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Analysis of Power System Failure Occurred on 09 February 2025 in Sri Lanka's Power System

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Abstract: This paper discusses the total power system failure that occurred in Sri Lanka on 9 February 2025 and reviews the key technical aspects intended to ensure the smooth and stable operation of the power system. The study examines the performance of (a) protection relays, (b) the Under Frequency Load Shedding (UFLS) scheme, (c) frequency-controlling machines, and (d) inverter-based solar and wind power plants during the disturbance. The analysis identifies deficiencies in system response, particularly in the coordination of protection systems and the behaviour of inverter-based generation under abnormal grid conditions. Based on the findings, the paper recommends the implementation of robust, grid-friendly inverter control settings and the enactment of regulatory provisions to ensure mandatory compliance by all stakeholders. These measures are essential to enhance power system resilience and prevent similar large-scale failures in the future.

Keywords: Blackout, Failure occurred on 9 February 2025, Load shedding Scheme, LVRT; Power System Failure, Power System Stability, Total Failure in Sri Lanka, UFLS

1. Introduction

1.1 Power System Failure

A power system failure, commonly referred to as a blackout, is a disruption in the electricity supply resulting in a partial or total loss of power to consumers. Such failures may be triggered by disturbances in generation, transmission, or distribution systems, and can arise from a variety of causes, including natural events (e.g., storms, lightning, landslides), technical issues (e.g., equipment failures, short circuits), human-related factors (e.g., construction accidents, vandalism, organizational or operational errors, cyberattacks), or system overloads when electricity demand exceeds available supply.

Power system failures can range from localized outages affecting limited areas to large-scale system collapses involving the entire interconnected grid. These events can significantly impact residential users, commercial activities, and critical infrastructure, and may result in substantial economic losses and safety risks.

1.2 Recent Power System Failures

Several major power system failures have occurred in Sri Lanka in recent years. A summary of selected incidents and their initiating causes is presented in **Table 1.**

Table 1 - Recent Power System Failures in Sri Lanka

Date	Description
2015-09-27	An island-wide power failure that was ultimately a voltage-related phenomenon after a fault. [5]
2016-02-25	Failure initiated due to tripping of Kolonnawa - Seethawaka 132 kV Transmission line.
2016-03-13	Failure initiated due to a tripping of a Transformer at Biyagama GSS.
2020-08-17	The primary cause of the blackout was a technical failure at the Kerawalapitya Grid Substation.
2021-12-03	The disconnection of the main transmission line (i.e. Biyagama - Kotmale Line) led to an imbalance between generation and demand, causing a cascading failure that tripped generators and other parts of the grid island-wide. [6]
2023-12-09	The total power failure in Sri Lanka on December 9, 2023, was caused by a fault in the transmission line running from Kotmale to Biyagama, which was triggered by a lightning strike. This initial failure led to a cascading system collapse. [3]

It is observed that power system failures are not unique to Sri Lanka, and similar large-scale blackouts have been reported in power systems worldwide, highlighting the global nature of grid reliability and stability challenges. [2]

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This paper analyses the Power System Failure occurred in Sri Lanka on 9 February 2025, affecting all transmission lines, power stations, and grid substations in the national power system. **Figure 1** shows the Net Generation Curve on Sunday February 9, 2025.

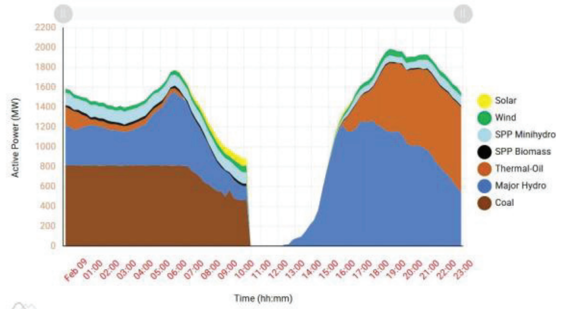


Figure 1 - Net Generation Curve on Sunday February 9, 2025

1.3 Overview of the Sri Lankan Power System

Figure 2 illustrates the Sri Lankan transmission network, providing an overview of the major power generation stations, grid substations, and the high-voltage transmission lines interconnecting these facilities across the country. The diagram highlights the geographical distribution of generation resources and the structure of the transmission system, which collectively enable bulk power transfer from generation sites to load centers.

1.3.1 Power stations and Grid Substations

The total installed generation capacity of Sri Lanka's power system is 6,009 MW. This capacity comprises generation assets owned by the Ceylon Electricity Board (CEB) and Independent Power Producers (IPPs), including conventional thermal and hydro plants as well as non-conventional renewable energy sources. The breakdown of installed capacity by plant type and ownership is summarized in **Table 2**.

Table 2 - Installed Capacity of Power Plants in Sri Lanka

Type of Power Plant	Capacity (MW)
CEB-Owned Plants	
Conventional Hydropower	1512
Mini Hydropower	20
Thermal Power Plants	1647
IPP-Owned Plants	
Thermal Power Plants	482
Non-Conventional Renewable Energy (NCRE)	2348
Total Installed Capacity	**6009**

The total installed capacity of Non-Conventional Renewable Energy (NCRE) plants in Sri Lanka amounts to 2,348 MW. These plants include wind, solar, mini-hydro, and biomass-based generation, owned by both CEB and IPPs. The composition of NCRE capacity by technology and ownership is presented in **Table 3**.

