



Your ref:

My ref:

DGM(CS&RA)/GEN/4-6

Date: April 11<sup>th</sup>, 2025

Director General,  
Public Utilities Commission of Sri Lanka  
6<sup>th</sup> Floor, BOC Merchant Tower  
No.28, St, Michael's Road  
Colombo 3.



Dear Sir,

**Total System Failure occurred on 09<sup>th</sup> February 2025**

In reference to PUCSL letter No. PUC/LI/C2025/CEB/06 dated 2025-02-10 on the above subject, detailed report on the above-mentioned power failure is attached for your reference please.

This is submitted to the Commission in fulfilling the Conditions 3(1) and 30(10) of Electricity Transmission & Bulk Supply License No. EL/T/25-02.

Yours faithfully,

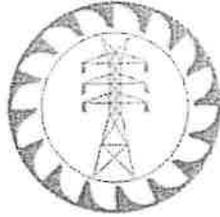
**CEYLON ELECTRICITY BOARD**

  
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Actg. General Manager  
Ceylon Electricity Board

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REPORT OF THE COMMITTEE TO INVESTIGATE  
THE TOTAL POWER SYSTEM FAILURE  
OCCURRED ON 09-02-2025 AT 11:14 HRS

April 2025  
Ceylon Electricity Board

## LIST OF ABBREVIATIONS

AGM	Additional General Manager
ANSI	American National Standards Institute
BESS	Battery Energy Storage System
CB	Circuit Breaker
CEB	Ceylon Electricity Board
CT	Current Transformer
DC	Direct Current
DFR	Disturbance Fault Recorder
DGM	Deputy General Manager
DT	Definite Time
FCB	Fast Cut Back
GCB	Generator Circuit Breaker
GS	Grid Substation
GWh	gigawatt-hour
IDMT	Inverse Definite Minimum Time
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IPP	Independent Power Producer
LECO	Lanka Electricity Company (Private) Limited
LP	Low Pressure
LVPP	Lak Vijaya Power Plant
NC	Normally Closed
NDEF	Non-Directional Earth Fault
NO	Normally Open
NSSC	National System Control Centre
OEM	Original Equipment Manufacturer
PRV	Pressure Relief Valve
PS	Power Station
PSM	Plug Setting Multiplier
pu	per unit
RMS	Root Mean Square
Rs or LKR	Sri Lankan Rupees
RTSPV	Roof Top Solar Photovoltaic
SCADA	Supervisory Control and Data Acquisition
SLD	Single Line Diagram
SS	Substation
TMS	Time Multiplier Setting
UFLS	Under Frequency Load Shedding
UPS	Uninterrupted Power Supply
VT	Voltage Transformer
WMS	Water Management Secretariat

## MEASURES AND WEIGHTS

°C	degree Celsius
A	ampere
GWh	gigawatt-hour
Hrs.	Hours
Hz	Hertz
kHz	kilohertz
km	kilometre
kV	kilovolt
kWh	kilowatt-hour
ms	millisecond
Mvar	megavar
MW	megawatt
V	Volt

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## EXECUTIVE SUMMARY

Sri Lankan Power system experienced a total power system failure at 11:14:01.826 on 09th February 2025 while the system was generating about 739 MW and 141 MVar (lagging) according to the data available at 11.13 hrs at the National System Control Center (NSCC). A double line to earth fault occurred at the 33 kV bus of the Panadura GSS and this led to trip the circuit breakers of 33 kV bus section and 132 kV/33 kV transformer 01. It was a sunny Sunday in which the system demand was low due to close down of many industrial loads and major commercial loads. The General Manager, CEB by his letter no. CEB/GM/CL4/06 and dated February 13, 2025 (Annex 1) appointed a committee to study the technical aspects of the total system failure and to recommend actions to be taken to avoid such failures in future. The committee has investigated many aspects related to the system failure and identified the root cause of it. This report presents the relevant information related the failure, analysis and cause of the failure and actions to be taken by the CEB to avoid happening such failures in future.

### **Total System Failure on February 09, 2025**

The day was a Sunday and it was a good sunny day with clear sky in many parts of the country. The power system was operating in electrical and mechanical equilibrium just before the 33 kV bus bar fault at the Panadura Grid Substation at 11.13.39.476 hrs. on the said date. According to the available data at the NSCC, only a very few conventional generators as given in Table E1 was running in the system feeding total of 739 MW to the system. Since the day was a Sunny day, a large amount of generation was feeding to the loads from Inverter Based Solar PV (IBSPVS) systems, especially Rooftop Solar. Out of 739 MW, 126 MW (17%) was dispatched from major hydropower plants, 60 MW (8.1%) from Manar wind, 472 MW (63.8) from three Units of Lakvijaya coal power plant and the balance from small hydropower plants.

According to the DFR record at the Kesbewa Grid Substation (GSS), a double line (R and Y phase) to ground fault occurred at 11.13.39.476 ms on the said date at 33 kV busbar of Pandura GSS as shown in Figure E1 due to contact of a Monkey. The fault was cleared partially with the operation of overcurrent protection of 33 kV Bus Section after 484 ms from fault initiation. It was noted that the 33 kV bus voltage has dropped to 60% of the normal voltage during the fault and recovered to 80% after the operation of overcurrent protection. With the opening of Bus Section breaker, the fault was feeding through Transformer 1 and it was cleared by the operation of overcurrent protection of 33 kV side breaker of transformer 1 after 1.034 sec from the fault initiation.

Table E1: Generation dispatch of power plant on the system at 11:13 hrs.

Generation Category	Active Power (MW)	Reactive Power (Mvar)
Laxapana Complex	66	12
Mahaweli Complex	50	09
Samanala Complex	10	-4
LVPS	472	58
Thermal Complex	0	0
IPP	0	0
Small Hydro (CEB)	2	0

Mini Hydro (IPP)	36	0
Wind	60	0
Biomass	10	0
Solar	33	0
Shunt Reactor Power (Capacitor Banks)	0	66
Total Load	<b>739</b>	<b>141</b>
Spinning Reserve	230	31.1% as a percentage total load
Frequency Control	Victoria Unit 02	

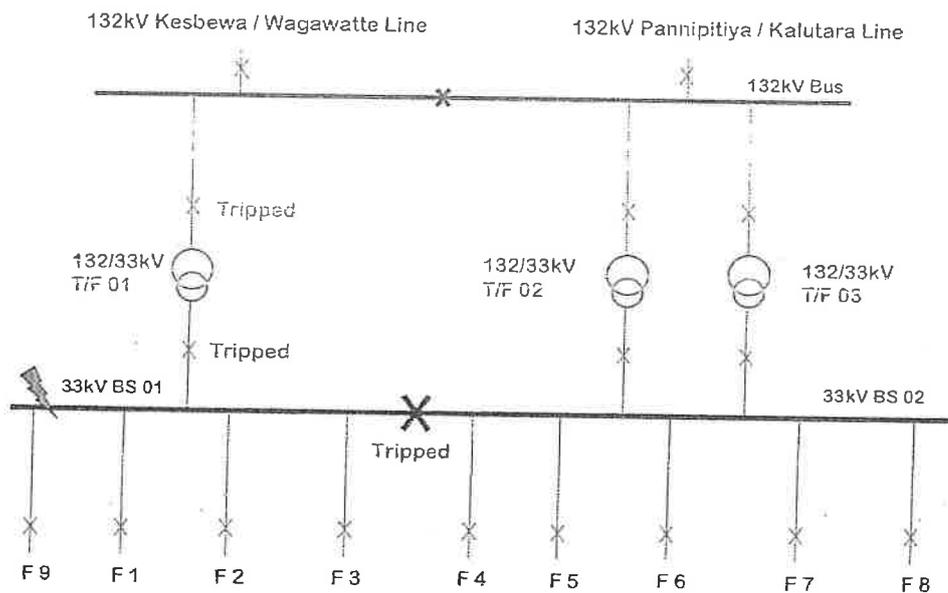


Figure E1: SLD of Panadura GSS with fault location and CB operations

### Sequence of Total System Failure

Figure E2 depicts Pannipitiya DFR record of 220 kV voltage and the system frequency at Pannipitiya GSS. As per the record in Figure E2, the system voltage was back to normal just after clearing the fault by operating the relevant circuit breakers. However, the system frequency was continuously dropping at rate of 0.11 Hz/sec till it reached to 49.5 Hz. The frequency falling rate was increased to about 0.18 Hz/sec just after the frequency was 49.5 Hz. The first stage of load shedding started at the frequency 48.75 Hz followed by stage II and III. It was noticed that frequency falling rate was increased worsening the situation on the system recovery. However, rate of change of frequency (ROCOF) has reduced to 0.12 Hz/sec from 0.47 Hz/sec with activation of four stages of load shedding scheme. It appeared that substantial amount of load has shed during this period. However, the shed load was not sufficient to bring the system frequency up. The load shedding stage 5 operated just after the frequency reached to 47.5 Hz. It was noticed that ROCOF has increased to 1.3 Hz/sec even with the activation of load shedding stage V. The sequence of conventional generator tripping was given in table E2.

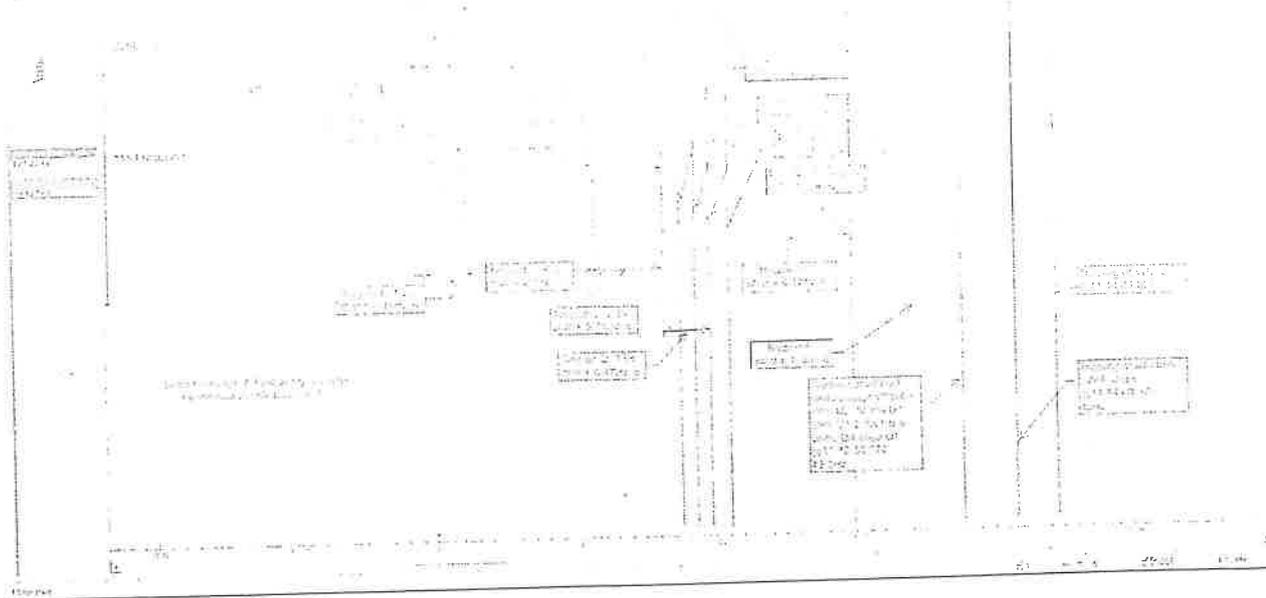


Figure E2- System frequency variation during the system failure on 09.02.2025

Source: Report submitted to AGM(Generation) by DGM(AMHE) on 25.02.2025

Table E2: Sequence of Conventional Generator Tripping

Equipment/Line	Failed Time	Indication/Reason
Panadura GSS - 33kV B/S CB	11:13:40.000	Over Current
Panadura GSS - 132/33kV T/F 01	11:13:40.580	Over Current
New Laxapana Power Station (NLPS) 1	11.13.58.404	Under Freq
Samanala Power Station (SPS) 1	11.13.58.422	Under Freq
Samanala Power Station (SPS) 2	11.13.58.422	Under Freq
Old Laxapana Power Station (OLPS) 1	11.13.58.-	Under Freq
Uma Oya 1	11.13.58.-	Under Freq
Old Laxapana Power Station (OLPS) 2	11.13.58.465	Under Freq
Victoria Power Station (VPS) 2	11.13.58.466	Under Freq
LVPP 1	11.14.00.375	Under Freq
LVPP 2	11.14.00.375	Under Freq
LVPP 3	11.14.00.375	Under Freq
Victoria Power Station (VPS) 3	11.14.01.866	Vol Res O/C

Source: Asset Management, Hydro Electrical, " Island Wide System Failure 09th February 2025"

It could be concluded that the double line to ground fault initiated at 33 kV busbar of Panadura GSS caused to drop 33 kV bus bar voltages of Panadura by 40%, Kesbewa by 32% and Kalutara by 34%. All these three GSS are in same 132 kV transmission line from Pannipitiya to Mathugama. This caused to take away certain amount of inverter-based generation from the system leading to draw more power from the running generators starting system frequency to fall. From the analysis of inverter settings of RTSPV systems, it was noticed that a certain portion of them were set to trip at 49.5 Hz and 94% of nominal voltage. Thus, continuous drop of the system frequency took place leading activation of four stages of UFLS. However, the shed load was not as expected due to integration of excessive embedded generations to UFLS feeders. It was noted that the UFLS scheme was not updated since 2014. It was noticed that

some feeders were back feeding and tripping of those feeders has aggravated the system condition bring to the stable operation. Due to the reasons stated above the total system failure was unable to stop.

## 1. CHAPTER 01-BACKGROUND

### 1.1. Background

A total system failure has occurred at 11.14.01.826 hrs. on 09th February 2025 while the system was generating about 739 MW and 141 MVAR (lagging) according to the data available at 11.13 hrs. The failure was initiated by an overcurrent fault at the 33 kV bus of the Panadura grid substation and this led to trip the circuit breakers of 33 kV bus section and 132 kV/33 kV transformer 01. The continuous system frequency drop has led to trip Victoria Power Station Unit 3 causing total system failure at 11.14.01.826 hrs. The day was sunny day and it was a Sunday during which the system load is very low with high penetration of solar energy to the system.

### 1.2. The Study Approaches

The committee met and decided to adopt following approach in order to investigate the total system failure incident, find causes of the failure and make recommendations to avoid such failures in future.

- Step 1: Collect all system information at the condition, pre-fault and during fault from the relevant branches.
- Step 2: Visit the location of the fault which triggered the system failure, National System Control Centre
- Step 3: Interview the relevant officers and staff in relevant branches
- Step 4: Collection & analysing RTSPV inverter behaviour from the randomly selected RTSPV data throughout the country
- Step 5: Analyse sequence of events that took place at the time of failure and carry out system simulation studies to support the analysis.
- Step 6: Identify causes of the system failure and make recommendations.
- Step 7: Analyze the generator behaviour of the connected major generator sources and transmission network loading behaviour during the fault.

## 2. CHAPTER 02- OVERVIEW OF SRI LANKAN POWER SYSTEM

### 2.1 Introduction

Sri Lankan power system transformed from a predominantly hydropower system to a mixed hydrothermal system over the last 3 decades. Until the mid-1990s, most of the power generation requirements were met with hydropower plants. With full exploitation of the economically viable large-scale hydropower potential in the country, the growing demand for electricity had to be met with the addition of more oil-based power plants since the 1990s. Coal-based power plants were introduced in 2011, further diversifying the energy mix of electricity generation, and reducing the dependency on oil-based power generation.

With the present technology developments and considering the low-cost power generation and the energy security of the country, Government of Sri Lanka declared a general policy guide line in November 2021 to obtain 70% of electricity generation from renewable energy resources by 2030. Since almost all the hydropower potential has been developed and connected to the grid, the Government target is to be achieved with the development of Variable Renewable Energy (VRE) such as Solar and wind. Both wind and solar resources, being variable renewable sources with inherent characteristics, introduce range of challenges to reliable and economic operation of power system. At present the power system of the country is moving to the stages where the integration challenges become much more significant requiring special operational, policy and investment-based interventions to ensure reliable operation of the power system.

The transmission network development commenced in 1950 with commissioning of the first major hydropower scheme, the Laxapana Power Station Hydro Electric Scheme Stage 1 (25 MW) in 1950. The grid was initially developed at 66 kV where some of the transmission lines were constructed at 132 kV and was initially operated at 66 kV. With the development of Mahaweli hydropower complex, the 220 kV transmission network was introduced and it has been now developed throughout the country as the transmission backbone network. The distribution network is predominantly 33 kV overhead and 11 kV underground distribution network has been operated in Colombo city and Kandy city area.

The transmission and distribution network were continuously upgraded and expanded to serve the entire country. The recorded peak demand in the year 2024 was 2673 MW and total electricity energy delivered to the consumers was 15,191GWh. The number of consumers in different tariff categories served through the national grid is about 7.3million. The per capita electricity consumption in the year 2023 was 642 kWh which is low value compared to the developing countries.

