser than the Transformer rated current (when two transformers are parallel)	100
Transformer 33 kV Feeder	IDMT OC	120% - 150% of transformer rated current	660
	IDMT EF	10% or lesser than the rated load current of the transformer	60
	SBEF	10% or lesser than the rated load current of the earthing transformer	80

Pickup settings of the protection devices in the MV network were selected from the values obtained according to the above defined criteria. For the convenience in configuring the settings to protective devices, rounded numerical values were selected for pickup settings.

Table 4.6: OC and EF Settings of MV System – Scenario 2

Bay	Fault Current (kA)	Protection Function	Protection Settings				
			Instantaneous Setting		IDMT Setting		
			I (A)	Delay (s)	I (A)	TMS	Operating Time (s)
Transformer 33 kV Feeder	4.00	SBEF			80	0.57	1.29
	4.00	OC			660	0.26	0.99
	0.76	EF			60	0.37	0.99
33 kV Bus Section	6.00	OC			1200	0.17	0.73
	1.15	EF			100	0.25	0.70
33 kV Distribution Feeder (Lynx)	12.00	OC	2200	0.0	400	0.18	0.41
	2.29	EF	900	0.0	40	0.18	0.41
33 kV Distribution Feeder (Raccoon)	12.00	OC	1600	0.0	200	0.18	0.41
	2.29	EF	900	0.0	20	0.18	0.41
Downstream AR 1 (Lynx)	1.96	OC	1200	0.0	300	0.04	0.10
	0.81	EF	600	0.0	30	0.14	0.10
Downstream AR 1 (Raccoon)	1.52	OC	1000	0.0	160	0.06	0.10
	0.73	EF	500	0.0	16	0.14	0.10

IEC VI standard characteristic curve was used for calculating operating time of ARs because AR device can response higher transient faults speedily. NI standard characteristic curve was applied for all other protective devices.

According to the above protection co-ordination, a fault in a distribution line can be cleared within 0.73 s with primary protection system and within 1.29 s with backup protection system. All selected operating times are in recommended range to clear the fault while minimizing damage to the system.

4.4 Scenario 3 – Two Downstream ARs in Series

Third scenario considers the 33 kV feeder having two downstream ARs installed. It is assumed that ARs were installed 20 km and 40 km distance from the GSS while total line length was 60 km. The arrangement of GSS similar to above scenarios was taken for this section also and SLD of the network is given in Figure 4.3.

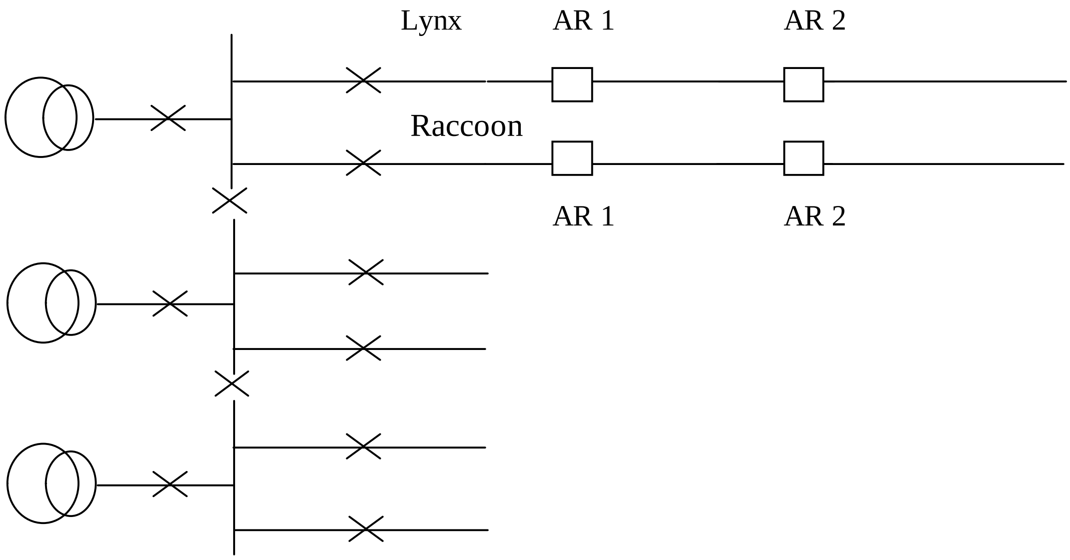


Figure 4.3: SLD of Scenario 3

Fault levels at the location of relays and ARs were calculated and given in the Table 4.7.

Table 4.7: Fault Levels used for Scenario 3

Location	Three phase fault level (kA)	Phase-to-earth fault level (kA)
GSS	12.00	2.29
AR 1 (Lynx)	1.96	0.81
AR 1 (Raccoon)	1.52	0.73
AR 2 (Lynx)	1.06	0.49
AR 2 (Raccoon)	0.80	0.43
Line end (Lynx)	0.73	0.35
Line end (Raccoon)	0.54	0.30

Pickup setting for relays and ARs were calculated similar to previous sections and TMS values were selected by using NI and VI standard characteristics curves for relays and ARs respectively. OC and EF setting co-ordination is given in Table 4.8.

Maximum short time loading of ARs installed at second location was assumed as given below and it was assumed to be equal to previous values for other locations.

At location AR 2 (Lynx conductor) : 175 A

At location AR 2 (Raccoon conductor) : 100 A

Table 4.8: OC and EF Settings of MV System – Scenario 3

Bay	**Fault Current (kA)**	**Protection Function**	**Protection Settings**				
			Instantaneous setting		**IDMT Setting**		
			I (A)	**Delay (s)**	**I (A)**	**TMS**	**Operating Time (s)**
Transformer 33 kV Feeder	4.00	SBEF			80	0.71	1.61
	4.00	OC			660	0.34	1.30
	0.76	EF			60	0.48	1.29
33 kV Bus Section	6.00	OC			1200	0.24	1.03
	1.15	EF			100	0.36	1.01
33 kV Distribution Feeder (Lynx)	12.00	OC	2200	0.0	400	0.31	0.70
	2.29	EF	900	0.0	40	0.31	0.70
33 kV Distribution Feeder (Raccoon)	12.00	OC	1600	0.0	200	0.31	0.70
	2.29	EF	900	0.0	20	0.31	0.70
Downstream AR 1 (Lynx)	1.96	OC	1200	0.0	300	0.16	0.39
	0.81	EF	600	0.0	30	0.56	0.40
Downstream AR 1 (Raccoon)	1.52	OC	1000	0.0	160	0.25	0.40
	0.73	EF	500	0.0	16	0.56	0.40
Downstream AR 2 (Lynx)	1.06	OC	900	0.0	200	0.03	0.09
	0.49	EF	400	0.0	20	0.14	0.10
Downstream AR 2 (Raccoon)	0.80	OC	600	0.0	120	0.04	0.10
	0.43	EF	300	0.0	12	0.14	0.10

In the third scenario, a fault can be cleared within 1.03 s with primary protection of protective devices while backup protection of the MV, it takes 1.61 s. Therefore, the operating times of protective devices are in recommended range as per standards and world practices.

4.5 Scenario 4 – Three Downstream ARs in Series

In this scenario, the 33 kV feeder having three downstream ARs installed was considered by assuming ARs were installed 20 km, 40 km and 60 km distance from the GSS while total line length was 80 km. The SLD of the MV network considered is given in Figure 4.4.

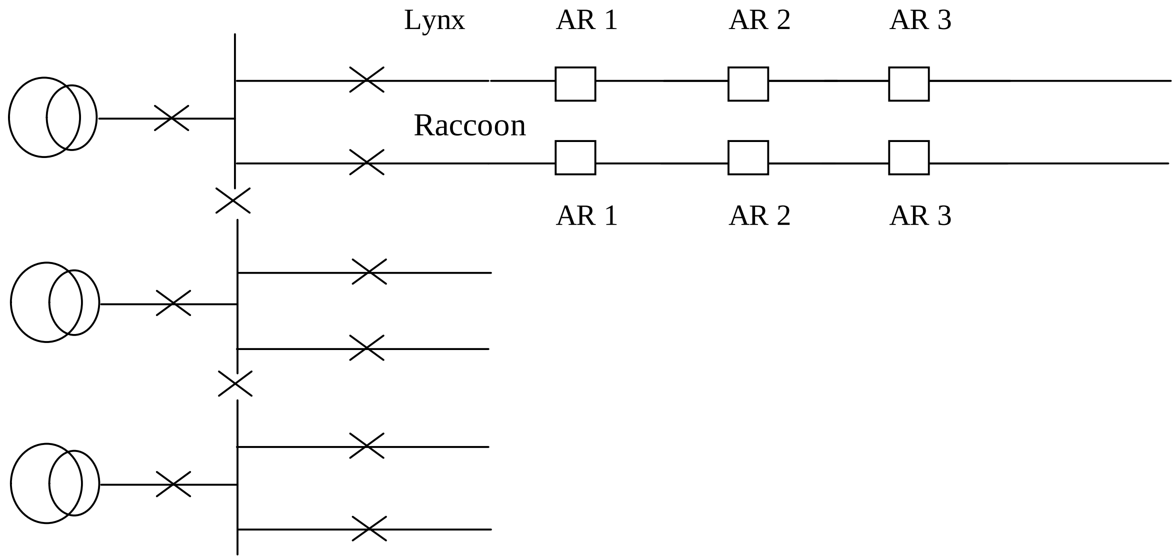


Figure 4.4: SLD of Scenario 4

By calculating fault levels as in previous scenarios, suitable settings for protective devices were calculated keeping grading margin of 0.3 s between protective devices. IEC standard characteristics curves for relays and ARs were used as before.

Maximum short time loadings at GSS, first AR and second AR were considered to be equal to that of in previous scenarios and following values were used for the third AR.

At location AR 3 (Lynx conductor) : 125 A
At location AR 3 (Raccoon conductor) : 75 A

Protection settings selected for the MV network is given in Table 4.9

Table 4.9: OC and EF Settings of MV System – Scenario 4

Bay	**Fault Current (kA)**	**Protection Function**	**Protection Settings**				
			Instantaneous setting		**IDMT Setting**		
			I (A)	**Delay (s)**	**I (A)**	**TMS**	**Operating Time (s)**
Transformer 33 kV Feeder	4.00	SBEF			80	0.84	1.90
	4.00	OC			660	0.42	1.60
	0.76	EF			60	0.6	1.61
33 kV Bus Section	6.00	OC			1200	0.31	1.33
	1.15	EF			100	0.47	1.32
33 kV Distribution Feeder (Lynx)	12.00	OC	2200	0.0	400	0.44	1.00
	2.29	EF	900	0.0	40	0.44	1.00
33 kV Distribution Feeder (Raccoon)	12.00	OC	1600	0.0	200	0.44	1.00
	2.29	EF	900	0.0	20	0.45	1.02
Downstream AR 1 (Lynx)	1.96	OC	1200	0.0	300	0.29	0.71
	0.81	EF	600	0.0	30	0.99	0.70
Downstream AR 1 (Raccoon)	1.52	OC	1000	0.0	160	0.44	0.70
	0.73	EF	500	0.0	16	0.99	0.70
Downstream AR 2 (Lynx)	1.06	OC	900	0.0	200	0.13	0.41
	0.49	EF	400	0.0	20	0.56	0.40
Downstream AR 2 (Raccoon)	0.80	OC	600	0.0	120	0.17	0.41
	0.43	EF	300	0.0	12	0.56	0.40
Downstream AR 3 (Lynx)	0.73	OC	900	0.0	200	0.02	0.10
	0.35	EF	400	0.0	20	0.12	0.10
Downstream AR 3 (Raccoon)	0.54	OC	600	0.0	120	0.03	0.12
	0.30	EF	300	0.0	12	0.14	0.10

The calculated OC and EF settings show that primary protection of the MV network cannot clear a fault within 1 s and backup protection system is in the defined range of 2 s. It is seen that, this scenario is not conforming to the standards and practices.

4.6 Optimum Protection Co-ordination for MV Network

After detailed analysis of above scenarios, third scenario which proposed two downstream ARs can be recommended as the optimum protection co-ordination system for the MV network of CEB.