Table 3 - Installed Capacity of NCRE Power Plants in Sri Lanka

Type of NCRE Power Plant	Capacity (MW)
CEB-Owned NCRE Plants	
Mannar Wind Power Plant	103
IPP-Owned NCRE Plants	
Mini Hydropower	423
Wind Power Plants	163
Ground-Mounted Solar PV	172
Rooftop Solar PV – CEB Area	1174
Rooftop Solar PV – LECO Area	259
Biomass Power Plants	54
Total NCRE Capacity	**2348**

The Sri Lankan transmission system presently comprises 82 grid substations and 16 switching stations.

1.3.2 Distribution regions

There are five distribution regions in total, of which four are under CEB and one is under Lanka Electricity Company (Private) Limited (LECO).

2. Fault at Panadura Grid Substation

2.1 Date and Time of the Failure

Date : 9 February 2025
Time : 11:13:39 hrs

2.2. Pre-Fault Condition

The generator active power output and reactive power generation immediately prior to fault initiation are presented in **Table 4**, while the available system spinning reserve at the same time is summarized in **Table 5**.

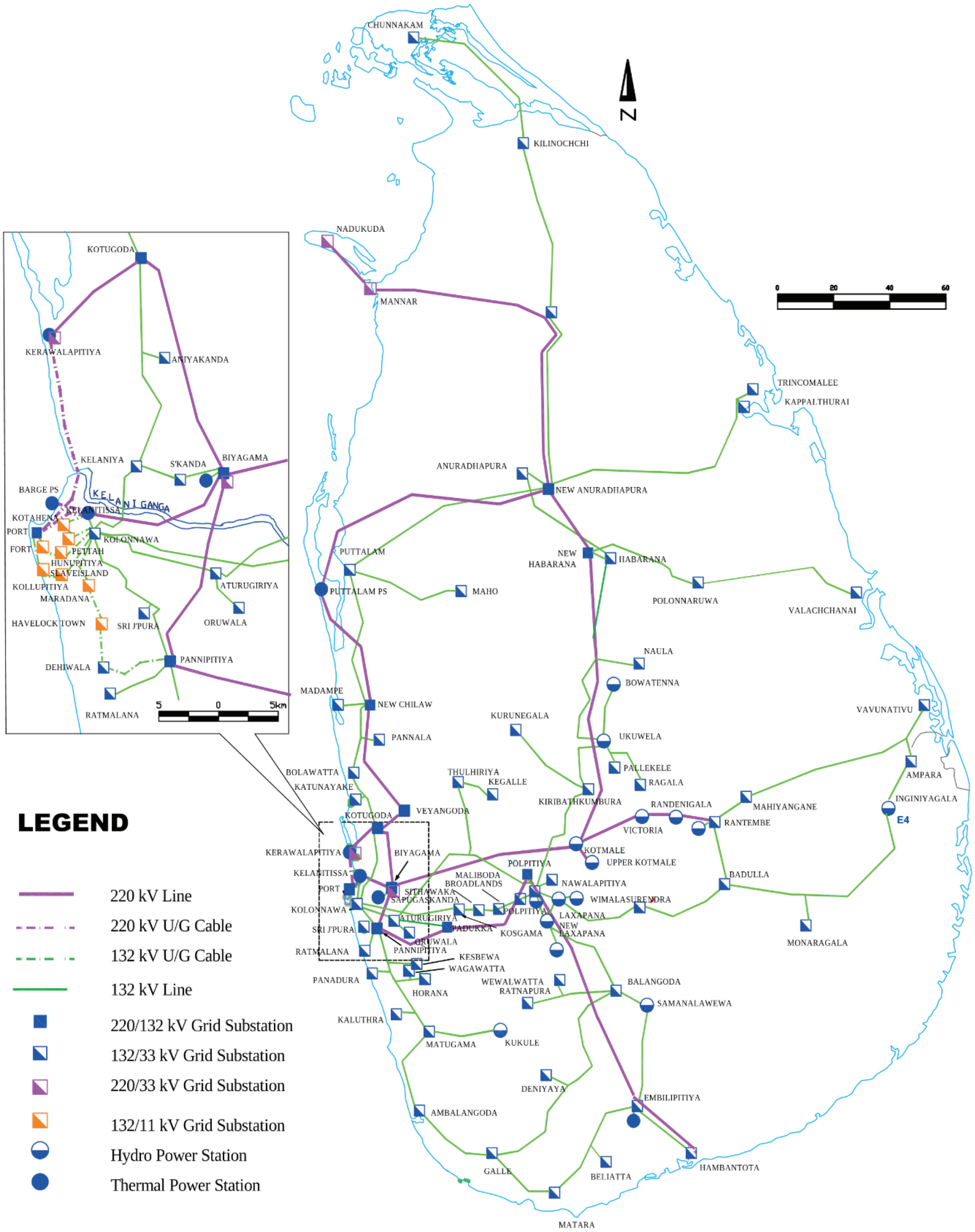


Figure 2 -The Map of Sri Lanka Transmission System

Table 4 - Generation Data at 11:13:39 hrs

Source	Active Power (MW)	Reactive Power (Mvar)
Laxapana Complex	66	12
Mahawali Complex	50	9
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	0	66
Total	**739**	**141**

