IMPROVEMENTS TO MAINTENANCE AND OPERATION PRACTICES TO ACHIEVE BETTER RELIABILITY IN DISTRIBUTION NETWORK

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Dissertation submitted in partial fulfilment of the requirements for the degree Master of Science in Electrical Engineering

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DECLARATION

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

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ABSTRACT

With the growing concerns on depletion of fossil fuels and enhancing demand for green energy the need of an alternative source of energy has arose. As a replacement to fossil fuel driven engines and machineries, electrically driven machineries and equipment have found way ahead. As a substitute to fossil fuel, electricity plays a vital role in supplying energy to world at present. With the enhancement of luxury living, the use of tools and machinery at home as well as in the industry, the man is forced to concern on the quality of electricity supply they receive.

The concept of reliability is considered as one of the priorities of the electricity utilities in order to improve customer satisfaction. There are interruptions to power supply unexpectedly due to unavoidable circumstances as well as planned interruptions for system maintenance and construction work in the system.

This project focuses on approaches for making the best use of outage data to plan interruptions for system maintenance work to minimize the frequency of interruptions and the duration of interruptions to improve reliability.

The three power quality problems discussed here are the voltage sags, momentary interruptions and sustain interruptions caused by faults on the utility power system, with most of them on the distribution system. This project concentrates on distribution maintenance, operation and construction practices that can be used to minimize interruptions and their impact on customers in Western Province South-II.

This project identifies the weaknesses of the existing operation and maintenance practices. Determine ways and means to minimize frequency of break downs and power failures to improve the quality of power supply and its reliability. Also propose remedial solutions to be taken for improving reliability of the system. Calculate reliability indices, System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI) to assess the reliability level. Find solutions and propose remedial action to be taken to improve reliability of the system.

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LIST OF ABBREVIATIONS

A	Air break switch
AV	Awissawella
BG	Bandaragama
BL	Bulathsinghala
CEB	Ceylon Electricity Board
CSC	Consumer Service Center
D	DDLO
DD2	Distribution Division 2
DD3	Distribution Division 3
DD4	Distribution Division 4
DDI	Distribution Division 1
DDLO	Drop Down Lift Off
DM	Distribution Maintenance
HM	Homagama
HN	Hanwella
HR	Horana
HT	High Tension
IN	Ingiriya
L	Load break switch

LT	Low Tension
LV	Low Voltage
MB	Malabe
MCCB	Molded Case Circuit Breaker
ML	Millaniya
MV	Medium Voltage
OH	Over Head
P &D	Planning and Development
PD	Padukka
PHM	Projects and Heavy Maintenance
PN	Pannipitiya
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SJ'pura	Sri Jayawardhanapura
SM	Service Maintenance
T/F	Transformer
TL	Thalangama
Tr(O&M)	Transmission Operation & Maintenance
WL	Weliwita
WPS II	Western Province South II

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CHAPTER 1

INTRODUCTION

1.1 Background

Ceylon Electricity Board (CEB) is responsible in providing electricity to consumers in a major part of Sri Lanka whilst Lanka Electricity Company Limited is responsible for the rest. CEB owns and operates the majority of Generation, entire Transmission and a majority of Distribution network in Sri Lanka.

The particular interest and knowledge on the subject gained as an Electrical Engineer attached to the Distribution Control Center of Western Province South-II of CEB, I was compelled to study the reliability level of electricity supply provided by CEB and the topic was selected.

"Enrich Life through Power" is the vision of CEB and mission is to "Develop and maintain an efficient, coordinated and economical system of electricity supply to the whole of Sri Lanka, while adhering to core values,

Quality

Service to the Nation

Efficiency and Effectiveness

Commitment

Safety

Professionalism

Sustainability

Therefore, CEB strives to provide a high-quality uninterrupted electricity supply together with a very high reliability in order to achieve its objectives. The Reliability is affected by any sort of outage of supply. Outages are caused by failures or maloperation of any of the three basic components; generation, transmission and distribution as well as planned or unplanned maintenance of them. Failures of those components are caused by natural causes as well as human or animal interventions. Natural causes consist of falling of trees on the lines due to heavy wind, floods, landslides, lightning etc. Failures or faults due to some of the natural phenomena can be reasonably mitigated whilst some are totally unavoidable and disastrous. The planned outages can be minimized if those are well-managed. Still then, there is a little control over the unplanned outages because those are of random nature and hard to be delayed because those are taken for urgent maintenance to avoid major breakdowns of components.

Maintenance work can be pre-planned to reduce the number of interruptions and the duration of interruptions contributing to improvements of SAIDI and SAIFI, which are the indices for measuring reliability level. Some maintenance work can be done while the network or equipment is functioning, without interrupting the electricity supply and hence without affecting the reliability.

The maintenance of electricity distribution systems is of two types. Preventive maintenance and Corrective maintenance.

Preventive Maintenance is the maintenance that is regularly performed on a piece of equipment in the system to lessen the likelihood of it failing. Preventive Maintenance is performed while the equipment is still healthy, so that it does not break down unexpectedly.

Corrective Maintenance is the maintenance that performed after fault recognition and is intended to put the component in a state in which it can perform a required function. The component is used until it fails. Corrective Maintenance might be considered as a last resort.

Maintenance of Power distribution Systems

Maintenance is crucial for distribution system operators both when acquiring new assets (apparatus) and when trying to utilize already existing assets in the best possible manner. The cost of maintenance and consequences of failures can be significantly higher than the cost of the equipment. Hence, it becomes important to study maintenance and its effects in all stages of the lifetime of the asset.

Maintenance Optimization

Maintenance optimization is defined as a method aimed at finding the optimal balance between preventive and corrective maintenance with respect to objectives. The objectives are assumed to be enhanced revenue and customer satisfaction. From a reliability viewpoint the reason for maintenance is quite clear, that is to increase the reliability by means of improving apparatus. Another aspect of maintenance is to reduce risk.

Maintenance of equipment and situations vary greatly, and sound engineering and management judgment must be exercised. Performing maintenance on electrical equipment can be hazardous. Electrical and mechanical energy can cause injury or death if not managed properly. All maintenance activity must be conducted in accordance with stipulated rules and regulations.

Maximum asset performance is one of the major goals for power distribution system Engineers. To reach this goal maintenance optimization become crucial, aiming at the right level of reliability, maintaining the system at a low total cost while meeting demands from customers and regulators. One of the fundamental objectives is consequently to relate maintenance and reliability in an efficient and effective way and further to identify the optimal balance between preventive and corrective maintenance.

1.2 Objective

This study focuses on identifying problems leading to power system breakdowns and power supply interruptions. It includes identification of the weaknesses of the existing maintenance, operation and construction practices. Determination of ways and means to minimize frequency of breakdowns and to improve the quality of power supply and its reliability. The study is based on;

- Assessment of the effect of maintenance and operational practices on reliability
- Assessment of the impact of planned interruptions on the reliability.

- Find and recommend solutions for improvements.
- Improvement of reliability of power supply to consumers connected to the network.

1.3 Scope of Work

This thesis quantitatively analyses the types of breakdowns of electricity network and equipment and the power interruption plan for maintenance work. Also, it analyses the shortcomings and weaknesses of the existing network and equipment through;

- Identification of the types of power failures and categorizes them according to the cause of the failure. Prepare power interruption plan to minimize number of interruptions and time taken for repairs. Study the effect of planning interruptions for maintenance work to improve SAIDI and SAIFI. Also estimates the improvement of SAIDI and SAIFI and hence reliability
- Study the performance of existing network, equipment and the prevailing practices in the existing operation and maintenance system in carrying out maintenance work and collection of fault data

This thesis analyses the gross effect of interruption planning for maintenance work and possibility of combining of construction and maintenance activities with a view to optimize the outage time.

1.4 Thesis Organization

Chapter 2 of the theses describes the Distribution Network of WPS II. It introduces the five administrative areas in the WPS II network. It gives the statistics of the area distribution and transformer distribution. It defines seven failure types. Also provide witness for causes for system outages.

Chapter 3 explains how the single line diagram of the distribution network of WPS II is prepared and updated prior to the research. How the failure data was collected from site visits and control center data reports. The method of interruption scheduling and procedure was discussed in this chapter.

Chapter 4 contains the analysis and the results of the research. In this chapter Area-wise and failure-wise SAIDI and SAIFI are calculated and presented in figure form. Statistics of MV failures, LV failures and SM failures during year 2016 have been presented area-wise in bar chart form for easy comparison. SAIDI and SAIFI for year 2016 have been presented area-wise. Variation of SAIDI and SAIFI of Horana area during year 2016 have been compared.

Chapter 5, reliability has been defined and definition of SAIDI and SAIFI is introduced. Three case studies were done for Malabe CSC, Homagama CSC and Bulathsinghala CSC and proved the possibility of improving reliability by proper planning of interruptions for maintenance work.

In Chapter 6, a format for an interruption intimation sheet has been proposed. The procedure for preparation of final interruption plan has been laid down.

In Chapter 7, conclusion of the report is given. The responsibilities of all branches involving in preparation of interruption plan have been recommended.

CHAPTER-2

WESTERN PROVINCE SOUTH II

2.1 Research Area

Ceylon Electricity Board has four divisions to handle electricity distribution in the country. Those are named as Distribution Division 1 (DD1), Distribution Division 2 (DD2), Distribution Division 3 (DD3) and Distribution Division 4 (DD4). Under DD3 there are three provinces, Uva province, Sabaragamuwa province and Western Province South II (WPS II). Out of these three provinces WPS II was selected for this research.

WPS II has five areas and 13 Consumer Service Centers (CSCs). Namely,

Avissawella(AV) area – Avissawella CSC (AV)

Padukka CSC (PD)

Hanwella CSC (HN)

Homagama(HM) Area – Homagama CSC (HM)

Pannipitiya CSC (PN)

Horana(HR) Area – Horana CSC (HR)

Ingiriya CSC (IN)

Bulathsinghala CSC (BL)

Bandaragama(BG) Area – Bandaragama CSC (BG)

Millaniya CSC (ML)

Sri Jayawardhanapura(SJ'pura) Area – Thalangama CSC (TL)

Malabe CSC (MB)

Weliwita CSC (WL)

The geographical area of WPS II is 1014.3 km^2. Division of geographical area among five areas is as shown in pie chart in figure(1).

