

POWER FAILURE INVESTIGATION

Investigation of the blackout incident Curaçao on 27 August 2025

Aqualectra

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1 EXECUTIVE SUMMARY

1.1 Introduction

On August 27, 2025, at 02:56:11, Curaçao's power system experienced a complete blackout, with the total loss of electricity supply across the island. According to Aqualectra, prior to the incident, the system was operating under normal conditions, with a significant share of generation coming from renewable sources, primarily wind energy. At approximately 02:30:00, wind output dropped by about 50% due to fluctuations, requiring the generation dispatch to compensate. Subsequent changes in operating conditions, control actions, and system interactions allowed the disturbance to escalate into a full system collapse, despite the absence of a single, clear initiating event. Within the next 26 minutes, all generators and wind farms tripped offline, leading to a complete loss of supply.

Blackouts and major brownouts are typically caused by a cascade of failures and events that are difficult to identify before an extensive investigation is performed, by which the causes of the failures can be identified. The complexity increases when multiple regions are involved.

Aqualectra asked DNV as a third party to conduct an independent root-cause analysis of the system-wide blackout and the subsequent restoration process. The investigation covered the overall system behaviours, with a focus on the power generation, including the coordination of the various regions within the system. The timeline of events was reconstructed, and it was determined how prevailing operating conditions, control actions, and system interactions allowed the disturbance to progress into a total blackout in the apparent absence of a single, discrete initiating event.

1.2 Main incident – evaluation of the Sequence of Events

The blackout is caused by a systemic imbalance in reactive power sharing among the diesel generators, which drove multiple units into under-excitation and triggered a cascading loss of generation. The sequence of events began when DG14 was shifted from frequency droop to kW control to avoid thermal overload. This was a justified action to avoid tripping the unit. This change automatically switched the generator from voltage-droop (essential for reactive power sharing and grid voltage support) to power factor (PF) control. The PF setpoint was significantly lower than the unit's previous operating point, causing DG14 to suddenly inject a large amount of reactive power into the power system. This disrupted the delicate reactive power balance and forced other units in voltage-droop mode to absorb excessive reactive power, pushing them toward their minimum excitation limits.

Operators did not promptly correct DG14's reactive output – likely due to alarm flooding and stress (total 814 Alarms in 10 mins) – so units remaining in voltage-droop absorbed excessive reactive power and approached their minimum excitation limits. To protect DG15, its absorption was reduced, unintentionally shifting the burden to other voltage-droop-controlled generators, particularly DG11 and DG12. The situation worsened when DG9 was transferred from automatic to manual control and increased its reactive output. This was the final trigger that pushed DG11 and DG12 below their limits and tripped them on under-excitation protection.

Compounding the voltage increase in the 66 kV grid, the NDPP 66/11 kV transformers' on-load tap changers (OLTC) responded with delayed automatic voltage reductions (40 s and again ~1 min later) at the NDPP generator terminals. Each voltage reduction caused NDPP units to increase reactive power sharply, which in turn forced remaining Dokweg units (DG15, DG9, DG13, later DG10 and DG14) to absorb even more reactive power. This repeated stress drove them past their under-excitation limits, leading to sequential trip of all DGs. The NDPP transformers' automatic changing OLTC resulted in voltage adjustments that acted as a secondary disturbance amplifier, worsening the reactive imbalance at critical moments.

At root, the system relied heavily on voltage-droop control for reactive sharing, but operator interventions and automatic mode changes introduced inconsistent control strategies (droop vs PF vs manual), creating instability. High stress and numerous alarms likely impaired situational awareness, delaying corrective actions.

1.3 Conclusions

The blackout on 27 August 2025 was triggered by significant wind fluctuations, which initiated a complex sequence of events related to unbalanced reactive power control. Importantly, this was not a single-point failure but rather the result of vulnerabilities in reactive power management amplified by justified yet uncoordinated operational actions and automatic voltage control responses.