Table 5 - Spinning Reserve

Parameter	Active Power (MW)	Reserve Margin (%)
Spinning Reserve	230	31.1

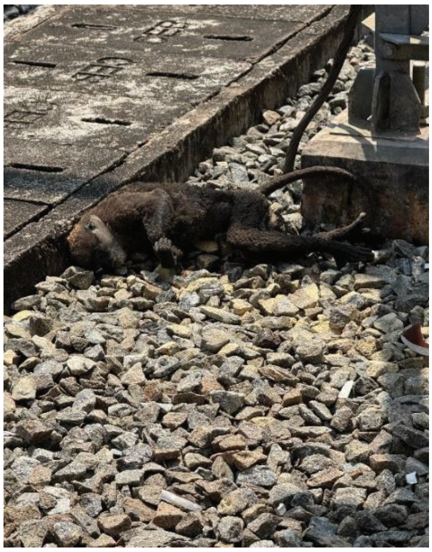
Frequency control at the time was provided by Unit 2 of the Victoria Power Station.

2.3 Fault Initiation

The fault was initiated when a monkey came into contact with the 33 kV bus bar section 1 and the lightning arresters installed on the bus section near the control room. Two surge arresters corresponding to phases R and Y were completely destroyed due to an arcing flash. The surge counters of both phases were damaged, and the arresters were likely short-circuited to ground, resulting in their failure.

Photograph 1 - The affected bus bar section

Photograph 2 - Possible monkey routes



Photograph 3 - Monkey carcass

Photographs 1, 2, and 3 illustrate the equipment failures and the monkey carcass found at the Panadura Grid Substation on the date of the failure.

2.4. Single Line Diagram of Panadura Grid Substation (GSS)

Figure 3 illustrates the electrical single-line diagram of the Panadura Grid Substation.

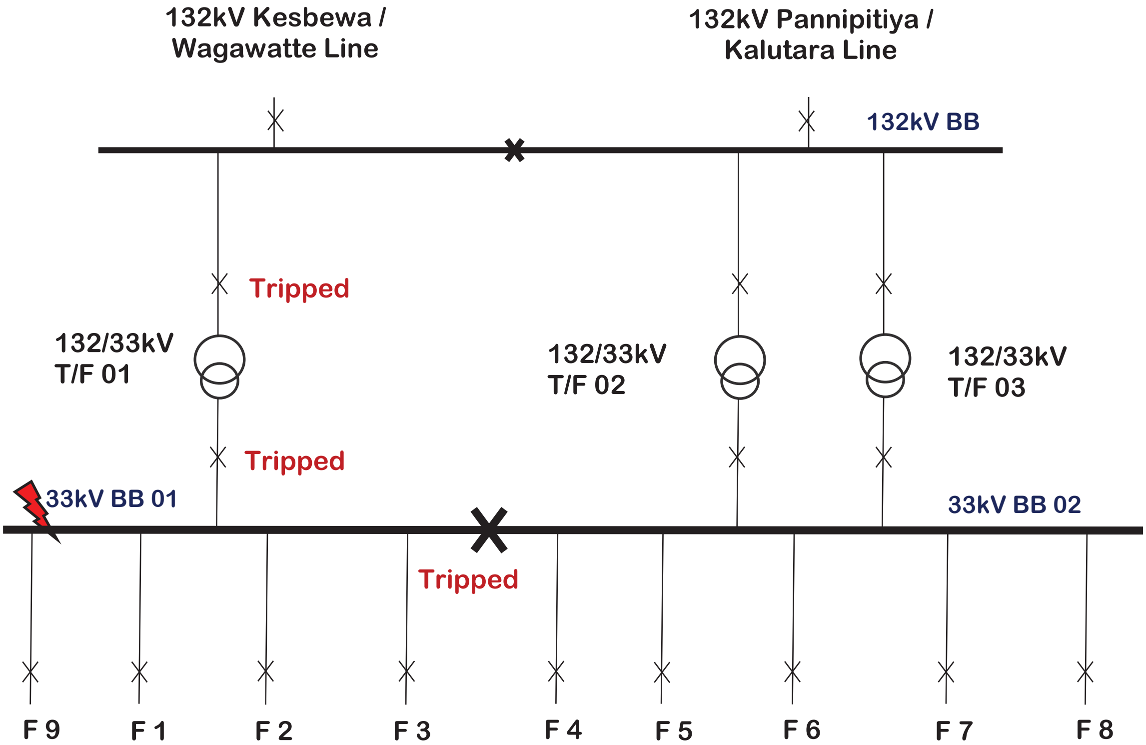


Figure 3- Single Line Diagram of Panadura GSS

2.5 Protection Block Diagram of Panadura Grid Substation (GSS)

Figure 4 illustrates the electrical protection block diagram of the Panadura Grid Substation