The fault level and the maximum short time loading of a GSS are different to each other. Therefore, as per the criteria defined in chapter 2, the maximum and minimum limit of pickup setting of protective devices can vary. Thereby, the TMS settings may also vary to maintain the operating times calculated in Table 4.8. But, normally, standardized settings are used in distribution network owing to the similar nature of the distribution network. This will lead to simple configuration and maintenance of protective devices. Therefore, settings obtained in chapter 4.3 can be applied with required changes by coordinating protective devices in suitable manner.

Behavior of both IDMT and Instantaneous / DT elements of protective devices with above settings against fault currents have to be analyzed to finalize the optimum settings for MV network. That can be achieved by plotting OC and EF co-ordination curves for MV network. More suitable settings, which give better use of both IDMT and Instantaneous / DT function to maintain required grading margin are achieved by plotting OC and EF curves for Raccoon and Lynx conductors.

EF co-ordination curves for Raccoon and Lynx conductors were plotted with some amendments to the proposed Pickup and TMS settings to obtain the better co-ordination. New DT EF setting of 660 A was introduced for Bus Section for better co-ordination with relays of 33 kV feeder and transformer. Similar settings for ARs and relays were selected for both Lynx and Raccoon distribution lines by considering the settings selected in Table 4.8. EF co-ordination curves for MV system were plotted in Figure 4.5 by considering the 0.3 s grading margin.

When co-coordinating OC settings of protective devices, DT OC setting for Bus Coupler was introduced because it is required to operate relays of bus couplers before relays of transformers for the protection of transformers. Some other settings proposed in Table 4.8 were amended for better co-ordination between protective devices considering the relay input capability of relays used in GSS. Figure 4.6 and Figure 4.7 show the OC co-ordination of protective devices installed in MV network having Lynx and Raccoon conductor lines respectively. When plotting these curves, 0.3 s of grading margin was maintained between each curve.

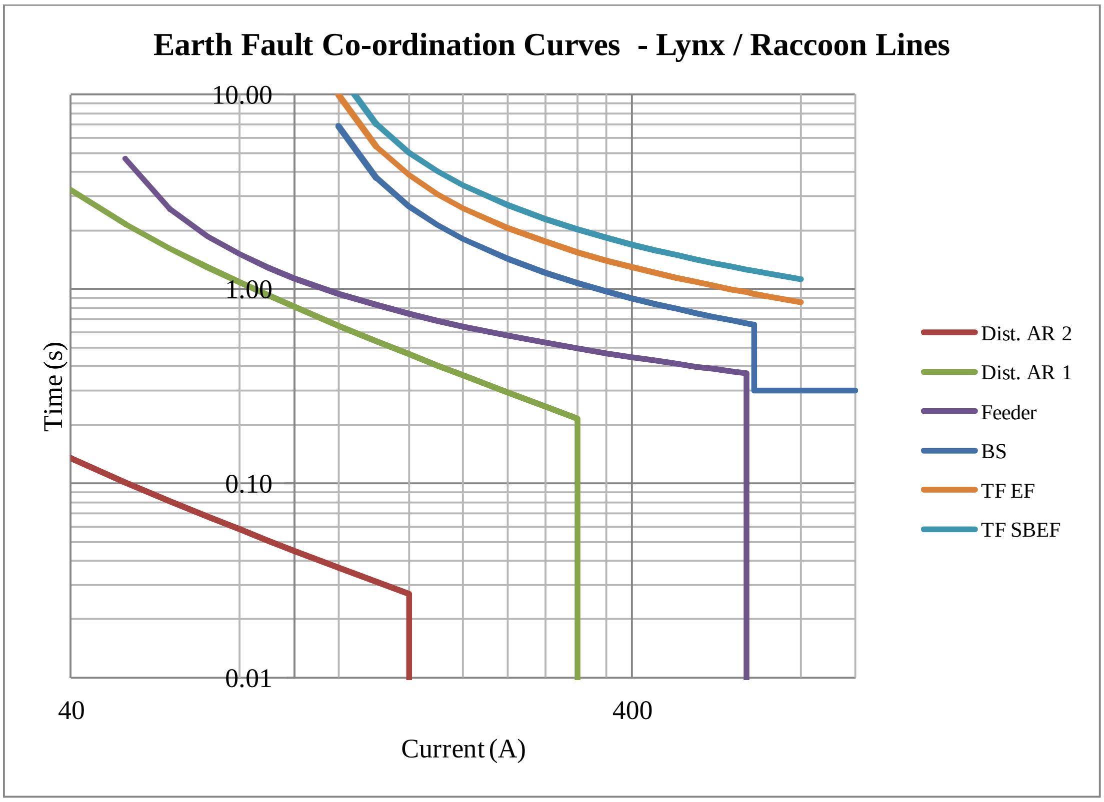


Figure 4.5: EF Co-ordination Curves – Lynx / Raccoon Lines

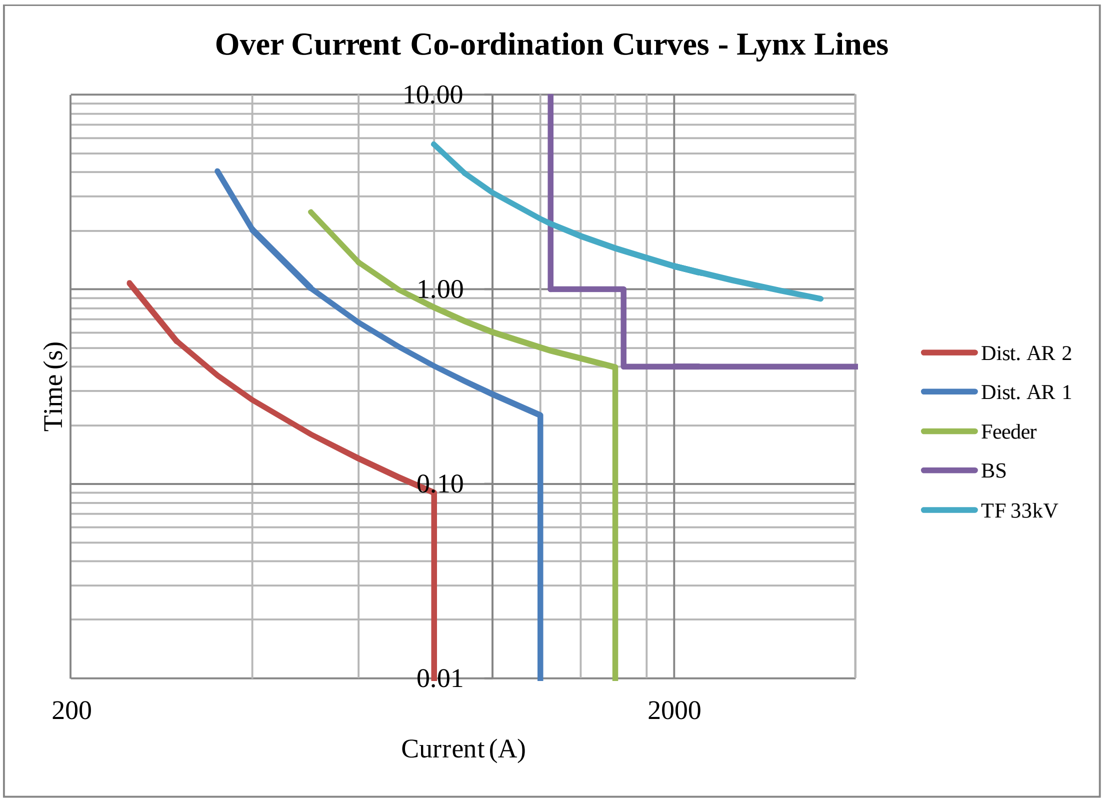


Figure 4.6: OC Co-ordination Curves – Lynx Lines

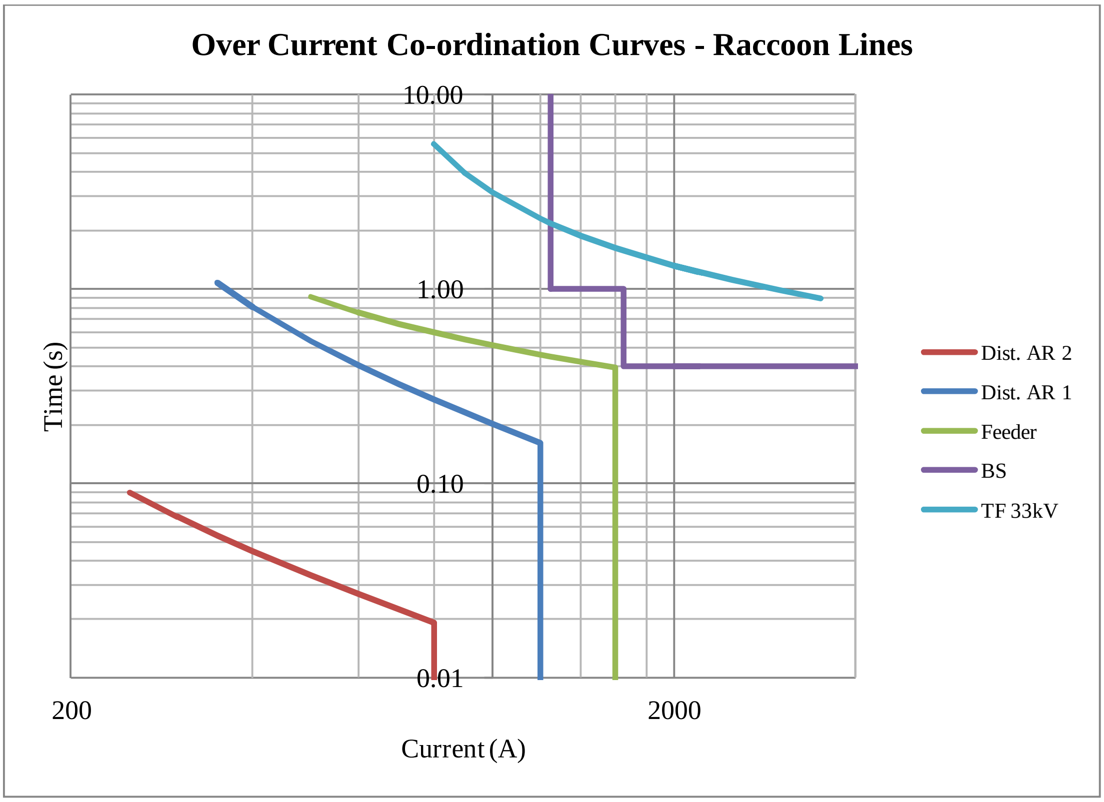


Figure 4.7: OC Co-ordination Curves – Raccoon Lines

Optimum EF and OC settings of MV network of CEB that was as achieved above are tabulated in Table 4.10 and Table 4.11. Since both IDMT and DT functions are used in combination, before the fault current reaches DT pickup settings, IDMT function will operate and when the current exceeds it, DT function will operate.

Table 4.10: Optimum EF Settings for MV Network – Lynx / Raccoon Lines

Bay	**Protection Function**	**Instantaneous / DT Setting**		**IDMT Setting**		
		I (A)	**Delay (s)**	**I (A)**	**TS**	**Curve**
Transformer 33 kV Feeder	SBEF			100	0.34	NI
	EF			100	0.26	NI
33 kV Bus Section	EF	660	0.0	100	0.18	NI
33 kV Distribution Feeder	EF	640	0.0	40	0.15	NI
Downstream AR 1	EF	320	0.0	20	0.24	VI
Downstream AR 2	EF	160	0.0	10	0.03	VI

Table 4.11: Optimum OC Settings for MV Network – Lynx / Raccoon Lines

Bay	Protection Function	Instantaneous / DT Setting		IDMT Setting		
		I (A)	Delay (s)	I (A)	TMS	Curve
Transformer 33 kV Feeder	OC			600	0.23	NI
33 kV Bus Section	OC	1650	0.4	1200	0.13	NI
		1250	1.0			
33 kV Distribution Feeder (Lynx)	OC	1600	0.0	400	0.08	NI
33 kV Distribution Feeder (Raccoon)	OC	1600	0.0	200	0.12	NI
Downstream AR 1 (Lynx)	OC	1200	0.0	300	0.05	VI
Downstream AR 1 (Raccoon)	OC	1200	0.0	200	0.06	VI
Downstream AR 2 (Lynx)	OC	800	0.0	200	0.02	VI
Downstream AR 2 (Raccoon)	OC	800	0.0	100	0.01	VI

4.7 Algorithm to Identify Optimum Protection Co-ordination in MV Distribution System of CEB

Algorithm (Figure 4.8) to identify optimum protection co-ordination in MV Distribution System of Sri Lanka is defined by using above finalized settings.