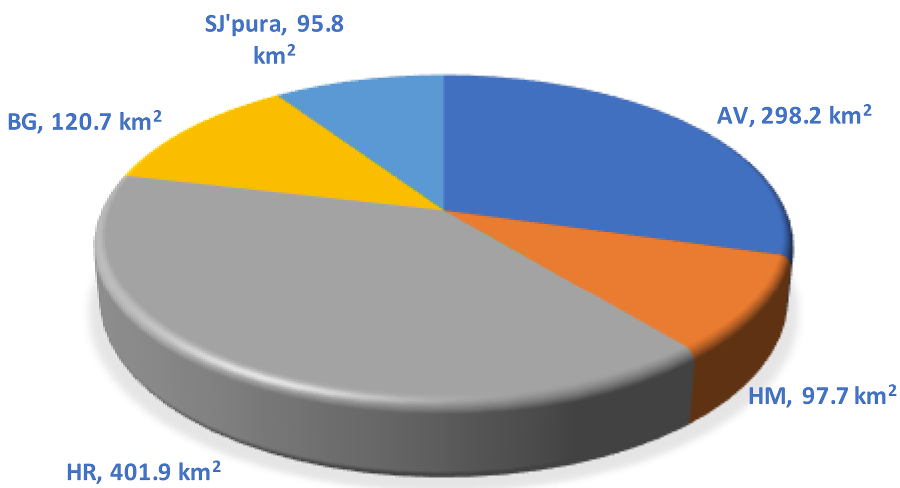

Figure 1:Area Distribution of WPS II

The distribution of customers in areas is shown in table1.

Table 1:Consumer Distribution in WPS II

Consumer Distribution in WPS-II			
Area	**Retail**	**Bulk**	**Total**
Avissawella	79682	220	79902
Homagama	89658	219	89877
Horana	71782	181	71963
Bandaragama	48016	60	48076
J'pura	105558	331	105889
Total			**395,707**

Transformer distribution in five areas is shown in table 2.

Table 2:Transformer Distribution in WPS II

Area	**Consumer Service Centre(CSC)**	**Bulk (B)**	**Distribution (D)**	**B+D**	**Total**
Avissawella	Avissawella	63	56	11	130
	Hanwella	55	68	6	129
	Padukka	66	94	5	165
Homagama	Pannipitiya	60	121	8	189
	Homagama	112	94	11	217
Horana	Horana	80	125	21	226
	Ingiriya	61	76	9	146
	Bulathsinhala	8	48	5	61
Bandaragama	Bandaragama	37	80	8	125
	Millaniya	14	49	2	65
J'pura	Malabe	80	119	13	212
	Thalangama	115	89	8	212
	Weliwita	97	67	14	178
Total					**2055**

2.2 Area Description

Avissawella area

Avissawella area has an area of 298.2 km^2 and has three CSCs, namely Avissawella CSC, Padukka CSC and Hanwella CSC. Total number of customers in the area is 79,902. It is a rural area and there are some industrial zones established. Tea, rubber, coconut and paddy are the main cultivations in the area. This is a hilly and forest area.

Homagama area

Homagama area has an area of 97.7 km^2 and it has two CSCs called Homagama CSC and Pannipitiya CSC. Total number of customers in the area is 89,877. Homagama is an urban area.

Horana area

Horana area has an area of 401.9 km^2. It has three CSCs, namely Horana CSC, Ingiriya CSC and Bulathsinghala CSC. It has 71,963 customers in the area. This area also has industrial zones and forests. The main cultivations in the area are tea and rubber. There are heavy rains and thunders. Mountainous area and it is a mix of semi urban areas and rural areas.

Bandaragama area

Bandaragama area has an area of 120.7 km^2 and it has two CSCs namely Bandaragama CSC and Millaniya CSC. The total number of customers in the area is 48,076. This is the area with lowest number of consumers in WPS II. This area is a rural area. Majority of people live on agriculture and paddy is the main cultivation in this area.

Sri Jayawardhanapura area

This area has 95.8 km^2 and it is the smallest area in WPS II. But it has the maximum number of customers. Number of customers in Sri Jayawardhanapra area is 105,889. It has three CSCs, Thalangama CSC, Malabe CSC and Weliwita CSC. This is also an urban area and most of government offices are situated in this area.

2.3 Failure types

Interruptions

A power failure means an interruption of power supply to consumers by any means. Power system interruptions are of two types; planned interruptions for operation and maintenance work and unplanned interruptions due to a break down in the system at an unexpected moment.

Planned Interruptions are accomplished by,

- Manual Tripping
- LV Switching
- MV Switching

Unplanned interruptions are due to failures in,

- LV lines
- MV lines
- Service Maintenance (SM)
- Auto Grid Tripping

2.3.1 Medium Voltage (MV) Failures

Failures on 33 kV, MV lines due to technical defects or natural incidents during disastrous situations such as tsunami, cyclone, flood and any other similar situations fall into this type of failures.

Table 3:MV Failures

Failure Cause	**Failure Description**
DDLO Fuse Blown	Substation DDLO Fuse Blown
OH Line	Accident due to vehicles
Switchgear Operation	Bad Whether
T/F failure	Cracked insulators
	DDLO carrier damage
	Due to birds and animals
	Due to lines overloading
	Terminal loose connection
	Vegetation
	Broken/damage HT conductor
	Burnt HT Conductor
	Insulator damaged
	Jumper failure
	Loose connection at jumper point
	Spark at the conductor due to
	Tree branches coming from distance
	Flashed due to loose connection
	Lightning
	Lightning Arrester damage
	LT tail wire terminal burnt
	LT/HT Bushing damage/cracked
	T/F & Arrester earth wire damage
	T/F & Arrester earth wire loose
	T/F Neutral Earth conductor damage
	T/F Neutral Earth conductor loose
	T/F oil leaking
	Tapchanger damage
	Transformer Fault

2.3.2 Low Voltage (LV) Failure

Failures on distribution transformers and LT distribution network due to technical defects or natural causes such as falling trees on the transformers and line conductors or accidents, fall into this type of failures.

Table 4:LV Failures

Failure Cause	**Failure Description**
Feeder fuse blown / MCCB tripping	Accident due to vehicle
Neutral leak	Broken earth conductor
O/H- Line	Broken/Burnt tail lines and cable
Problems of poles	Cable/conductor broken
	Due to birds and animals
	Due to broken poles
	Due to line overload
	Due to not using proper fuses
	Due to tree branches coming from distance
	Due to vegetation
	Terminal loose connection
	Due to Lightning
	Due to street light
	Broken / Burnt Tail Wire
	Burnt / Damage bundle conductor
	Burnt LT Fuse Box
	Jumper point failure
	Loose span and entanglement
	Low Voltage Problem
	LT Tail wire terminal burnt
	Midspan joint failure
	T/F Neutral earth conductor damaged
	T/F Neutral earth conductor loose connection
	Pole slanted

2.3.3 MV Switching

Interruption of power supply purposely by the maintenance staff in order to perform repairs or to replace some equipment or do construction works on the MV network is called as MV switching.

2.3.4 LV Switching

Interruption of power supply purposely by the maintenance staff in order to perform repairs or replace equipment or do construction work on the LT network is called as LV switching.

2.3.5 Auto Grid Tripping

Tripping of equipment installed in the grid substation activating automatically due to defects is called auto grid tripping.

2.3.6 Manual Grid Tripping

Interruption of grid substation purposely by maintenance staff for any maintenance work is called manual grid tripping.

2.3.7 Service Maintenance (SM) Failures

These are the failures taking place within the network of power supply to the customer.

Table 5:SM Failures

Failure Cause	Failure Description
Connection point at pole	Loose connection at crimp
Consumer Fault	Loose connection at line tap
kwh Meter	Loose connection at pg clamp
Service Cutout/MCB	Loose connection at wire joint
Service pole	Loose connection of piercing connector
Service Wire	Oxide at the tapping point
	Service wire disconnected at tapping point
	Unspecified problem of connection at pole
	Consumer internal fault
	Internal fault in the meter
	Loose connection at meter terminal
	Loose connection at meter terminal wires
	Meter burnt
	Meter damaged
	Meter terminal burnt
	Meter wire burnt
	Oxide in the meter terminal
	Perished meter box/board
	Cutout Burnt/Damaged
	Cutout fuse blown due to overload
	Cutout/MCB terminal burnt
	Cutout/MCB wire damage
	Cutout/MCB wire loose connection
	MCB Burnt/Damage
	MCB tripped
	Misplace of Service Cutout
	Oxide in the termination
	Service pole damage
	L Iron Broken
	Loose connection at D-Bracket

	Loose connection at wire joint
	Over sag of service wire
	Service wire broken / burnt / damaged
	Wire broken at middle pole

2.4 Causes for system outages / current practices

Figure 2:Uncleared way leaves

Line conductors, insulators and pole top were covered with creepers. During rains and wet conditions conductor short circuit and earth leakage is possible. These creepers should be cleared regularly.

Figure 3:Disturbance by way leaves.

Branches of trees and coconut leaves touching conductors in an outdoor substation leaving room for short circuits.

Figure 4: Damage fuse boxes

Lids of the LT fuse boxes are broken and fuses are open to atmosphere. This can lead to accidents and breakdowns.

Figure 5: Poor workmanship

Untidy wire connections could cause short circuits and burn conductors.

Figure 6: Negligence of workman

Untidy and poor arrangement of cables and conductors causing break downs and short circuits.

Figure 7: Poor workmanship

Untidy cable connections in a substation.

Figure 8:Neatly arranged substation

Conductor spacing, jumper connection and other parts properly arranged.

Figure 9: Abandoned power line

Towers, conductors and other equipment of an abandoned power line are covered with creepers and wayleaves.

CHAPTER 3

METHODOLOGY

3.1 Updating the single line diagram of MV network.

A single line diagram of distribution network is drawn to mark the locations of each equipment accurately on the diagram with a cord of identification. The cord of identification comprises a cord for area, cord for consumer service center, a cord for the equipment and a cord for the position of the equipment in the network.