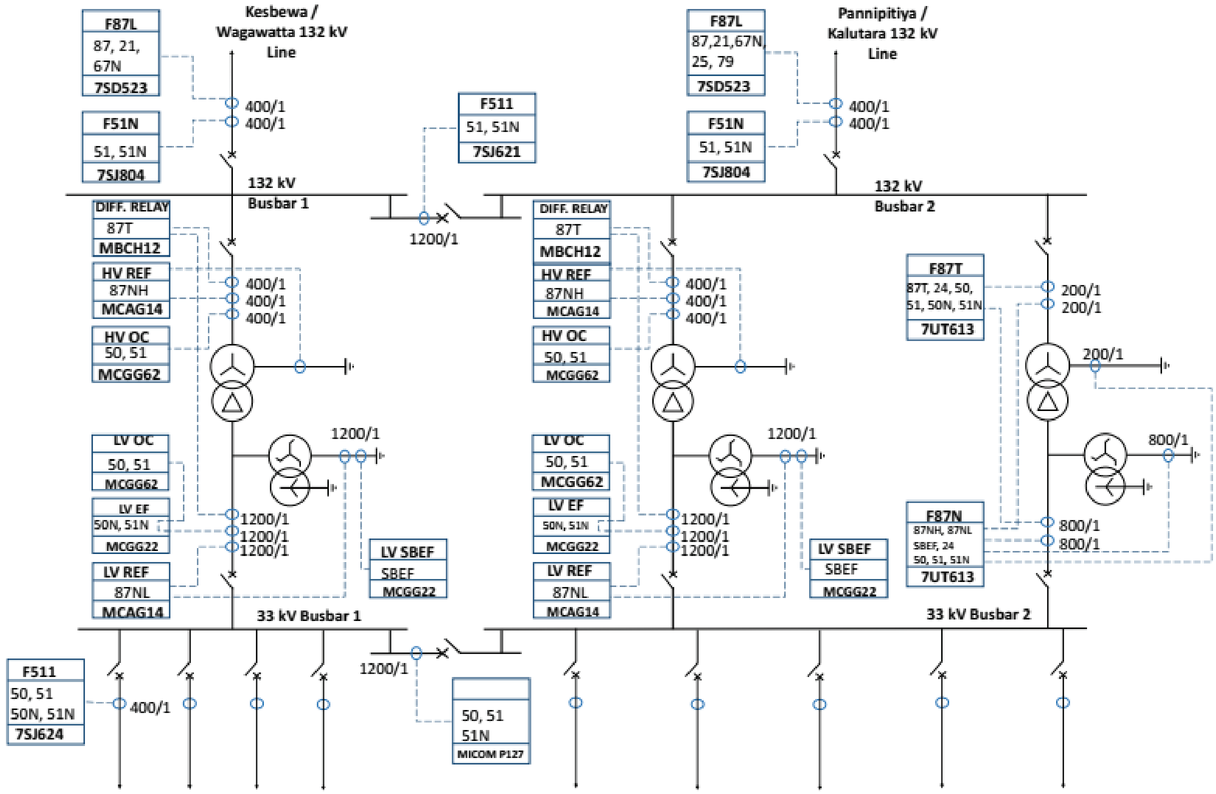


Figure 4 - Protection Block Diagram of Panadura GSS

2.6. Equipment Tripped and Protection Relays Operated at Panadura GSS

The protection relay operations recorded at the Panadura Grid Substation (GSS) during the event are summarized in **Table 6**. The table lists the equipment that tripped, the corresponding protection relays that operated, and the associated trip times.

Table 6 - Protection Relays Operated

Equipment Tripped	Relays Operated	Trip Time
33kV Bus Section	MiCOM P127 – Over Current I>>	11:13:40.00hrs*
132/33kV Transformer 1	MCGG 82 IDMT Overcurrent	11:13:40.58hrs*

Note: * Trip times are approximate, based on the Digital Disturbance Record (DDR) of the 132 kV Panadura–Wagawatte line at Kesbewa GSS.

2.7. Sequence of Events

Figure 5 provides an overview of the system frequency versus time and 132 kV busbar voltage versus time at the Kesbewa Grid Substation, which is adjacent to the Panadura Grid Substation.

The sequence of incidents that occurred during the system failure at the Panadura GSS is summarized below:

1. A fault occurred in the 33 kV Bus Bar 1 of Panadura GSS at 11:13:39.520 hrs on 9 February 2025, as shown in **Figure 3**. The fault was initiated when a monkey came into contact with the energized bus bar.
2. The overcurrent function of the MiCOM P127 relay of the 33 kV bus section operated correctly and cleared the fault at 11:13:40.000 hrs.
3. Subsequently, the 132/33 kV Transformer 1 of Panadura GSS tripped due to the operation of transformer overcurrent protection at 11:13:40.580 hrs.
4. Based on DDR records of Kesbewa GSS, the 132 kV R-phase voltage dropped by 40% for approximately 450 ms, followed by a further 20% drop lasting approximately 550 ms, before recovering to nominal voltage within 1.1 seconds.

Subsequently, a sequence of cascading events was observed. A reduction in system voltage in and around the Panadura Grid Substation (GSS) caused the inverters of several solar photovoltaic (PV) plants—particularly those not properly configured with adequate Low Voltage Ride-Through (LVRT) capability—to disconnect from the grid due to the operation of under-voltage protection. This loss of solar PV generation resulted in a reduction in overall system generation and a consequent decline in system frequency.