A key disturbance was introduced when DG14 was manually switched to a different control mode to prevent thermal overload. While the action was technically justified, it led to a severe reactive power imbalance due to incorrect control mode settings and delayed corrective interventions—decisions made under operator stress (total 814 Alarms in 10 mins).

The lack of immediate adjustment to DG14's reactive output, combined with subsequent manual interventions on DG15 and DG9, further destabilized reactive power sharing among the DGs. These actions, though intended to protect individual units, increased the stress across the remaining generators, pushing several into deep under-excitation conditions.

Ultimately, the NDPP transformer's automatic voltage control action resulted in tripping of the remaining units due to the unbalanced reactive power.

To review What-If scenarios relevant to the events building up to the blackout, DNV has developed a quantitative model. The model outcome indicates that:

- 1) The blackout could have been avoided with 99.98% and 99.90% certainty, respectively, with:
 - a. Automatic following the Power Factor (or higher set point), not having changed the operating mode of DG9/DG15 and the 66/11kV transformer OLTCs set to manual mode.
 - b. Manual operator Power Factor adjustment of DG14, not having changed the operating mode of DG9/DG15 and the 66/11kV transformer OLTCs set to manual mode.
- 2) The Load Shedding could have been avoided with 99.7% and 97.0% certainty, respectively, with:
 - a. Automatic following the Power Factor (or higher set point), not having changed the operating mode of DG9/DG15.
 - b. Manual operator Power Factor adjustment, not having changed the operating mode of DG9/DG15.
- 3) The incident could have been restricted to Load Shedding with 95.0% certainty with the 66/11kV transformer OLTCs set to manual mode.

1.4 Recommendations

Based on the findings of this investigation, DNV recommends the following for implementation:

Short-term recommendations

Control Philosophy & Operating Modes

- Keep generators in voltage-droop control as the default, even when the diesel engine is run in kW (power) mode.
- Keep all units in frequency-droop by default; only exit droop if a unit is at credible risk of tripping at high output or during rapid ramps; maintain adequate spinning reserve.
- Reconsider with Wärtsilä the automatic transfer to PF control when entering kW mode; either disable the auto-switch or require operator confirmation, so the generator can remain in voltage-droop with appropriate ramp limits.

- NDPP units (operated at reduced continuous output): Investigate enabling frequency-droop or temporarily higher outputs with safeguards. Note these units will auto-return to pre-disturbance output when system frequency is restored to 50 Hz by Dokweg 1/2A/2B in isochronous mode.
- Test/activate bump less transfer automatic voltage regulators of generators when control mode switches from voltage-droop-power factor and vice versa

Transformer OLTC & Voltage Control

- Operate the 66 kV OLTCs at NDPP in manual mode in manual mode and ensure all tap changes are coordinated with power plant operators.
- Specifically for Nijlweg-Weis to investigate the conditions automatic voltage control by performing system studies.

Mid-term recommendations

Supervisory Control & Procedures

- Develop a comprehensive strategy and detailed procedures for reactive power balancing and voltage control, taking into account the generator, engine control modes and transformer automatic voltage control in applicable operational scenarios. This should include performing load flow studies to accurately model reactive power flows and system voltage profiles under major generation or network disturbances. Review and update comprehensive and clear SOPs for (a) control mode changes and (b) reactive power balancing.
- Implement a two-person verification and interlocking for unit operating mode transitions and major reactive setpoint changes. Log all changes.

2 INTRODUCTION

2.1 Investigation introduction

The utility in Curaçao Aquallectra is a government owned company that produces and distributes water and electricity to over 80.000 households and companies. The electricity network operates in an island mode, meaning there are no interconnections to mainland. The main network and load centre is in the centre of the island where also the largest production (Dokweg 2) is located. The transmission system is operating at 66kV level down to 30kV and 12kV for distribution.