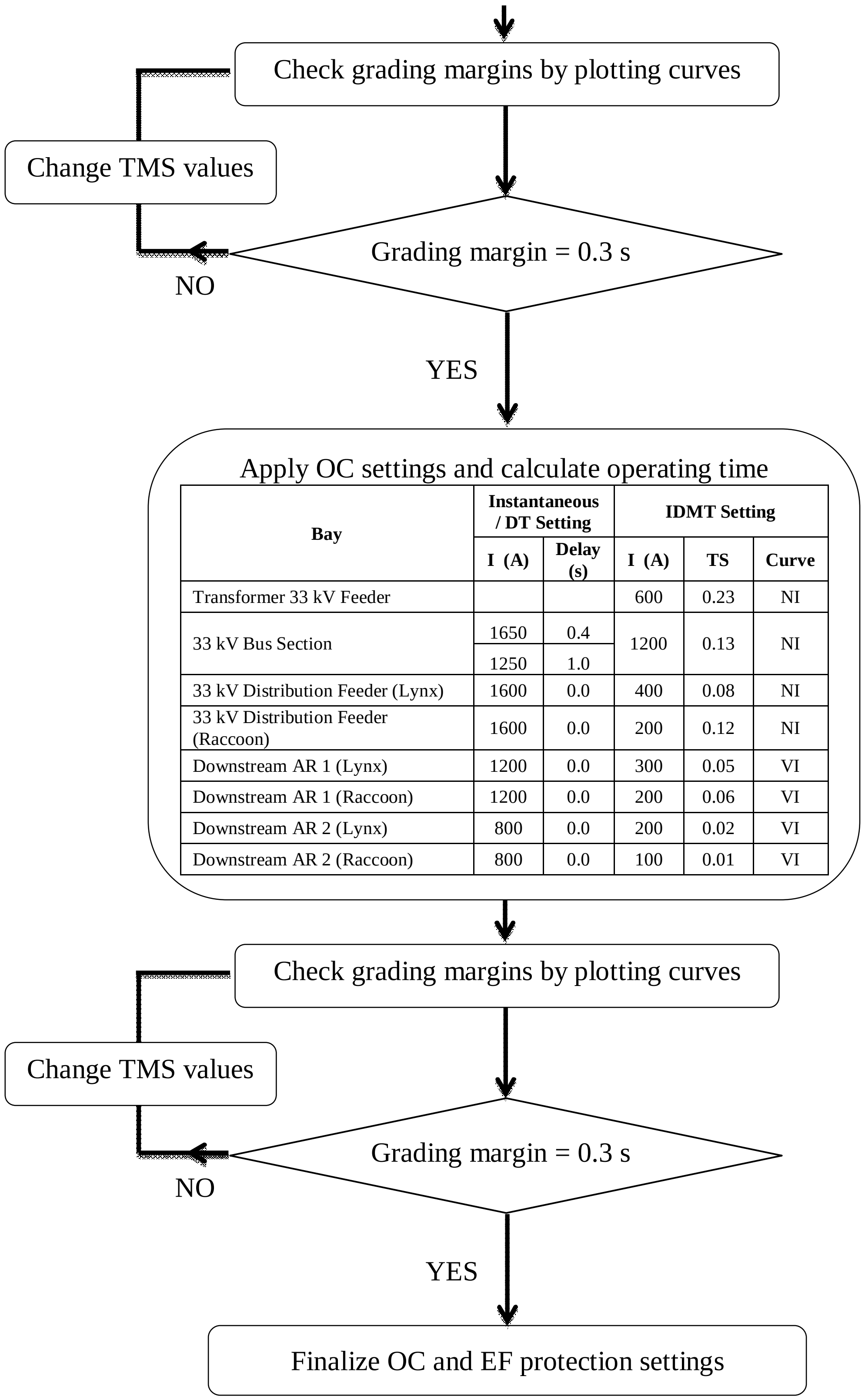
Obtain details of the MV system concerned

1. SLD of MV system
2. Details of downstream ARs
3. Distribution Conductor type, lengths and Impedance
4. Maximum fault level of GSS (33 kV level)
5. Maximum load current through protective devices
6. Details of Earthing Transformer

Calculate the maximum fault level at location of protective devices

Apply EF settings and calculate operating time

Bay	Instantaneous / DT Setting		IDMT Setting		
	I (A)	Delay (s)	I (A)	TS	Curve
Transformer 33 kV Feeder (SBEF)			100	0.34	NI
Transformer 33 kV Feeder (EF)			100	0.26	NI
33 kV Bus Section	660	0	100	0.18	NI
33 kV Distribution Feeder	640	0	40	0.15	NI
Downstream AR 1	320	0	20	0.24	VI
Downstream AR 2	160	0	10	0.03	VI



Bay	Instantaneous / DT Setting		IDMT Setting		
	I (A)	Delay (s)	I (A)	TS	Curve
Transformer 33 kV Feeder			600	0.23	NI
33 kV Bus Section	1650	0.4	1200	0.13	NI
	1250	1.0			
33 kV Distribution Feeder (Lynx)	1600	0.0	400	0.08	NI
33 kV Distribution Feeder (Raccoon)	1600	0.0	200	0.12	NI
Downstream AR 1 (Lynx)	1200	0.0	300	0.05	VI
Downstream AR 1 (Raccoon)	1200	0.0	200	0.06	VI
Downstream AR 2 (Lynx)	800	0.0	200	0.02	VI
Downstream AR 2 (Raccoon)	800	0.0	100	0.01	VI

Figure 4.8: Algorithm to Identify Optimum Protection Co-ordination in MV System

4.8 Application of the Algorithm to Badulla GSS

4.8.1 Implementing Settings to Badulla GSS

According to the first step of the algorithm, initial data had to be collected. SLD of MV system, details of downstream ARs, distribution conductor type, lengths and impedance, maximum fault level of GSS (33 kV level) and details of earthing transformer collected in the case study 2, depicted in Figure 3.18, Table 3.17, Figure 3.19, Table 3.11, Table 3.22 and Figure 3.14. Maximum load current through protective devices of F5 (which had more frequent trippings) of Badulla GSS were then collected and given in Table 4.12.

Table 4.12: Maximum Load Current Through Protective Devices of F1

Feeder	Maximum Load Current (A)	Conductor Type
F5	155	Lynx
AR 1	110	Lynx
AR 2	65	Lynx

According to the second step, maximum fault current through all protective devices had to be calculated. But, these fault currents were calculated in Chapter 3.3 and were given in Table 3.23.

In the third step, both IDMT and DT EF settings had to be calculated to the MV system by plotting EF co-ordination curves to verify the better co-ordination. The derived EF co-ordination curves are given in Figure 4.9. There is 0.3 s or more grading margin between each curve.

Then, in the next step OC co-ordination had to be done. Derived OC co-ordination curves received by undergoing given process are given in Figure 4.10. There is 0.3 s or more grading margin between each curve.

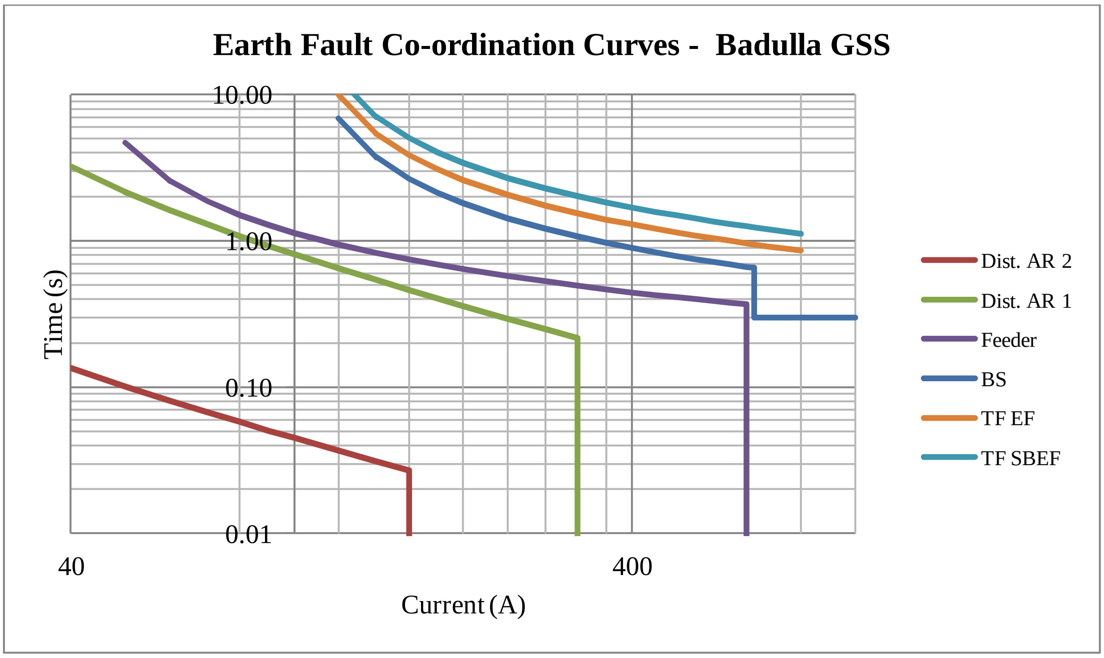


Figure 4.9: EF Co-ordination Curves – Lynx / Raccoon Lines

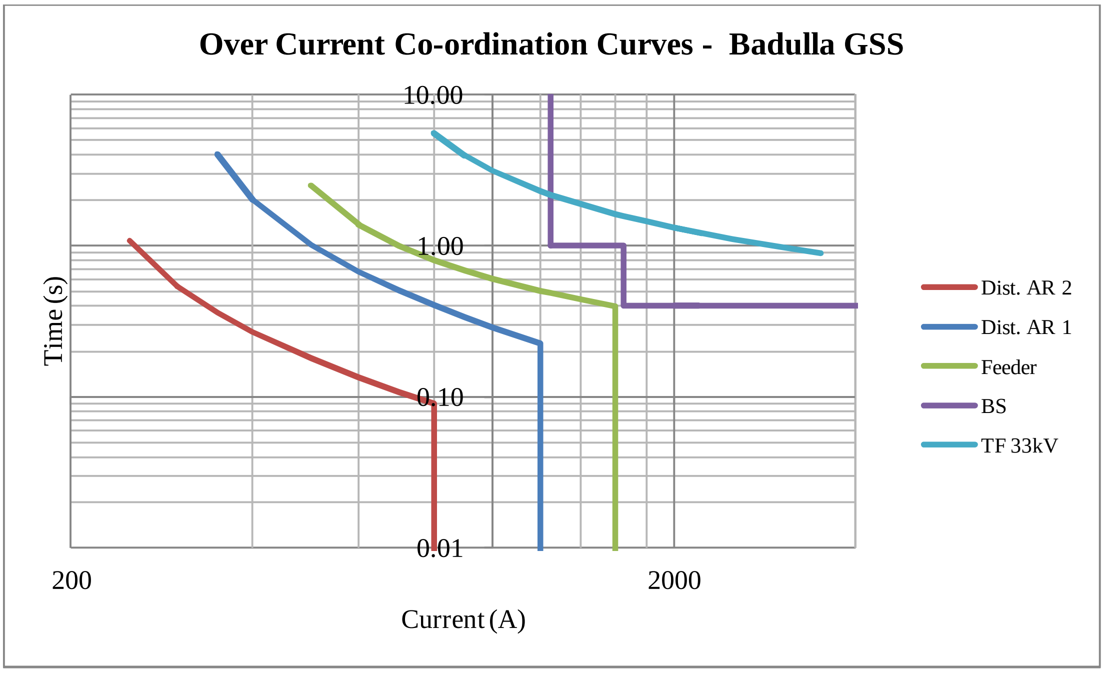


Figure 4.10: OC Co-ordination Curves – Lynx Lines

As the final step, finalized OC and EF settings are shown with comparison of existing settings at Badulla GSS in Table 4.13. Some OC and EF settings have changed with the introduction of new settings.