Single line diagram of a distribution network

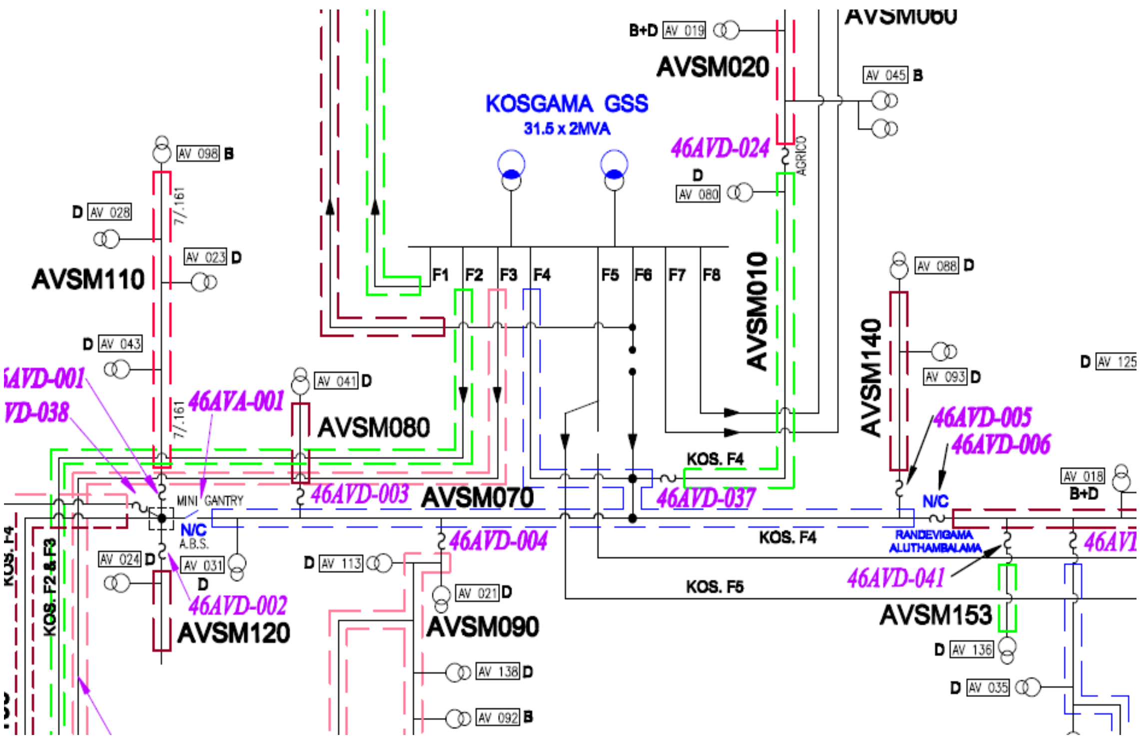

Figure 10:Single Line Diagram

Example:- If we consider Kosgama grid substation, it is situated in Avissawella area. If we name a Drop Down Lift Off (DDLO) switch located in the Avissawella area we use,

1. Area cord for Avissawella– 46
2. The CSC cord for Avissawella CSC – AV
3. Cord for DDLO switch –D
4. Cord for first DDLO – 001

The cord of identification for the first DDLO in Avissawella CSC is written as

46 AVD 001.

The above code defines the location of the first DDLO precisely.

Field visits were done first and single line diagram of the WPS II was updated.

3.2 Data Collection

Data was collected during site visits and from the Breakdown Management System records available in the control center of WPS II. While collecting breakdown data total breakdown records of year were studied.

In the meantime, interruption schedules of WPS II for the year 2016 were also studied. During the study, the system interruptions related to different occasions and causes for the break down were noted.

The data collected from the control center of WPS-11 were analyzed under following topics.

- Type of customers
- Type of faults
- Restore time
- Effect of planned interruptions
- Study the arrangement of existing equipment in the network and rearrange for easy and better operation
- Compare the economic impact of new changes over the existing system

- Improvement of reliability achieved were judged by SAIDI and SAIFI.

3.3 Interruption scheduling

By the analysis of interruption schedules of each branch it was found that interruptions are requested by following branches.

- Projects and Heavy Maintenance (PHM) branch
- Provincial construction branch
- Provincial Distribution Maintenance (DM) branch
- Transmission Operation and Maintenance [Tr.(O&M)] branch
- Area offices

Respective duties of each branch are given below.

PHM Branch	• Gantry Maintenance • New MV tower line construction
Construction Branch	• New distribution line and MV pole line construction work • New transformer erection, transformer augmentation and maintenance • 33 kV line and LT line shifting
DM Branch	• Pole changing • Line shifting • Maintenance work • Rehabilitation work • Line conversion
Tr.(O&M)	• Grid Substation Routine Maintenance
Area office	• Way leave clearing • LT maintenance work • LT Bulk and retail service connection

Duties performed and the time period requested for each interruption by different branches for their work were studied.

3.4 Procedure

Field visits were done and observed the physical condition of the distribution lines and equipment connected to the network. Details of existing condition of the lines and the equipment were recorded by photographs. The single line diagram was updated. Information of breakdowns and interruption plans of the past were collected from the relevant branches given below,

WPS- II call-center data base.

Avissawella Area office

Homagama Area office

Horana Area office

Bandaragama Area office

Sri Jayawardhanapura Area office

The information gathered were analyzed, and the causes for the breakdown, affected part of the line or the equipment, and time taken for the repair of the breakdown were studied. The interruption plans were examined and simultaneously (parallel jobs) performable jobs and the combinable jobs were sorted. Then, sample calculations were done to determine the SAIDI and SAIFI indices with original interruption plan and the adjusted plan. SAIDI and SAIFI indices which were calculated using data from original interruption plan and data from adjusted interruption plan were compared. Then, the improvement of SAIDI and SAIFI indices were assessed. It was observed that SAIDI and SAIFI indices could be improved by reducing number of power interruptions. Number of power interruptions can be reduced by performing certain maintenance work in parallel and certain work in combination.

CHAPTER 4

ANALYSIS AND RESULTS

The statistics of customers and network equipment were analyzed area wise, failure wise and month wise to study the comparative changes and improvement of parameters and the reliability level. Results were presented in tables and figures form for easy and clearly understanding.

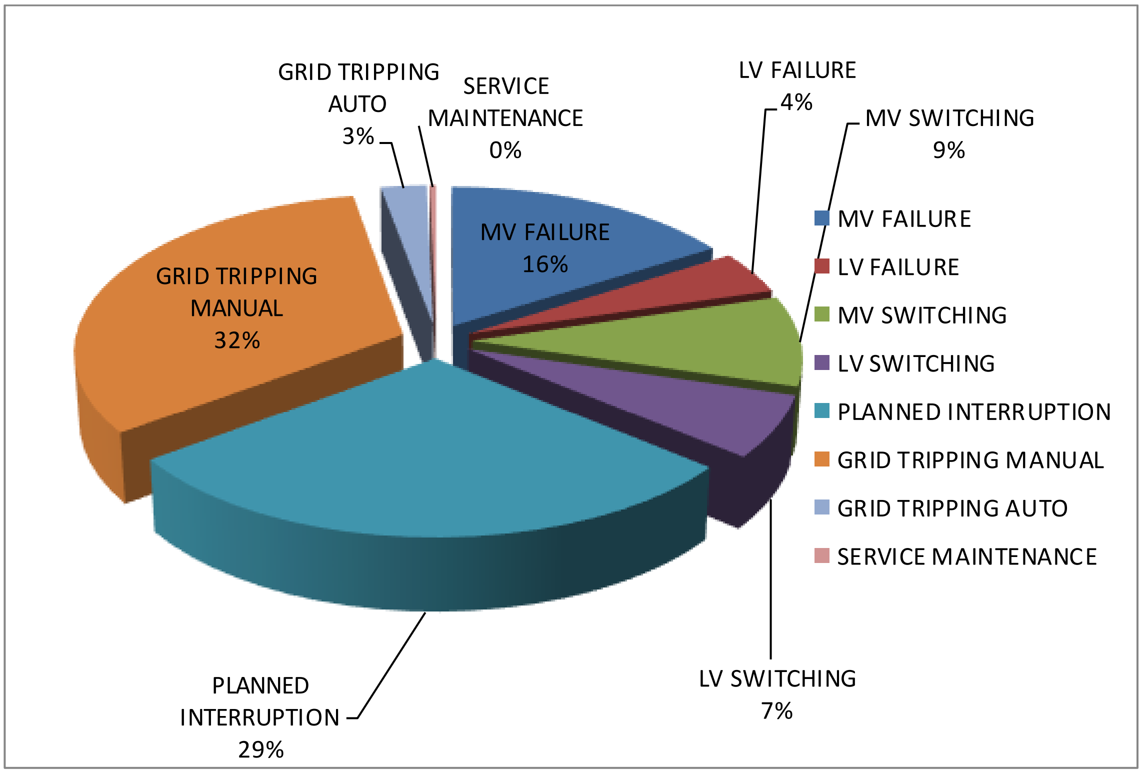

Figure 11: SAIDI January 2016 – WPS II

SAIDI-February 2016

Table 6 : SAIDI February 2016

	Avissawella	Bandaragama	Homagama	Horana	Sri J'Pura	WPS II
MV Failure	5,357,559	813,828	595,128	5,548,777	7,376,312	19,691,604
LV Failure	2,336,059	599,688	1,561,338	1,961,746	3,061,007	9,519,837
MV Switching	2,356,235	-	1,944,036	-	866,231	5,166,502
LV Switching	2,258,323	2,873,061	4,134,128	1,996,442	1,669,953	12,931,906
Planned Interruption	4,602,208	7,377,042	7,411,659	7,311,763	20,048,300	46,750,972
Grid Tripping Manual	1,912,320	1,143,615	-	11,121,440	26,255,258	40,432,632
Grid Tripping Auto	524,791	302,766	294,918	426,853	-	1,549,328
Service Maintenance	178,917	56,878	131,927	123,079	986,068	1,476,869
Sigma(Interrupted Time(min)X Total No of Customers affected)	19,526,410	13,166,878	16,073,134	28,490,099	60,263,127	137,519,649
Total No of Customers connected	81,541	48,508	90,900	74,702	96,930	392,581
SAIDI (min)	**239**	**271**	**177**	**381**	**622**	**350**

SAIFI- February 2016

Table 7 : SAIFI February 2016

	Avissawella	Bandaragama	Homagama	Horana	Sri J'Pura	WPS II
MV Failure	35,045	10,818	5,313	30,694	25,601	107,471
LV Failure	8,851	6,570	7,394	8,863	10,792	42,470
MV Switching	12,874	-	29,404	-	25,787	68,065
LV Switching	13,090	8,605	13,736	5,713	6,460	47,604
Planned Interruption	8,950	13,702	14,342	15,060	44,371	96,425
Grid Tripping Manual	4,479	26,290	-	89,004	127,138	246,910
Grid Tripping Auto	45,634	32,046	27,295	37,216	-	142,191
Service Maintenance	555	354	658	427	1,401	3,395
Sigma(Interrupted Frequency X Total No of Customers affected)	129,478	98,385	98,142	186,976	241,549	754,530
Total No of Customers connected	81,541	48,508	90,900	74,702	96,930	392,581
SAIFI	**2**	**2**	**1**	**3**	**2**	**2**