### 2.2 Present Power Generating System

The existing power generating system in the country mostly own and operated by the Government own utility, the Ceylon Electricity Board (CEB) with substantial capacity from the private developers. The investment for power generation by the private developers started in 1996 and major portion of renewable energy are now connected with the investment from the private parties.

The current total installed capacity of the national power grid as at 31st December 2024 is 6069 MW which consists of 64% renewable energy sources and 36% fossil fuels. Out of the fossil fuel portion, 15% comes coal and 21% is from thermal oils. Major Hydro is the main source of renewable energy in the capacity mix, which has a share of 25%. Other renewable energy sources such as wind, Solar (Ground Mounted & Solar rooftops), Mini hydro, Biomass and municipal solid waste are also used in power generation and have 39% share of the capacity mix. Table 2.1 depicts the present generating system as at 31st December 2024.

Table 2.1- installed capacity as at 31.12.2024

Plant Type	Installed Capacity (MW)
CEB Hydro	1,532
CEB Wind	103
CEB Thermal Oil	807
CEB Coal	900
IPP Thermal	482
Non-Conventional Renewable Energy (NCRE)	2,245
Total Generation Capacity	6,069

All the NCRE plants were embedded in the distribution network, and they are operating throughout the day based on the availability of the resources such as solar irradiance, wind etc. Hence these plants are non-dispatchable. Several generators would be operating at any given moment to meet the needs of customers and the reserve requirements. The following factors are considered when determining which generators should be operated.

**For large and medium hydroelectric generators;**

- Each power plant will be operated prioritizing the discharge of water for drinking and irrigation, based on a weekly schedule for water releases jointly agreed among the authorities on irrigation, agrarian services, water supply and electricity generation (CEB)
- Water availability, to avoid reservoir spilling during periods of heavy rainfall or when heavy rainfall is expected

**For oil-fired generators;**

- Minimization of the operating cost
- Minimization of the starting and stopping the generators

**For all major generators;**

- The criteria for all grid substations to maintain the standard voltage levels
- Accommodating any scheduled or unscheduled maintenance

**Renewable energy based embedded generators;**

- Small hydropower generators, wind power plants, solar parks, and rooftop solar units are constantly operated to effectively maximize their contribution to the generating

system while avoiding wastage of water, wind, or solar energy resources. All such power plants operate on must-run and must-take principles.

The general principle is that the generating system should be controlled in such a way that the cost of producing electricity is kept as low as possible. Economic dispatch planning is done over 12 months since rainfall is a primary driver of hydropower supply. The institutional responsibilities are as follows:

- The transmission licensee of CEB operates the transmission system and so bears overall responsibility for maintaining the safe, reliable, and cost-effective operation of the whole generating and transmission system.
- The generation licensee of CEB owns and operates all of its power plants.
- Regarding IPPs, the appropriate owner operates their power plant under dispatch instructions of CEB.
- In the case of small power producers (SPPs, using mini-hydro, wind, solar parks and biomass), the relevant owner operates their plant independently of CEB. However, such power plants can only function while the related medium voltage distribution line (33 kV) is operational.

### **2.3 Present Transmission Network**

The Transmission Network of Sri Lanka consisting of 998 km of 220kV transmission lines and 2,405 km of 132kV lines. There are 82 no. of Grid substations and 16 no. of switching stations in the network. The entire transmission network is own and operated by the CEB as per the prevailing electricity Act. Major generating plants are connected either to the 220 kV network or 132 kV network through power plant interconnections while almost all the NCRE plants are connected to the distribution network. The transmitted power from generating stations is received at Grid Substation at 132 kV voltage or 220 kV voltage in which power is stepped down to either 33 kV or 11 kV to feed consumers in the distribution system.

The National Dispatch Center of CEB is required to carry out the real time operation of entire power system which consists of all the connected generators, all the transmission lines and all the Grid Substations meeting real time supply demand balance within specified frequency and voltage. Figure 2.1 shows the geographical layout of the transmission network as at December 2024. The national grid which refers in this document consists of power interconnection, transmission lines at different voltage levels, distribution lines and customers.

### **2.4 Distribution System**

There are five distribution licensees in the country. they are Distribution Division 1, Distribution Division 2, Distribution Division 3, Distribution Division 4 and Lanka Electricity Company (LECO) Ltd.. Out of five distribution divisions, four distribution divisions are own and operated by the CEB. Table 2.2 depicts the CEB distribution and LECO network components.

Distribution components	CEB	LECO
33 kV lines/ km	44,413	-
11 kV lines/km	2,533	1,107
33 kV/11 kV Primary Substations/nos.	133	-
33 kV/LV or 11 kV/LV Distribution Substations/nos.	36,872	4,659
Low Voltage (LV) -0.4 kV lines/km	153,174	4,400

Electricity is provided at 33 kV (or 11 kV) to medium and large industrial and commercial customers while electricity is supplied to retail customers, including households, at 400 V (three-phase) or 230 V (single-phase) through low voltage distribution lines.

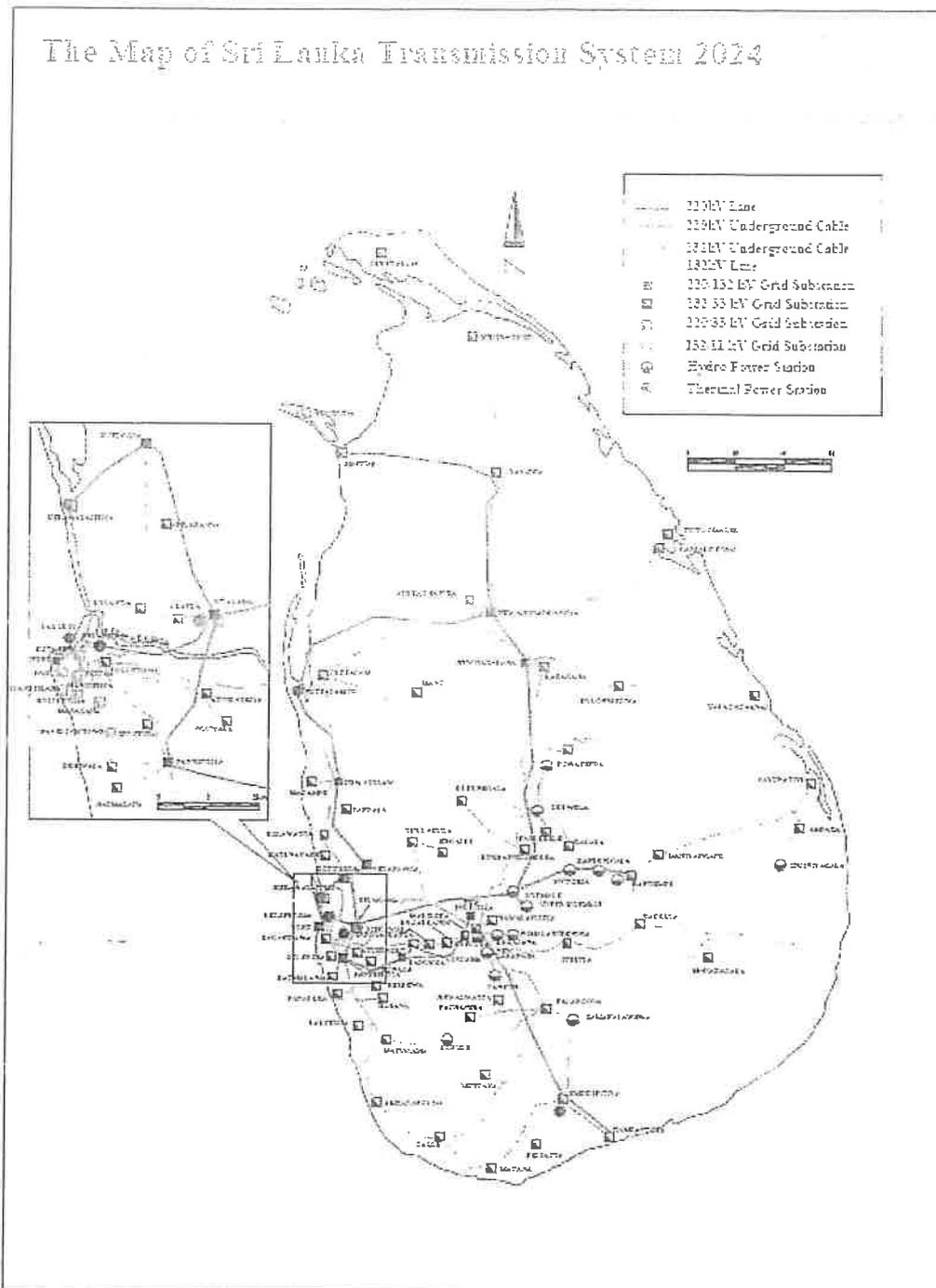


Figure 2.1- Geographical Layout of Sri Lanka Transmission Network

Note: All lines and substations shown in this map may not be operational at any given time and some of them may be taken for routine maintenance

Source: Long Term Transmission Development Plan 2023-2032.

## 2.5 Power System Security and Reliability

Power system reliability refers to the ability of the electrical grid to consistently and predictably deliver electricity to customers without interruptions or degradation. This encompasses adequacy, security, quality of supply and resilience.

Power system security, which refers to the capability of a power system using its existing resources to maintain reliable power supplies in the face of unexpected shocks and sudden disruptions in real time, such as the unanticipated loss of key generation or network components, or rapid changes in demand. Therefore, the power system security could be divided into two categories;

- a. Security against outages of generating unit
- b. Security against sudden change in customer demand

### **2.5.1 Security against Outages of Generation and Transmission Lines**

The world practice for power system operation is n-1 criteria which is defined as a power system can be described as being N-1 secure when it is capable of maintaining normal operations in the event of a single contingency event, such as the unplanned loss of a transmission line, generator or transformer. This criterion has been adopted by system operators around the world to inform operational contingency planning, to guide management of system operation, and to guide emergency efforts to return systems to a secure and stable operating condition within a reasonable time following a single contingency event, usually within 15 to 30 minutes. The same criteria have been adopted by the operation of Sri Lankan power system as well as long term planning of the power system. However, this is only applicable to transmission network. Due to the radial nature of the distribution network, it is unavoidable that a customer or group of customers will be without electricity when an outage occurs in 33 kV distribution network. Further, it is to be noted here that when the largest generating unit in the system (300 MW unit in Lakvijaya power plant) trips, the under-frequency load shedding will operate and group of customers in those under-frequency load shedding feeders will not have electricity. Therefore, Sri Lanka grid does not meet the n-1 reliability criterion in large generation since load shedding is required to overcome a sudden loss of a generator. However, the transmission network for the most part, meets the n-1 reliability criterion.

### **2.5.2 Security against Sudden Change in Customer Demand**

If there is an unexpected increase in customer demand, the generating system should be able to meet the demand without interrupting the service to that customer or any other customers. Such sudden increases may occur when an industry begins operations or when a distribution line is restored following an outage or malfunction. Thus, sufficient spare generating capacity must be already in operation to meet the demand at the same time it is required. This criterion is called 'spinning reserve' since extra capacity must be spinning/rotating rather than stationary.

The system operator CEB decides how much spinning reserve is available at any moment. Spinning reserve consumes water and fuel while the energy output is small or zero, and hence incurs a cost. The usual spinning reserve retained in power networks across the world is about 10% of customer demand. The CEB policy is to maintain a spinning reserve of greater than 5% of gross generation at all times. However, if the predicted time of the violation is short, CEB's system operators are given the option of not initiating extra generation only to fulfill the spinning reserve requirement. The latter option was made exclusively for economic reasons, to

avoid starting up more generations closer to severe demand peaks observed in the morning and evening, and merely to preserve the spinning reserve limitations.

Even though the world practice is to keep spinning reserve to the size of largest unit in the system, current practice in Sri Lanka does not meet this criterion instead the load shedding scheme will activate in an event of tripping of 300 MW unit in Lakvijaya power plant. At present, the day demand in Sri Lanka dominates by Solar PV and most of the solar capacity does not record in the National Dispatch Center. Therefore, keeping proper reserve requirement to maintain system stability has become challenge. Therefore, a comprehensive analysis should be carried out in order to arrive at a required reserve requirement.

## **2.6 Present Challenges in Operating the System**

Operating a power system with high penetration of variable renewable energy is great challenge for a system operator throughout the world. In Sri Lanka 36% of the installed capacity is from non-conventional renewable energy sources and 70-80% of this capacity is not seen from the system control center. This becomes worst in a day with very low (Sunday and Poya day) demand in which a very few conventional power plants are running in the system. Therefore, the system operator has to take some extra generators to the system for maintaining minimum system inertia requirement and catering fluctuations due to the intermittency of the VRE.

### **2.6.1 Main Requirements to Maintain a Reliable Power System**

The System Operator should ideally have complete control over which generators are used to meet the customer demand for the power system to operate safely, reliably, and economically. The system operator should have the following skills to efficiently run the system with a high degree of reliability:

#### **Reliable information**

- High resolution RE forecast
- RE desk at the National Dispatch Center
- On the status of all equipment in the system
- On the operating status, such as the currents and voltages
- Demand forecast and historical information
- On factors contributing to demand and generation, such as weather and rainfall, and their forecasts
- On any special problems/concerns about equipment, such as limitations

#### **Supervisory Control**

- Remote operation of all critical equipment of the system
- Ability to remotely intervene to improve system reliability
- Online displays on widescreen (mimic diagram) and consoles
- Software tools to determine the most economical and safe mode of operating the system

## Guidelines and Experience

- Clear guidelines on system operation
- Procedures in case of regular emergencies
- Experience in power plant and transmission operations
- Adequate experience in system operations
- Hands-on experience in managing emergencies

### 3. CHAPTER 03- TOTAL SYSTEM FAILURE ON 09.02.2025

#### 3.1 Background

This chapter of the report focusses on the total system failure occurred at 11.14.01.826 hrs on February 09, 2025 considering all the available information in various forms. The failure incident is discussed in detail, and an analysis is carried out gathering all the relevant information related to the incident. The failure was initiated with a phase-phase-earth fault at the 33kV busbar at Panadura Grid Substation, which led to the tripping of 33 kV bus section breaker, followed by tripping of 33 kV and 132 kV circuit breakers of transformer 01. With the tripping of 33 kV side breaker of transformer 1, the 132 kV side breaker too was operated simultaneously.

#### 3.2 Power System Status Just Before Total Failure

The power system was operating in electrical and mechanical equilibrium just before the 33 kV bus bar fault at the Panadura Grid Substation at 11.13.39.512 hrs.

##### 3.2.1 Weather at the Time of Failure

It was a Sunday, and weather was sunny with clear skies in many parts of the country. The temperature was around 30 °C in Colombo and the humidity was around 71%.

##### 3.2.2 System Generation and Load

Due to the low system demand, most of the conventional power plants were not in operation, and a substantial portion of the demand was supplied by the solar PV systems, especially rooftop installations. According to the data provided by NSCC, the active and reactive power shares among the power plant groups before the fault are given in table 3.1. A total of 66 MW of real power was dispatched through Laxapana complex, where all five units of old Laxapana were operating at minimum load, while New Laxapana unit 1, along with Polpitiya unit 1 and unit 2 were also in operation to collectively dispatch the 66 MW. The Mahaweli Complex contributed 50 MW, which was supplied by Victoria Unit 2 and Unit 3. In the Samanala Complex, Uma Oya unit 1 was operating with a 10 MW output. All three units of Lakvijaya power plant were operating at minimum load adding 472 MW to the system at the time of the failure. According to the recorded data in the SCC which is depicted in table 3.1, the total system load seen by the NSCC was 739 MW. However, it was noted that a substantial amount of embedded generation, especially solar rooftop installations was operating in the system, serving the loads. Thus, tripping of these inverters resulted in taking that demand from the system, causing a drop in the system frequency.

Generation Category	Active Power (MW)	Reactive Power (Mvar)
Laxapana Complex	66	12
Mahaweli Complex	50	09
Samanala Complex	10	-4
LVPS	472	58
Thermal Complex	0	0
IPP	0	0
Small Hydro (CEB)	2	0
Mini Hydro (IPP)	36	0
Wind	60	0
Biomass	10	0
Solar	33	0
Shunt Reactor Power (Capacitor Banks)	0	66
<b>Total Load</b>	<b>739</b>	<b>141</b>

Spinning Reserve	230	31.1% as a percentage total load
Frequency Control	Victoria Unit 02	

Source: National System Control Centre, "Detailed Report on Total System Failure at 11:13 Hrs on 09th February 2025,"

### 3.2.3 Transmission System and Line Flows

Even though the transmission network is operated in loops, there are many opening points which are kept open due to system constraints. The Opening points of 132kV and 220kV system ring connections were as follows, just before the fault at Panadura Grid Substation.