Table 4.13: Old and New OC and EF Setting Comparison of F5 of Badulla GSS

Bay	Protection Function	Old Protection Settings					New Protection Settings				
		Instantaneous / DT Setting		IDMT Setting			Instantaneous / DT Setting		IDMT Setting		
		I (A)	Delay (s)	I (A)	TMS	Curve	I (A)	Delay (s)	I (A)	TMS	Curve
Transformer 33 kV Feeder	SBEF			100	0.33	NI			100	0.34	NI
	OC			600	0.23	NI			600	0.23	NI
	EF			80	0.26	NI			100	0.26	NI
33 kV Bus Section	OC	1660	0.4	1200	0.13	NI	1250 1650	1.0 0.4	1200	0.13	NI
	EF	360	0.4	100	0.16	NI	660	0.0	100	0.8	NI
33 kV Distribution Feeder (F5)	OC	1600	0.1	400	0.08	NI	1600	0.0	400.0	0.08	NI
	EF	320	0.1	40	0.11	NI	640	0.0	40.0	0.15	NI
Downstream AR 1	OC	1600	0.0	200	0.1	NI	1200	0.0	300.0	0.05	VI
	EF	160	0.0	30	0.08	NI	320	0.0	20.0	0.24	VI
Downstream AR 2	OC	600	0.0	200	0.05	NI	800	0.0	200.0	0.02	VI
	EF	80	0.0	20	0.05	NI	160	0.0	10	0.03	V

4.8.2 Results After Implementing New Settings

These new settings were configured to the protective devices of F5 at Badulla GSS in the first week of December 2014 and analyzed the frequency of tipping of F5 for last two months. Figure 4.11 illustrate that number of trippings of F5 are reduced drastically.

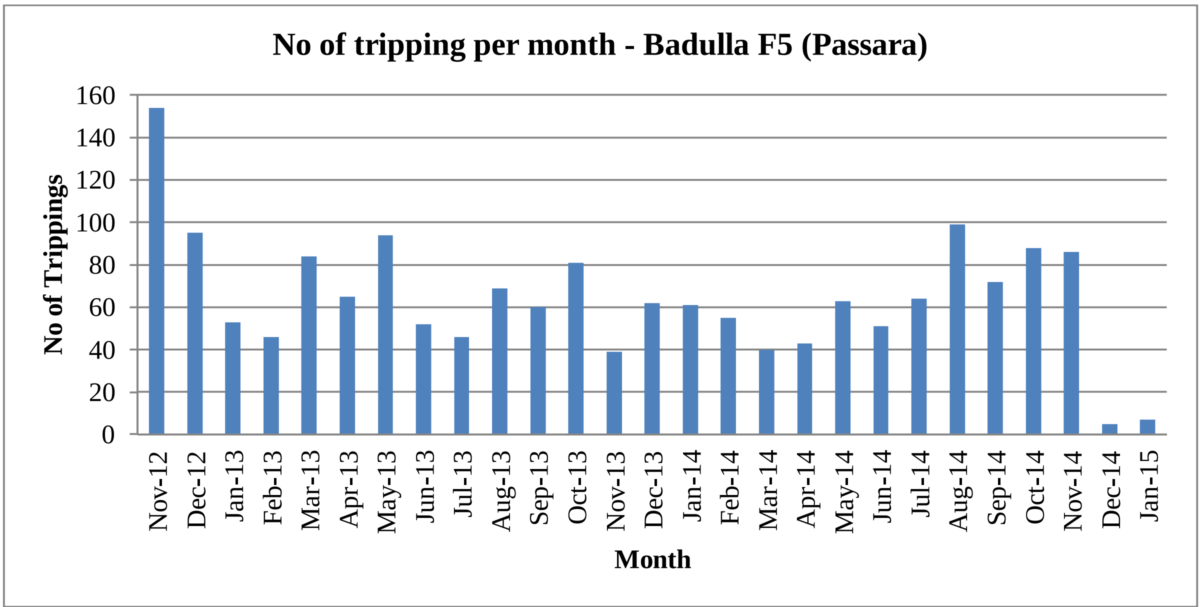


Figure 4.11: Comparison of no of Trippings of F5 of Badulla GSS After New Settings Implementation

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

Case studies 1 and 2 showed that the most of the 33 kV feeder trippings were due to EF which last for less than 100 ms. In-depth analysis of existing protection settings of protective devices in MV distribution network revealed that revising of settings is required for better co-ordination between protective devices to avoid nuisance trippings of 33 kV feeders.

To identify the optimum protection co-ordination between protective devices, four scenarios where 33 kV feeder has none, one, two and three downstream ARs were studied. The study revealed that 33 kV feeder with two downstream ARs is the optimum solution which can be satisfactorily applied to the MV network with adhering to the standards and practices in the world. Third AR should not be applied to the MV distribution line and it can be replaced by sectionalizer if required.

Optimum protection settings for a typical GSS having both Lynx and Raccoon conductor lines with two downstream ARs were derived by plotting co-ordination curves for both OC and EF. The summary of the proposed protection settings are given in Table 5.1.

Algorithm was defined (Figure 4.8) with using above derived setting (Table 5.1) to find the optimum protection settings for any other GSS. This algorithm was then applied to Badulla GSS and found the optimum protection settings for the GSS. The requirement of having a third AR already installed in the F5 of Badulla has become null and void after defining these settings. It was able to configure the derived settings to the feeder and later found that frequency of tripping of the feeder has reduced considerably.

Hence the derived settings and algorithm can be recommended to be applied for the MV network of CEB to reduce nuisance trippings of the MV feeders.

Table 5.1: Optimum Protection Settings for MV Network of Sri Lanka

<table>
<tr><th rowspan="2">Bay</th><th rowspan="2">Protection Function</th><th colspan="2">Instantaneous / DT Setting</th><th colspan="3">IDMT Setting</th></tr>
<tr><th>I (A)</th><th>Delay (s)</th><th>I (A)</th><th>TMS</th><th>IEC Curve</th></tr>
<tr><td rowspan="3">Transformer 33 kV Feeder</td><td>SBEF</td><td></td><td></td><td>100</td><td>0.34</td><td>NI</td></tr>
<tr><td>OC</td><td></td><td></td><td>600</td><td>0.23</td><td>NI</td></tr>
<tr><td>EF</td><td></td><td></td><td>100</td><td>0.26</td><td>NI</td></tr>
<tr><td rowspan="3">33 kV Bus Section</td><td rowspan="2">OC</td><td>1250</td><td>1.0</td><td rowspan="2">1200</td><td rowspan="2">0.13</td><td rowspan="2">NI</td></tr>
<tr><td>1650</td><td>0.4</td></tr>
<tr><td>EF</td><td>660</td><td>0.0</td><td>100</td><td>0.18</td><td>NI</td></tr>
<tr><td rowspan="2">33 kV Distribution Feeder (Lynx)</td><td>OC</td><td>1600</td><td>0.0</td><td>400</td><td>0.08</td><td>NI</td></tr>
<tr><td>EF</td><td>640</td><td>0.0</td><td>40</td><td>0.15</td><td>NI</td></tr>
<tr><td rowspan="2">33 kV Distribution Feeder (Raccoon)</td><td>OC</td><td>1600</td><td>0.0</td><td>200</td><td>0.12</td><td>NI</td></tr>
<tr><td>EF</td><td>640</td><td>0.0</td><td>40</td><td>0.15</td><td>NI</td></tr>
<tr><td rowspan="2">Downstream AR 1 (Lynx)</td><td>OC</td><td>1200</td><td>0.0</td><td>300</td><td>0.05</td><td>VI</td></tr>
<tr><td>EF</td><td>320</td><td>0.0</td><td>20</td><td>0.24</td><td>VI</td></tr>
<tr><td rowspan="2">Downstream AR 1 (Raccoon)</td><td>OC</td><td>1200</td><td>0.0</td><td>200</td><td>0.06</td><td>VI</td></tr>
<tr><td>EF</td><td>320</td><td>0.0</td><td>20</td><td>0.24</td><td>VI</td></tr>
<tr><td rowspan="2">Downstream AR 2 (Lynx)</td><td>OC</td><td>800</td><td>0.0</td><td>200</td><td>0.02</td><td>VI</td></tr>
<tr><td>EF</td><td>160</td><td>0.0</td><td>10</td><td>0.03</td><td>VI</td></tr>
<tr><td rowspan="2">Downstream AR 2 (Raccoon)</td><td>OC</td><td>800</td><td>0.0</td><td>100</td><td>0.01</td><td>VI</td></tr>
<tr><td>EF</td><td>160</td><td>0.0</td><td>10</td><td>0.03</td><td>VI</td></tr>
</table>

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Appendix 1 : Sample Incident Reord for One Week

To : DGM (System Control) / CE (SO)

33kV Feeder Breakdowns on 03/11/2014

	Grid Substation	Feeder No	Tripped Time	Restored Time	Load Prior to Tripping [A]	Indication	
						AUTO	LOAD SHEDDING STAGE
1	BADULLA	6	18.48	18.50	95	E/F	
2	WIMALASURENDRA	5	7.30	9.13	9	.O/C,F/F	
3		4	8.25	8.30	64	.O/C,F/F	
4		8	8.28	9.21	17	.O/C,F/F	
5	THULHIRIYA	5	5.45	5.46	58	.O/C,F/F	
6		5	5.47	6.20	58	.O/C,F/F	
7		6	5.58	5.59	80	.O/C,F/F	
8		1	19.01	19.02	87	O/C	
9	UKUWELA	10	9.57	9.58	120	E/F	
10		12	18.16	18.17	144	.O/C,F/F	
11	KIRIBATHKUMBURA	7	10.00	10.02	60	E/F	
12		6	10.00	10.03	90	O/C	
13	KURUNEGALA	3	9.36	9.37	110	.O/C,F/F	
14		4	15.24	15.25	60	.O/C,F/F	
15	SEETHAWAKA	2	2.25	2.26	40	E/F	
16		1	11.14	11.15	110	.O/C,F/F	
17		8	11.14	11.16	215	E/F	
18	VAVUNIYA	2	1.18	1.19	18	E/F	
19		6	4.56	4.57	8	E/F	
20		6	11.39	11.40	9	E/F	
21		2	13.07	13.08	24	E/F	
22	TRINCOMALEE	7	7.34	7.35	22	E/F	
23		7	8.12	8.13	18	E/F	
24		7	8.31	8.32	19	E/F	
25		1	10.14	10.15	64	E/F	
26		5	11.15	11.16	30	E/F	
27		5	11.52	11.53	36	E/F	
28		1	12.13	12.14	68	E/F	
29	VALACHCHENA	6	11.50	11.51	96	E/F	
30	PUTTALAM	4	8.30	8.31	20	E/F	
31		3	9.05	9.06	60	E/F	
32		1	12.06	12.07	80	O/C	
33	KILINOCHCHI	4	5.38	5.45	27	E/F	
34		5	5.51	5.52	16	E/F	
35		4	6.32	6.33	18	E/F	
36		2	12.30	12.30	47	E/F	
37	CHUNNAKKUM	9	10.36	10.37	39	E/F	

38	BIYAGAMA	6	8.31	8.32	145	E/F	
39	SAPUGASKANDA	2	10.01	10.02	283	E/F	
40	PANNIPITIYA	7	18.59	19.00	169	E/F	
41	RATHMALANA	3	11.28	12.12	150	E/F	
42	PANADURA	1	3.10	3.11	66	E/F	
43		5	11.58	11.59	160	E/F	
44	HORANA	3	13.49	13.50	211	E/F	
45		6	16.31	16.32	21	E/F	
46	J'PURA	3	11.10	11.11	180	O/C	
47		3	11.11	11.40	0	O/C	

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33kV Feeder Breakdowns on 04/11/2014