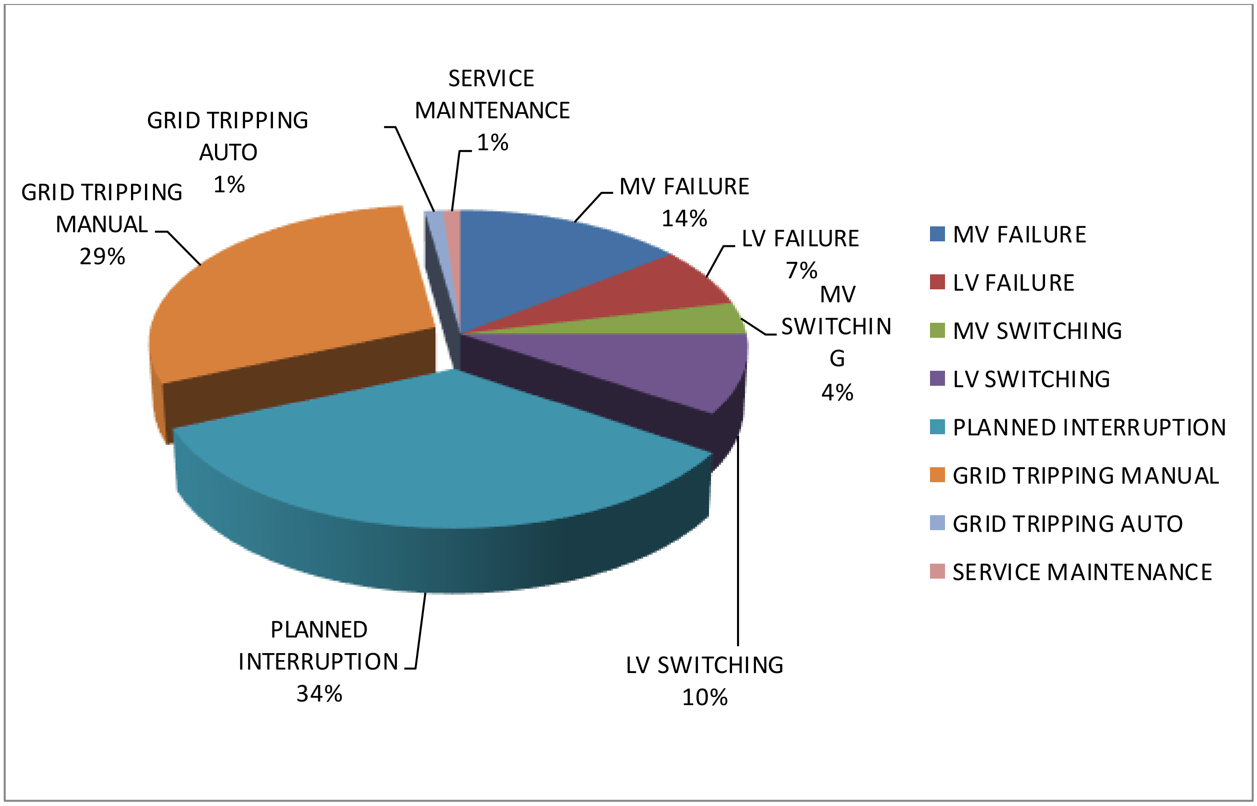

Figure 12: SAIDI February 2016 – WPS II

This chapter also presents the existing condition of the network and the equipment connected to the network. It also addresses the possibility of performing the system maintenance work and other break down work parallelly or, combine some jobs to reduce number of interruptions and the duration of interruptions to improve the System Average Interruption Duration Index (SAIDI) and the System Average Interruption Frequency Index (SAIFI).

Parallel work is the two or more work that can be performed by separate work groups at one place during same time slot.

Combined work is the two or many separate works that can be performed as a single job.

Individual work is the any work that has to be performed separately as a single job.

4.1 MV Failures

Table 8: Number of MV failures area wise

	Avissawella	Bandaragama	Homagama	Horana	Sri J'pura	Total
Jan-16	25	13	16	43	32	129
Feb-16	36	12	21	37	30	136
Mar-16	42	14	21	49	43	169
Apr-16	57	11	25	54	36	183
May-16	53	25	35	107	46	266
Jun-16	50	24	45	80	44	243
Jul-16	47	19	26	69	41	202
Aug-16	54	25	31	72	51	233
Sep-16	46	9	24	41	40	160
Oct-16	49	12	20	40	41	162
Nov-16	39	9	18	72	28	166
Dec-16	32	15	25	37	40	149

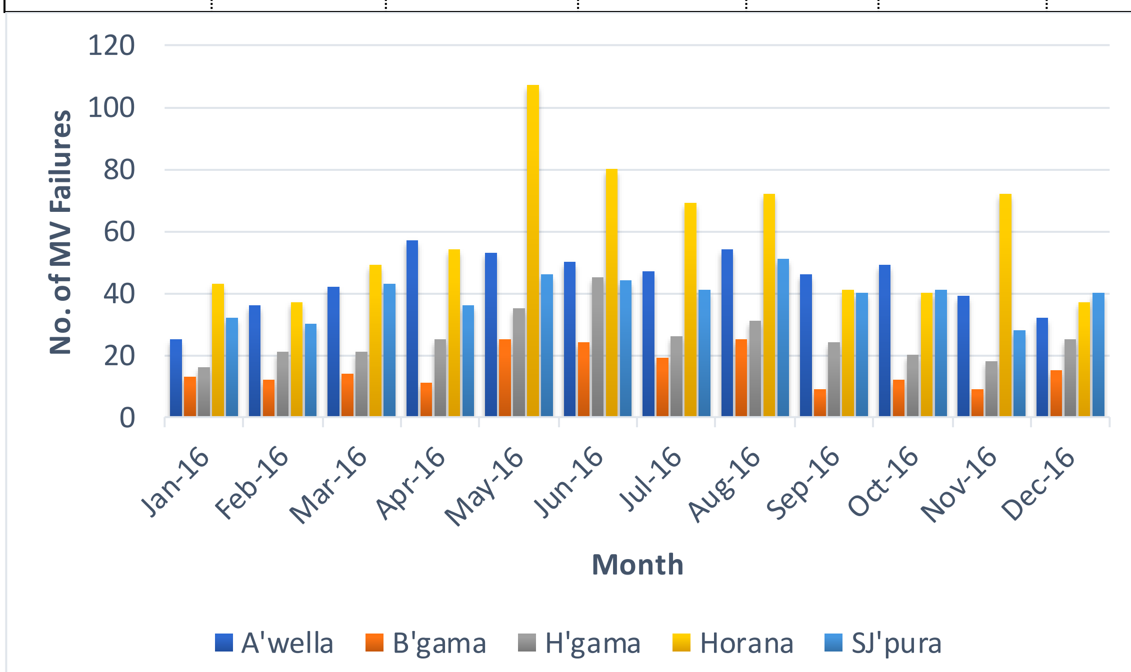

Figure 13 : Area wise MV Failures during year 2016

Area wise MV failures during year 2016 highlight that the highest number of failures occur in Horana area during May 2016, it is the highest over the year. Sri Jayawardhanapura area stands next to Horana area.

4.2 LV Failures

Table 9 : Number of LV failures area wise

	Avissawella	Bandaragama	Homagama	Horana	Sri J'pura	Total
Jan-16	138	66	146	171	263	784
Feb-16	174	64	124	159	254	775
Mar-16	269	84	261	214	416	1244
Apr-16	253	106	190	237	370	1156
May-16	286	150	252	617	362	1667
Jun-16	341	131	188	423	355	1438
Jul-16	185	74	181	183	233	856
Aug-16	250	79	201	169	257	956
Sep-16	171	67	130	173	159	700
Oct-16	227	66	123	187	186	789
Nov-16	214	72	129	307	181	903
Dec-16	158	45	139	160	183	685

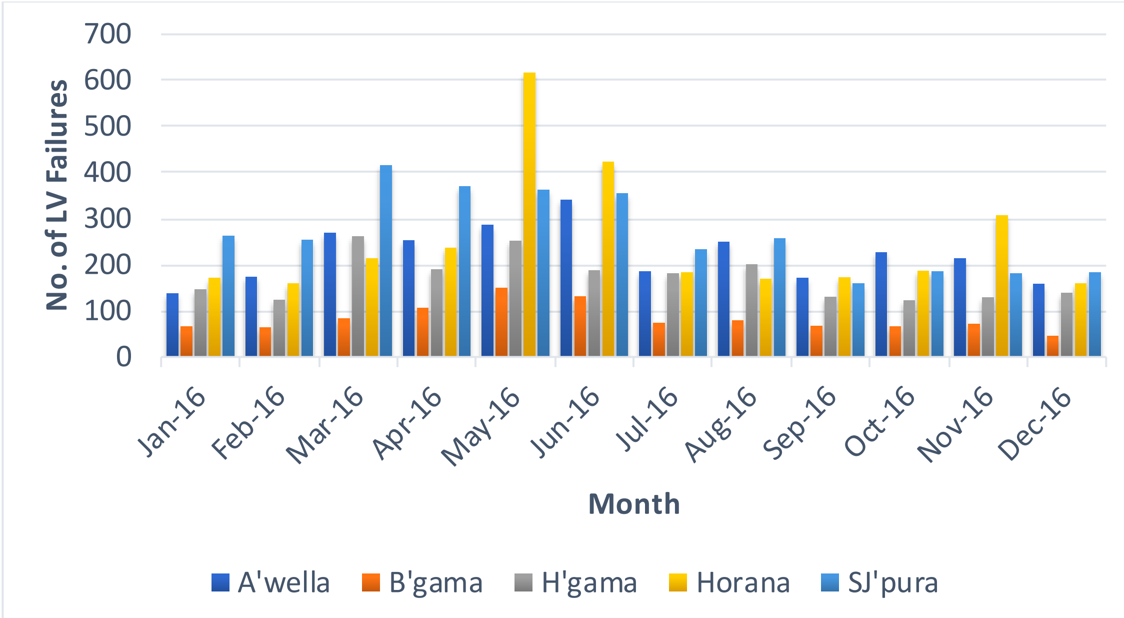

Figure 14 : Area wise LV Failures during year 2016

Area wise LV failures during year 2016 highlight that the highest number of failures occur in Horana area during May 2016. Also, frequency of the highest number of failures during the year occur in Sri Jayawardhanapura area.