1. Havelock - Maradana 132 kV cable from Havelock end
2. Kolon - Japura - Panni 132 kV both ccts from Kolon end
3. Ambalangoda - Galle both ccts from Ambalangoda end
4. Ukuwela 132kV B/C
5. Rantabe 132kV B/C
6. O/Laxa-N/Eliya-Badulla cct 02 from O/Laxapana end
7. O/Laxa-Polpitiya 132kV cct from both ends
8. O/Laxa-WPS 132kV cct 02 from both ends
9. Katu-Bola-N/Chillaw 132kV cct from Katunayake end
10. Katu-Bola-Pannala 132kV cct from Katunayake end
11. Puttalam-N/Chilaw 132kV cct 01 from both ends
12. Puttalam-New Anuradhapura 132kV cct 01 from both ends
13. Puttalam-New Anuradhapura 132kV cct 02 from New Anuradhapura end
14. Puttalam - Maho cct 01 and 02 form both ends
15. New Anuradhapura 132kV B/C
16. Col N-Col F cable from both ends

17. Col B - Kolonnawa cable from Kolonnawa end
18. Col E - Kolonnawa cable from Col E end
19. Padukka - Athurugiriya 132kV cct from Padukka end
20. Athurugiriya - Oruwala 132kV cct from Oruwala end
21. Pannipitiya 220kV B/C, 132kV B/C
22. Padukka-Pannipitiya both ccts from Padukka end

### Transmission Line Flows

Load flow prior to the total failure in critical transmission lines are shown in Table 3.2.

Table 3.2 Lines flow in Critical 220 kV and 132 kV lines

Line	Voltage (kV)	Load (A) - Line 1/2	Trip Setting (A)	Availability of (N-1) Contingency
Biyagama – Pannipitiya	220	175/190	850	Operate as separate systems
LVPS-New Chilaw	220	555/561	2175	Y
New Chilaw - Veyangoda	220	419/410	1560	Y
Veyangoda - Kotugoda	220	415/400	1500	Y
Kotugoda - Biyagama	220	145/148	900	Y
New Polpitiya - Hambantota	220	27/30	1660	Y
Kothmale - Biyagama	220	255/260	1600	Y
Kotugoda - Kerawalapitiya	220	138/133	1200	Y
Kerawalapitiya – Sub L	220	246	1320	Only one cable
Kolonnawa - Athurugiriya	132	157/155	480	Y
Kolonnawa – Kosgama - Seethawaka	132	167/137	480	Y
Kolonnawa - KPS	132	146/148	1169	Y
Kotugoda – Aniyakanda - Kelaniya	132	182/187	744	Y
Kelaniya - Kolonnawa	132	364/366	960	Y
New Laxapana - Balangoda	132	91/89	480	Y
Pannipitiya – to Ambalangoda	132	158/157	712	Y
Embilipitiya – Matara & Beliatta	132	73/69	400	Y

Source: National System Control Centre, "Detailed Report on Total System Failure at 11:13 Hrs on 09th February 2025,"

### 3.3 Analysis of System Failure

The committee has conducted an analysis of the various factors contributing to a total system failure. The assessment has been carried out in a structured manner, considering multiple aspects that could have lead to such a critical failure. The key areas examined by the committee are as follows:

### 3.3.1 Major Busbar Voltages (Pre-fault & Post-fault)

The pre fault and post fault system voltages of major busbars and nearby substations to the fault location are listed in Table 3.3 while table 3.4 depicts the voltages at major busbars during the fault. It was observed based on the DDR records of Kesbewa GSS, 132kV Voltage of R phase has dropped by 40% for a period of approximately 484 ms and the voltage has recovered to 80% with the opening of bus section circuit breaker. The voltage was fully recovered to normal voltage after operating of 33 kV circuit breaker of transformer 1 within 1.1 sec after the busbar fault.

It can be observed that a significant voltage drop has occurred in the substations connected to 132kV lines from Pannipitiya to Mathugama.

Table 3.3- Pre-fault and Post-fault Major Busbar Voltages

GSS	Line / Busbar	Voltage Level (kV)	Pre-fault			Post Fault		
			Voltages (kV)			Voltages (kV)		
			R	Y	B	R	Y	B
Kesbewa	Panadura/Horana Line	132	131.5	131.6	131.4	130.6	131.4	132.2
	Busbar	132	131.4	131.7	131.3	130.7	131.6	131.3
	Busbar	33	32.9	32.9	33.0	33.0	32.7	33.2
Kalutara	Panadura/Pannipitiya Line	132	130.1	130.6	131.2	129.8	130.6	131.5
	Busbar	132	130.7	131.2	130.4	130.0	131.0	132.2
	Busbar	33	32.4	32.7	32.9	32.4	32.5	32.8
Pannipitiya	Busbar 1	220	221.4	222.7	222.3	220.7	222.3	222.0
	Busbar 2	220	222.4	223.0	223.0	221.1	222.4	222.8
Biyagama	Pannipitiya Line 1	220	225.0	223.8	223.9	224.2	223.4	223.7
	Pannipitiya Line 2	220	223.4	224.0	224.1	222.6	223.6	224.0
Kotugoda	Biyagama Line 1	220	223.5	231.9	233.3	222.8	231.5	233.0
	Biyagama Line 2	220	223.1	222.9	222.7	222.5	222.6	222.6
	Busbar 1	220	223.2	221.9	224.2	222.3	221.6	224.0
	Busbar 2	220	222.5	221.5	225.8	224.0	221.2	223.1
Kotmale	Biyagama Line 1	220	228.5	227.4	224.8	225.5	226.3	228.0
	Biyagama Line 2	220	229.1	227.2	224.9	226.1	228.6	225.4
Kolonnewa	Busbar 1	132	132.5	132.7	132.6	132.0	132.5	132.9
	Busbar 2	132	132.6	132.8	132.7	132.0	132.6	132.5
Sri Japura	Busbar	132	131.8	132.1	131.9	131.4	131.9	131.7
New Galle	Busbar 1	132	130.2	130.7	131.7	130.9	129.2	131.0
	Busbar 2	132	129.9	130.2	131.9	130.9	130.0	131.3

Note: (Phase Voltage) x  $\sqrt{3}$  for easy reference

Source: Relevant DFR Records

GSS	Line / Busbar	Voltage Level (kV)	Voltage Drop %							
			Stage 1			Duration (ms)	Stage 2			Duration (ms)
			R	Y	B		R	Y	B	
Kesbewa	Panadura/Horana Line	132	41.52%	12.79%	15.11%	450	20.83%	5.80%	8.05%	550
	Busbar	132	41.46%	12.74%	15.57%	450	20.76%	5.76%	8.64%	550
	Busbar	33	32.68%	28.22%	6.80%	450	17.19%	14.45%	3.00%	550
Kalutara	Panadura/Pannipitiya Line	132	44.18%	14.52%	16.82%	450	22.02%	6.50%	9.23%	550
	Busbar	132	43.43%	13.86%	17.12%	500	22.29%	6.58%	9.60%	650
	Busbar	33	34.69%	29.50%	8.86%	500	18.26%	15.32%	4.68%	650
Pannipitiya	Busbar 1	220	7.18%	1.31%	3.86%	450	3.25%	0.30%	1.72%	550
	Busbar 2	220	13.89%	3.28%	6.98%	450	6.62%	1.16%	3.37%	550
Biyagama	Pannipitiya Line 1	220	7.88%	1.36%	4.08%	450	3.63%	0.26%	1.80%	600
	Pannipitiya Line 2	220	8.05%	1.48%	4.17%	500	3.67%	0.24%	1.75%	600
Kotugoda	Biyagama Line 1	220	7.08%	1.40%	3.87%	500	3.16%	0.23%	1.60%	600
	Biyagama Line 2	220	7.08%	1.39%	3.86%	500	3.18%	0.24%	1.60%	600
	Busbar 1	220	7.55%	0.98%	3.76%	500	3.76%	-0.58%	1.75%	600
	Busbar 2	220	7.40%	1.01%	3.76%	500	3.74%	-0.50%	1.81%	600
Kotmale	Biyagama Line 1	220	5.72%	1.46%	2.71%	500	2.30%	0.60%	0.48%	600
	Biyagama Line 2	220	5.90%	1.43%	2.92%	500	2.41%	0.49%	0.56%	600
Kolonnawa	Busbar 1	132	6.16%	1.15%	3.36%	500	2.80%	0.20%	1.46%	600
	Busbar 2	132	6.24%	1.26%	3.35%	500	2.79%	0.19%	1.46%	600
Sri Japura New	Busbar	132	6.56%	1.45%	3.90%	500	2.88%	0.28%	1.69%	600
New Galle	Busbar 1	132	2.77%	0.19%	2.09%	500	1.14%	-0.66%	1.14%	600
	Busbar 2	132	2.60%	0.07%	1.65%	500	0.97%	-0.73%	0.87%	600

Source: Relevant DFR Records

### 3.3.2 The Fault at Panadura 132 kV/33 kV Grid Substation

According to the records, a phase to phase to earth fault has occurred at 33kV bus section 1 of Panadura GSS at 11:13:39.520 hrs on 09th February 2025 caused by the contact of a monkey with L1 and L2 phases of 33kV bus bars and the earth as shown in figure 3.1.

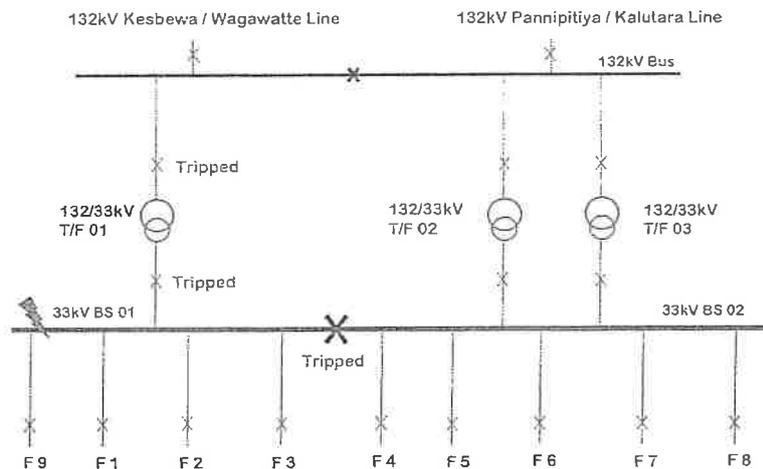


Figure 3.1- SLD of Panadura GSS with fault location and CB operations

### 3.3.3 Protection Setting at the Time of Failure

The 33kV side protection settings are configured to maintain a 300 ms gap between the 33kV Feeder, Bus Section and the transformer 33kV incomer at the highest fault current. The 33kV feeder exit settings shall also provide sufficient allowance for the operation of downstream protection devices, such as auto reclosers. This minimizes unnecessary tripping of grid breaker

for a fault downstream to an Auto Reclosure in a distribution feeder and reduces the number of affected consumers. The existing over current and earth fault protection setting of Panadura GSS are summarized in Table 3.5 and Table 3.6 respectively while table 3.7 shows the tripping sequence of 33 kV circuit breakers of Panadura GSS.

Table 3.5- 33kV side over current settings of Panadura GSS

Over Current Settings					
		33kV Feeder	33 kV BS	TF 33 kV	TF 132 kV
I > IDMT	I <sub>pick</sub> (A)	400	1200	600	160
	TMS (s)	0.15	0.13	0.25	0.35
I >> DT	I <sub>pick</sub> (A)	1600	1248	5400	1440
	Delay	0.1	1	0	0
I >>> DT	I <sub>pick</sub> (A)	-	1704	-	-
	Delay (s)	-	0.4	-	-

Source: Transmission Control & Protection Branch

Table 3.6- 33kV side earth fault current settings of Panadura GSS

Earth Fault Settings					
		33 kV Feeder	33 kV BS	TF 33 kV	TF 132 kV
I > IDMT	I <sub>pick</sub> (A)	40	60	120	40
	TMS (s)	0.25	0.3	0.225	0.225
I >> DT	I <sub>pick</sub>	1000	-	960	320
	Delay	0.35	-	0	0

Source: Transmission Control & Protection Branch

Table 3.7- Tripping sequence of circuit breakers

Equipment Tripping	Relay Type	Relay indications	Trip Time
Panadura GSS - 33kV Bus Section	Areva MiCom P127	Over Current I >> I <sub>pick</sub>	11:13:40.00hrs*
Panadura GSS – 132/33kV TF 1	MCGG	Over Current IDMT	11:13:40.58hrs*

Source: Transmission Control & Protection Branch

Note: \* Trip times were approximated based on the DDR record of 132kV Panadura/Wagawatta line at Kesbewa GSS

### 3.3.4 Setting Coordination with Operational Curves

Setting coordination graphs to verify the availability of adequate coordination for above settings between the circuit breakers for a fault occurred in a 33kV feeder is shown figure 3.2 and 3.3. Numerical relays with fault recorders are not available in transformer 1. Hence, fault currents during the incident were derived from numerical relay records and Ben disturbance recorders installed at nearby substations.

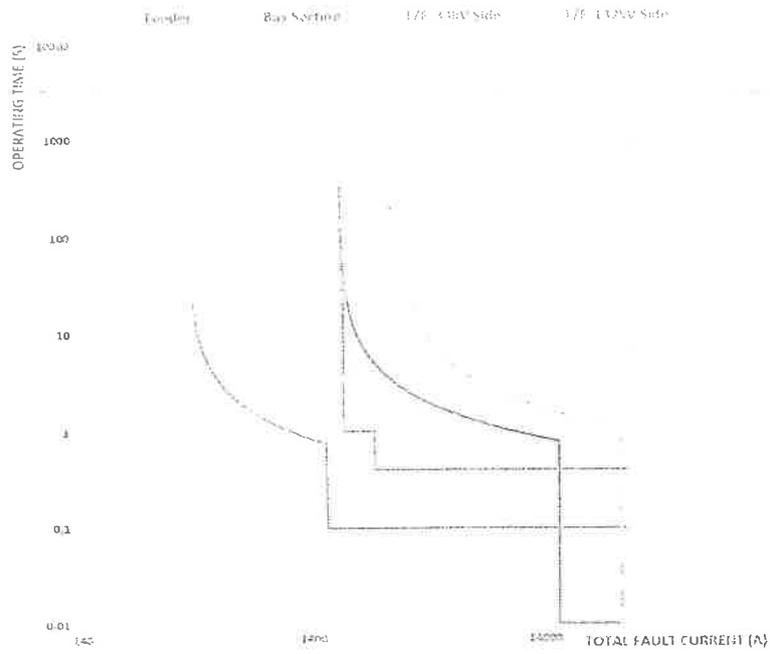


Figure 3.2- Overcurrent setting coordination at 33kV side of Panadura GSS

Source: Transmission Control & Protection Branch

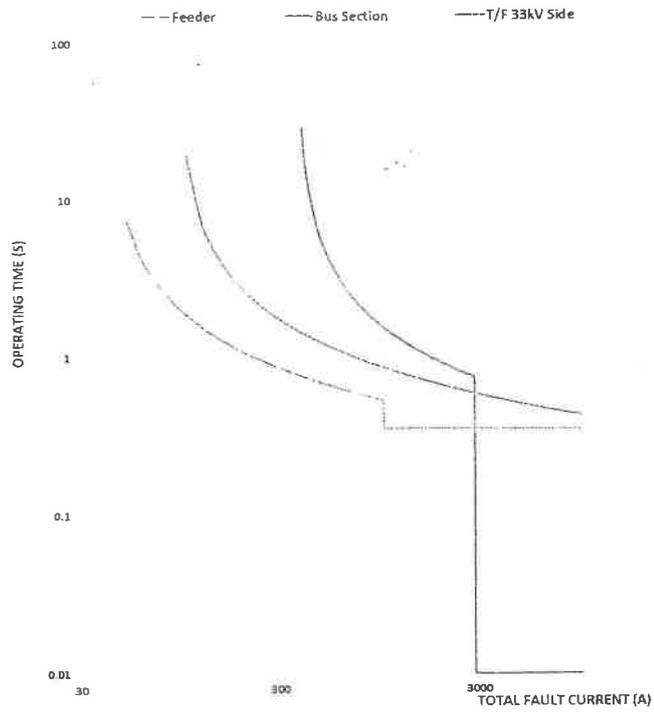


Figure 3.3- Earth fault setting coordination at 33kV side of Panadura GSS

Source: Transmission Control & Protection Branch

## 4. CHAPTER 4- ANALYSIS OF SYSTEM FAILURE ON 09.02.2025

### 4.1 Initial Incidents

Total system failure occurred on February 9, 2025 due to a fault initiated at the 33 kV busbar of the Panadura Grid Substation at 11:13:39.512 hrs, causing the 33kV Bus Section circuit breaker and 132/33kV T/F 01 circuit breaker to trip, caused by the operation of over-current protection. Even though fault was cleared according to the trip setting of circuit breakers and restored the system voltage to the normal value, the system frequency was continuing to drop resulting tripping of the Lakvijaya PS Unit 01, 02 & 03, New Laxapana Unit 01, Old Laxapana Stage I & II, Polpitiya Units 01 & 02, Victoria Unit 02 at 11.13.58.376 hrs triggered by the operation of Under Frequency Protection System while the Victoria Unit 03 at 11.14.01.826 hrs triggered by Voltage Restrained Over-Current protection.