	Grid Substation	Feeder No	Tripped Time	Restored Time	Load Prior to Tripping [A]	Indication	
						AUTO	LOAD SHEDDING
1	BIYAGAMA	8	5.42	5.43	60	E/F	
2	SAPUGASKANDA	7	12.58	12.59	225	NIL	
3		7	23.30	23.31	155	NIL	
4	ANIYAKANDA	3	13.15	13.16	57	.E/F,O/C	
5		6	13.17	13.18	84	.E/F,O/C	
6		6	13.36	13.37	68	.E/F,O/C	
7	PANNALA	5	12.43	13.03	98	.E/F,O/C	
8	KATUNAYAKE	8	9.54	9.58	154	.E/F,O/C	
9		1	17.36	17.37	112	.E/F,O/C	
10	PANNIPITIYA	12	11.50	11.51	116	O/C	
11		12	13.43	13.44	109	O/C	
12	RATHMALANA	2	19.33	19.34	159	E/F	
13	PANADURA	3	6.02	6.18	48	E/F	
14		3	7.00	7.02	60	E/F	
15		1	9.25	9.26	96	E/F	
16		6	9.85	9.59	140	O/C	
17	HORANA	5	4.54	4.54	70	E/F	
18	DEHIWALA	6	22.57	23.12	176	O/C	
19	GALLE	1	2.47	3.32	50	.E/F,O/C	
20		1	4.43	4.44	50	.E/F,O/C	
21		5	12.26	12.27	155	E/F	
22	EMBILIPITIYA	3	4.03	5.06	30	.E/F,O/C	
23		3	7.50	7.51	44	.E/F,O/C	
24	RATHNAPURA	5	4.10	4.11	15	E/F	
25		8	4.13	4.14	80	E/F	
26		1	9.27	9.28	48	E/F	
27		1	9.45	9.46	48	E/F	
28	BADULLA	5	7.24	7.29	85	E/F	
29	MAHIYANGANE	2	3.34	3.35	5	O/C	
30	THULHIRIYA	7	8.08	8.09	77	O/C	
31		5	11.20	11.21	71	.E/F,O/C	
32		7	12.05	12.06	89	.E/F,O/C	
33	KIRIBATHKUMBURA	3	22.23	22.37	60	.E/F,O/C	
34	KURUNEGALA	4	13.11	13.12	110	.E/F,O/C	
35		4	16.01	16.02	90	.E/F,O/C	
36	KOSGAMA	4	13.50	15.51	50	O/C	

37		3	14.11	14.13	100	E/F	
38		3	14.29	14.30	100	E/F	
39		3	14.57	14.58	20	E/F	
40		3	16.07	16.08	55	E/F	
41		3	16.41	16.42	55	E/F	
42		3	17.22	17.24	55	E/F	
43	OLD ANURADHAPU	8	7.08	7.09	42	E/F	
44		7	12.37	12.38	66	E/F	
45		8	22.03	22.04	47	E/F	
46	VAUNIYA	2	3.42	3.43	12	E/F	
47		2	10.57	10.58	23	E/F	
48		1	13.25	13.26	29	E/F	
49		2	14.04	14.05	28	E/F	
50		6	15.33	15.34	8	E/F	
51	TRINCOMALLEE	7	6.44	6.45	30	E/F	
52		7	10.27	10.28	20	E/F	
53		1	13.22	13.23	30	E/F	
54		5	15.49	15.50	30	E/F	
55		1	16.19	16.20	58	E/F	
56	PUTTALAM	1	7.48	7.49	30	E/F	
57	KILINOCHCHI	4	5.38	5.40	27	E/F	
58		4	5.40	5.45	27	E/F	

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33kV Feeder Breakdowns on 05/11/2014

	Grid Substation	Feeder No	Tripped Time	Restored Time	Load Prior to Tripping [A]	Indication	
						AUTO	LOAD SHEDDING STAGE
1	MATARA	7	10.41	10.42	70	E/F	
2		2	14.41	15.12	95	O/C	
3	DENIYAYA	G-2	16.51	16.52	43	E/F	
4	GALLE	1	4.43	4.44	50	E/F	
5		5	12.26	12.27	155	E/F	
6		7	17.42	17.45	10	E/F	
7	EMBILIPITIYA	4	11.03	11.46	35	O/C,E/F	
8	RATHNAPURA	8	3.55	5.02	145	E/F	
9		6	6.09	6.10	31	E/F	
10	BADULLA	5	6.06	6.08	138	E/F	
11		5	12.18	12.21	81	E/F	
12		5	14.21	14.23	79	E/F	
13		5	22.57	22.58	73	E/F	
14	MAHIYANGANAYA	7	9.16	9.17	38	E/F	
15	THULHIRIYA	1	3.35	3.35	26	O/C,E/F	
16		7	23.45	23.46	54	O/C,E/F	
17	KIRIBATHKUBURA	13	8.46	8.47	50	E/F	
18		2	12.03	12.04	230	E/F	
19		2	18.11	18.13	260	E/F	
20		2	18.13	18.25	0	E/F	
21		2	20.13	20.15	160	E/F	
22	KURUNEGALA	1	5.50	5.51	70	O/C,E/F	
23		4	7.01	7.02	80	O/C,E/F	
24	UKUWELA	10	5.46	5.47	143	E/F	
25		12	12.24	12.25	126	O/C,E/F	
26		12	12.26	12.49	126	O/C,E/F	
27		9	12.29	15.35	8	O/C,E/F	
28		10	15.01	15.02	93	O/C,E/F	
29		1	15.03	15.04	54	O/C,E/F	
30	KOSGAMA	8	19.43	19.45	130	E/F	
31		2	23.44	23.45	85	E/F	
32	SEETHAWAKA	1	2.50	2.51	120	E/F	
33	VAUNIYAWA	3	4.32	4.33	23	O/C	
34		6	5.50	5.51	10	E/F	

35	TRINCO	5	8.20	8.21	25	E/F	
36		2	8.45	8.46	60	E/F	
37		7	17.05	17.06	21	E/F	
38	CHUNNAKKAM	9	8.25	8.26	24	E/F	
39		9	8.27	8.39	24	E/F	
40	MAHO	1	11.28	11.30	43	E/F	
41	SAPU	7	2.00	2.01	116	NO INDICATION	
42		2	13.51	13.52	171	NO INDICATION	
43		2	18.57	18.58	212	NO INDICATION	
44	VEYANGODA	10	9.34	9.35	15	E/F	
45	ANIYAKANDA	3	19.24	19.25	88	O/C,E/F	
46		3	21.03	21.04	84	O/C,E/F	
47	PANNALA	6	6.22	6.23	48	O/C,E/F	
48	PANNIPITIYA	4	17.41	17.42	193	O/C	
49	HORANA	6	10.13	10.13	21	E/F	
50		6	11.05	11.06	22	E/F	
51		3	13.29	13.30	270	E/F	
52		3	14.29	14.37	265	E/F	
53	MATUGAMA	1	6.00	6.01	18	E/F	
54		4	10.57	10.58	6	E/F	
55	SRI' JAPURA	6	2.50	2.53	86	O/C	
56		5	5.05	5.06	15	E/F	
57		4	9.45	9.47	55	E/F	
58		3	4.24	4.25	217	E/F	

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33kV Feeder Breakdowns on 06/11/2014

	Grid Substation	Feeder No	Tripped Time	Restored Time	Load Prior to Tripping [A]	Indication AUTO	Indication LOAD SHEDDING STAGE
1	EMBLIPITIYA	7	12.02	12.03	30	O/C,E/F	
2	MATATA	3	7.29	7.30	35	E/F	
3		6	11:02	11:12	165	U/F	I
4		3	8.30	8.31	30	E/F	
4	RATNAPURA	8	3.43	3.44	200	E/F	
5		6	8.36	8.37	69	E/F	
2		1	11:02	11:08	50	U/F	I
6		6	13.01	13.02	36	E/F	
1	ATHURUGIRIYA	3	11:02	11:08	35	U/F	I
3	MATUGAMA	5	11:02	11:10	49	U/F	II
4		10	11:02	11:10	174	U/F	II
5	KOTUGODA	13	11:02	11:09	73	U/F	I
6		11	11:02	11:09	275	U/F	I
7		3	11:02	11:09	195	U/F	II
8	SAPUGASKANDA	9	11:02	11:11	65	U/F	I
9		11	11:02	11:10	108	U/F	I
10		2	11:02	11:11	148	U/F	II
11		4	11:02	11:11	93	U/F	II
23		7	5.54	5.55	143	E/F	
24		4	9.35	9.36	109	NO INDICATION	
12		7	11:02	11:11	106	U/F	II
13	KOSGAMA	1	11:02	11:11	60	U/F	I
14		8	11:02	11:11	85	U/F	I
15		2	11:02	11:11	100	U/F	II
16	UKUWELA	1	11:02	11:10	55	U/F	IV
17	HABARANA	3	11:02	11:12	72	U/F	I
18		1	11:02	11:12	50	U/F	II
19		7	11:02	11:12	62	U/F	II
20		8	11:02	11:12	25	U/F	V
21	Galle	2	11:02	11:10	45	U/F	I
22	THULHIRIYA	5	11:02	11:10	58	U/F	I
23		6	11:02	11:10	7	U/F	I
25	BADULLA	1	11:02	11:11	36	U/F	I
7		5	6.33	6.34	100	E/F	
26	KELANIYA	3	11:02	11:12	170	U/F	I
27		1	11:02	11:12	0	U/F	VI
28	BELIATTA	4	11:02	11:05	98	U/F	II
29		5	11:02	11:05	13	U/F	II
30		6	11:02	11:05	63	U/F	II
31	AMBALANGAODA	2	11:02	11:13	66	U/F	II
32		3	11:02	11:13	75	U/F	II
33		4	11:02	11:12	42	U/F	II
34		6	11:02	11:12	92	U/F	II

35	KIRIBATKUMBURA	6	11:02	11:05	80	U/F	II
36		14	11:02	11:05	100	U/F	II
37	DEHIWALA	7	11:02	11:13	0	U/F	II
38	RATMALANA	F7	11:02	11:13	120	U/F	II
39	VEYANGODA	7	11:02	11:12	110	U/F	II
40	PANADURA	3	11:02	11:13	60	U/F	II
41	PANNIPITIYA	2	11:02	11:13	75	U/F	IV
8	MAHIYANGANAYA	7	6.31	6.33	33	E/F	
9		8	6.31	6.34	10	E/F	
10	O/ANU	8	7.19	7.20	48	E/F	
11	VAUNIA	3	7.03	7.04	37	O/C	
12		6	10.12	10.13	10	E/F	
13		2	10.52	10.53	31	E/F	
14		6	12.29	12.30	10	E/F	
15	TRINCO	5	8.53	8.54	29	E/F	
16		2	15.50	15.51	52	E/F	
17		5	17.36	17.37	30	E/F	
18	PUTTALAM	4	12.07	12.09	30	E/F	
19	KILINOCHCHI	2	15.45	15.46	39	E/F	
20	CHUNNAKKAM	9	5.45	5.46	29	E/F	
21	MAHO	1	5.52	6.06	38	E/F	
22	BIYAGAMA	6	2.56	2.57	20	E/F	
23	KOTUGODA	9	7.41	7.42	135	O/C	
24	VEYANGODA	7	1.01	1.01	70	O/C,E/F	
25	ANIYAKANDA	3	12.08	12.09	38	O/C,E/F	
26		7	2.21	2.22	63	O/C,E/F	
27		3	9.14	9.15	41	O/C,E/F	
28		7	17.15	17.16	117	O/C,E/F	
29	PANNIPITIYA	8	6.47	6.48	32	E/F	
30		3	11.45	11.46	111	O/C	
31	PANADURA	9	18.08	18.09	164	O/C,E/F	
32	HORANA	6	4.28	4.28	15	E/F	
33	JA'PURA	4	15.07	15.08	19	E/F	

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33kV Feeder Breakdowns on 07/11/2014