4.3 SM Failures

Table 10 : Number of SM failures area wise

	Avissawella	Bandaragama	Homagama	Horana	Sri J'pura	Total
Jan-16	594	383	723	497	951	3148
Feb-16	555	352	658	427	1401	3393
Mar-16	699	398	774	539	1100	3510
Apr-16	1011	425	1048	700	1422	4606
May-16	1748	742	1532	1445	2287	7754
Jun-16	1046	571	1139	911	1603	5270
Jul-16	718	419	896	586	1203	3822
Aug-16	605	393	801	514	1062	3375
Sep-16	582	341	736	484	1003	3146
Oct-16	638	436	855	519	1193	3641
Nov-16	1000	464	1042	771	1610	4887
Dec-16	571	379	776	480	994	3200

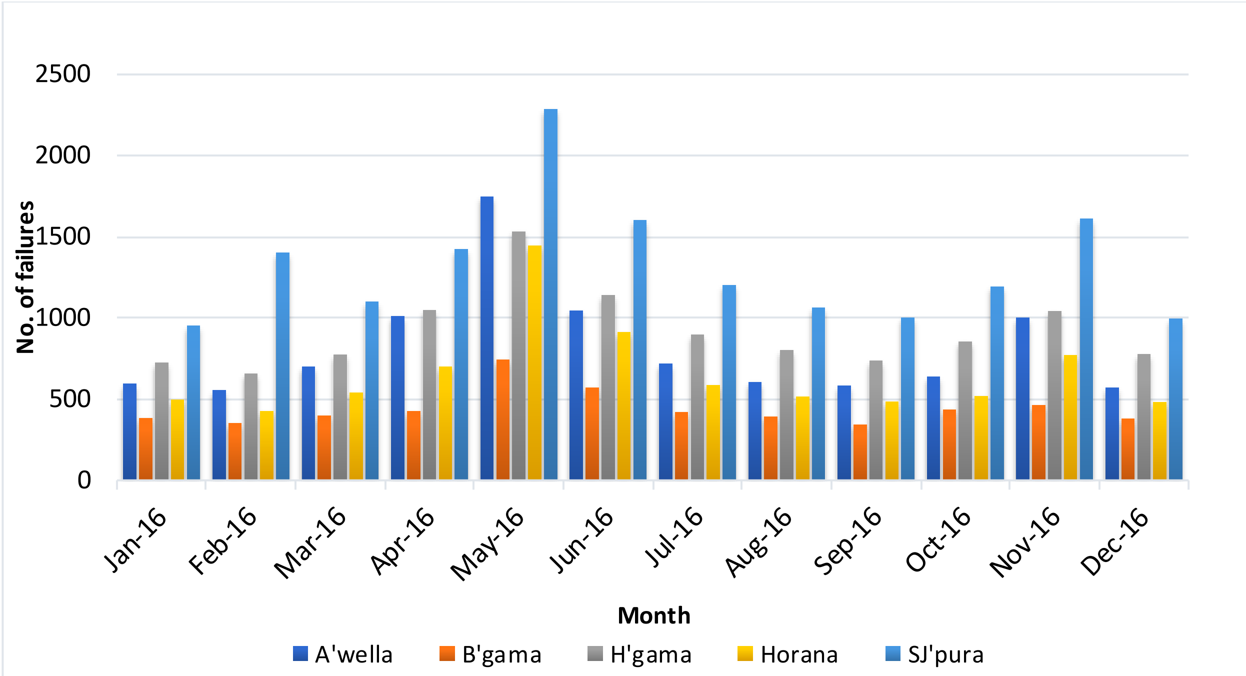

Figure 15 : Area wise SM during year 2016

Area wise SM during year 2016 highlights that SM failures are maximum in Sri Jayawardhanapura all over the year and it is highest in May 2016.

Table 11 : Total number of failures area wise

	Avissawella	Bandaragama	Homagama	Horana	Sri J'pura	Total
Jan-16	968	586	1197	980	1728	5459
Feb-16	1025	541	1040	839	2476	5921
Mar-16	1319	599	1362	1044	2268	6592
Apr-16	1816	683	1636	1362	2511	8008
May-16	2897	1163	2443	2679	3766	12948
Jun-16	2011	867	1806	1853	2761	9298
Jul-16	1227	603	1407	1085	1866	6188
Aug-16	1168	605	1376	982	1812	5943
Sep-16	964	477	1101	870	1541	4953
Oct-16	1195	621	1297	966	1858	5937
Nov-16	1560	640	1500	1481	2288	7469
Dec-16	958	526	1198	851	1597	5130

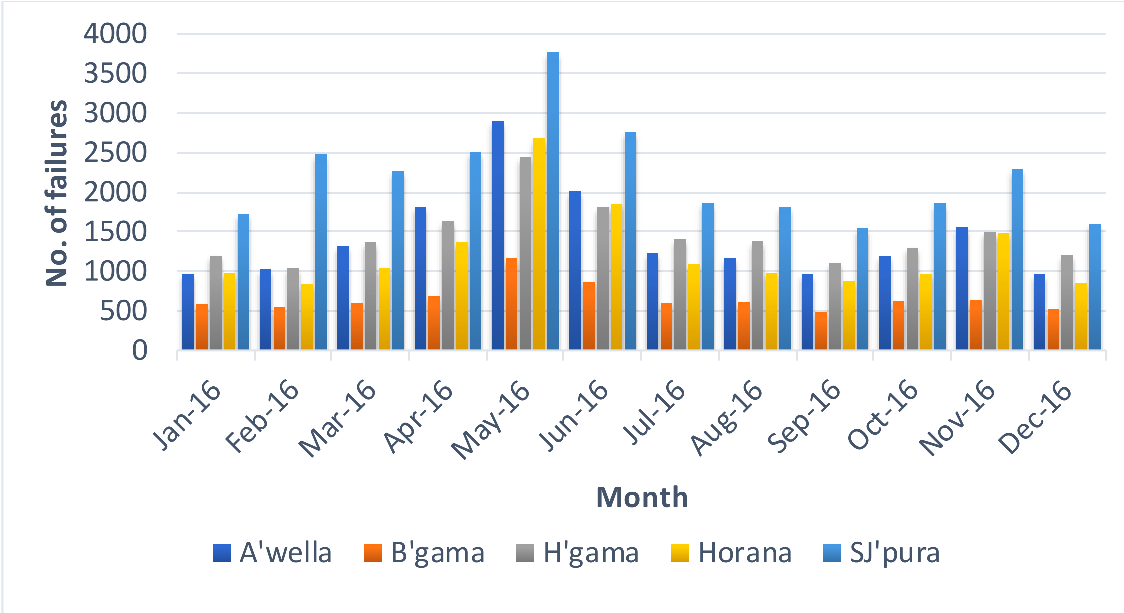

Figure 16 : Area wise total number of failures 2016

Area wise total number of failures shows that Sri Jayawardhanapura area has the highest number of failures during the year.

Table 12 : SAIDI (min)

Month	Area					WPS II
	Avissawella	Bandaragama	Homagama	Horana	SJ'pura	
Jan	358.65	711.47	498.81	743.44	399.87	524.05
Feb	236.10	271.50	172.92	375.33	613.43	350.30
Mar	1,213.59	762.01	677.25	1,457.68	1,075.66	1,051.01
Apr	750.94	617.68	206.77	630.44	298.34	480.91
May	838.49	623.58	337.76	928.51	453.44	637.12
Jun	1,672.20	308.55	462.92	451.07	294.39	657.33
Jul	438.25	472.08	529.24	391.50	398.01	446.83
Aug	524.25	361.75	154.55	318.81	292.25	324.18
Sep	282.74	1,018.16	265.62	1,271.40	419.23	596.58
Oct	369.16	577.51	345.96	270.84	363.97	371.29
Nov	271.17	297.93	256.46	489.18	414.62	352.47
Dec	236.18	223.14	307.39	250.26	222.79	252.00

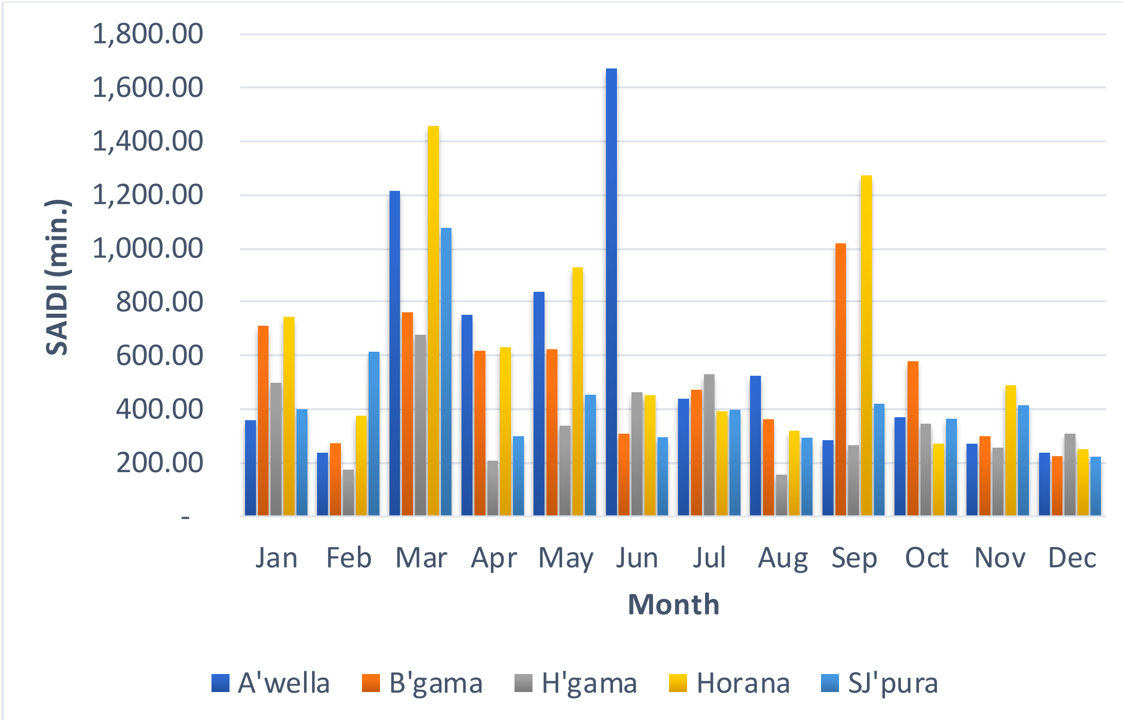

Figure 17 : Area wise SAIDI for year 2016

Highest value of SAIDI is found in Avissawella. It is high in Horana and Sri Jayawardhanapura.