As discussed in Chapter 3 above, the visible load to the National System Control Center was 739 MW and 141 Mvar, just before the fault at Panadura Grid Substation. This chapter focusses on the analysis of the total system failure to determine its root cause. The committee appointed to investigate the cause of the failure gathered all relevant information from different branches related to the system operation and visited the place where the incident took place. Further, the committee met staff at Panadura Grid Substation, Engineers at System Control Center and relevant Engineers from generation division to gather facts based on their experiences during and after the failure. Further, the Committee obtained randomly selected inverter log data of rooftop solar systems throughout the country. The recorded information from different staff members and Engineers are attached in Annex 2A to 2F.

### 4.2 Present Operating Policies and Priorities

Following operating policies and priorities are adopted for the operation of the power system under steady state

#### **Priority No.01 (WEIP)**

The System operation Priority No.1, (Water, Environment, Irrigation and Power generation-WEIP) order shall be as follows;

1. Water (Drinking)
2. Environment
3. Irrigation
4. Power generation

#### **Priority No.02 (SPAQuE)**

The System Operation Priority No.2 (Safety Protection Availability Quality Economy - SPAQuE), order shall be as follows;

1. Safety of persons
2. Protection of equipment
3. Availability of supply
4. Quality of electricity
5. Economy of Operations

Therefore, system operation is carried out as "Security Constrained Economic Dispatch".

To achieve the stability of the Transmission System, the following parameters should be maintained at all times,

- The system frequency shall be between 49.5 and 50.5Hz under normal circumstances as defined in the Grid Code.
- 220kV & 132kV voltages at all nodes shall be within 10% (at least for major transmission nodes).
- The maximum unit size which is synchronized shall be less than 25% of the demand.
- Hot spinning reserve is maintained at 5% of the demand at the time.
- All major transmission lines shall have (N-1) reliability criteria.

### 4.3 Sequence of System Failure Based on the Recorded Data

The sequence of tripping of various components of the system that were operated leading to the total system failure is given in table 4.1 while figure 4.1 depicts the Pannipitiya DFR records of 220 kV voltage and System Frequency. The fault has partially cleared with the operation of 33 kV Bus Section overcurrent protection after 484 ms and the busbar voltage at the 33 kV busbar of Panadura GSS has recovered to 80% from 60% during the Fault. Then the fault is fed through transformer 1 and 33 kV overcurrent protection of transformer 1 has operated after 1.034 sec clearing the busbar fault and recovering the voltage to the normal value. Even though the system voltage was returned to normal, the system frequency was continuously dropping at rate of 0.11-0.18 Hz/sec over a period of 7.1 sec according the recorded frequency shown in figure 4.1. The load shedding as given in table 4.2 at first stage operated at about 7.65 s after the fault was cleared and the system frequency was then dropping at a rate of 0.47 Hz/sec which was higher rate than that was before load shedding. This trend was continued till the operation of load shedding stage 2 and stage 3 till the frequency dropped to 47.99 Hz. The load shedding stage 4 started at the frequency of 47.99 Hz and still the frequency was dropping but at lower rate of 0.12 Hz/sec. It appeared that substantial amount of load has shed during this period. However, the shed load was not sufficient to bring the system frequency up. The load shedding stage 5 operated at the frequency of 47.5 Hz and the system frequency started to drop at very high rate of 1.3 Hz/sec from 0.12 Hz/sec. It appears that substantial amount distributed generation has been taken out from the system together with load. The rate of frequency drops after operation of load shedding stage 5, caused to trip the all the hydropower plants running in the system except Victoria unit 3. The tripping of these generators increased the system frequency dropping rate and LVPS all three units were tripped at the frequency of 40 Hz, followed by the tripping of Victoria unit 03.

Table 4.1- Sequence of Failure

Equipment/Line	Failed Time	Indication/Reason
Panadura GSS - 33kV B/S CB	11:13:40.000	Over Current
Panadura GSS - 132/33kV T/F 01	11:13:40.580	Over Current
New Laxapana Power Station (NLPS) 1	11.13.58.404	Under Freq
Samanala Power Station (SPS) 1	11.13.58.422	Under Freq
Samanala Power Station (SPS) 2	11.13.58.422	Under Freq

Old Laxapana Power Station (OLPS) 1	11.13.58.-	Under Freq
Uma Oya 1	11.13.58.-	Under Freq
Old Laxapana Power Station (OLPS) 2	11.13.58.465	Under Freq
Victoria Power Station (VPS) 2	11.13.58.466	Under Freq
LVPP 1	11.14.00.375	Under Freq
LVPP 2	11.14.00.375	Under Freq
LVPP 3	11.14.00.375	Under Freq
Victoria Power Station (VPS) 3	11.14.01.866	Vol Res O/C

Source: Asset Management, Hydro Electrical, "Island Wide System Failure 09th February 2025"

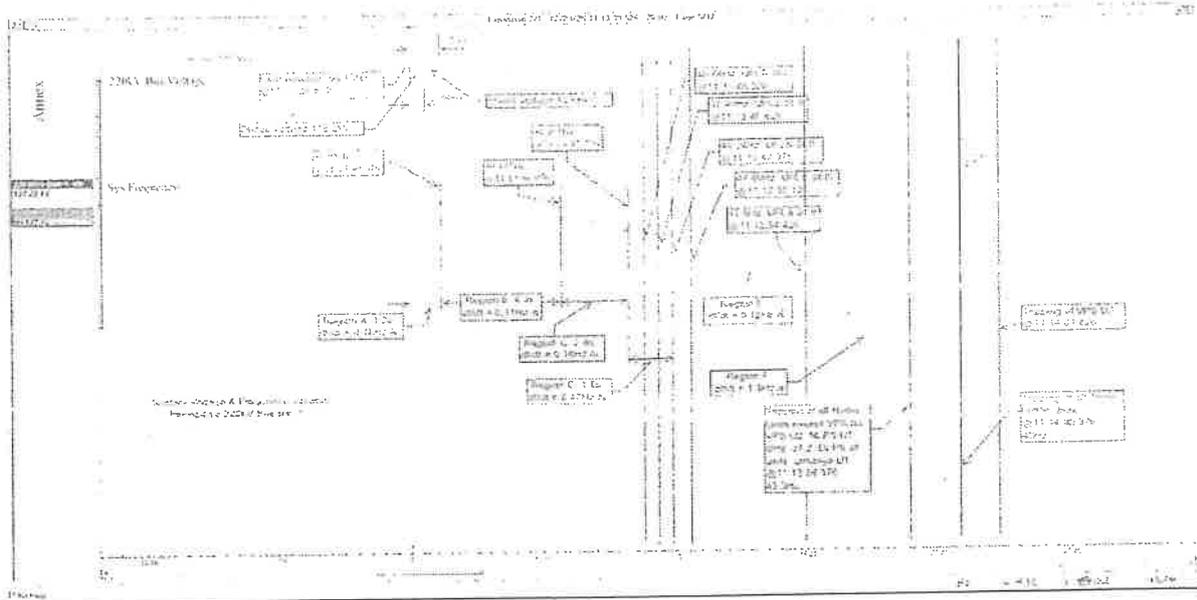


Figure 4.1- Extracts of DFR records

Source: Report submitted to AGM(Generation) by DGM(AMHE) on 25.02.2025

#### 4.4 Load Shedding Scheme of CEB

Table 4.2- Load shedding scheme of CEB

Stage	Load Shedding Criteria	Load per stage
I	48.75 Hz+100 ms	7.5%
II	48.5 Hz+500ms	7.5%
III	48.25+500ms	11.0%
IV	48.0% instantaneous	11%
V	47.5 Hz instantaneous	5.5%
	47.5 Hz instantaneous OR 49 Hz AND df/dt > -0.85Hz/s +100 ms	4.5%
df/dt	49 Hz AND df/dt >-0.85+100 ms	13.5% and 4.5% embedded in V
Total	df/dt	18% +(4.5% embedded in V)
	Frequency only	42.5%

Source: National System Control Centre Guideline

#### 4.5 Operation of Protection System at Panadura Grid Substation

The recorded fault currents of 33 kV side of transformer 3 is shown figure 4.2 below while currents in different sections of the Panadura GSS during fault are shown in Figure 4.3, 4.4 and

4.5 below. According to the disturbance records available in Siemens 7UT main protection relay in Transformer 3, it can be observed that initially Phase R to earth fault with magnitude of around 740 A has occurred, which is approximately a fault current of 2.2kA assuming equal contribution from all three transformers. After 75ms as shown in Figure 3.2, fault developed in to L1-L2-Earth fault of 2.65kA, which resulted in a total fault current of around 7.95kA, and a fault current of 5.3kA through 33kV bus section triggering the operation of Definite Time Over Current protection set to pick up at 1700A and operate with a time delay of 400ms. Accordingly, the bus section has tripped in 480ms inclusive of circuit breaker operation time.

The earth fault current as shown in Figure 4.2 has increased to around 750 A for 100 ms and dropped to around 375 A. Therefore, it takes about 800 ms to activate the earth fault relay for this fault current. Thus, bus section fault will activate before the earth fault for the existing relay settings. Therefore, the earth fault relay was not operated at this instant.

With the tripping of the 33kV bus section, fault was fed only through Transformer 1. Based on the currents recorded in the incoming lines, the 33kV fault current of Transformer 1 was approximately 4 kA. The transformer 1 has tripped by the operation of IDMT over current protection within 1.1 seconds completely isolating the faulty bus section with the simultaneous operation of both 132kV and 33kV side circuit breakers.

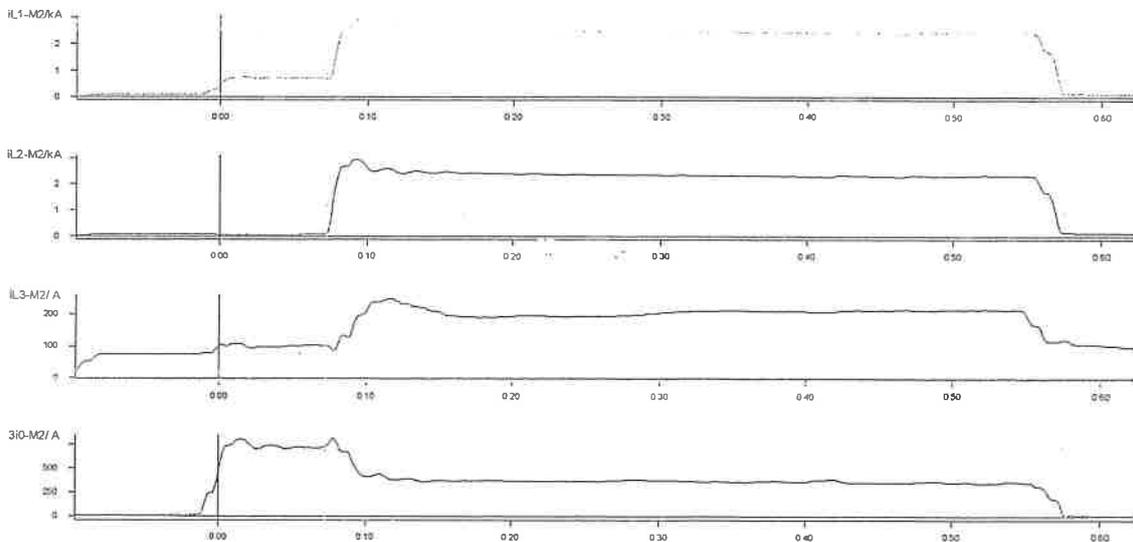


Figure 4.2- Recorded current of 33 kV side of transformer 3

Source: Control & Protection Branch

Further, the maximum fault current in transformer 1 in this incident was around 4kA at 33kV side. The instantaneous OC trip setting of the transformer 33 kV side has been set at 5.4 kA, which is just below the transformer through fault current of 5.5kA. These are standard settings employed for similar 132/33kV grid substations, with minor adjustments depending on the fault level and number of available transformers.

### Phase Fault Currents During Stage 1 of the Fault

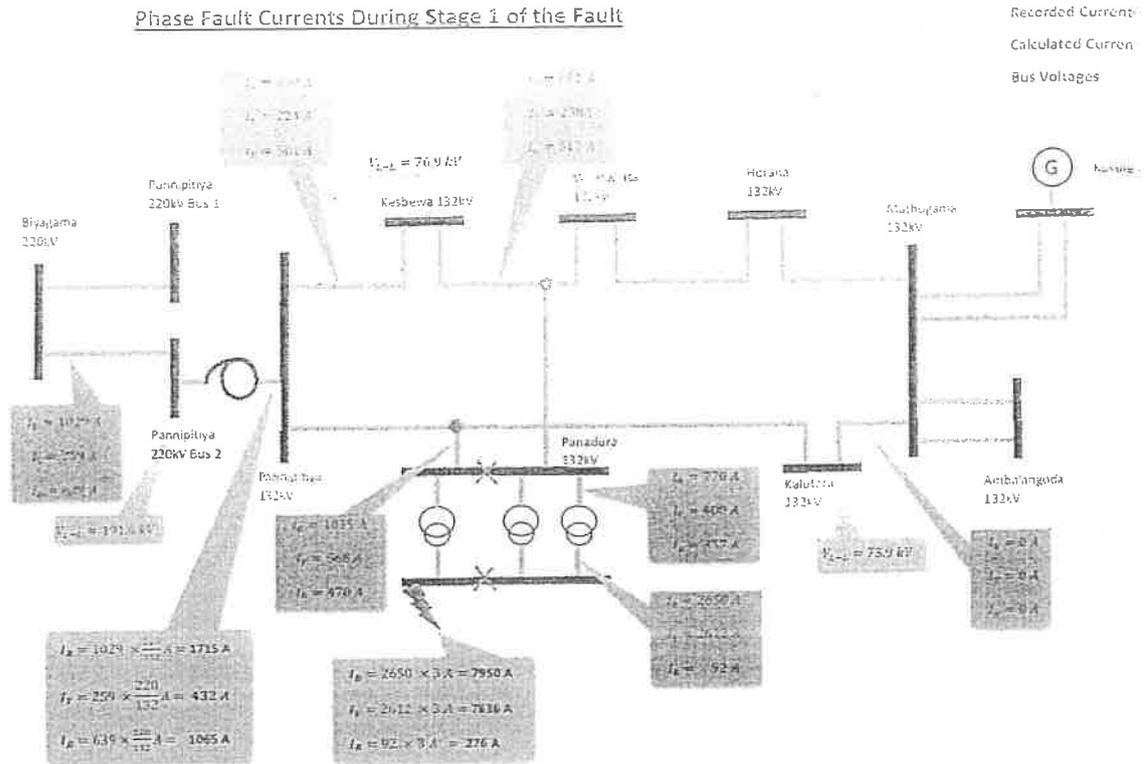


Figure 4.3- Fault currents during the incident derived to validate operating times

Fault has been cleared in 1.064 seconds and no other transmission lines/ transformers or generation plants have tripped. System voltage has returned to normal values with the clearing of the fault. During the fault period, system frequency has sustained within the normal limits. No other faults or disturbances were observed during the above fault time.