	Grid Substation	Feeder No	Tripped Time	Restored Time	Load Prior to Tripping [A]	Indication	
						AUTO	LOAD SHEDDING STAGE
1	SAPUGASKANDA	6	18.13	18.14	136	E/F	
2	ANIYAKANDA	3	10.32	10.32	45	.O/C,E/F	
3		3	10.43	11.12	0	.O/C,E/F	
4	KATUNAYAKA	4	6.15	6.17	62	E/F	
4		7	14.40	14.41	80	E/F	
5	PANADURA	5	12.29	12.30	140	O/C	
2		6	15.23	15.24	110	O/C	
6		5	15.46	15.47	105	O/C	
1	HARANA	6	10.4	1.06	24	E/F	
3		6	2.02	2.03	22	E/F	
4		6	2.34	2.38	18	E/F	
5	MATHUGAMA	1	5.50	5.51	19	E/F	
6	MATARA	3	6.52	6.53	40	E/F	
7		7	10.43	10.44	61	E/F	
8		2	15.36	15.37	100	E/F	
9	GALLE	7	14.50	14.51	10	E/F	
10		1	16.05	16.06	65	E/F	
11	HAMBANTHOTA	3	17.05	17.06	76	.O/C,E/F	
23	BADULLA	5	8.48	8.49	70	E/F	
24		5	10.54	10.56	81	E/F	
12		5	12.47	12.49	83	E/F	
13		5	13.37	13.53	77	E/F	
14	MAHIYANGANAYA	5	5.37	5.46	12	E/F	
15		8	17.32	17.33	13	E/F	
16		7	18.12	18.20	28	E/F	
17	THULHIRIYA	7	6.08	6.09	67	.O/C,E/F	
18		5	8.44	8.45	69	.O/C,E/F	
19	KURUNAGALA	6	12.25	12.26	130	E/F	
20	UKUWELLA GS	1	22.27	23.38	57	E/F	
21	SEETHAVAKA	1	6.38	6.39	30	E/F	
22		1	17.19	17.20	80	E/F	
23		1	23.32	23.33	50	E/F	
25	VAVUNIYAWA	6	6.52	6.53	16	E/F	
7		6	9.07	9.08	11	E/F	

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33kV Feeder Breakdowns on 08/11/2014

	Grid Substation	Feeder No	Tripped Time	Restored Time	Load Prior to Tripping [A]	Indication	
						AUTO	LOAD SHEDDING STAGE
1	MATARA	3	12.50	12.51	50	E/F	
2	RATHNAPURA	5	7.11	7.32	29	E/F	
3	AMPARA	1	3.55	3.56	40	E/F	
4		1	6.56	6.57	40	E/F	
5	BADULLA	5	17.27	17.28	91	E/F	
6	MAHIYANGANE	7	6.33	6.35	31	E/F	
7		8	6.33	8:38	10	E/F	
8		7	11.07	11.09	56	E/F	
9		2	11.07	11.09	75	E/F	
10		8	16.42	16.45	8	O/C	
11	THULHIRIYA	2	4.58	4.59	35	E/F	
12		1	7.36	7.37	80	.O/C,E/F	
13		4	8.56	8.57	137	.O/C,E/F	
14	KIRIBATHKUMBURA	3	4.37	4.39	10	.O/C,E/F	
15		7	8.34	8.35	40	.O/C,E/F	
16	SEETAWAKE	1	11.18	11.19	90	E/F	
17	VAUNIA	2	8.25	8.26	34	E/F	
18		6	11.22	11.23	11	E/F	
19		6	13.30	13.31	10	E/F	
20		6	14.03	14.04	10	E/F	
21	TRINCOMALLEE	5	0.54	0.55	30	E/F	
22		7	5.33	5.34	22	E/F	
23		1	6.21	6.22	70	E/F	
24		5	18.01	18.02	18	E/F	
25		2	20.47	20.48	114	E/F	
26		2	20.49	21.06	114	E/F	
27		5	21.38	21.39	20	E/F	
28	SAPUGASKANDA	2	6.03	6.04	132	E/F	
29	ANIYAKANDA	3	2.26	2.26	31	O/C	
30		5	14.36	14.39	124	O/C	
31	PANNALA	3	7.26	7.26	47	.O/C,E/F	
32		6	12.06	12.06	36	.O/C,E/F	
33		5	19.17	**19.17**	69	.O/C,E/F	
34	HORANA	5	8.46	8.46	96	E/F	
35		6	14.37	14.39	23	E/F	
36	DEHIWALA	6	2.30	2.31	78	O/C	
37	JAYAWARDHANAPURA	3	17.33	17.35	164	E/F	

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33kV Feeder Breakdowns on 09/11/2014

	Grid Substation	Feeder No	Tripped Time	Restored Time	Load Prior to Tripping [A]	Indication	
						AUTO	LOAD SHEDDING STAGE
1	MATARA	3	5.55	5.56	25	E/F	
2	HAMBANTOTA	6	11.59	12.00	76	O/C	
3		1	12.52	12.52	100	O/C	
4	NUWARA ELIYA	1	20.48	20.49	80	E/F	
5	AMPARA	1	5.07	5.20	40	E/F	
6		1	6.27	7.11	40	E/F	
7		1	7.13	3:21	40	E/F	
8		10	17.05	17.07	50	E/F	
9	BADULLA	5	4.22	4.24	47	E/F	
10		5	8.40	8.43	78	E/F	
11		5	8.46	8.47	78	E/F	
12	EMBILIPITIYA	7	9.16	9.17	87	.O/C,E/F	
13		7	22.51	22.52	53	.O/C,E/F	
14	THULHIRIYA	6	14.04	14.05	7	.O/C,E/F	
15	KIRIBATHKUMBURA	3	22.45	22.47	30	O/C	
16	SEETHAWAKA	1	1.55	1.56	40	E/F	
17		1	5.36	5.37	40	E/F	
18		1	18.41	18.42	30	E/F	
19		1	18.42	18.46	0	E/F	
20		1	23.06	23.07	40	O/C	
21	TRINCOMALEE	1	6.24	6.25	79	E/F	
22		5	12.31	12.32	32	E/F	
23		5	17.43	17.44	34	E/F	
24	PUTTALAM	7	11.14	11.15	30	E/F	
25		7	12.34	12.35	30	E/F	
26		7	14.33	14.34	35	E/F	
27	SAPUGASKANDA	2	1.40	1.42	122	E/F	
28		2	1.42	1.57	0	E/F	
29		2	2.17	2.19	54	E/F	
30	KOTUGODA	13	7.31	7.32	59	E/F	
31	ANIYAKANDA	5	7.45	7.46	92	O/C,E/F	
32	RATHMALANA	8	6.16	12.24	16	O/C,E/F	
33		9	6.16	6.18	60	O/C,E/F	
34		7	7.23	7.25	10	E/F	
35		6	8.38	**8.39**	76	E/F	
36		6	9.25	9.27	100	E/F	
37	PANADURA	3	6.33	6.34	54	E/F	

38	MATHUGAMA	9	14.37	14.5	34	E/F	
39	J'PURA	4	4.13	4.14	13	E/F	
40	DEHIWALA	8	8.38	8.39	87	O/C,E/F	

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Appendix 2 – 33 kV Feeder Trippings (more than 40 times per month)

October 2012		November 2012		December 2012	
GSS/Feeder	**No. of Trippings**	**GSS/Feeder**	**No. of Trippings**	**GSS/Feeder**	**No. of Trippings**
Kilinochchi F4	42	Kilinochchi F4	43	Habarana F7	47
Kilinochchi F5	56	Pannala F4	60	Trincomalee F1	70
Pannala F4	79	Trincomalee F1	68	Habarana F6	69
Pannala F7	42	Habarana F5	40	Seethawaka F1	74
Kiribathkumbura H3	55	Habarana F6	53	Badulla F6	95
Habarana F3	59	Ampara F1	45	Balangoda F1	42
Habarana F5	47	Seethawaka F1	127	Balangoda F2	40
Habarana F6	71	Balangoda F7	52	Balangoda F5	62
Habarana F7	72	Badulla F6	154		
Habarana F8	63	Balangoda F6	58		
Trincomalee F1	100	Balangoda F1	62		
Trincomalee F5	57	Balangoda F2	74		
Ampara F1	55	Balangoda F5	65		
Ampara F6	73				
Aniyakanda F5	41				
Seethawaka F1	194				
Deniyaya F1	42				
Badulla F1	59				
Badulla F3	48				
Balangoda F1	52				
Balangoda F5	41				
Balangoda F7	56				
Ambalangoda F2	61				

January 2013		February 2013		March 13	
GSS/Feeder	No. of Trippings	GSS/Feeder	No. of Trippings	GSS/Feeder	No. of Trippings
Trincomalee F1	42	Habarana F7	52	Habarana F7	50
Habarana F6	53	Seethawaka F1	71	Pannala F4	50
Ampara F1	45	Badulla F6	46	Vavuniya F2	54
Seethawaka F1	58			Aniyakanda F5	44
Badulla F6	53			Habarana F3	47
Balangoda F2	44			Seethawaka F1	102
Balangoda F4	45			Badulla F6	84
				Badulla F1	65
				Balangoda F1	42

April 2013		May 2013		June 2013	
GSS/Feeder	**No. of Trippings**	**GSS/Feeder**	**No. of Trippings**	**GSS/Feeder**	**No. of Trippings**
Puttalam F4	45	Puttalam F1	43	Habarana F3	52
Kilinochchi F4	44	Vavuniya F2	42	Habarana F6	63
Trincomalli F1	55	Habarana F5	97	Habarana F8	98
Ukuwela F8	71	Vavuniya F4	40	Vaunia F4	45
Seethawaka F1	78	Pannala F4	60	Trinco F1	50
Badulla F6	65	Kilinochchi F4	49	Balangoda F1	66
Badulla F1	41	Trincomalli F1	71	Balangoda F5	62
		Ukuwela F8	75	Balangoda F6	54
		Trincomalli F5	43	Balangoda F7	49
		Habarana F6	84	Balangoda F8	46
		Habarana F8	76	Kiribathkumbura H2	49
		Habarana F3	77	Kiribathkumbura H3	65
		Aniyakanda F5	42	Ukuwela F8	86
		Seethawaka F1	144	Ukuwela F10	72
		Badulla F6	94	Puttalam F1	106
		Balangoda F1	53	Pannala F4	55
		Balangoda F5	40	Kilinochchi F5	68
		Balangoda F7	41	Seethawaka F1	144
		Matara F7	45	Badulla F1	48
				Badulla F6	48

July 2013		August 2013		September 2013	
GSS/Feeder	**No. of Trippings**	**GSS/Feeder**	**No. of Trippings**	**GSS/Feeder**	**No. of Trippings**
Habarana F3	46	Puttalam F1	53	Habarana F7	42
Habarana F8	70	Habarana F7	51	Vavuniya F4	62
Vaunia F2	43	Vavuniya F6	44	Kilinochchi F4	54
Vaunia F4	94	Habarana F7	51	Trincomalli F2	69
Vaunia F6	43	Vavuniya F4	94	Trincomalli F8	57
Trinco F2	109	Puttalam F3	75	Habarana F3	49
Trinco F8	50	Kilinochchi F4	53	Seethawaka F1	107
Balangoda F1	76	Trincomalli F2	75	Badulla F6	60
Balangoda F5	55	Trincomalli F1	41	Balangoda F1	48
Hambanatota F3	49	Trincomalli F8	66		
Ukuwela F8	124	Balangoda F1	63		
NuwaraEliya F3	45	Badulla F6	69		
Puttlam F1	120	Seethawaka F1	102		
Pannala F4	48	Balangoda F5	42		
Seethawaka F1	159				
Badulla F6	45				

October 2013		November 2013		December 2013	
GSS/Feeder	**No. of Trippings**	**GSS/Feeder**	**No. of Trippings**	**GSS/Feeder**	**No. of Trippings**
Vavuniya F4	54	Puttalam F4	46	Vavuniya F4	43
Habarana F7	76	Kilinochchi F4	77	Pannala F4	51
Puttalam F4	45	Habarana F6	47	Kilinochchi F4	59
Pannala F4	44	Trincomalee F2	46	Habarana F6	43
Habarana F3	82	Trincomalee F7	42	Valachchane F5	52
Habarana F6	80	Seethawaka F1	91	Trincomalee F2	55
Trincomalee F2	44	Balangoda F5	58	Trincomalee F8	56
Trincomalee F8	47	Balangoda F1	56	Seethawaka F1	91
Trincomalee F7	44			Badulla F5	62
Seethawaka F1	81			Balangoda F5	43
Balangoda F5	42			Balangoda F1	45
Badulla F5	81				

January 2014		February 2014		March 2014	
GSS/Feeder	**No. of Trippings**	**GSS/Feeder**	**No. of Trippings**	**GSS/Feeder**	**No. of Trippings**
Habarana F7	41	Seethawaka F1	47	Kilinochchi F4	41
Habarana F6	59			Vavuniya F2	46
Valachchane F5	49			Habarana F3	50
Trincomalee F1	43			Habarana F5	41
Seethawaka F1	46			Habarana F6	41
Badulla F5	61			Seethawaka F1	77
Balangoda F5	42				