As the frequency continued to decrease, inverters of additional solar and wind power plants across the country were further disconnected through the operation of under-frequency protection. In response to the rapid frequency decay, Under-Frequency Load Shedding (UFLS) relays were activated in an attempt to arrest the decline in system frequency. Concurrently, the frequency-controlling unit at the Victoria Power Station increased its active power output to support system frequency and mitigate the rate of frequency reduction. A detailed analysis of these events, corresponding to the above sequence, is presented in Sections 3 to 7.

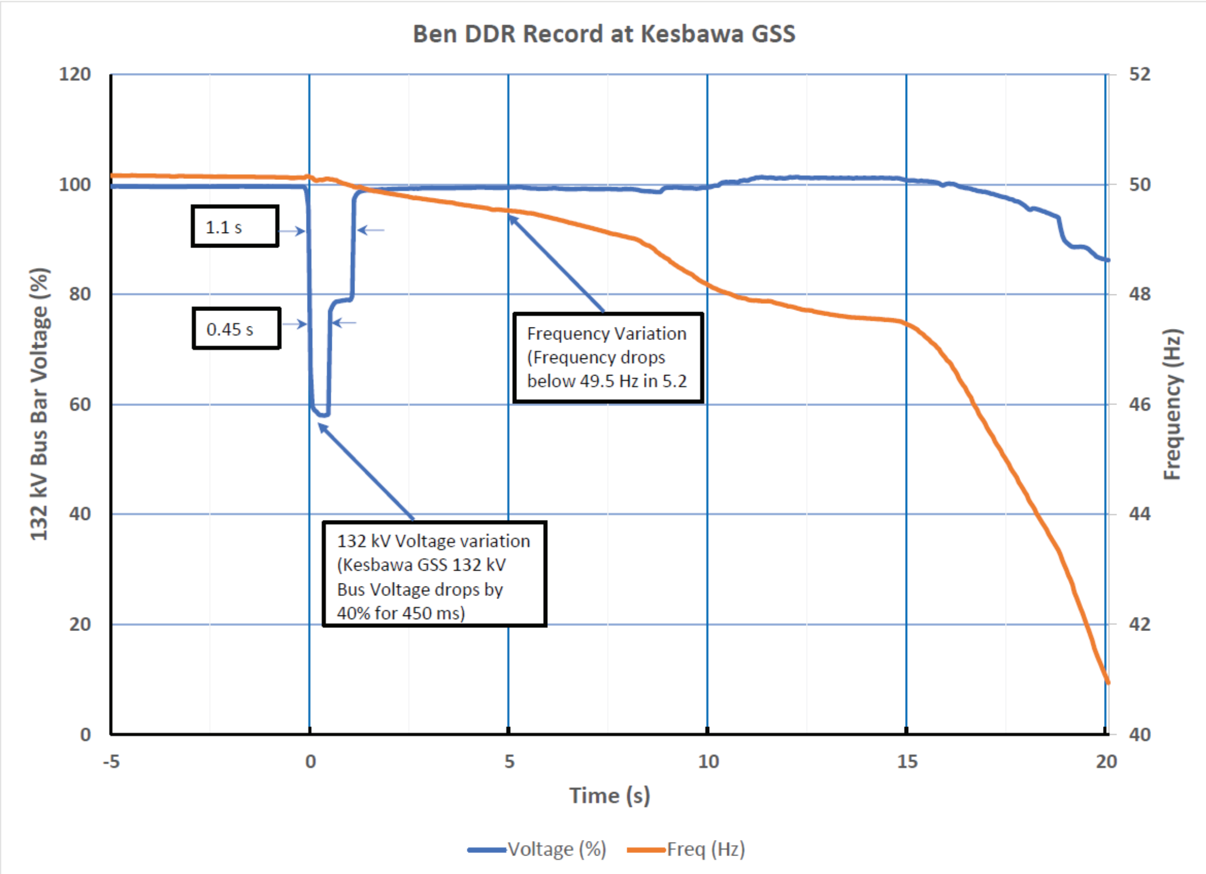


Figure 5 - Voltage and Frequency vs. Time graph

3. Operation of the Under Frequency Load Shedding Scheme (UFLS)

3.1. Function of the UFLS Scheme

When a large generator is suddenly disconnected (tripped) from the power system, the system frequency decreases due to the generation–load imbalance.

In most cases, the frequency-controlling machine is neither fast enough nor of sufficient capacity to arrest the frequency decline following the tripping of a large generator.

Therefore, the UFLS scheme is employed to stabilize the system frequency and restore it to nominal levels.

3.2. Operation of the UFLS on the Day of Total Failure

Although the 33 kV bus bar fault was cleared within 1.1 seconds, a continuous decline in system frequency was observed. Consequently, all UFLS stag were activated, as summarized in **Table 7**.