On August 27, 2025, at 02:56:11, Curaçao's power system experienced a complete blackout, resulting in the total loss of electricity supply across the island. Prior to the incident, the system was operating under normal conditions. A significant share of generation comes from renewable sources, primarily wind energy. At approximately 02:30:00, wind output dropped by about 50% due to fluctuations, requiring the generation dispatch to compensate. Subsequent changes in operating conditions, control actions, and system interactions allowed the disturbance to escalate into a full system collapse, despite the absence of a single, clear initiating event. Within the next 26 minutes, all generators and wind farms tripped offline, leading to a complete loss of supply.

Blackouts and major brownouts are typically caused by a cascade of failures and events that are difficult to identify before an extensive investigation is performed, by which the causes of the failures can be identified. The complexity increases when multiple regions are involved. In this case the investigation covers the overall system behaviours including the coordination of the various regions within the system.

Aquallectra asked DNV to conduct an independent root-cause analysis of the system-wide blackout and the subsequent restoration process. The investigation will reconstruct the timeline of events and determine how prevailing operating conditions, control actions, and system interactions allowed the disturbance to progress into a total blackout in the apparent absence of a single, discrete initiating event.

2.2 List of abbreviations

AC	Alternating Current
CB	Circuit Breaker
DC	Direct Current
DG	Diesel generator
GCB	Generator Circuit Breaker
GPS	Global Positioning System
GT	Gas Turbine
Hz	Hertz
kV	kilo Volt
ms	milli second
MVA	Mega Volt-Ampere
MVA _r	Mega Volt-Ampere reactive
MW	Mega Watt
OEM	Original Equipment Manufacturer
PP	Power Plant
RCA	Root Cause Analysis
rpm	revolutions per minute
SAT	Site Acceptance Test

SoE	Sequence of Events
SOP	Standard Operating Procedure
SoW	Scope of Work
UFLS	Under-Frequency Load Shedding.

2.3 Scope of the investigation

DNV has been engaged to conduct an independent root-cause analysis of the system-wide blackout and the subsequent restoration process. The investigation will reconstruct the timeline of events and determine how prevailing operating conditions, control actions, and system interactions allowed the disturbance to progress into a total blackout in the apparent absence of a single, discrete initiating event.

The scope covers technical and operational aspects—including generation dispatch and control modes, reserve adequacy, frequency and voltage behavior, reactive power and power-factor management, protection settings and coordination, alarm behavior and operator responses within WOIS/SCADA, and relevant external influences. The objective is to establish a clear causal chain with contributing and systemic factors, and to translate these findings into practical, prioritized mitigation measures.

Deliverables will include a most probable root-cause supported by evidence, a detailed event timeline, analysis of contributing factors, and a set of actionable recommendations to prevent recurrence and strengthen system resilience.

The investigation focuses only on the technical causes of the failure and its technical escalation, to provide insight in how to improve system reliability and avoid system blackout in the future. Hence, the following main investigation objectives were agreed upon during the kick-off meeting:

1. Event Chronology & Escalation
 - Reconstruct the blackout timeline, identify triggers and escalation points, and analyze interactions between generation, load, and protection systems.
2. Root Cause Analysis
 - Determine probable technical causes, highlight contributing factors, and recommend further investigation where data gaps exist.
3. Protection & Generation Behavior
 - Assess protection system and generator performance, identify mis-operations or coordination issues, and suggest initial setting or logic improvements.
4. Scenario & Operator Impact
 - Analyze alternative scenarios, evaluate operator actions, and use insights to guide training, automation, and contingency planning.
5. Restoration Evaluation
 - Review restoration sequence, operational procedures, control modes, and operator decisions using SCADA logs and plant records.
6. System Improvement Recommendations
 - Propose actionable measures for protection, fault tolerance, restoration readiness, and long-term grid stability.

In agreement with Aquallectra, and considering the urgency of the matter, DNV will prioritize the investigation of the blackout incident before addressing the restoration process. Consequently, this report does not include a review of the restoration process (Item 5), which will be covered in a subsequent phase.