April 2014		May 2014		June 2014	
GSS/Feeder	No. of Trippings	GSS/Feeder	No. of Trippings	GSS/Feeder	No. of Trippings
Kilinochchi F4	50	Kilinochchi F4	66	Habarana F7	48
Vavuniya F2	51	Kilinochchi F2	48	Puutalam F1	61
Vavuniya F4	41	Vavuniya F4	41	Puttalam F3	79
Habarana F3	42	Habarana F6	70	Trinco F7	57
Habarana F5	47	Badulla F5	57	Badulla F5	50
Habarana F7	71	Seethawaka F1	68	Sapugaskanda F 7	42
Madampe F7	42	Balangoda F5	42	Seethawaka F1	126
Puttalam F4	48			Balangoda F4	66
Habarana F6	49			Balangoda F1	70
Badulla F5	42			Kosgama F5	48
Seethawaka F1	129			Balangoda F5	68
Seethawaka F8	56				
Balangoda F5	46				

July 2014		August 2014		September 2014	
GSS/Feeder	**No. of Trippings**	**GSS/Feeder**	**No. of Trippings**	**GSS/Feeder**	**No. of Trippings**
Habarana F7	55	Vavuniya F4	58	Kilinochchi F4	82
Vavuniya F4	75	Kilinochchi F2	46	Vavuniya F3	49
Kilinochchi F4	83	Kilinochchi F4	82	Habarana F7	48
Puutalam F1	82	Madampe F7	70	Puttalam F1	73
Trinco F7	98	Puttlam F4	78	Chilaw F7	50
Badulla F5	57	Puttlam F1	164	Kilinochchi F2	55
Seethawaka F1	62	Puttlam F3	74	Vavuniya F4	43
Balangoda F7	46	Trinco F7	60	Habarana F6	42
Balangoda F4	56	Trinco F2	68	Kiribathkumbura H3	42
Balangoda F1	48	Badulla F5	50	Badulla F5	68
Kosgama F5	45	Seethwaka F1	78		
Balangoda F5	67	Balangoda F5	52		
		Balangoda F1	46		

Appendix 3 – 33 kV Feeder List Which Having Downstream Auto Reclosers Installed

Name of GSS	**Feeders which having Downstream Auto Reclosers installed**
Ambalangoda	F2, F3, F4, F5
Ampara	F1, F2, F3, F4, F5, F6, F8, F9
Aniyakanda	F3, F4, F5, F6
Old A’pura	F1, F3, F7, F8
New A’pura	F4, F5, F6, F7
Athurugiriya	F2, F6
Badulla	F5
Balangoda	F2, F4, F6
Beliatta	
Biyagama	F3, F4, F6, F8
Bolawatta	H7, H8
Chunnakkam	
Colombo A	
Colombo B	
Colombo C	
Colombo E	
Colombo F	
Colombo I	
Dehiwala	
Deniyaya	G1, F1, F2, F3
Embilipitiya	F4, F6, F7
Galle	F2, F3, F5, F6, F7
Habarana	F1, F2, F3, F4, F5, F6, F7, F8
Hambantota	F5, F6
Horana	F3, F4, F5, F6
Kelaniya	
Katunayake	F1, F4
Kilinochchi	
Kiribathkumbura	H2, H3, H5, H6, H7, H13, H14
Kolonnawa	
Kosgama	F1, F2, F3, F5, F6, F8
Kotugoda	F3, F5, F7, F9, F12, F13

Name of GSS	Feeders which having Downstream Auto Reclosers installed
Kurunegala	H4, H11, H12, H13
Madampe	F2, F3,F4, F7
Mahiyanganaya	
Maho	
Matara	F2, F3, F6, F7, F8
Matugama	F2, F3, F5, F7, F8
Naula	
New Chillaw	
Nuwara_Eliya	F4, F5, F6, F7
Pallekelle	
Panadura	F3, F4, F5
Panala	F4, F5
Pannipitiya	F2, F4
Puttalum	F3, F4, F7
Ratnapura	F1, F3, F6
Ratmalana	F3, F9
Sapugaskanda	F2, F8
Seethawaka	F1, F2, F8
Sri Jayawardenapura	
Thulhiriya	F4, F5, F6, F7, F8, F9
Trincomalee	F1, F5, F7
Ukuwela	F3, F4, F9, F10, F12
Valaichchenai	F2, F5, F6
Vauniya	
Veyangoda	F3, F4, F5, F6, F7, F8, F9
Wimalasurendra	F1, F3, F5, F6, F8

Appendix 4 : Maximum Three-Phase Short Circuit Levels of GSS

Table 4.24 - Maximum three-phase short circuit levels

Grid Substation/Power Station	Voltage Level (kV)	Existing Switch Gear Capacity (kA)	Maximum Three Phase Fault Level					
			2013		2017		2022	
			kA	deg.	kA	deg.	kA	deg.
Akkaraipattu	132		-	-	-	-	2.9	-78.6
	33		-	-	-	-	6.8	-83.3
Ambalangoda	400		-	-	-	-	11.7	-88.3
	132		5.2	-79.2	8.4	-76.3	16.1	-87.8
	33		7.2	-86.3	8.3	-86.6	13.2	-89.6
Ampara	132	31.5	1.4	-70.7	3.4	-78.5	3.5	-78.5
	33	25	4.4	-75.8	8.1	-83.8	8.1	-83.9
Aniyakanda	132		14.8	-83.0	15.6	-83.3	12.5	-84.3
	33		9.3	-88.9	13.1	-88.6	12.4	-88.6
Anuradhapura	132		6.4	-76.7	8.1	-83.5	7.9	-84.2
31.5MVA TF	33		4.6	-87.7	10.8	-87.8	10.8	-88.0
20MVA TF			2.9	-88.5	-	-	-	-
Asia Power	132		19.1	-83.9	26.3	-86.0	-	-
Aturugiriya	132	40	14.4	-76.4	19.4	-86.0	18.2	-87.0
	33	25	9.3	-87.8	9.7	-89.5	13.5	-89.4
Badulla	132	31.5	6.9	-76.1	10.1	-78.9	10.5	-78.6
	33	25	10.5	-85.0	12.0	-86.9	12.2	-87.0
Balangoda	132	31.5	9.3	-77.9	12.1	-81.0	11.0	-82.5
	33	25	12.1	-86.5	13.0	-87.9	12.7	-88.1
Baththaramulla	132		-	-	20.8	-86.0	18.9	-87.0
	33		-	-	9.7	-89.5	13.6	-89.5
Beliatta	132		3.5	-75.5	5.2	-74.7	5.4	-75.8
	33		6.2	-83.7	7.2	-84.7	9.4	-83.8
Biyagama	220	50	18.9	-86.8	23.7	-87.1	24.6	-86.7
	132	50	20.8	-85.7	22.4	-86.3	15.9	-87.2
	33	25	10.9	-88.7	12.2	-88.2	10.9	-88.7
Bolawatta	132	40	9.5	-81.0	10.0	-82.1	9.8	-82.5
	33	25	10.9	-87.4	11.0	-87.8	10.9	-87.9
Bowatenna PS	132	31.5	3.8	-73.8	4.0	-76.2	4.1	-76.6
Broadlands PS	132		-	-	14.1	-79.5	14.4	-79.3
Canyon PS	132	40	10.0	-75.3	10.7	-76.3	10.7	-76.2
Chemmuni	132		-	-	2.1	-82.3	2.4	-81.9
	33		-	-	5.6	-84.9	6.1	-84.9
Chunnakam	132		1.9	-78.0	2.2	-82.8	2.5	-82.3
	33		5.6	-83.3	7.2	-86.5	7.4	-85.4
Colombo A	132		14.8	-82.6	22.6	-85.5	17.7	-86.3
	11		9.9	-89.6	15.4	-89.8	15.1	-89.7
Colombo B	132		-	-	25.7	-85.9	20.6	-86.9
	11		-	-	10.6	-89.9	15.3	-89.8
Colombo C	132		21.0	-84.0	26.1	-86.1	20.9	-87.1

Grid Substation/Power Station	Voltage Level (kV)	Existing Switch Gear Capacity (kA)	Maximum Three Phase Fault Level					
			2013		2017		2022	
			kA	deg.	kA	deg.	kA	deg.
	11		10.6	-89.8	10.6	-89.9	10.6	-89.9
Colombo E	132	25	19.5	-80.9	21.6	-86.0	19.1	-86.9
	11	25	15.1	-89.4	15.3	-89.8	15.2	-89.8
Colombo F	132	25	19.2	-81.4	24.1	-86.6	20.9	-87.5
	11	25	15.1	-89.4	15.3	-89.8	15.2	-89.9
Colombo I	132		18.6	-83.5	24.8	-86.4	19.8	-87.2
	11		11.2	-89.7	15.4	-89.8	15.2	-89.8
Colombo K	132		-	-	20.4	-85.4	18.0	-86.5
	11		-	-	10.5	-89.8	5.4	-89.9
Colombo Port	220		-	-	21.8	-87.3	21.2	-86.8
	132		-	-	24.1	-86.7	21.0	-87.6
Colombo L1	11		-	-	14.9	-89.8	15.3	-89.9
Colombo L2	11		-	-	14.9	-89.8	15.3	-89.9
Colombo M	132		-	-	22.3	-86.2	19.6	-87.2
	11		-	-	14.9	-89.8	15.2	-89.8
Colombo N	132		-	-	24.7	-86.5	20.9	-87.4
	11		-	-	15.0	-89.8	10.6	-89.9
Colombo P	132		-	-	-	-	21.4	-87.5
	11		-	-	-	-	14.8	-89.9
Dehiwala	132		8.6	-86.5	22.6	-85.5	17.7	-86.3
	33		8.5	-89.1	14.0	-89.3	13.4	-89.3
Deniyaya	132	31.5	3.1	-65.8	5.3	-70.8	4.4	-68.6
	33	25	7.2	-76.8	7.5	-83.5	7.1	-81.9
Eluwankulama	132		-	-	3.8	-70.8	3.9	-73.1
	33		-	-	4.1	-84.9	6.5	-83.0
Embilipitiya	132	31.5	6.1	-79.4	9.2	-78.9	9.8	-81.4
	33		7.5	-86.8	8.5	-87.4	11.7	-87.5
Galle	132	31.5	2.4	-64.0	8.1	-75.3	8.5	-81.2
	33		5.0	-76.6	11.0	-85.1	11.2	-87.1
Habarana	132	31.5	5.2	-72.5	9.9	-83.9	11.1	-85.4
	33	25	7.0	-84.1	11.4	-88.2	11.8	-88.8
Hambantota	132	25	4.0	-79.3	8.7	-82.5	9.3	-83.3
31.5MVA TF	33	25	4.1	-87.3	11.0	-87.6	12.2	-88.0
16MVA TF	33		2.2	-88.5	-	-	-	-
Hambantota-Port	132		-	-	7.1	-81.8	7.5	-82.4
	33		-	-	10.1	-87.1	10.7	-87.3
Horana	132	40	5.2	-83.0	7.4	-79.7	4.5	-77.6
	33	25	8.1	-87.8	11.7	-86.5	8.7	-84.1
Inginiyagala	132	12.5	1.8	-71.3	3.0	-75.3	3.1	-75.2
	33		3.7	-82.7	4.4	-86.0	4.4	-86.1
Kelaniya	132	40	22.9	-84.8	26.3	-86.0	14.9	-85.8