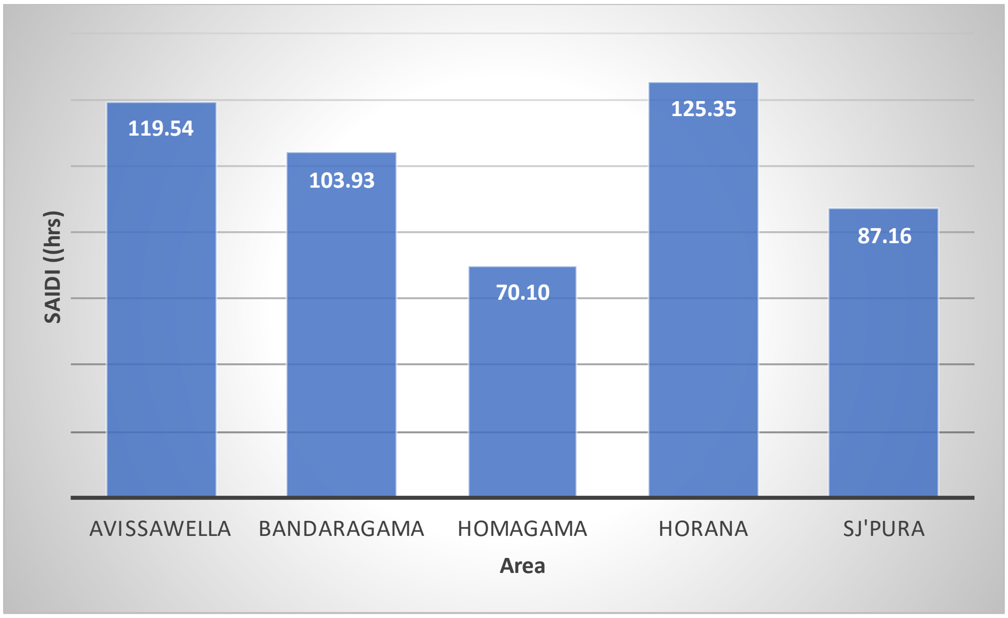

Figure 18 : Annual SAIDI

Table 13 : SAIFI for year 2016

Month	Area					WPS II
	Avissawella	Bandaragama	Homagama	Horana	SJ'pura	
Jan	1.43	2.50	2.11	3.21	2.70	2.39
Feb	1.57	2.03	1.06	2.47	2.49	1.92
Mar	7.47	3.13	3.95	7.18	7.22	6.01
Apr	5.18	3.30	1.60	2.81	2.34	2.98
May	4.87	3.62	2.20	6.88	2.96	4.04
Jun	4.97	1.02	1.51	2.96	1.39	2.43
Jul	2.87	2.33	1.80	1.22	2.46	2.15
Aug	2.11	1.73	1.26	1.52	1.21	1.54
Sep	1.07	2.95	1.43	2.94	1.77	1.93
Oct	5.18	4.48	3.11	3.33	3.37	3.82
Nov	1.77	2.18	1.51	3.51	2.11	2.19
Dec	0.69	3.25	1.56	2.75	1.22	1.76

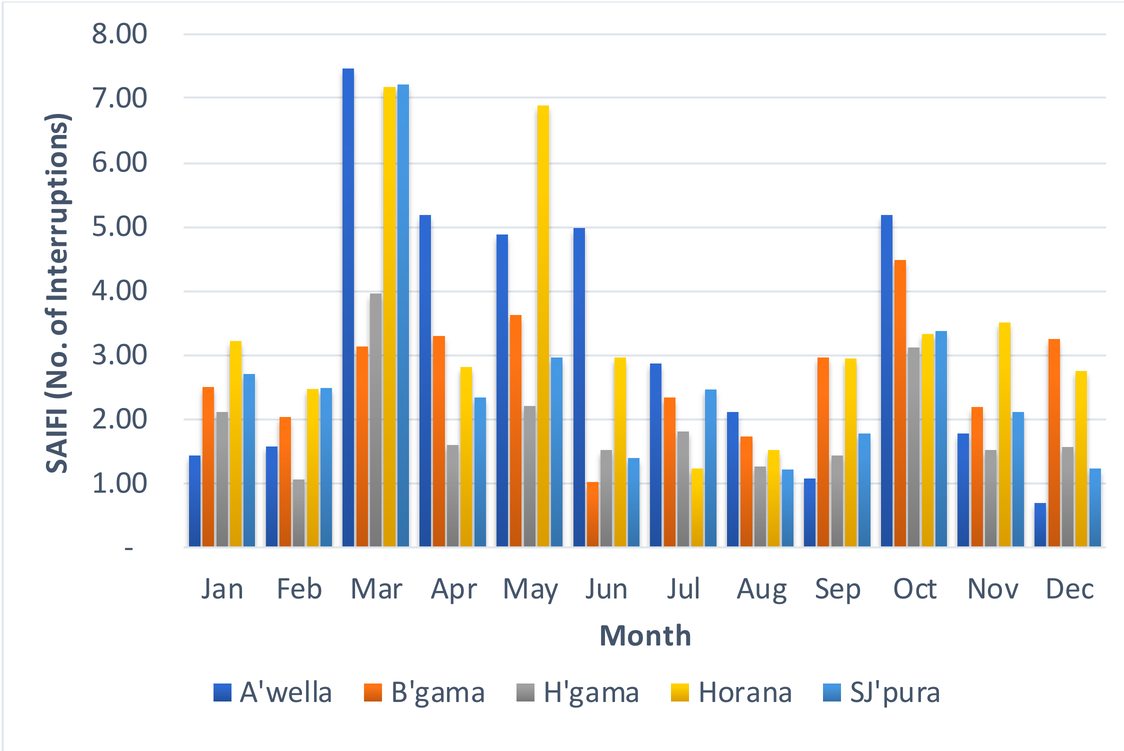

Figure 19 : Area wise SAIFI for year 2016

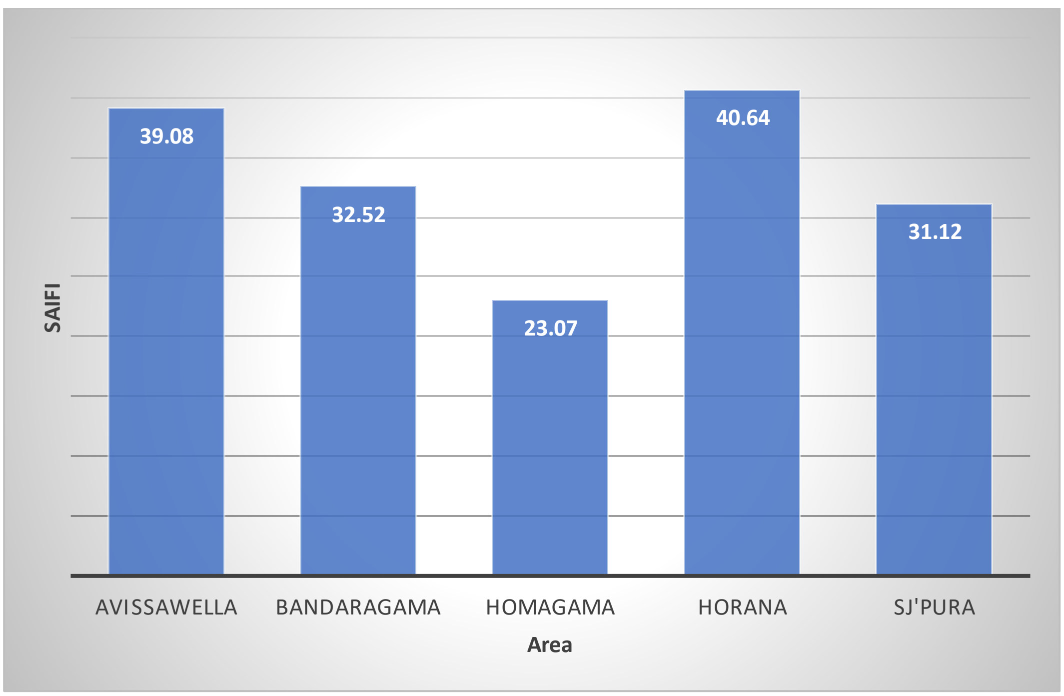

Figure 20 : Annual SAIFI

Horana area has the highest SAIFI, 40.64 interruptions per customer.

Since both SAIDI and SAIFI are high in Horana area, it was selected for further study.

Table 14 : SAIDI Horana area

Months	Failure/switching Type							
	MV Failure	LV Failure	MV Switching	LV Switching	Planned Interruption	Grid Tripping Manual	Grid Tripping Auto	Service Maintenance
Jan	307.25	42.92	30.44	56.76	156.53	132.87	16.67	1.98
Feb	73.42	25.96	-	26.42	96.74	147.15	5.65	1.63
Mar	111.55	45.90	31.24	23.69	348.25	872.92	24.14	2.49
Apr	277.00	64.90	52.12	10.31	119.67	82.71	23.73	3.85
May	252.52	261.45	12.10	1.08	26.97	187.58	186.81	13.59
Jun	134.97	109.93	35.97	10.05	124.36	34.37	1.42	6.19
Jul	179.20	35.20	35.27	24.81	114.91	1.21	0.90	2.28
Aug	130.45	23.79	5.92	41.74	101.51	15.40	-	1.66
Sep	47.58	20.89	9.16	27.59	304.23	3.63	858.32	1.29
Oct	37.42	22.23	5.72	12.41	111.68	5.41	75.97	1.48
Nov	224.39	72.23	4.90	22.53	90.55	49.31	25.26	3.47
Dec	39.77	18.61	17.61	30.42	107.01	1.31	1.30	1.32