Table 7 - Operation of UFLS Stages on 9 February 2025

UFLS Stage	Criteria	Shedded load in [MW]	Shedded load as a %
Stage 1	48.75 Hz + 100 ms	65.4	8.90%
Stage 11	48.50 Hz + 500 ms	58.5	8.00%
Stage 111	48.25 Hz + 500 ms	65.7	9.00%
Stage 1V	48.00 Hz + 500 ms	75.2	10.30%
Stage V	47.5 Hz instantaneous	5.8	0.80%
Stage V or df/dt	47.5 Hz instantaneous OR 49 Hz AND df/dt > -0.85 Hz/s + 100 ms	23.2	3.20%
df/dt		112.3	15.30%
Total		**406.1**	**55.50%**

The effectiveness of the load shedding scheme is significantly reduced by the presence of embedded generation (e.g., solar, wind, mini-hydro, biomass) in the system.

On the day of total failure (9 February 2025, 11:13 hrs), centrally dispatched generation accounted for only **49.6%** (739 MW) of the estimated total generation (1,489 MW). Accordingly, the effectiveness of the UFLS scheme was also reduced to approximately **49.6%**.

By contrast, UFLS is generally more effective during nighttime, as embedded generation is minimal due to the unavailability of rooftop and ground-mounted solar power plants.

Figure 6 illustrates the system frequency versus time profile, covering the period from fault initiation to total system collapse, i.e., from t = 0 s to t = 22.5 s. When the system frequency declined to 48.75 Hz, Stage 1 of the Under-Frequency Load Shedding (UFLS) scheme was activated. Subsequently, the remaining UFLS stages were triggered at predefined frequency thresholds, with Stage 5 operating when the frequency reached 47.5 Hz. During this period, conventional large power plants remained connected to the system and were not disconnected until the system frequency further declined to approximately 43.3 Hz. [1]

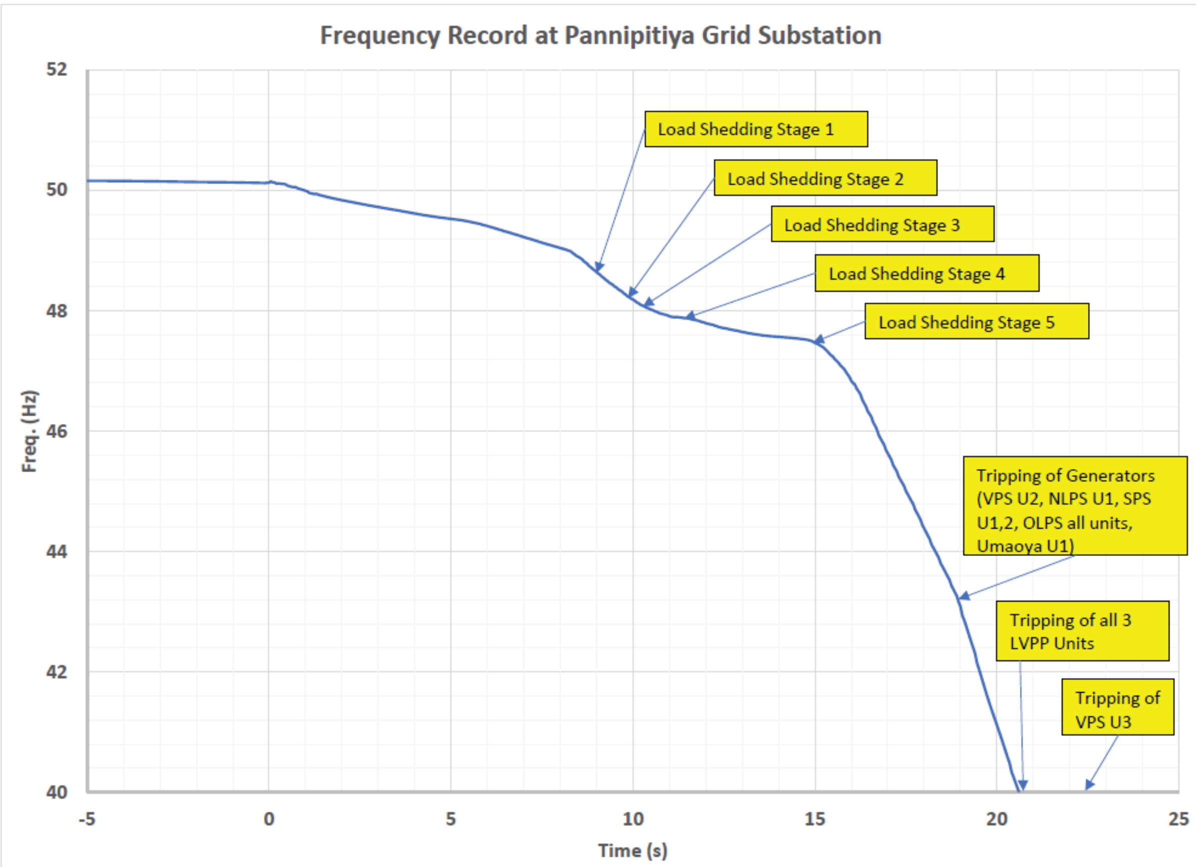


Figure 6 - Frequency Record at Pannipitiya GSS with UFLS Operation & Generator Trippings

4. Performance of the Frequency-Controlling Machine at Victoria Power Station

On the day of the total failure, frequency control was carried out by **Unit 2 of the Victoria Power Station**. According to the station's recorded data, the unit responded rapidly to the decline in system frequency by increasing its power output. The system frequency and corresponding output power of Unit 2 are summarized in **Table 8**.