Grid Substation/Power Station	Voltage Level (kV)	Existing Switch Gear Capacity (kA)	Maximum Three Phase Fault Level					
			2013		2017		2022	
			kA	deg.	kA	deg.	kA	deg.
	33	31.5	5.2	-89.7	10.0	-89.6	12.9	-89.1
Kalutara	132		-	-	8.1	-78.7	6.4	-77.6
	33		-	-	8.2	-87.1	7.7	-86.3
Kappalturai	132/220		-	-	2.8	-72.7	7.5	-86.4
	33		-	-	7.4	-78.7	19.3	-88.6
Katunayake	132		14.3	-83.3	16.5	-84.2	15.0	-85.1
	33		9.3	-88.9	13.2	-88.8	13.0	-89.0
Kegalle	132		-	-	4.4	-85.2	4.8	-86.7
	33		-	-	6.8	-88.2	8.9	-88.5
Kelenitissa PS	220	40	17.1	-86.5	22.6	-87.3	22.1	-86.7
	132	25	22.0	-84.4	27.5	-86.5	21.8	-87.4
Tertiary wdg.	33	25	7.0	-89.5	7.1	-89.7	7.0	-89.8
Kelenitissa-3A	33		8.4	-89.7	7.4	-89.8	6.5	-89.8
Kelenitissa-3B	33		8.4	-89.7	7.2	-89.8	6.5	-89.8
Kerawalapitiya	220		14.6	-86.3	22.1	-87.4	21.4	-86.9
	33		-	-	12.8	-89.8	23.4	-89.5
Kesbewa	132		-	-	-	-	14.2	-84.6
	33		-	-	-	-	9.2	-89.1
Kilinochchi	132		2.4	-76.1	2.9	-82.2	3.8	-82.5
	33		5.1	-82.5	5.7	-86.3	7.9	-86.1
Kiribathkumbura	132	25	8.2	-73.3	8.1	-81.1	8.4	-81.8
	33	25	11.5	-85.5	13.4	-86.4	13.8	-86.8
Kirindiwela	220		-	-	18.4	-86.2	23.0	-86.5
	132		-	-	7.3	-89.1	7.7	-89.3
Load Bus	33		-	-	14.0	-89.6	14.5	-89.7
Kolonnawa	132	40	22.7	-84.2	29.3	-86.9	22.8	-87.8
Kolonnawa	33		10.0	-89.4	10.3	-89.7	10.0	-89.8
Kolonnawa-Colombo	33	25	14.2	-89.1	14.8	-89.6	14.2	-89.7
Kosgama	132	25	7.8	-71.2	6.2	-87.6	6.5	-87.7
	33	25	8.3	-85.1	7.7	-89.3	10.0	-89.1
Kothmale PS	220	40	14.5	-86.8	21.4	-86.9	24.2	-86.8
Kotugoda	220	40	17.1	-86.2	22.0	-86.7	22.6	-86.4
	132	31.5	17.9	-85.0	20.1	-85.7	17.4	-86.7
Tertiary wdg.	33	13.1	10.3	-88.5	11.6	-88.1	11.2	-88.5
Kotugoda-New	33		9.6	-89.3	9.7	-89.5	9.5	-89.6
Kukule PS	132		4.3	-81.5	5.3	-74.7	7.6	-74.2
	33		1.7	-89.3	4.9	-86.6	5.3	-87.4
Kurunegala	132	25	4.6	-70.0	4.5	-74.4	4.6	-74.7
	33	25	6.9	-82.6	8.6	-82.7	8.7	-82.9
Laxapana PS	132	31.5	18.6	-80.6	21.9	-85.1	21.9	-85.2
Madampe	132	31.5	4.9	-72.9	11.9	-80.9	12.2	-81.3

Grid Substation/Power Station	Voltage Level (kV)	Existing Switch Gear Capacity (kA)	Maximum Three Phase Fault Level					
			2013		2017		2022	
			kA	deg.	kA	deg.	kA	deg.
	33	25	7.1	-83.9	12.1	-87.7	12.2	-87.9
Mahiyanganaya	132		5.5	-81.1	7.6	-82.2	8.3	-82.7
	33		7.4	-87.0	8.5	-88.0	9.2	-88.3
Maho	132		-	-	3.8	-75.6	3.9	-79.2
	33		-	-	6.4	-83.9	8.0	-84.4
Maliboda	132		-	-	17.2	-85.0	17.6	-85.1
	33		-	-	5.1	-89.6	5.2	-89.7
Mannar	132		-	-	2.8	-82.3	3.8	-83.2
	33		-	-	3.7	-87.4	4.1	-88.2
Matara	132	31.5	3.2	-74.6	6.9	-76.3	7.2	-78.6
	33	25	7.0	-83.1	11.6	-85.0	10.7	-85.7
Matugama	132	40	5.3	-83.2	8.4	-78.0	15.2	-77.7
	33	25	9.3	-87.0	11.3	-86.1	13.2	-87.4
Monaragala	132		-	-	3.5	-71.9	3.5	-71.7
	33		-	-	4.0	-84.9	6.3	-82.0
Moragolla PS	132		-	-	-	-	9.7	-81.8
New Chilaw	220		-	-	14.7	-85.4	16.0	-85.5
	132		-	-	15.4	-85.3	15.8	-85.9
Naula	132		-	-	5.2	-73.7	8.1	-82.9
	33		-	-	7.3	-84.4	8.2	-88.2
Nawalapitiya	132		-	-	9.5	-81.6	9.6	-81.7
	33		-	-	8.2	-88.2	8.3	-88.2
New Anuradhapura	132	40	6.4	-76.8	8.4	-84.1	8.1	-84.9
	220	25	3.4	-79.6	10.5	-83.1	12.2	-83.5
	33		3.4	-88.1	4.5	-88.7	4.5	-88.9
New Habarana	400		-	-	-	-	7.5	-86.0
New Polpitiya	220		-	-	19.4	-86.5	22.1	-86.5
	132		-	-	22.0	-86.8	22.8	-86.9
New Habarana	132		-	-	10.4	-84.9	11.8	-86.7
	220		-	-	11.7	-82.6	15.8	-84.5
	33		-	-	11.7	-88.5	12.1	-89.1
New Laxapana	132	31.5	18.6	-80.7	22.0	-85.2	22.0	-85.2
Nuwala Eliya	132	31.5	8.4	-73.9	10.0	-74.7	10.3	-74.5
	33	25	11.3	-84.9	12.1	-85.8	12.3	-85.8
Oruwala	132		12.7	-75.1	16.5	-82.9	15.6	-83.9
	33		1.1	-89.7	1.1	-89.9	1.1	-89.9
Padukka	132		-	-	17.7	-86.7	17.7	-87.6
	220		-	-	18.3	-86.1	23.8	-87.0
Tertiary wdg.	33		-	-	10.7	-88.5	11.1	-88.8
Load Bus	33		-	-	13.9	-89.6	15.0	-89.7
Pallekele	132		-	-	5.8	-80.6	5.9	-81.6

Grid Substation/Power Station	Voltage Level (kV)	Existing Switch Gear Capacity (kA)	Maximum Three Phase Fault Level					
			2013		2017		2022	
			kA	deg.	kA	deg.	kA	deg.
	33		-	-	7.5	-87.0	9.7	-86.5
Panadura	132	25	7.5	-83.6	13.0	-79.0	10.9	-80.8
	33	25	8.1	-88.3	12.3	-87.4	11.8	-87.5
Pannipitiya	220	50	13.4	-84.5	20.2	-86.1	22.7	-86.4
	132	31.5	10.2	-87.5	25.2	-85.4	21.1	-87.4
Load Bus	33	25	10.9	-89.3	13.6	-89.4	13.3	-89.6
Pannala	132		5.1	-76.4	7.5	-81.4	7.5	-81.8
	33		7.2	-85.3	8.1	-87.7	10.7	-87.1
Polonnaruwa	132		-	-	3.6	-79.8	3.9	-81.5
	33		-	-	6.3	-85.6	6.6	-86.5
Polpitiya PS	132	40	18.7	-80.0	22.5	-85.8	22.8	-85.8
Port City	220		-	-	21.1	-87.0	20.6	-86.5
Port City 1	11		-	-	5.1	-89.9	5.2	-89.9
Port City 2	11		-	-	5.1	-89.9	5.2	-89.9
Puttlam GS	132	25	6.1	-77.2	6.4	-73.4	6.7	-79.4
Load Bus	33		7.8	-86.1	8.0	-85.1	10.4	-86.0
Narakkalliya	33		4.9	-87.8	4.9	-87.2	5.0	-88.3
Puttlam PS	220		7.8	-86.7	16.9	-87.5	17.7	-87.4
Puttlam PS -Wind Collecting bus	33		9.8	-89.5	10.5	-89.8	10.6	-89.8
Ragala	132		-	-	7.7	-75.7	7.8	-75.6
	33		-	-	8.2	-86.2	8.2	-86.3
Randenigala PS	220	31.5	9.4	-85.8	11.3	-85.3	13.6	-85.5
Rantambe PS	220	31.5	8.9	-85.6	10.6	-85.1	12.6	-85.3
	132	20	7.0	-81.7	10.2	-83.3	11.2	-83.9
Tertiary wdg.	33	20	9.2	-88.5	10.5	-89.1	10.5	-89.2
Generator-1	12.5		21.6	-89.1	22.1	-89.4	23.1	-89.6
Generator-2	12.5		21.6	-89.1	23.0	-89.5	23.1	-89.6
Rathmalana	132	25	8.6	-83.9	17.0	-79.0	15.4	-85.1
	33	25	11.0	-88.1	13.1	-87.9	12.8	-89.0
Rathnapura	132	40	4.9	-78.8	5.3	-80.2	5.1	-80.9
	33	25	9.6	-85.1	9.9	-85.9	9.9	-86.1
Samanalawewa PS	132	31.5	8.7	-80.9	11.0	-81.6	10.8	-83.0
Sampoor	400		-	-	-	-	6.6	-87.0
	220		-	-	-	-	12.6	-88.8
Sapugaskanda GS	132	40	21.4	-85.1	23.5	-85.8	15.2	-86.4
	33		14.7	-89.3	17.9	-89.3	15.1	-89.1
Sapugaskanda PS	132	31.5	19.1	-85.3	20.3	-85.7	14.7	-86.6
Sithawake	132	25	8.2	-71.7	5.5	-85.2	5.7	-85.2
	33	25	11.4	-84.2	9.8	-88.0	10.0	-88.1
Sri J'Pura	132		8.6	-83.9	23.7	-82.6	20.1	-86.7

Grid Substation/Power Station	Voltage Level (kV)	Existing Switch Gear Capacity (kA)	Maximum Three Phase Fault Level					
			2013		2017		2022	
			kA	deg.	kA	deg.	kA	deg.
	33		8.3	-88.5	14.1	-88.9	13.7	-89.4
Suriyawewa	132		-	-	6.3	-79.9	6.3	-75.9
	33		-	-	7.7	-86.9	7.7	-85.7
Thulhiriya	132	40	6.4	-70.3	4.8	-85.7	5.2	-87.3
	33	25	10.3	-82.4	8.8	-88.0	11.2	-88.6
Tissamaharama	132		-	-	-	-	6.1	-81.7
	33		-	-	-	-	9.9	-86.7
Trincomalee	132	31.5	2.3	-71.1	2.5	-72.2	2.5	-72.6
	33	25	5.6	-80.1	5.7	-81.2	7.4	-77.9
Ukuwela PS	132	31.5	7.0	-74.4	7.9	-81.2	8.1	-82.6
	33	25	10.5	-84.4	10.9	-87.1	11.2	-87.6
Umaoya PS	132		-	-	7.7	-81.3	7.9	-81.2
	33		-	-	-	-	8.2	-87.7
Upper Kothmale PS	220		11.0	-85.2	14.2	-84.5	15.3	-84.2
Valachchenai	132		2.1	-72.7	2.7	-76.0	2.9	-80.9
	33		2.5	-85.0	5.5	-82.9	5.7	-85.6
Vaunativ	132		-	-	2.9	-79.6	3.2	-80.2
	33		-	-	5.8	-85.2	6.8	-85.9
Vauniya	220	40	-	-	-	-	7.1	-83.6
	132	25	3.4	-72.9	4.6	-82.7	8.4	-85.8
	33		5.5	-83.2	6.9	-87.3	11.3	-88.6
Veyangoda	220		13.7	-85.7	18.4	-85.8	22.7	-86.4
	132	25	10.3	-88.1	7.2	-89.0	7.5	-89.3
	33	25	8.6	-89.6	10.3	-89.7	10.5	-89.8
Victoriya PS	220	40	12.0	-86.5	15.2	-86.1	16.3	-86.0
Wewelwaththa	132		-	-	5.9	-80.1	5.7	-80.9
	33		-	-	4.5	-88.1	4.5	-88.2
Wimalasurendra	132	31.5	15.1	-78.2	17.5	-84.0	17.5	-84.0
	33	25	13.7	-87.6	14.0	-88.9	14.0	-88.9