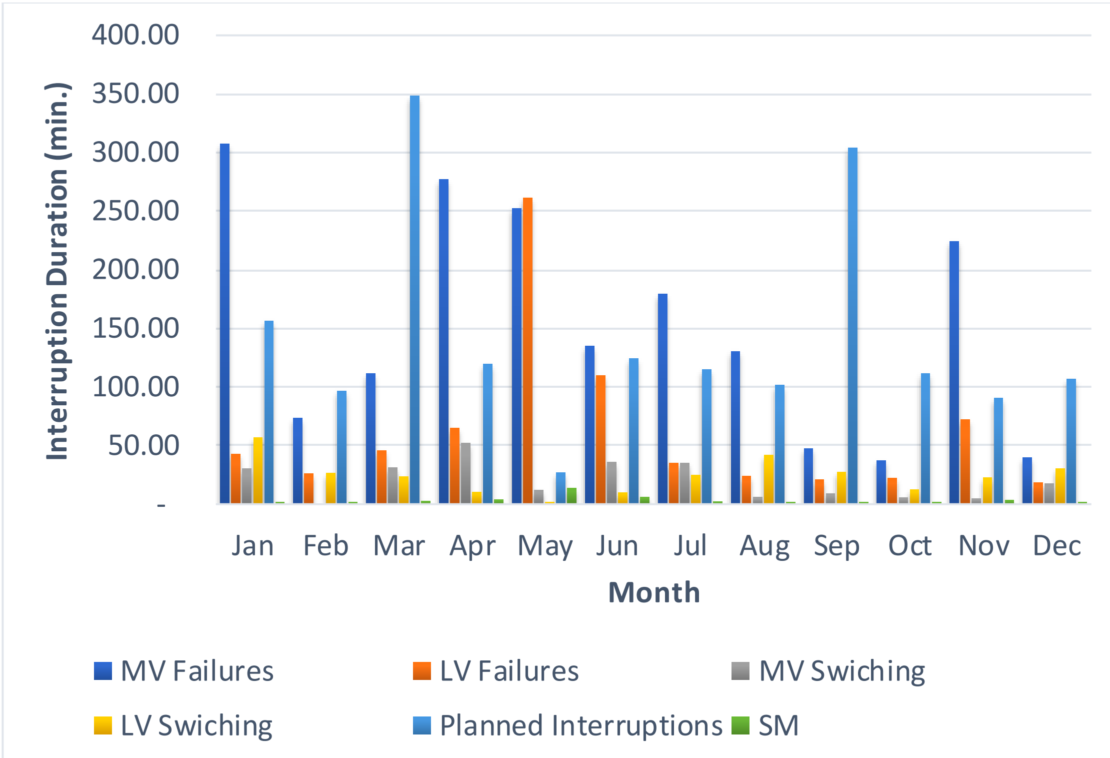

Figure 21 : Variation of SAIDI during 2016 – Horana area failure type wise

SAIDI values are high due to planned interruptions and MV failures. Both of these interruptions influence the MV lines.

Table 15 : SAIFI Horana area

Months	Failure/switching Type							
	MV Failure	LV Failure	MV Switching	LV Switching	Planned Interruption	Grid Tripping Manual	Grid Tripping Auto	Service Maintenance
Jan	0.51	0.14	0.10	0.16	0.31	1.50	0.48	0.01
Feb	0.41	0.12	0.00	0.08	0.20	1.18	0.49	0.01
Mar	0.76	0.16	0.24	0.07	0.64	4.52	0.78	0.01
Apr	0.59	0.19	0.27	0.03	0.22	0.35	1.17	0.01
May	0.88	0.36	0.03	0.02	0.05	1.47	4.07	0.02
Jun	0.65	0.27	0.11	0.03	0.25	1.65	0.00	0.01
Jul	0.52	0.14	0.14	0.06	0.21	0.16	0.01	0.01
Aug	0.87	0.12	0.03	0.10	0.20	0.20	0.00	0.01
Sep	0.36	0.12	0.06	0.09	0.58	0.15	1.57	0.01
Oct	0.27	0.15	0.01	0.03	0.22	0.57	2.07	0.01
Nov	0.62	0.17	0.07	0.07	0.19	2.11	0.29	0.01
Dec	0.51	0.10	0.15	0.08	0.22	0.14	0.04	0.01

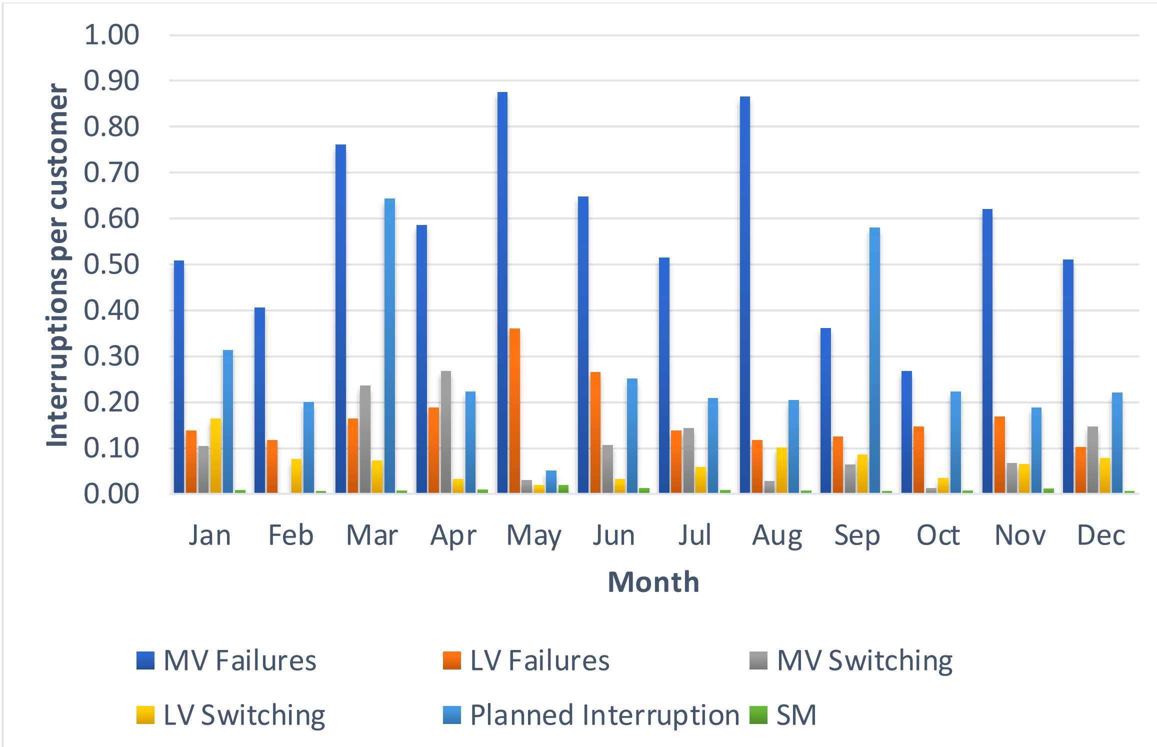

Figure 22 : Variation of SAIFI during 2016 –Horana area failure type wise

SAIFI values are high due to planned interruptions and MV failures. Both of these interruptions influence the MV lines.

Therefore, we understand that both planned interruptions and MV failures significantly influence the reliability.

CHAPTER 5

CALCULATION

5.1 Definition of Reliability

Reliability of a power system can be defined as the probability of functioning the system at any given time. Reliability is a concept. In order to apply this concept to a power system and for the purpose of understanding we can size up or level or index it. We can use indices like SAIDI and SAIFI to judge the level of reliability of a power system.

5.2 Reliability Indicators by electric power utilities.

SAIDI – System Average Interruption Duration Index

SAIDI is the average outage time for customers over a reported period.

- $SAIDI = \frac{\Sigma\, Customer\ Outage\ Duratons}{\Sigma\ \text{Customer Served}}$
- $SAIDI = \frac{\Sigma r_i N_i}{N_T}$
- r_i – Outage time for location i
- N_i – Number of customers for location i
- N_T – Total number of customers served

SAIFI – System Average Interruption Frequency Index

SAIFI is the average number of interruptions that a customer would experience.

- $SAIFI = \frac{\Sigma\, Customer\ Interruptions}{\Sigma\ \text{Customer Served}}$
- $SAIFI = \frac{\Sigma \lambda_i N_i}{N_T}$
- λ_i – Failure Rate
- N_i – Number of customers for location i
- N_T – Total number of customers served

For the purpose of minimizing the number of interruptions in an interruption program for maintenance work, Work can be categorized as,

- **Parallel work**

Two or many separate works that can be performed by separate work groups at one place during same time slot.

- **Combined work**

Two or many separate works that can be performed as a single job.

- **Individual work**

Any work that has to be performed as a single job.

5.3 Sample Analysis

- Planned interruption schedules of Malabe, Homagama, and Bulathsinghala Consumer Service Centers were considered as examples for further studies.

5.3.1 Case Study (1) – Malabe CSC

Table - 16 planned interruption schedule of Malabe CSC for January 2016 is prepared using the data given in interruption schedule for the month of January 2016 – Sr Jayawardhanapura area in Appendix A.

Table 16 : Planned interruption schedule of Malabe CSC for January 2016

Item No.	Date	Purpose and requested by	Feeder No.	Off Time	On Time	Interrupted Time/(min)	Interrupted Time/ (min)	Affected Substations D	B	D+B	Total No of Customers Affected	Interrupted Time(min)X total No of Customers affected
1	1/4/2016	Construction work(Const.)	Athu.F6	8:00	17:00	9:00	540	5	1		1711	923940
2	1/5/2016	Construction work(Const.)	Athu.F1	8:00	17:00	9:00	540	3			1026	554040
3	1/5/2016	Construction work(Const.)	Athu.F2	8:00	17:30	9:30	570	5	4		1714	976980
4	1/7/2016	Construction work(Const.)	Athu.F6	8:00	17:00	9:00	540		1		1	540
5	1/9/2016	Maintenance work(DM)	Athu.F6	8:45	18:05	9:20	560	1			342	191520
6	1/11/2016	Construction work(Const.)	Athu.F4	8:00	17:00	9:00	540	1	2		344	185760
7	1/12/2016	Construction work(Const.)	Athu.F6	8:40	16:40	8:00	480	5	1		1711	821280
8	1/18/2016	Pole shifting(DM)	Athu.F6	8:45	17:20	8:35	515	2	1		685	352775
9	1/19/2016	Construction work(Const.)	Athu.F6	9:05	18:10	9:05	545	5	1		1711	932495
10	1/28/2016	Construction work(Const.)	Athu.F6	8:30	17:35	9:05	545	5	1		1711	932495
											10956	5871825

Total No. of customers in Malabe consumer service center=40,082 no's

Total outage duration for the month of January 2016 = 5871825 min

Total no. of customers effected = 10956

Therefore,

1) System average interruption duration index, SAIDI=$\frac{5871825}{40082}$ = 146.49 min

2) System average interruption frequency index, SAIFI = $\frac{10956}{40082}$ = 0.27 no;s

If jobs 1, 7, 9 and 10(similar jobs) were done in one day(9 hrs), then,

Total outage duration for the month of January 2016 = 3185555min

Then,

3) System average interruption duration index, SAIDI =$\frac{3185555}{40082}$ = 79.47 min

4)System average interruption frequency index, SAIFI = $\frac{5823}{40082}$ = 0.15no's

(1)-(3) Difference of SAIDI indices = 146.49-79.47

Improvement of SAIDI = 67.02min

(2)-(4) Difference of SAIFI indices =0.27-0.15

Improvement of SAIFI =0.12no's

There is a clear improvement of SAIDI by 67.02 min and SAIFI by 0.12 interruptions. This result shows that the reliability can be improved by planning to reduce no. of interruptions.