2.4 DNV general investigation approach

The DNV team brings together expertise across multiple disciplines to ensure an independent and objective investigation. Our approach follows three key steps:

- Determine what happened – Reconstruct the sequence of events and system behavior.
- Understand why it happened – Identify root causes and contributing factors.
- Prevent recurrence – Develop actionable recommendations to avoid similar incidents in the future

The DNV investigation approach is explained below in detail. Note that this section and subsections describe DNV's general approach, to provide you with this insight in general, and can therefore contain elements that are not part of the scope of this particular proposal.

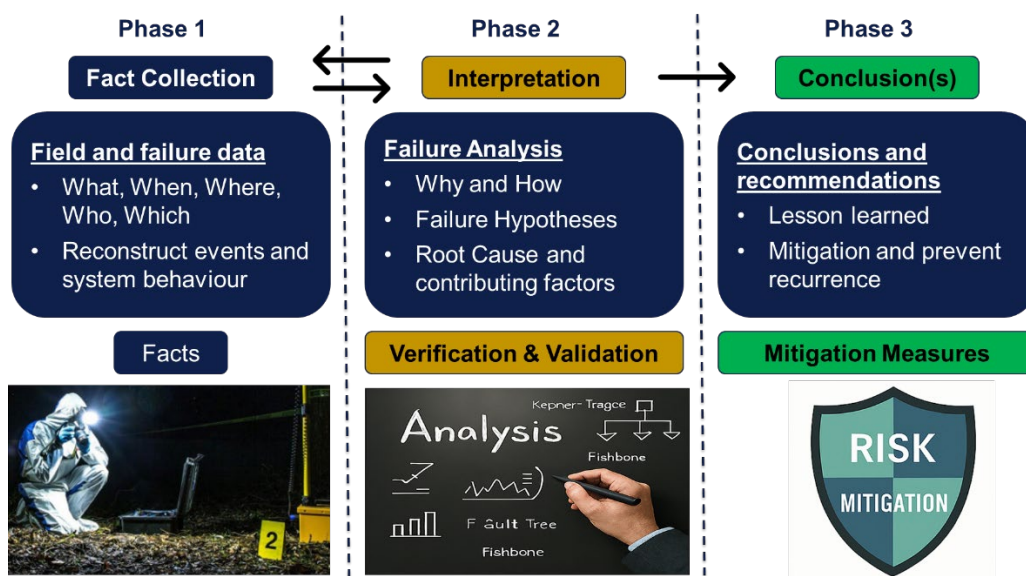


Figure 2-1 DNV three-steps approach for black-out incidents

2.4.1 Step 1: Facts, Events & Understanding the occurrence of the event

The purpose of this step is to collect all relevant facts and events needed to reconstruct the sequence that triggered the incident and led to its escalation into a total blackout. This initial phase is essential for documenting evidence, understanding the nature of the incident, analyzing the surrounding circumstances, and providing a technical evaluation of the chronological chain of events that resulted in system failure and its progression toward a blackout.

The investigation into the technical causes of the blackout focuses on, but is not limited to, the following key questions:

- What is the chronological sequence of events that led to the blackout?
- What is the most likely primary technical cause that allowed the incident to escalate into a blackout?
- What immediate measures have been identified for implementation?

2.4.2 Step 2: Root Cause Analysis including escalation to blackout

Building on the evidence from Step 1, this step determines the proximate and systemic root causes of the wide blackout and explains how an initial disturbance escalated into system collapse. The analysis concentrates on frequency and voltage stability, generation dispatch and control modes, protection settings and coordination, operator actions and Event records/SCADA behavior, and the prevailing network topology. The outcome is a clear, evidence-based most probable root-cause statement with the causal pathway and contributing factors, alongside immediate risk-control

measures to prevent recurrence or, at minimum, confine future events to a contained brownout rather than a total blackout.

2.4.3 Step 3: Mitigation & Improvement plan

Following the root-cause analysis described in Steps 1 and 2, the process typically includes a gap analysis of operational procedures, protection schemes and settings, system design, and related areas. The purpose is to identify opportunities for improvement in technology, processes, and human factors. This step has not yet been carried out for Aqualectra.