### Phase Fault Currents During Stage 2 of the Fault

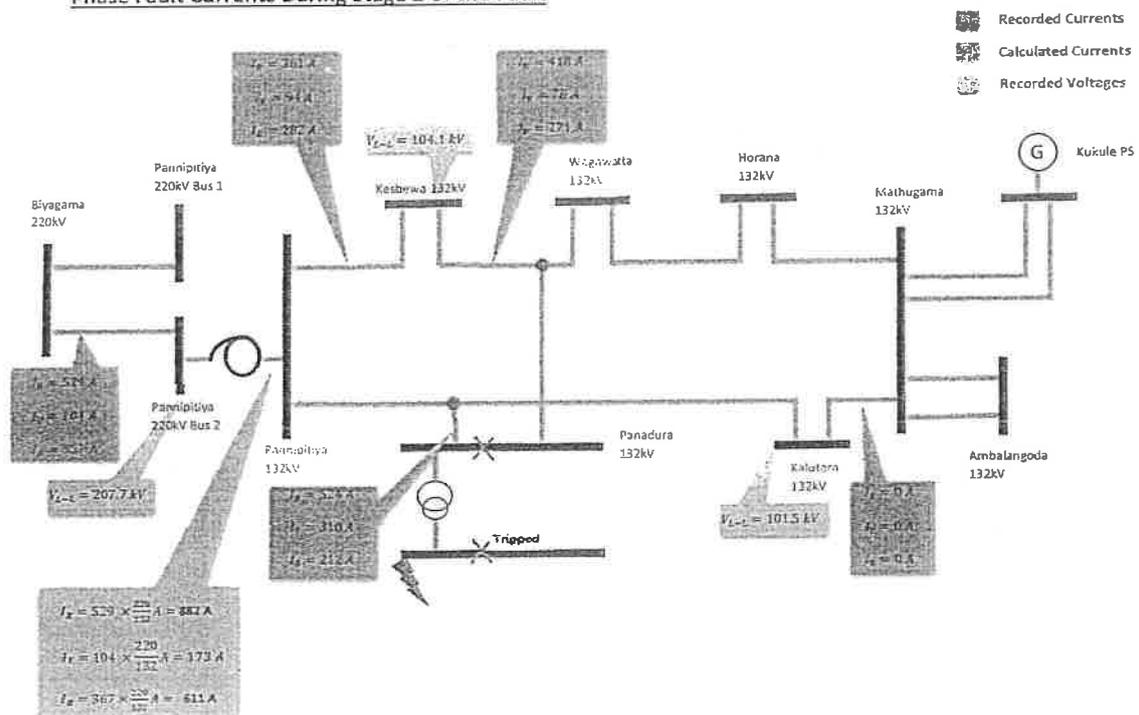


Figure 4.4- Fault currents during the incident derived to validate operating times

### Earth Fault Currents and Operating time of each relay During the Stage I of the Fault

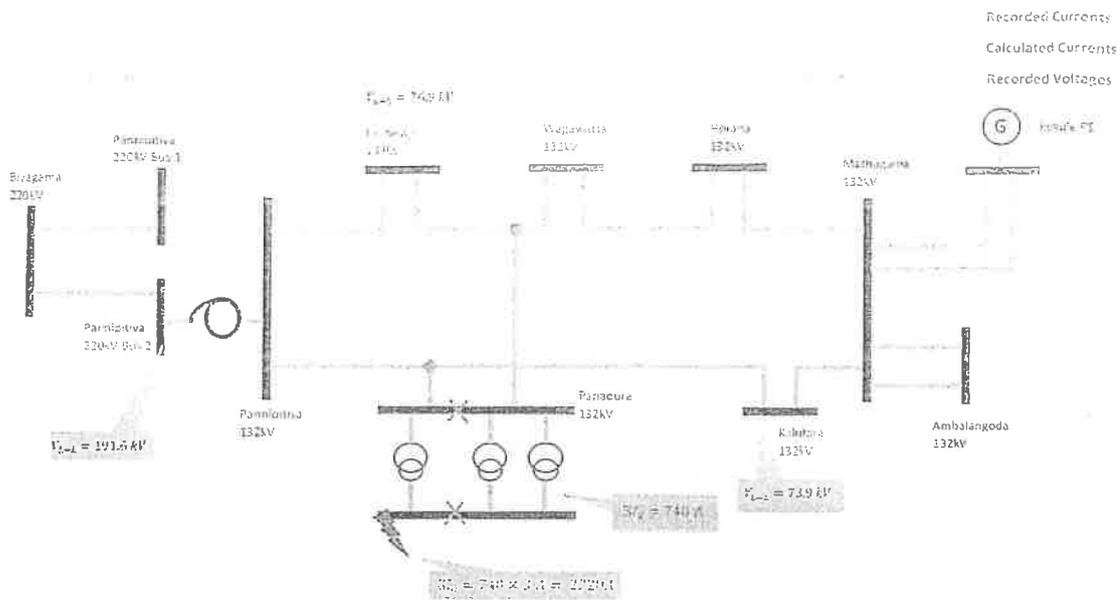


Figure 4.5- Earth fault currents derived to validate operating times

#### 4.6 Determination of Fault Current through Set Protection Curves

According to the overcurrent and earth fault protection setting of Bus, the coordination curves were given in Figure 3.2 and 3.3 in Chapter 3 above. Since there was no fault current through 33 kV feeders the protection coordination was between Bus Section and 33 kV side of the transformers. Thus, for a fault current of 5.3 kA through bus section, the relay will operate instantaneously after 0.4 s delay. It was noted from the recorded operating time was 0.485 s which is the delay plus the breaker operation time. Hence the relay has operated according to the set value. Once the bus section breaker was operated, the fault current has flown only through the transformer 1. Hence, the overcurrent relay of transformer 1 was operated. The operation time will follow the IDMT curve. The time to operate for IDMT curve with IEC 60255 is given by following equation.

$$t(I) = TMS \left[ \frac{0.14}{\left( \frac{I_F}{I_S} \right)^{0.02} - 1} \right] \text{ sec where } I_S = \text{current setting of the relay, } I_F = \text{Fault current, TMS} = \text{time}$$

multiple setting.

For this case  $I_F = 4000 \text{ A}$ ,  $I_S = 600 \text{ A}$ , from the above equation the calculated value is 0.905 sec. The breaker has operated within 1.1 sec which includes 0.195 sec breaker operation time. Thus

it is evident that the protection relays have operated as expected during the 33kV side busbar fault at Panadura GSS. It should be noted that the maximum fault current during this bus bar fault was approximately 8kA, whereas the 33kV fault level is 13.1kA.

## 5. CHAPTER 5- DISTRIBUTION RTSPV INVERTERS BEHAVIOR DURING THE TOTAL FAILURE

It appeared that the outage was influenced by the "Sunny Sunday" effect, a condition where low weekend demand combined with high generation from solar PV creates grid instability. With most industrial and commercial customers being on low consumption, the grid was operating with very low demand, making it more vulnerable to system disturbances.

The committee initiated an investigation into the behavior of embedded generation, specially RTSPV, to determine whether there was any contribution leading to cascaded disconnections and ultimately resulting in a total system failure.

The committee further decided to analyzed RTSPV inverter behavior and the accuracy of the frequency and voltage set points of the existing RTSPV inverters to verify the following possibilities.

- **Solar PV Disconnection:** The behavior and the reasons for the RTSPV tripping during the total failure
- **Frequency and the Voltage set Points of RTSPV Inverters:** The accuracy of the existing frequency and the voltage set points of RTSPV inverters attached to distribution network
- **RTSPV inverter Trippings due to Inaccurate Set Points:** Whether the inaccurate frequency and the voltage set points of RTSPV inverters has affected the tripping.

### 5.1 Data Collection of Randomly Selected RTSPV Inverters

In order to verify the behavior and the accuracy of the frequency and voltage set points of the existing RTSPV inverters on 9th of February to verify the above specified assumptions, Committee decided to obtain the following information regarding the rooftop solar PV systems connected to the distribution network.

Table 5.1- Data collection of randomly selected RTSPV inverters

Customer Name & A/C No.	Location	Connected GSS/ Feeder	Inverter Solar Capacity	Inverter Tripping Time	Inverter Tripped Reason	Inverter Setting	
						Over /Under Voltage	Over /Under Frequency

Minimum 10 nos. of random solar customers to be selected from each Consumer Service Center (CSC) attached to the respective Area office of CEB and LECO

- Capacity of Installed Solar Generating Facility; < 40 kW → Min. 5 nos.
- Capacity of Installed Solar Generating Facility; > 40 kW & < 1 MW → Min. 3 nos.
- Capacity of Installed Solar Generating Facility; > 1 MW → Min. 2 nos.
- Total no. of selected Solar Generating Facilities → Min. 10 nos.

Approximately 2% of the all RTSPV inverter data has been collected and the summary of sample selection is depicted in following table.

Organization / Division	No of RTSPV Accounts	Total Installed Capacity kW	No of samples collected	Sample collection %
CEB / DD 1	21,760	368,177.4	503	2.31%
CEB / DD 2	23,853	405,422.0	569	2.39%
CEB / DD 3	19,144	297,465.1	406	2.12%
CEB / DD 4	16,058	214,925.3	130	0.81%
Total	80,815	1,285,989.7	1,608	2.00%
LECO	24,611	278121	44	0.18%

## 5.2 Island wide RTSPV behavior during Total failure

As per the collected data from the randomly selected samples of the RTSPV inverters, it was identified that the RTSPV inverter tripping have occurred based on the main three reasons. Although the different types of inverters have presented the tripping reason in a slightly different way, the collected data are summarized and shown in the map as follows.

- ▣ RTSPV Inverter tripping reasons due to No Grid / Grid Loss / Utility power loss/ CEB power failure/ No AC power are shown in **green dots**
- ▣ RTSPV Inverter tripping reasons due to Under frequency of the network/ frequency fault/Grid UF fault/ Grid UF/ low frequency / UFP2 are shown in **red dots**
- ▣ RTSPV Inverter tripping reasons due to Grid under voltage/Grid Low voltage/ AC voltage too low / U voltage / Grid OV are shown in **yellow dots**

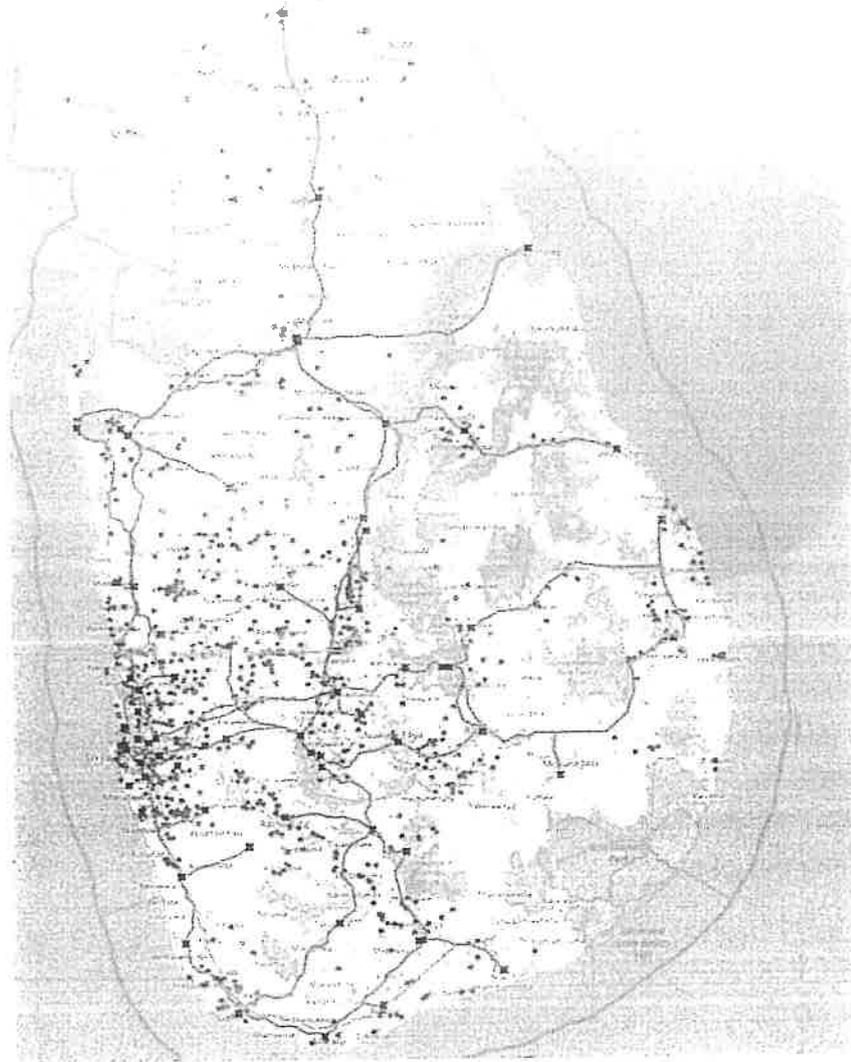


Figure 5.1- Graphical representation of island wide RTSPV Inverter behavior of the randomly collected samples

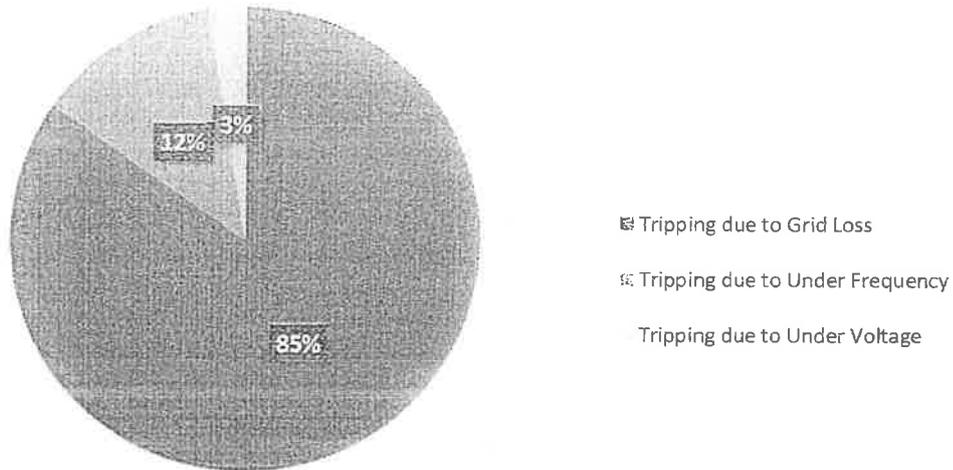
As per the collected data, committee observed that the most of the RTSPV inverters connected to the distribution network fed from Wimalasurendra, Nawalapitiya, Ragala, Nuwaraeliya, Embilipitiya, Balangoda, Ambalangoda, Bolawatta, Balangoda have been disconnected due to under frequency of the network.

Table 5.3- Summary of the RTSPV inverter tripping as per the no. of samples/ capacity of the system

Reason for the RTSPV inverter tripping relevant to CEB customers	No's of samples of RTSPV systems		Capacity of RTSPV systems	
	Number of samples	Percentage	Capacity MW	Percentage
Tripping due to Grid Loss	1318	84.76	138	69.70
Tripping due to Under Frequency	196	12.60	43	21.72
Tripping due to Under Voltage	41	2.64	17	8.58
Total	1555	100	198	100

It is identified that more than 15% of the RTSPV systems attached to CEB out of total selected samples have been disconnected from the distribution network due to under frequency and the under voltage of the network during the fault.

**Representation of Reasons for Inverter Trippings for the Randomly Selected Samples (Number of RTSPV)**



*Figure 5.2- Identified number of RTSPV systems disconnected due to Grid loss/ Under Frequency of the network/ Under Voltage of the network*

Further as per the table 3 above, it is identified that more than 30% of the RTSPV systems capacities attached to CEB out of total selected RTSPV systems capacities have been disconnected from the distribution network due to under frequency and the under voltage of the network during the fault.

Representation of Reasons for Inverter Trippings for the Randomly Selected Samples (Capacity of RTSPV)

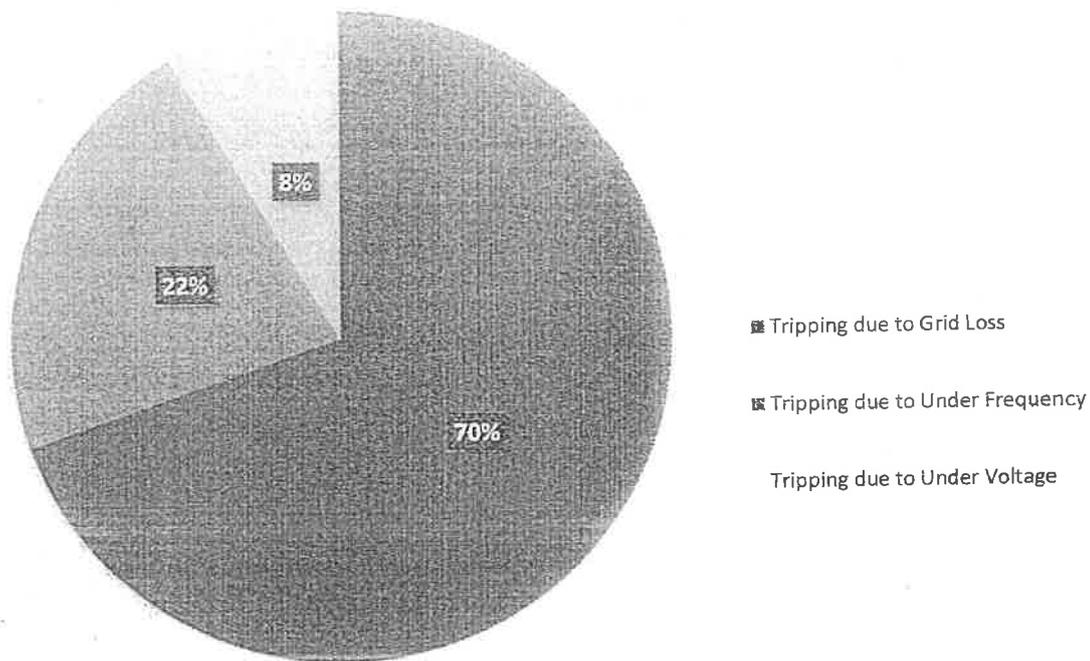


Figure 5.3- Capacity of RTSPV systems disconnected due to Grid loss/ Under Frequency of the network/ Under Voltage of the network

Detail analysis of the RTSPV inverter tripping due to under frequency of the network in different frequency low settings are summarized below in Table 5.4 below.