Table 8 - Recorded System Frequency and Output Power of Unit 2 at Victoria Power Station

	Time	Power (MW)	Frequency (Hz)
01	11:13:40.0	29	50.12
02	11:13:45.0	33	49.51
03	11:13:50.0	47	48.27
04	11:13:55.0	55	47.48
05	11:13:56.8	72	46.07
06	11:13:57.8	70	44.86
07	11:13:58.7	71	43.48

The recorded data indicate that Unit 2 at Victoria responded appropriately by increasing its active power output in an attempt to restore system frequency.

5. Tripping of Conventional Generators

According to the available records, all major conventional large generators remained in operation and connected to the system until 11:13:58.376 hrs, when the frequency had fallen to 43.3 Hz. [1]

This indicates that conventional generators stayed online until the system frequency reached critically low levels.

6. Power Flow in the Pannipitiya–Panadura–Horana Transmission Line

Figure 7 presents the following plots: (a) system frequency versus time, and (b) active power flow versus time for the Pannipitiya–Panadura–Horana 132 kV transmission line. The plots indicate a noticeable increase in power flow along the Pannipitiya–Panadura–Horana corridor immediately after the 33 kV busbar fault at the Panadura Grid Substation (GSS) was cleared.

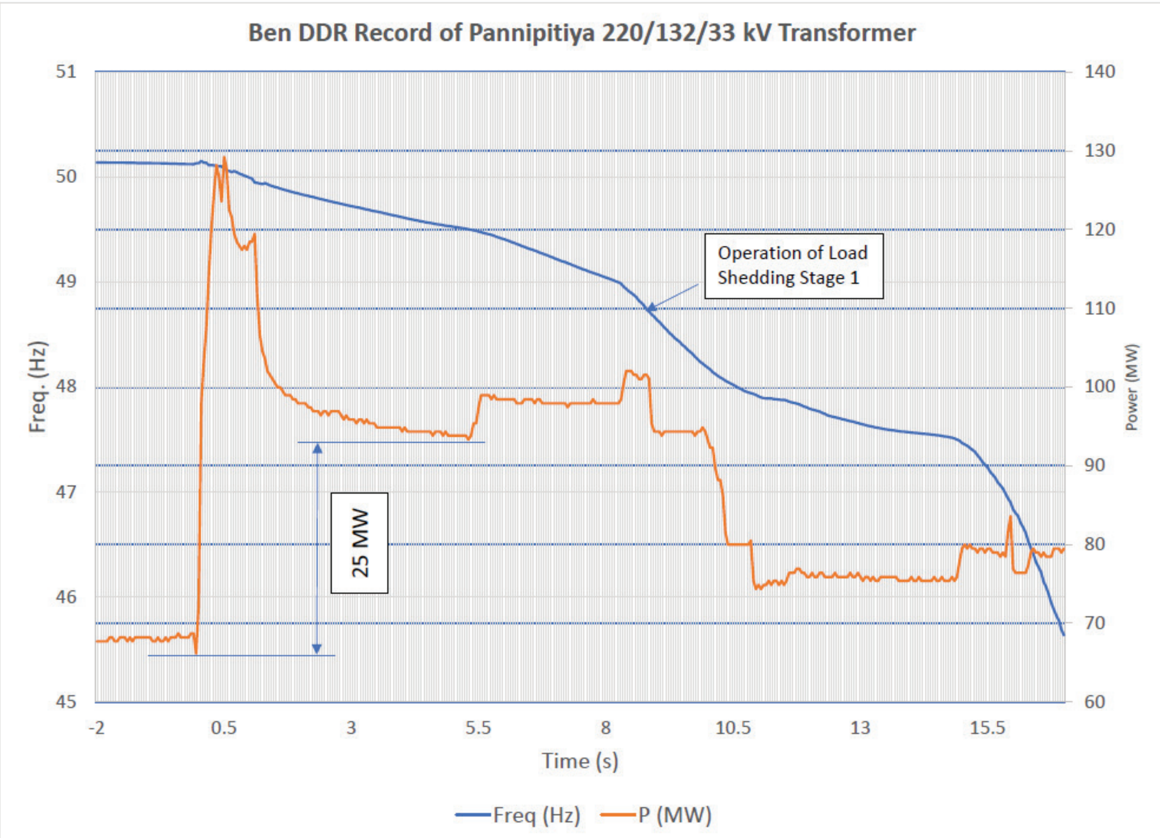


Figure 7 - Frequency Record & Power flow in 220/132kV Transformers at Pannipitiya GSS

A comparison of pre-fault and post-fault operating conditions shows an approximate 25 MW increase in active power flow through this transmission corridor. The Kesbewa, Panadura, Kalutara, Horana, Matugama and Ambalangoda Grid Substations are supplied through the Pannipitiya–Panadura–Horana 132 kV corridor.