5.3.2 Case Study (2) – Homagama CSC

Table - 17 planned interruption schedule of Homagama CSC for January 2016 is prepared using the data given in interruption schedule for the month of January 2016 – Homagama area in Appendix B.

Table 17: Planned interruption schedule of Homagama CSC for January,2016

Item No.	Date	Purpose and requested by	Feeder No.	Off Time	On Time	Interrupted Time/(min)	Interrupted Time/ (min)	Affected Substations			Total No of Customers Affected	Interrupted Time(min)X total No of Customers affected
								D	B	D+B		
1	1/5/2016	Construction work-1(Const.)	Panni.F4	8:00	18:04	10:04	604	4	2		1638	989352
2	1/13/2016	Construction work-1(Const.)	Panni.F4	8:00	17:00	9:00	540	4	2		1638	884520
3	1/26/2016	Construction work-2(Const.)	Panni.F4	8:00	17:00	9:00	540	1			409	220860
4	1/26/2016	Construction work-3(Const.)	Panni.F4	8:00	17:00	9:00	540		3		3	1620
5	1/29/2016	Maintenance (Area)		8:10	18:00	9:50	590	4			1636	965240
											5324	3061592

Total No. of customers in Homagama consumer service center= 40,810 no's

Total outage duration for the month of January 2016 = 3061592 min

Total no. of customers effected = 5324

Therefore,

1) System average interruption duration index, SAIDI= $\frac{3061592}{40810}$ = 75.02 min
2) System average interruption frequency index, SAIFI = $\frac{5324}{40810}$ = 0.13

If jobs 1 and 2(similar jobs) were done in one day(9 hrs) then,

Total outage duration for the month of January 2016 = 2072240 min

Then,

3) System average interruption duration index, SAIDI $= \frac{2072240}{40810} = 50.77$ min

4) System average interruption frequency index, SAIFI $= \frac{3686}{40810} = 0.09$

(1)-(3) Difference of SAIDI indices = 75.02-50.77

Improvement of SAIDI = 24.25 min

(2)-(4) Difference of SAIFI indices =0.13-.09

Improvement of SAIFI =0.04 no's

There is a clear improvement of SAIDI by 24.25 min and SAIFI by 0.04 interruptions. This result shows that the reliability can be improved by planning to reduce no. of interruptions.

5.3.3 Case Study (3) – Bulathsinghala CSC

Table - 18 planned interruption schedule of Bulathsinghala CSC for February 2016 is prepared using the data given in interruption schedule for the month of February 2016 – Horana area in Appendix C.

Table 18 : Planned interruption schedule of Bulathsinghala CSC for February,2016

Item No.	Date	Purpose and requested by	Feeder No.	Off Time	On Time	Interrupted Time/(min)	Interrupted Time/ (min)	Affected Substations			Total No of Customers Affected	Interrupted Time(min) X total No of Customers affected
								D	B	D+B		
1	2/3/2016	Preventive Maintenance-1(DM)	Horana F6	9:00	17:25	8:25	505	11	1		3180	1605900
2	2/5/2016	Preventive Maintenance-2(DM)	Horana F6	8:30	17:30	9:00	540	4	1		1157	624780
3	2/6/2016	Tower construction (P&HM)	Horana F6	8:20	17:28	9:08	548	1			289	158372
4	2/12/2016	Preventive Maintenance-2(DM)	Horana F6	8:35	17:45	9:10	550	4	1		1157	636350
											5783	3025402

Total No. of customers in Bulathsinghala consumer service center=14,458 no's

Total outage duration for the month of January 2016 = 3025402 min

Total no. of customers effected = 5783

Therefore,

1) System average interruption duration index, SAIDI= $\frac{3025402}{14458}$ = 209.25 min

2) System average interruption frequency index, SAIFI = $\frac{5783}{14458}$ = 0.40

If jobs 2 and 4(similar jobs) were done in one day(9 hrs) then,

Total outage duration for the month of February 2016 = 2389052 min

Then,

3) System average interruption duration index, SAIDI $= \frac{2389052}{14458} = 165.24$

4) System average interruption frequency index, SAIFI $= \frac{4626}{14458} = 0.32$

(1)-(3) Difference of SAIDI indices = 209.25-165.24

Improvement of SAIDI = 44.01 min

(2)-(4) Difference of SAIFI indices =0.40-0.32

Improvement of SAIFI =0.08 no's

There is a clear improvement of SAIDI by 44.01 min and SAIFI by 0.08 interruptions. This result shows that the reliability can be improved by planning to reduce no. of interruptions.

The results of case studies 1, 2 and 3 proves that SAIDI and SAIFI can be improved by reducing the number of interruptions by combined maintenance job.

5.4 Generalization

Consider the interruption schedule of Bandaragama area for January 2016 given in Appendix D.

Bandaragama area is fed by feeder1, feeder3 and feeder 6 of Panadura grid substation. The value of SAIDI and SAIFI for those feeders shown in table19 have been calculate the using the data given in Appendix D.

Table 19 : Schedule of interruptions with adjustments - Bandaragama

Area	Feeder	No. of interruptions per month planned	No. of interruptions Per month adjusted (t_i)	No. of customers	Interruption Duration(Hrs) (d_i)	Feeder wise		Improvement (%)
						SAIDI	SAIFI	
B'gama	Panadura F1	3	-	n1	9	27	3	
	Panadura F1	-	2	n1	9	18	2	33%
	Panadura F3	3	-	n2	9	27	3	
	Panadura F3	-	2	n2	9	18	2	33%
	Panadura F6	2	-	n3	9	18	2	
	Panadura F6	-	1	n3	9	9	1	50%

SAIDI and SAIFI for Kosgama feeder 1 also have been calculated using data given in Appendix E and results have been tabulated in table 20 given below.

Table 20 : Schedule of interruptions with adjustments - Avissawella

Area	Feeder	No. of interruptions per month	No. of interruptions Per month adjusted (t_i)	No. of customers	Interruption Duration(Hrs) (d_i)	Feeder wise		Improvement (%)
						SAIDI	SAIFI	
A'wella	Kosgama F1	9	-	n4	9	81	9	
	Kosgama F1	-	5	n4	9	40	5	44%

Similarly, we can calculate SAIDI and SAIFI for an area by the relations

SAIDI for area $= \frac{\sum_{i=1}^{n} d_i n_i}{\sum_{i=1}^{n} n_i}$

SAIFI for area $= \frac{\sum_{i=1}^{n} t_i n_i}{\sum_{i=1}^{n} n_i}$

Where d_i – Interruption duration for feeder i

t_i – Failure rate for feeder i

n_i – Number of customers in feeder i

Obviously, we can improve the reliability by reducing d_i and t_i through proper interruption planning.

CHAPTER 6

INTERRUPTION INTIMATION SHEET

An interruption requesting form (Interruption Intimation Sheet) in the given format must be used by each branch for requesting interruptions. The interruption intimation sheet must carry the details of Grid Substations, Interrupted areas, branches involved and date of interruption. This interruption intimation sheet is mainly based on the maintenance requirements of the grid substation.

6.1 Format of the interruption intimation sheet

Refer Appendix F for the format of the interruption intimation sheet.

6.2 Procedure for preparing interruption plan.

- Transmission (O & M) branch should prepare a maintenance plan for 3 months period and forward it to provincial planning branch of WPS II.
- Provincial planning branch must prepare the interruption schedule for feeder maintenance on the interruption intimation sheet and indicate the date of interruption and the number of the interrupting feeder based on the maintenance plan of Transmission(O&M) branch. This is called original schedule or plan.
- Original schedule should be distributed to other branches for them to indicate their interruption requirements on the same sheet feeder-wise and return it to planning branch.
- After collecting intimation sheets from all branches planning branch should analyze the schedules and check for parallel and combine jobs.
- If parallel and combine jobs are found then prepare the final interruption plan with adjustments to parallel and combine jobs.
- Distribute the approved final interruption plan to each branch for them to plan their work.

Refer Appendix G for completed final approved interruption plan.

CHAPTER 7

CONCLUSION AND RECOMMENDATION

7.1 CONCLUSION

Power system can fail naturally. These natural failures occur unexpectedly. Therefore, natural failures cannot be totally avoided. But some of the failures like breaking of poles, conductors or insulators, MV breakdowns and LV breakdowns can be avoided or minimized if the network and the equipment were properly maintained.

In addition to power interruptions due to natural causes the power systems are purposely interrupted for maintenance and operation purposes. Interruptions arranged for maintenance and operation activities can be controlled and minimized by planning maintenance and operation activities.

To improve the reliability of the power system the frequency of the interruptions and duration of the interruptions have to be minimized.

The frequency of interruptions and the duration of interruptions can be minimized by arranging some maintenance and operation activities to be performed in parallel or in combination.

The results of SAIDI and SAIFI calculations in three case studies have proved that SAIDI and SAIFI was improved by performing maintenance and operation activities in parallel and combined form.

Hence the reliability of the power system can be improved by proper planning of maintenance and operation activities of the power system.

7.2RECOMMENDATION

Recommended Interruption Planning Process for Maintenance and Operational work.

- **Responsibilities of the interruption requesting branches**
  - Branches should use only the proposed interruption intimation sheet for arranging interruptions.
  - Use a segment numbering system for interruption requests.

Responsibilities of the Provincial Planning Branch

- Updating single line diagram according to segment changes.
- Updating proposed interruption intimation sheet accordingly.
- Collect the Maintenance and Operational activities plan in advance to expected interruption date keeping sufficient time interval, between collecting date and expected date (lead time).
- Discuss the interruption programs of all branches at a common meeting, and if possible, arrange several jobs of same unit or different units to do in one common day to reduce the number of interruptions.
- In such cases, if the available labour force is insufficient additional labour should be hired from other units.
- Date and time have to be finalized after collecting and analyzing interruption intimation sheets from all branches.
- As way leave clearing is done by contractors, it is possible to do way leave clearing in parallel with some other maintenance work done on that line so that interruptions arranged only for way leave clearing is cut down.

- Some areas are fed with one feeder. Therefore, reliability is very low. In such cases alternative feeders should be arranged for these areas to improve the reliability.

- Maintenance and operation staff should be well educated and trained on the job to improve the workmanship.