Table 5.4- Summary of the RTSPV inverter tripping due to under frequency in different frequency low setting ranges

Description	Frequency Setting - Low level (Hz)	Qty	Capacity kW	Percentage, %
RTSPV inverter tripping due to Under Frequency of the network	f=47	120	22,260	61.22%
	47<f<=48	31	13,473	15.82%
	48<f<49.5	37	5,006.5	18.88%
	49.5<=f<50	1	5.0	0.51%
	Not mentioned	7	2,082	3.57%
<b>Total</b>		<b>196</b>	<b>42,826.5</b>	<b>100%</b>

Further with activation of the load shedding schemes, all the RTSPV systems attached to the load shedding outgoing feeders had been disconnected from the network prior to the total failure. Therefore, the considerable capacity of RTSPV generations have been disconnected from the network prior to the total failure.

The detail of the RTSPV customers and the capacities taken from the CEBAassist connected to the load shedding feeders are described on table 5.5 below.

Load shedding Stage	No.s of RTSPV connections attached to the feeder	Capacity of RTSPV Generation kW
Stage I	4,665	71,280
Stage II	3,593	50,536
Stage III	6,582	82,557
Stage IV	5,557	70,489
Stage V	48	5,321
df/dt	9,469	116,388
V or df/dt	1,057	22,244
<b>Total</b>	<b>30,971</b>	<b>418,814</b>

Source: CEBAassist & LECO Data

- It is observed that more than 419 MW, RTSPV capacity has been connected to the load shedding feeders during the system failure on 9<sup>th</sup> of February 2025.

It was identified that the RTSPV inverter tripping related to LECO customers have occurred mainly due to two reasons.

Table 5.6- Summary of the RTSPV inverter tripping as per the no. of samples/ capacity of the system

Reason for the RTSPV inverter tripping relevant to LECO customers	Nos. of samples of RTSPV systems		Capacity of RTSPV systems	
	Number of samples	Percentage	Capacity kW	Percentage
Tripping due to Grid Loss	42	95.56	6856	99.35
Tripping due to Under Frequency	1	2.27	5	0.07
Tripping due to Under Voltage	1	2.27	40	0.58
<b>Total</b>	<b>44</b>	<b>100</b>	<b>6901</b>	<b>100</b>

Source: LECO Data

- RTSPV inverter tripping due to No Grid / Grid Loss (95.56% of the total selected sample)
- RTSPV inverter tripping due to Grid frequency fault (2.27% of the total selected sample)
- RTSPV inverter tripping due to grid frequency low & grid voltage low (2.27% of the total selected sample)

Based on the randomly collected sample data from RTSPV inverters belonging to LECO customers, only 5.54 % of RTSPV customers were disconnected from the network due to under-frequency and under-voltage of the network. The real figure may slightly differ as the data were collected from the randomly selected samples across the country.

RTSPV tripping reasons of randomly selected CEB customers are summarized with different RTSPV capacity range as below.

RTSPV Inverter Capacity of the randomly selected samples	Reason for RTSPV Inverter Tripping					
	No Grid		Under Frequency		Under Voltage	
	No. of Samples	Percentage (%)	No. of Samples	Percentage (%)	No. of Samples	Percentage (%)
RTSPV Capacity ≤ 100kW	1138	86	158	12	32	2
100kW < RTSPV Capacity ≤ 1MW	162	80	34	17	7	3
1MW < RTSPV Capacity	18	75	4	17	2	8

### 5.3 Behavior of the RTSPV Inverters Connected to Distribution Network attached to the Panadura GSS and Surrounding Areas during Total Failure

#### Detailed Description of Panadura GSS

Initial fault occurred at Panadura GSS has been cleared in 1.064 seconds and no other transmission lines/ transformers or generation plants have tripped. System voltage has returned to normal values with the clearing of the fault.

It was observed based on the DDR records of Kesbawa GSS, 132kV Voltage of R phase has dropped by 40% for a period of approximately 484ms followed by a drop of 20% for a period of approximately 550ms before recovering to nominal voltage within 1.1 second.

With the isolation of 33kV BS 01, all the outgoing 33kV feeders attached to bus section deenergized.

Table 5.8- RTSPV Capacities Connected to Panadura GSS 33 kV Bus-section 1-

Feeder No. Connected to Panadura GSS, 33kV, BS 01	F9 (LECO)	F1	F2 (LECO)	F3	Total
Connected RTSPV Capacities MW	8.7	4.0	27.2	5.03	44.9

It was observed that total capacity of 44.9 MW of RTSPV had been disconnected from the system within 1.1 second.

### 5.4 Analysis of Frequency and Voltage Set points of the RTSPV inverter

#### Summary of the analysis of frequency Set points of sample RTSPV inverters

Frequency set points of the randomly selected RTSPV customers attached to CEB were analyzed and the summary is attached below.

Organization / Division	Number of Samples	Frequency Setting - Low level (Hz)			
		f=47	47<f<=48	48<f<49.5	49.5<=f<50
Distribution Division 1 of CEB	503	263	67	70	103
Distribution Division 2 of CEB	569	281	74	206	8
Distribution Division 3 of CEB	406	345	55	3	3
Distribution Division 4 of CEB	130	64	0	3	63
<b>Total of CEB</b>	<b>1608</b>	<b>953</b>	<b>196</b>	<b>282</b>	<b>177</b>
<b>Percentage</b>	<b>100%</b>	<b>59.3%</b>	<b>12.2%</b>	<b>17.5%</b>	<b>11.0%</b>
<b>LECO</b>	<b>44</b>	<b>22</b>	<b>19</b>	<b>3</b>	<b>0</b>
<b>Percentage</b>	<b>100%</b>	<b>50%</b>	<b>43.18%</b>	<b>6.82%</b>	<b>0</b>

Frequency set point of the RTSPV inverters of the randomly selected 1608 customers attached to CEB were critically analyzed.

Only 59.3% of the selected customers attached to CEB, were identified that their low frequency set points of the RTSPV inverters were configured at 47Hz, which fulfilled the specified settings. Conversely, in 655 inverters (40.7% of the total), this setting was found to be higher than 47Hz which is beyond the specified setting. It was identified in 177 inverters (11.0% of the total sample), where the frequency low set points of the RTSPV inverters was set to 49.5Hz which may have caused unnecessary tripping.

Frequency set point of the RTSPV inverters of the randomly selected 44 customers attached to LECO were critically analyzed.

Only 50% of the selected customers attached to LECO, were identified that their low frequency set points of the RTSPV inverters were configured at 47Hz, which fulfilled the specified settings. Conversely, in 17 inverters (50% of the total), this setting was found to be higher than 47Hz which is beyond the specified setting.

#### Summary of the voltage set points of RTSPV customers attached to CEB

Table 5.10- Voltage set points of the randomly selected RTSPV customers

Organization / Division	Number of Samples	Voltage Setting - Low level (+6%)	
		V=216V	V>216V
Distribution Division 1 of CEB	493	468	25
Distribution Division 2 of CEB	568	567	1
Distribution Division 3 of CEB	405	403	2
Distribution Division 4 of CEB	130	130	0
<b>Total of CEB</b>	<b>1596</b>	<b>1568</b>	<b>28</b>
<b>Percentage</b>	<b>100%</b>	<b>98.2%</b>	<b>1.8%</b>
<b>LECO</b>	<b>44</b>	<b>43</b>	<b>1</b>
<b>Percentage</b>	<b>100%</b>	<b>97.7%</b>	<b>2.3%</b>

The voltage set point of the RTSPV inverters of the randomly selected 1596 customers attached to CEB were analyzed.

98.2% of the selected customers attached to CEB, were identified that their voltage set points of the RTSPV inverters were configured at  $\pm 6\%$ , which fulfilled the specified settings. Conversely only 28 inverters (1.8% of the total), this setting was found to be beyond the specified setting.

The voltage set point of the RTSPV inverters of the randomly selected 39 customers attached to LECO were analyzed.

97.7% of the selected customers attached to LECO, were identified that their voltage set points of the RTSPV inverters were configured at  $\pm 6\%$ , which fulfilled the specified settings. Conversely only 1 inverter (2.3% of the total), this setting was found to be beyond the specified setting.

### **Summary**

- A. The total installed capacity of RTSPV is around 1,285MW.
- B. During the fault duration of 1.1S, 45MW (installed) of embedded generation isolated from the system. The frequency drops from 50.13Hz to 49.95Hz.
- C. As per the collected data, since the low-level frequency setting has been kept between 49.5 Hz to 48Hz of the 19.4% of the RTSPV systems which were tripped due to under frequency such portion of RTSPV systems may have gradually declined and reached to the stage i of UFLS.
- D. UFLS stage I to IV operated and the corresponding RTSPV tripped associated were around 275MW of installed capacity, resulting net generation loss and frequency dropped further instead of correcting the frequency.
- E. As per the collected data, since the low-level frequency setting has been kept between 48 to 47Hz of the 16% of the RTSPV systems which were tripped due to under frequency and might have reached the Stage V.
- F. It is observed that after clearing the fault at Panadura GSS, the frequency dropped gradually with the associated RTSPV even with UFLS feeders and after 47.5Hz rest of embedded generation tripped leading to a system collapse.

## 6. CHAPTER 06-GENERATOR BEHAVIOR DURING THE TOTAL SYSTEM FAILURE

### 6.1 Introduction

As discussed in previous chapters, the system frequency at the time, 11.13.39.500 hrs of fault initiated at Panadura Grid Substation was 50.13 Hz just little above the normal frequency 50 Hz. The day was sunny and the system net generation seen by the system control center was around 739 MW. The net generation was low since substantial amount of the consumer demand was fed by the embedded generators mainly from roof top solar PV systems. In order to maintain system stability in event of a disturbance, 230 MW of spinning reserve has been maintained as per record of system control center. All 3 units of Lakvijaya Power Plant was dispatching about 470MW. The other conventional generators running in the system were New Laxapana Unit 01 at 30MW, Victoria unit 02 on frequency control mode at 28MW, Victoria Unit 03 at 22MW, all units of Old Laxapana at 36 MW, Samanala (SPS) Unit 1 and Unit 2 at 16MW and Umaoya Unit 01 at 10MW.

It appeared as shown in Figure 6.1 that the system frequency started to drop with the fault. Once the fault was cleared by opening of 33 kV bus section beaker and 33 kV transformer 1 beaker, isolating four feeders, feeder 1, 2, 3 and 9, the system voltage was back to normal and there was no any conventional generator seen from the system control center tripped. Ideally, the system frequency should be back to normal. However, it was seen as per the Figure 6.1, the system frequency was dropping at slow rate of 0.18 H/sec. In order to drop the frequency, either some generation should be taken out from the system or a large load should be connected during that period. Since the distributed generators, especially inverter base solar rooftops were running in the system, it could be decided that a chunk of solar PV rooftops might have tripped with the fault. This was justified in the Chapter 5 that under frequency settings of substantial amount of rooftop solar inverter were 49.0 Hz to 50 Hz.

In order to further validate this argument, load currents of transmission lines were analyzed through the DFR records which were shown in Annex 11. The extract from these records is shown in Figure 6.1. The Pandura, Kesbewa, Kalutara, Mathugama Grid Substations were fed through 132 kV transmission line emanating from Pannipitiya 220/132 kV Substation. The incoming 220 kV line for this substation is Biyagama-Pannipitiya 2 and it was supplying 69 MW just before the fault. However, it was noticed the flow has increased to 106 MW which was a 37 MW increase. Similar behavior could be observed in other major transmission lines as well. Since there was no other generator tripping, there was a substantial amount of generation lost just after fault. Thus, this has led to start the system frequency to drop at a rate of 0.11 Hz/sec. The rate of change system frequency has increased from 0.11 H/sec to 0.18 Hz/sec just after the frequency reached to a value below 49.5 Hz. This was due to the reason that underfrequency setting of certain amounts of rooftop solar PV inverters as discussed in Chapter 5 was 49.5 Hz. The same could be further justified when the 220 kV and 132 kV line flows as shown in Figure 6.2 were analyzed. The system frequency was continuously reducing for approximately 2.8 sec till the system frequency reached to 49.0 Hz. Once the system frequency reached just below 49 Hz the RTSPV inverters which have been configured to disconnect just below 49.5 Hz has been tripped and the system frequency falling rate then increased to 0.47 Hz/sec. The load shedding stage I was activated at the frequency of 48.75 Hz. However, there

was no decrease in the falling rate of the frequency. This is mainly due to the fact that many RTSPV systems were feeding the loads in the feeders which were under load shedding scheme. The same could be assumed in the activation of Under Frequency Load Shedding (UFLS) scheme II and III too.

It was noticed that substantial amount of expected loads were shed in stage IV of the UFLS and falling rate of frequency increased to 0.12 Hz/sec from 0.47 Hz/sec. However, the frequency was falling at this rate till it reached to 47 Hz which was the frequency set to trip all inverters remaining in the system. With the tripping of remaining solar PV inverters feeding the system, falling rate of system frequency increased to 1.3 Hz/sec which activated the UFLS stage V. The amount of load shed in this stage was not sufficient to bring up the frequency of the system and conventional generators running in the system started to trip.

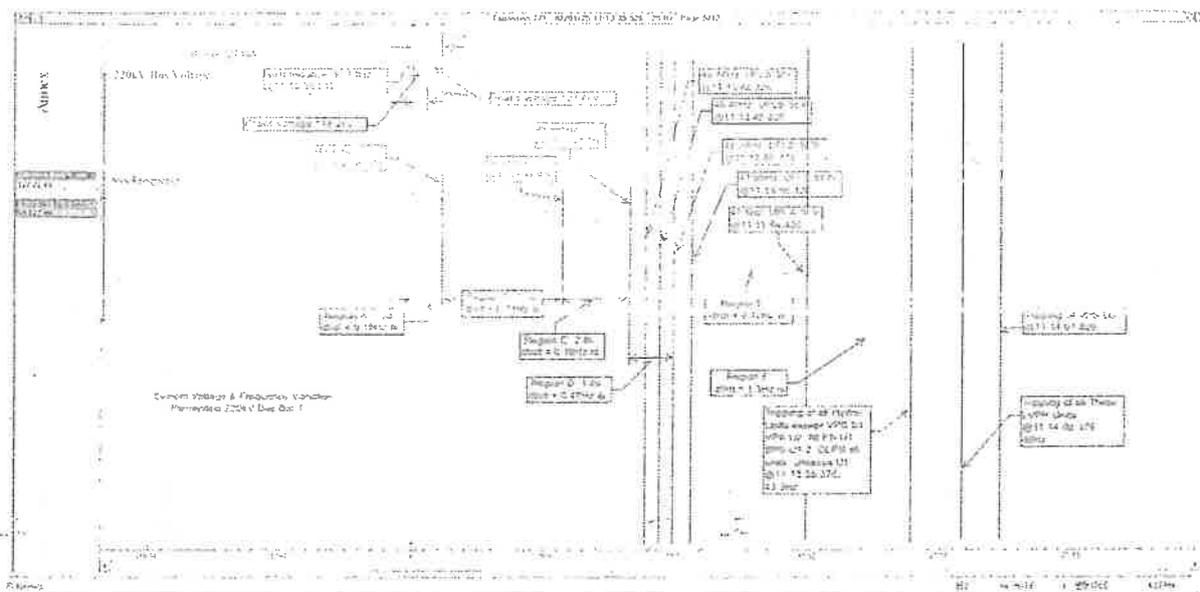


Figure 6.1- System frequency variation during the system failure on 09.02.2025

Source: Report submitted to AGM(Generation) by DGM(AMHE) on 25.02.2025

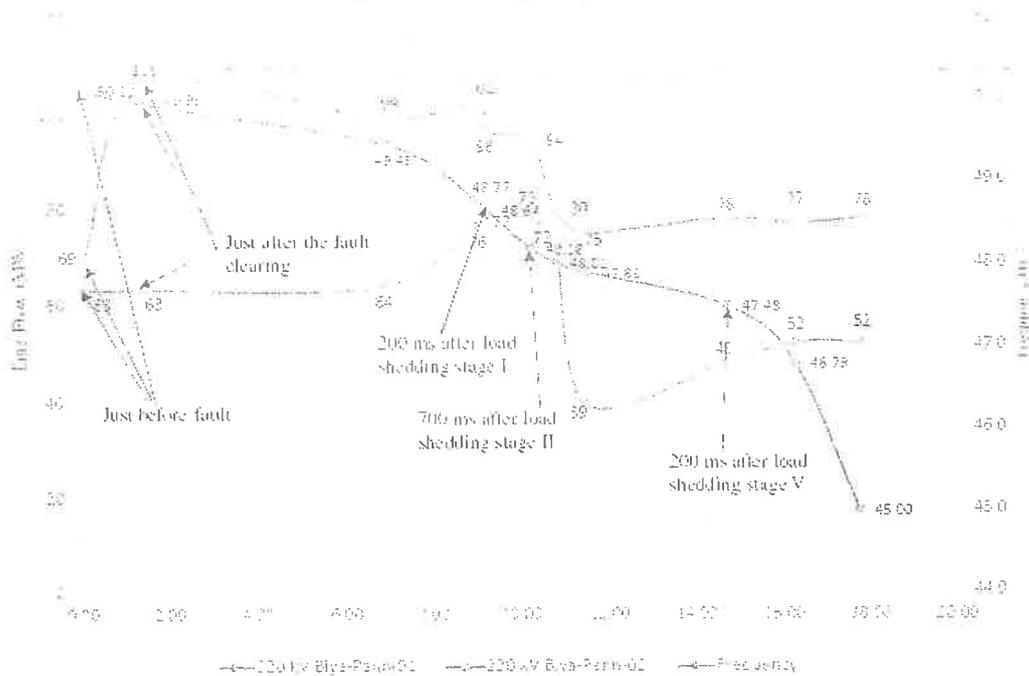


Figure 6.2- Biyagama-Pannipitiya Line 1 and Line 2 active power flows during the system failure

## 6.2 Generator response during the failure to ride through the frequency drop

The active power response of 11 Unit of six power plants have been depicted in Figure 6.3 to Figure 6.9. The analysis was carried out using the frequency response given in Figure 6.1.