7. Inverter Settings of Rooftop and Ground-Mounted Solar PV Systems

In previous years, the contribution of solar PV systems to the national grid was relatively small. To prevent unintentional islanding of PV systems in the event of grid outages (e.g., tripping of 33 kV or 11 kV feeders), the Ceylon Electricity Board (CEB) implemented the following inverter protection settings:

- **Frequency:** 49.5 Hz – 50.5 Hz
- **Voltage:** 94% – 106% for inverters connected to LV networks; 95% – 105% for inverters connected to MV networks

These protection thresholds were designed to ensure that, in the event of feeder tripping, solar PV inverters would not maintain islanded operation, thereby safeguarding customers connected to the distribution network.

However, this configuration introduces a critical drawback. When solar PV accounts for more than 50% of total system generation, even a minor disturbance in voltage or frequency can trigger the widespread disconnection of inverters, significantly increasing the risk of a system-wide collapse.

Thus, while the inverter protection strategy ensures safety and power quality at the consumer level, it inadvertently undermines overall system resilience under conditions of high solar penetration, as observed in the events leading to the blackout of 9 February 2025.

8. Remedial Actions to Prevent Future Failures

8.1. Implementation of Robust Voltage, Frequency and Fault Ride-Through Settings in Inverters

It is essential to implement robust voltage, frequency, and fault ride-through settings in inverter-based power plants (solar and wind) to prevent unnecessary tripping during grid disturbances such as bus bar faults. The CEB's internal committee reviewing the *Guide for Grid Interconnection of Embedded Generators of Capacity 10 MW and Below* has already proposed revised settings, which were formally adopted and communicated through a circular issued by the Distribution Coordination Committee (DCC) on 11 March 2025.

8.2. Adoption of Grid Support Functions in Inverter-Based Plants

The same committee has also recommended the incorporation of advanced grid support functionalities in inverter-based generation units, including:

- Volt-Var control mode
- Volt-Watt control mode
- Frequency droop (P-f) function

Adoption of these functionalities will enable inverter-based plants to actively support both system frequency and voltage stability during disturbances.

8.3. Mandatory Reconfiguring of Existing Inverter-Based Plants

The above recommendations (Sections 8.1 and 8.2) must also be applied to all existing inverter-based power plants currently connected to the Sri Lankan power system.

It is therefore recommended that a regulation be enacted under the provisions of the Electricity Act, mandating all inverter-based power suppliers to implement these grid-supportive settings. This regulatory step is critical to ensuring that embedded generation contributes to, rather than undermines, system stability in future disturbances.

The remedial actions outlined above are not only necessary to prevent a recurrence of the 9 February 2025 blackout but are also pivotal for ensuring the long-term stability of Sri Lanka's power system in the context of rising renewable energy integration. As the nation advances toward ambitious renewable energy targets, the share of inverter-based generation is expected to increase substantially, amplifying both the opportunities and risks associated with a cleaner energy mix. Strengthening inverter performance standards, mandating grid-supportive functionalities, and enforcing regulatory compliance will enable Sri Lanka to harness the full potential of solar and wind power without compromising reliability. In this way, the lessons from the system failure can be transformed into a catalyst for building a more resilient, sustainable, and future-ready power system.

9. Discussion and Conclusions

9.1 Discussion

The following key observations emerge from the system failure event of 9 February 2025:

1. The system was operating with a high proportion of embedded generation (estimated at 50.4%), with rooftop solar contributing the largest share.
2. A 33 kV bus bar fault occurred at Panadura GSS and was cleared within 1.1 seconds. This fault caused a voltage drop of approximately 40% lasting about 450 ms.
3. Following fault clearance, the active power flow through the Pannipitiya–Panadura–Horana 132 kV lines increased by about 25 MW.
4. The increased power flow was attributable to the tripping of inverter-based embedded generators (mainly rooftop and ground-mounted solar PV) connected to this transmission corridor. The voltage dip initiated by the 33 kV bus bar fault triggered these inverter disconnections.
5. The loss of approximately 25 MW of embedded generation caused system frequency to fall below 49.5 Hz, which in turn triggered the under-frequency tripping of additional inverter-based generators across the country.
6. Once frequency fell below 48.75 Hz, the Under-Frequency Load Shedding Scheme (UFLS) activated and disconnected multiple 33 kV/11 kV feeders. However, given that centrally dispatched generation accounted for only 49.6% of the total at the time, the effectiveness of UFLS was limited to approximately half of its designed capacity. Consequently, the scheme was unable to stabilize the system.
7. Records from the Victoria Power Station indicate that Unit 2 (the frequency-controlling machine) attempted to counteract the frequency decline by increasing its generation output from 29 MW to 71 MW. Despite this response, it was unable to arrest the system-wide collapse.
8. Conventional large generators remained connected until the frequency dropped to 43.3 Hz, at which point they disconnected, marking the final stage of system collapse.

9.2 Conclusions

The total system failure was primarily initiated by the disconnection of large amounts of inverter-based embedded generation (solar and wind) following the voltage disturbance caused by the 33 kV bus bar fault at Panadura GSS.

The subsequent chain reaction—comprising further inverter disconnections due to frequency decline, the limited effectiveness of the UFLS scheme, and the insufficient corrective response of the frequency-controlling machine—culminated in the collapse of the Sri Lankan power system.

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