### 6.2.1 During the fault shown as Region A

Assuming initiation time of the fault as 0.0 sec (Actual time was 11:13:39.476 hrs) for the convenience of the analysis, Region A considered as during the fault which last for 1.2 sec. the rate of change of frequency (ROCOF) during this was approximately 0.18 H/sec and the fault current was about 7.9 kA with a R and Y phase to ground fault. It was seen from Figure 6.3 to Figure 6.9 that all the units were responded to correct system frequency and the voltage. The calculated inertial responses and voltage correction responses are given table 6.1.

Table 6.1- Calculated inertial Response and Voltage support

Plant / Unit	Inertia (H)/(sec)	Rated MVA/(MVA)	Calculated initial response /(MW)	% Q increment from inertial Value /(%)
VPS	3.45	95	2.4	150
NLPS	3.30	72	1.7	NA
SPS	2.84	54.5	1.1	450
Umaoya	3.23	72	1.7	NA
LVPP	4.376	353	11.1	500

Source: Report submitted to AGM(Generation) by DGM(AMHE) on 25.02.2025

### 6.2.2 Region B with Frequency 49.95 Hz to 49.5 Hz and ROCOF of 0.11 Hz/sec

After the fault was cleared by opening of 33 kV Bus Section breaker and 33 kV side breaker of transformer 1 at Panadura Grid Substation, system frequency was 49.95 and the system ROCOF was 0.11Hz/sec. It was clear that the system frequency was slowly decreasing and it reached to 49.5 Hz after 5.5 sec from the fault initiation time. The Ruring Units were supporting to correct the frequency as given in Figure 6.3 to Figure 6.8. The calculated inertial responses and Primary Responses are given table 6.2.

Table 6.2- Calculated inertial Response and Primary Response in Region B

Plant / Unit	Inertia (H)/(sec)	Rated MVA/(MVA)	Calculated initial response /(MW)	Inertial +Primary response at the end of Region A
VPS U2	3.45	95	1.4	6.5
VPS U3	3.45	95	1.4	2.7
NLPS Unit 1	3.30	72	1.0	5%
SPS	2.84	54.5	0.7	1.5
Umaoya	3.23	72	1.1	NA
LVPP	4.376	353	6.8	7.5

Source: Report submitted to AGM(Generation) by DGM(AMHE) on 25.02.2025

### 6.2.3 Region C with Frequency 49.487 Hz to 48.995 Hz and ROCOF of 0.18 Hz/sec

The ROCOF has increased to 0.18 Hz/sec from 0.11 Hz/sec in Region B. The system frequency was falling down little higher rate than that in Region B due to the reason which was mentioned in Section 6.1. The calculated inertial responses and voltage correction responses are given table 6.3.

Table 6.3- Calculated inertial Response and Primary Response in Region C

Plant / Unit	Inertia (H)/(sec)	Rated MVA/(MVA)	Calculated initial response /(MW)	Inertial +Primary response at the end of Region A
VPS U2	3.45	95	2.4	15.5
VPS U3	3.45	95	2.4	8.5
NLPS Unit 1	3.30	72	1.7	7.5%
SPS	2.84	54.5	1.1	3.8
Umaoya	3.23	72	1.7	NA
LVPP	4.376	353	11.1	12

Source: Report submitted to AGM(Generation) by DGM(AMHE) on 25.02.2025

#### 6.2.4 Region D with Frequency 48.995 Hz to 48.240 Hz and ROCOF of 0.47 Hz/sec

The ROCOF has increased to 0.47 Hz/sec in Region D from 0.18 Hz/sec. Three stages of UFLS were operated during this period. However, the shed loads were unable to bring the system frequency up to recover the system. As mentioned in Section 6.1, the load shed was not as expected from the scheme due to the RTSPV generation feeding to those feeders classified as UFLS. Even though the running conventional generators responded to correct the system frequency, that was not sufficient to bring up the system to a stable operation region. The calculated inertial responses and voltage correction responses are given table 6.4.

Table 6.4- Calculated inertial Response and Primary Response in Region D

Unit	Inertia (H)/(sec)	Rated MVA/(MVA)	Calculated initial response /(MW)	Inertial +Primary response at the end of Region A
VPS U2	3.45	95	6.2	18.8
VPS U3	3.45	95	6.2	11.5
NLPS Unit 1	3.30	72	4.5	11.5%
SPS	2.84	54.5	2.9	6.5
Umaoya	3.23	72	4.4	NA
LVPP	4.376	353	29	36

Source: Report submitted to AGM(Generation) by DGM(AMHE) on 25.02.2025

#### 6.2.5 Region E with Frequency 48.24 Hz to 47.5 Hz and ROCOF of 0.12 Hz/sec

At the beginning of the Region E, stage IV of UFLS was activated and ROCOF was brought to 0.12 Hz/sec. All the running generators responded and their response was given in table 6.5. However, machines response and activation of UFLS scheme IV were not sufficient to stop falling system frequency to the critical area which 47 Hz.

Table 6.5- Calculated inertial Response and Primary Response in Region E

Unit	Inertia (H)/(sec)	Rated MVA/(MVA)	Calculated initial response /(MW)	Inertial +Primary response at the end of Region A
VPS U2	3.45	95	1.6	36.3
VPS U3	3.45	95	1.6	38
NLPS Unit 1	3.30	72	1.1	34%
SPS	2.84	54.5	0.7	16
Umaoya	3.23	72	1.1	NA
LVPP	4.376	353	7.4	4

Source: Report submitted to AGM(Generation) by DGM(AMHE) on 25.02.2025

### 6.2.6 Region F with Frequency 47.5 Hz to 43.3 Hz and ROCOF of 1.3 Hz/sec

When the frequency reached to 47.0 Hz, all the inverters-based generation was taken out from the system and ROCOF was increased to 1.3 Hz/sec from 0.12 Hz/sec in Region E. Since the contribution from inverter-based generation at the time fault was estimated to be more than the 40% of the system actual load. The amount of generation loss at this stage was very high compared to the other time Regions. Even though this led to activation of UFLS stage IV with machine responses, the system frequency was unable to bring up. The calculated inertial responses and voltage correction responses are given table 6.6.

Table 6.6- Calculated inertial Response and Primary Response in Region F

Unit	Inertia (H)/(sec)	Rated MVA/(MVA)	Calculated initial response /(MW)	Inertial +Primary response at the end of Region A
VPS U2	3.45	95	17	43.3
VPS U3	3.45	95	17	49.6
NLPS Unit 1	3.30	72	12.4	45%
SPS	2.84	54.5	8	26
Umaoya	3.23	72	12.1	NA
LVPP	4.376	353	80.3	81

Source: Report submitted to AGM(Generation) by DGM(AMHE) on 25.02.2025

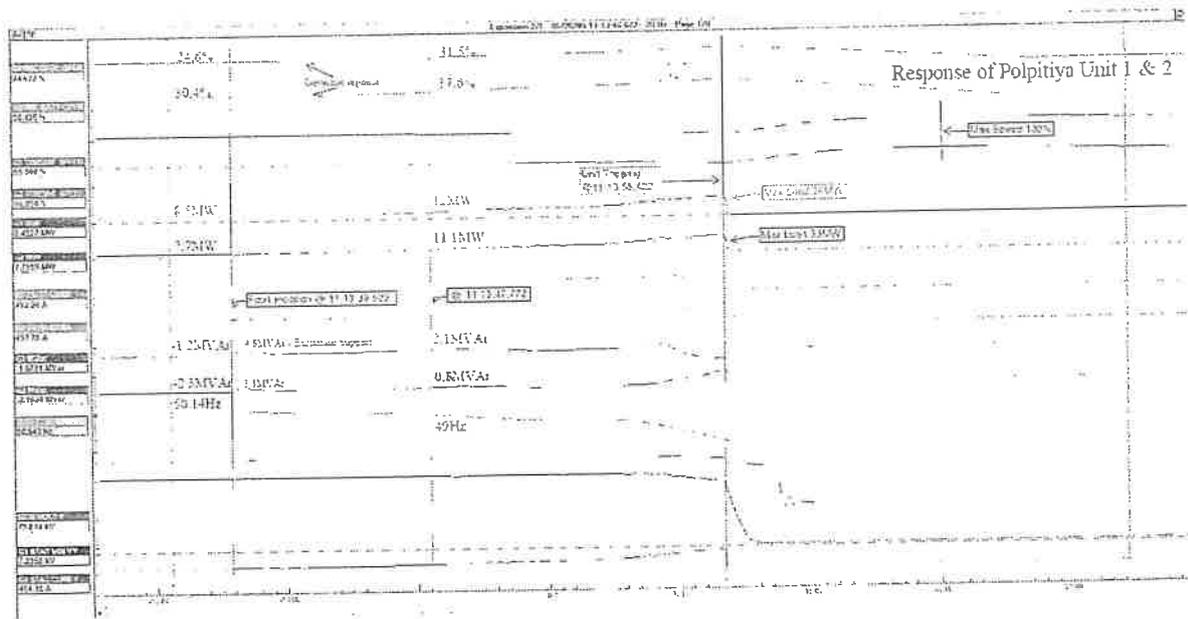


Figure 6.3- Response of Polpitiya Unit 1 and Unit 2 during the system failure

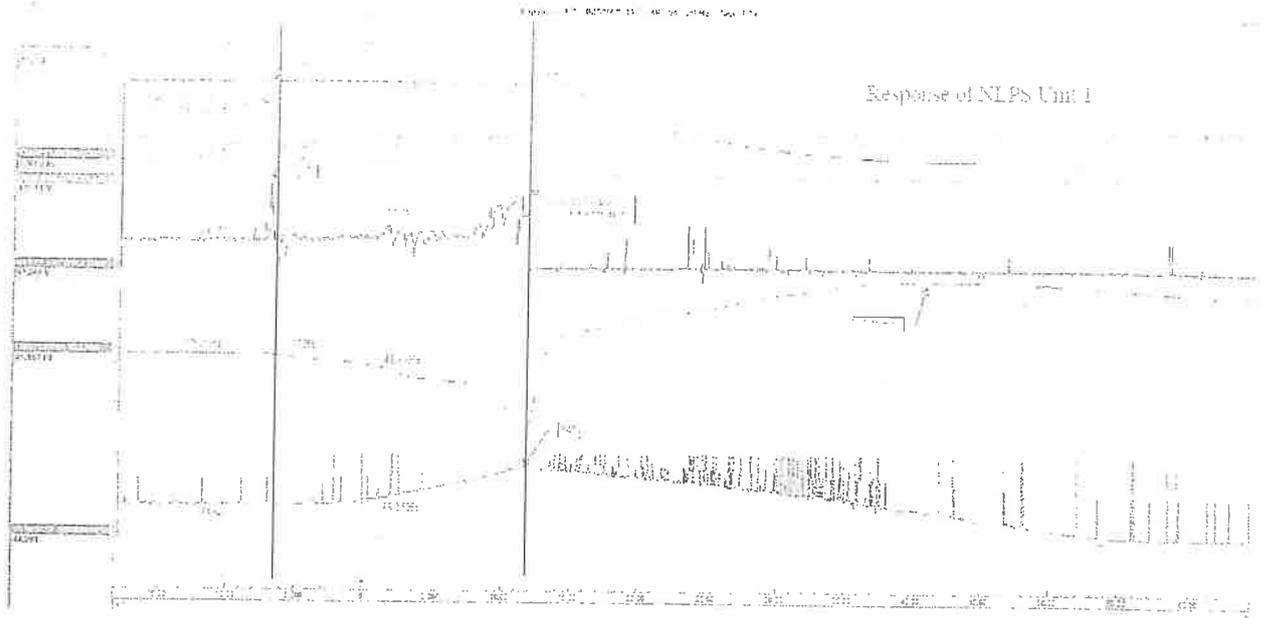


Figure 6.4 Response of New Laxapana Unit 1 during the system failure

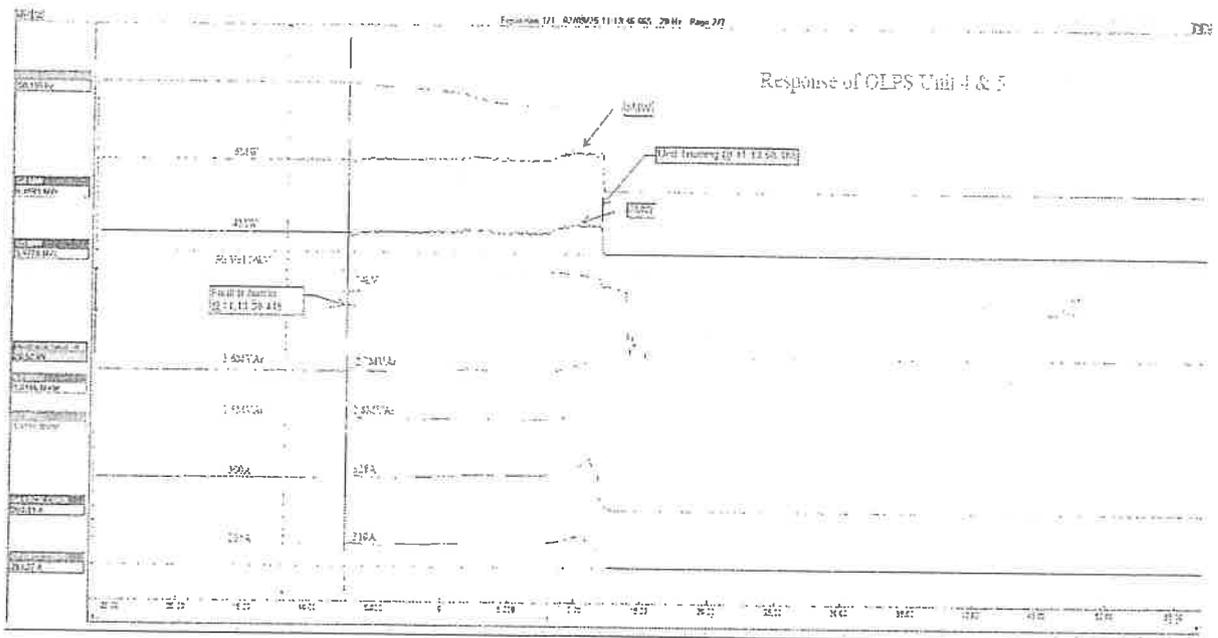


Figure 6.5- Response of Old Laxapana Unit 4 and Unit 5 during the system failure

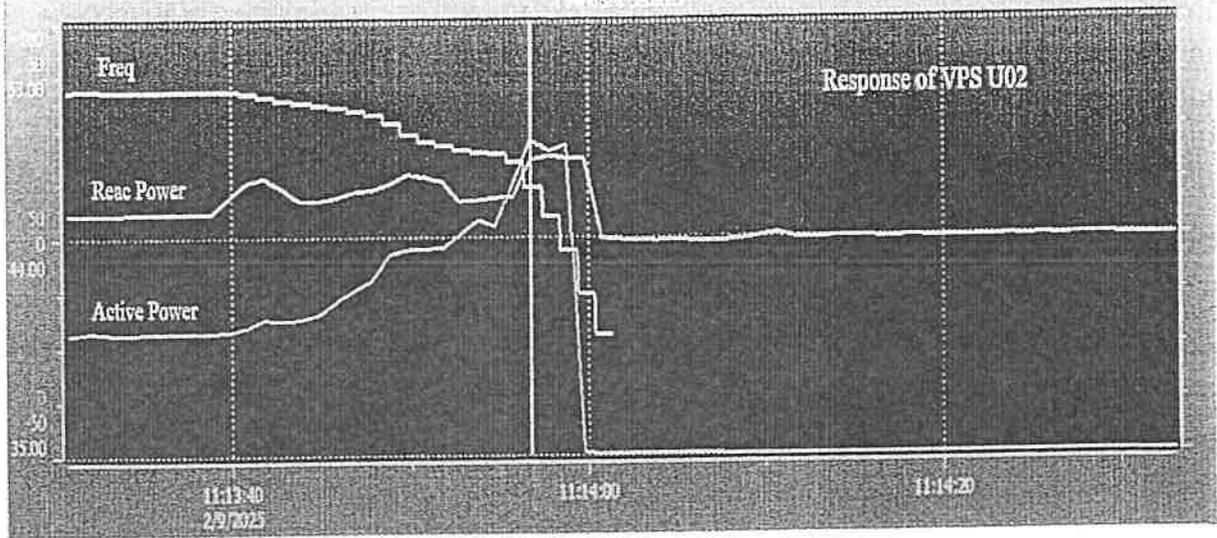


Figure 6.6- Response of Victora Unit 2 during the system failure

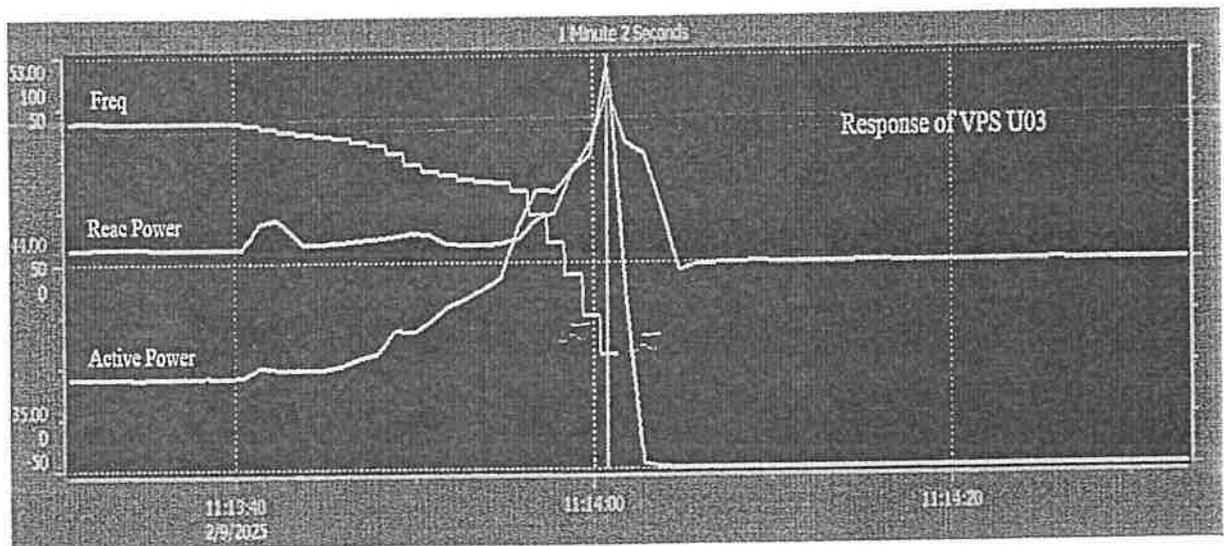


Figure 6.7- Response of Victora Unit 3 during the system failure

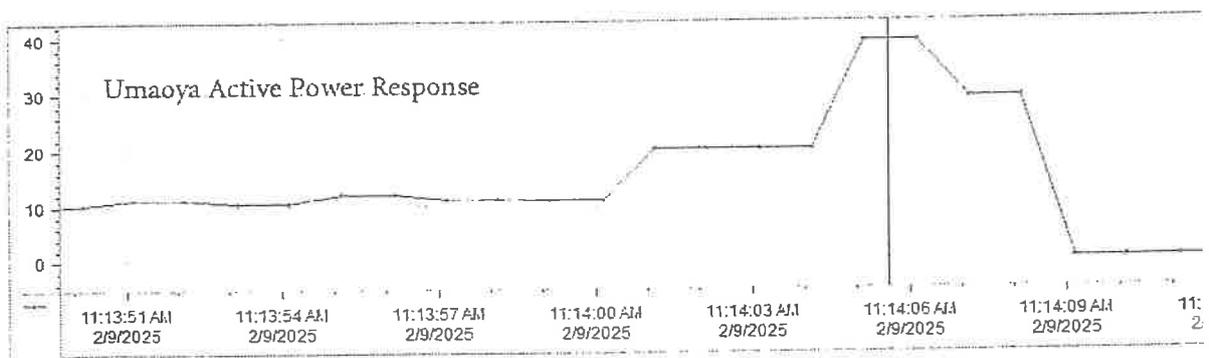


Figure 6.8- Response of Umaoya during the system failure

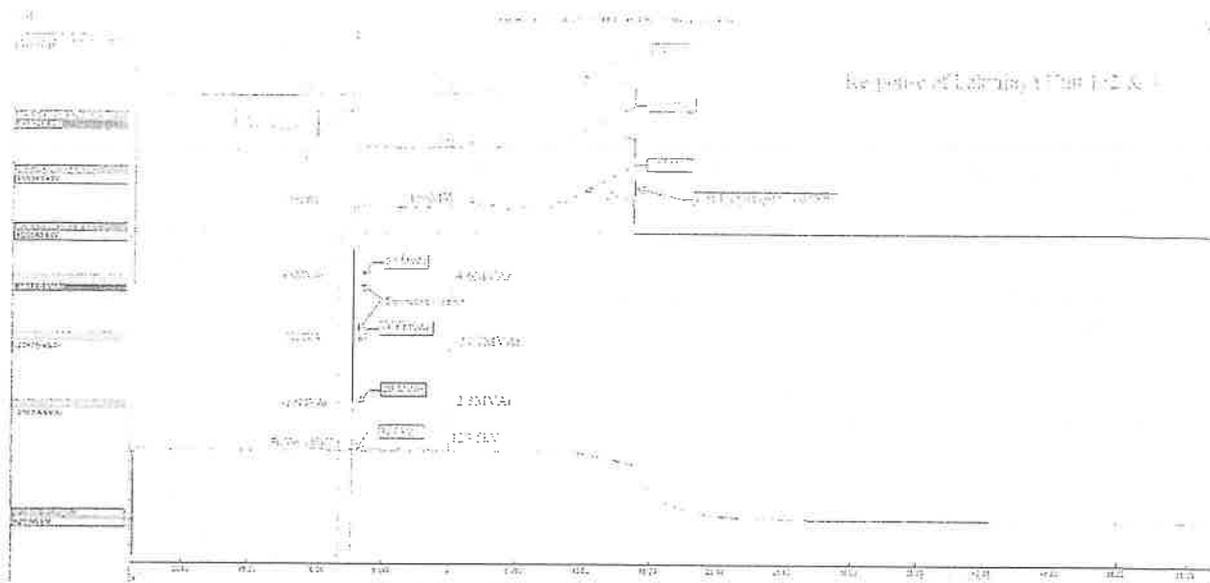


Figure 6.9- Response of Lakvijaya Unit 1, Unit 2 and Unit 3 during the system failure

It appeared that due to the double line to ground fault initiated at 33 kV busbar of Panadura GSS led to drop the system voltage by nearly 40% at Panadura and other Grid Substations nearby to Panadura Grid Substation. This caused to take away certain amount of inverter-based generation from the system leading draw more power from the running generators starting system frequency to fall. The analysis of inverter settings of RTSPV systems, considerable portion of them were set to trip 49.5 Hz and 94% of nominal voltage. Thus, continuous drop of the system frequency took place leading activation of IV stages of UFLS. However, the shed load was not as expected due to not updating the UFLS since 2014. The UFLS feeders too connected with Solar PV generation and fed the consideration number of loads in those feeders. It was noticed that some feeders were back feeding and tripping of these feeders has aggravated the system condition bring to the stable operation. Due to the reasons stated above the total system failure was unable to stop.

## 7. Chapter 7: RESTORATION AFTER THE FAILURE

### 7.1 Introduction

Following the total system failure triggered in 33 kV busbar in Panadura GSS, the system restoration has been started as follows;

System restoration was carried out based on the restoration manual (Rev.08 / Feb.2024) prepared by NSCC.

#### 1. Laxapana System

Except WPS unit No.01 in islanding mode, entire laxapana Complex failed to restore the System.

#### 2. Mahaweli System

As indicated above this is the main back born system to restore the entire System, except one unsuccessful attempt.

#### 3. Southern System

Samanalawewa both machines were released for maintenance and unable to support for restoration process and Kukule machines also failed to support the restoration process.

#### 4. Colombo system restoration

Restoration started at 13.05 hrs. through a Frame V machine (GT-02), but it failed to restore and finally restored through from Mahaweli machines.

#### 5. Islanding operation of Kukule machines failed and WPS was successful.

First Energized : 12.52hrs on 9<sup>th</sup> Feb.2025 (Biyagama GSS)

Last Energized : 15.44hrs. on 9<sup>th</sup> Feb.2025 (Mannar/Padukka GSS)

A. First attempt of restoration started at 12.01hrs. and failed at 12.40hrs

B. Second attempt started at 13.00hrs. and was successful.

C. Auxiliary supply to LVPP started at 12.01hrs. by Upper Kothmale unit No.02 machine and was abundant due to Diaphragm failure of all three units of LVPS.

D. Colombo restoration started at 13.05hrs. through GT2 but it was delayed and finally all Colombo GSS's energized at 15.30hrs.

(Source: National System Control Centre)

### 7.2 Restoration Summary

Table 7.1- Timeline-based restoration of Grid Substations / Power Stations

Restored Duration	Grid Substations / Power Stations
Restored within half an hour ( 0 - 1/2 hr)	0
Restored within the next half an hour (1/2hr-1hr)	3
Restored within the next half an hour (1hr-1 1/2 hr)	4
Restored within the next half an hour (1 1/2hr-2hr)	3
Restored within the next half an hour (2hr-2 1/2 hr)	4
Restored within the next half an hour (2 1/2 hr-3hr)	7
Restored within the next half an hour (3 hr-3 1/2hr)	9
Restored within the next half an hour (3 1/2 hr-4 hr)	21

Restored within the next half an hour (4 hr-4 1/2 hr)	43
More than 4 1/2 hrhr	4

Status	Primary SS	Time (hrs)	GSS	Time (hrs)
First Energized	Sub J	13.27	Biyagama	12.52
Last Energized	Sub G	14.56	Padduka/Mannar	15.44

LVPS all units delayed for synchronizing due to Diaphragm failure.

Source: National System Control Centre

### 7.3 Sequence of Restoration

Please refer Annexure 8 (Source: National System Control Centre Report)

### 7.4 Problems Encountered during the restoration of the failure

Table 7.2- Issues Encountered in the Restoration Process

STATION	EQUIPMENT	PROBLEM / COMMENT	Whether a delay is caused (Y/N)
Kelanithissa GSS	KPS GT 02	KPS GT02 could not be utilized for the Colombo City restoration due to the failure of the synchronizing breaker. Hence, Colombo City supply had to be restored from Mahaweli Complex via Kelanitissa GSS.	Y
N'Laxapana PS	Unit 01	New Laxapana Unit 01 could not be loaded after line charging due to an issue in the auxiliary system (It should also be noted the unit tripped three times during the startup). Hence, restoration from Laxapana complex could not be continued. The unit 01 could only be synchronized and loaded once the New Laxapana switchyard was energized via Polpitiya.	Y
New Laxapana PS	Balangoda 132kV cct 01	The incorrect indication of the breaker position for the New Laxapana – Balangoda Circuit 01 resulted in a delay in the restoration of the Southern system. Subsequently, the restoration was carried out via cct 02.	Y
Kukule PS	Unit 02	Auxiliary failure at Kukule PS resulted in Kukule Unit 02 tripping multiple times. Therefore, restoration from Kukule PS could not be initiated.	Y
Kotugoda GSS	Auxiliary system	220 kV operations could not be performed at Kotugoda GSS due to auxiliary failure. Later, the GSS was energized via Biyagama GSS.	Y
Kotmale PS	Diesel Generator	The repeated failures of the Kotmale DG (Diesel Generator) caused delays powering up the auxiliary system, which was needed to prepare Kotmale	Y

		machines for restoration.	
General	General	In general, lack of awareness among control room operators (CROs) at grid substations (GSSs) was observed as they didn't have a clear understanding on the standing instructions to be followed during a total failure. Adding to that, Under Frequency Load Shedding (UFLS) scheme had not been disabled in some GSSs after the total failure.	Y

Source: National System Control Centre

8. CHAPTER 8: COMMITTEE OBSERVATIONS & RECOMMENDATIONS

## Recommendations

1. Compared to power systems in the past which had unidirectional power flow, present power systems are multi directional power flow systems where Distribution systems has become more active. Therefore, conventional over current and earth fault protection systems are not adequate to keep the system safe, reliable and stable. Therefore, distribution system protection schemes are recommended to be revisited. Further transmission system protection schemes are too be revisited as there are many transmission segments where flow direction and magnitude changes are too dynamic in present system.
2. Since Inverter settings play a vital role for maintaining system stability, special attention should be paid to develop inverter settings rather than following an improper methods and systems. All inverter settings should be revisited and it is required to ensure that the settings are accurately configured.
3. Since inverter manufacturers have access to the settings, there could be an issue with system stability affecting national security. Hence, a mechanism should be developed to avoid the change of the settings by manufactures after the inverters were commissioned and connected to the power system.
4. Since the present UFLS scheme was developed just after the commissioning of Lakvijaya Power Plant (LVPS) and the same has been not updated for more than 10 years, UFLS should be revisited as soon as possible. Hence, it is required to devise an Adaptive Load Shedding (ALS) scheme. ALS schemes have to be analyzed regularly and updated in suitable time intervals at least once a year.
5. Since National System Control Center (NSCC) has lack of visibility of embedded generators mainly RTSPV systems, a methodology should be developed and implemented to monitor the relevant information for system operations.
6. In order to make an estimation of the embedded generator dispatch in advance (day ahead, hour ahead etc.), an accurate forecasting system should be available to the National System Control Center.
7. Penetration of non-synchronous based generation are very high at present. This has led not to operate conventional generators in the system thereby reducing system inertia where the system is more vulnerable even for small disturbances. Therefore, inertia support devices like BESS, Synchronous condensers proposed in Long Term Generation Expansion Plan (LTGEP) and Long-Term Transmission Plan should be implemented as planned.
8. Since the demand seen by the NSCC is very low especially in sunny Sundays and Public Holidays, a suitable scheme is needed for consumers to use more power from the grid.
9. Since, NSCC basically follows 5% of the present demand as reserve margin and lack of estimator for gross demand, a revision to reserve margin policy should be done as soon as possible.

10. It was noticed that the Automatic Generation Control was not utilized though the system is equipped with it. The AGC has to be utilized at all times with multiple machines.
11. Since system studies at present play a vital role in real time as well as off line, the power system models such as generator, lines, loads should be updated on regular basis to represent accurate system response. Therefore, accurate system models should be developed as soon as possible.
12. There are several bottle necks including low fault levels in the transmission system and some of them to be rectified with ongoing critical projects. Special attention should be paid to complete these projects with close monitoring.
13. Lack of Engineers in Planning and Operation branches has found difficulties in running these branches and young engineers should be recruited to these branches as early possible. A proper succession plan to be adopted not to disturb the work flow of these branches when trained Engineers were leaving these branches.
14. The system inertia plays a vital role in system stability in an event of a disturbance. Therefore, the system operator should have an idea of the system inertia for the machine configuration operating in the power system. Therefore, it is recommended to indicate system inertia at the mimic board.
15. Since it experiences low demand in sunny Sundays and Public Holidays, a special operational policy should be developed for Sunny Sundays and Public Holidays by getting special permission to run Mahaweli machines from Water Management Secretariat.
16. With the high penetration of inverter-based resources, the system inertia will reduce and system is susceptible to even for small disturbance. Thus, it is better to have the facility to run conventional generators in the system in synchronous condenser mode. Hence, the Generation Division is required to take actions and make modifications to implement the same.
17. It was noticed that the system has no machines to restore Colombo with a higher priority. Hence, it is recommended to check the possibility of Colombo restoration through Sobadanavi Power plant with amendments to existing PPA or other alternatives. NSCC shall be responsible for whole restoration including Colombo and the restoration manual shall be updated accordingly.
18. The restoration manual shall be reviewed each year by using off line & real time simulations.
19. Since there is no back up for the existing system control center, the system operation cannot be guaranteed if anything happened to it. Therefore, it highly recommended to establish a backup system control center to transfer operation in the event of failure of the existing NSCC.
20. Initial charging capabilities of Laxapana machines to be reviewed and adjust accordingly and real time simulation has to be carried out in order to verify the machine capabilities.
21. Development of RE desk is predominant and it is suggested to incorporate Met masts data which are constructed by Renewable Energy Development Branch (six nos. already

constructed and another six have to be constructed). This will cover the wind regime across the coastal area of the Island. It is required to obtain real time wind & solar data which is a very useful tool for forecasting.

22. SCADA system shall be updated with correct time tags (Communication Branch with NSCC)
23. Remove the auxiliary supply restoration to LVPP through Upper Kothmale Machines (from the restoration manual)
24. First energization feeders to be reviewed (composition of embedded generation with the help of DCC)