3 THE NETWORK AND THE INCIDENT

3.1 Aqualectra Power Supply System

The backbone of the Aqualectra power supply is shown in Figure 3-1. Main substations are located at Isla and Dokweg 2, both 66 kV substations with 66 kV connections to Parera, Weis, Nijlweg. At these main distribution locations, the power is supplied to the 30 kV distribution grid.



Figure 3-1 Aqualectra power supply system overview. Red: 66 kV, blue 30 kV

The island peak load demand can reach up to 147 MW and the current rated available capacity of generation is 218 MW, including renewable generation. The wind generation capacity is 67.5 MW. The Main power is supplied from Aqualectra diesel generator (DG) plants at Dokweg (Dokweg 1, 2A and 2B), and at Isla (NDPP). External power supply to the Aqualectra grid is supplied from the captive generation at the Isla refinery (BOO/CRU gas turbine), however this generation is normally not on line. Table 3-1 provides an overview of the installed generation of Aqualectra in Curacao.

Table 3-1 Generation Capacity Aqualectra power system excluding contribution CRU

Power Plant	Unit	Rated Power [MW]	Power Plant	Unit	Rated Power [MW]	Power Plant	Unit	Rated Power [MW]
Dokweg 1	DG1	6.25	Dokweg 2A	DG9	8.9	Isla NDPP	DG1	8.3
	DG2	6.25		DG10	8.9		DG2	8.3
	DG3	6.25		DG11	8.9		DG3	8.3
	DG4	6.25		DG12	8.9		DG4	8.3
	DG5	6.25	Dokweg 2B	DG13	9.8	Wind farm Playa Canoa		15
	DG6	6.25		DG14	9.8	Wind farm Tera Cora 1		15
	DG7	5.3		DG15	9.8	Wind farm Tera Cora 2		16.5
				DG16	9.8	Wind Farm Koral Tabak		21

3.2 Reconstruction and analysis Sequence of Events Blackout August 27, 2025

The system operational conditions (voltage, frequency, load, generation and spinning reserve) prior to the time for the renewable energy production (Wind energy) are taken from /1/ and /2/ and summarized in Figure 3-2 and Table 3-2.

Sequence of Events

System in normal operational conditions

- Absolute time: 02:30:00

Pre-incident conditions

- Total Island Demand: 114.1 MW
- Total Generation: 114.1 MW
 - Thermal generation: 72.6 MW
 - Dokweg 2A/B: 42MW
 - Dokweg 1: 6.6MW
 - NDPP: 24MW
 - Wind Energy: 41.5 MW
 - TK1: 8.2MW
 - TK2: 6.4MW
 - KT: 16.3MW
 - PC: 10.6MW
- Spinning reserve: 20.6 MW
- Cold reserve (standby): 31.2 MW

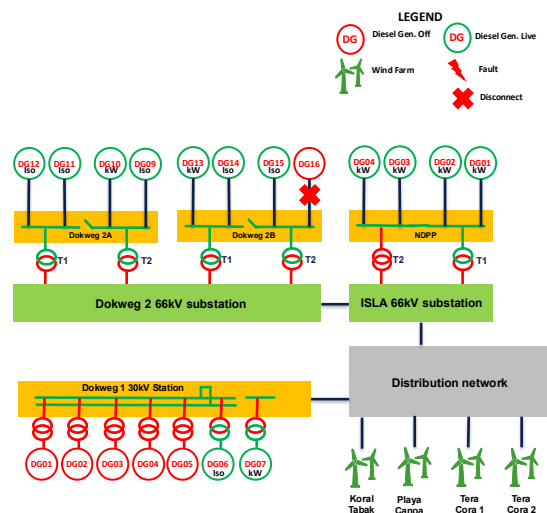


Figure 3-2 System operational conditions prior the blackout

Table 3-2 Pre-incident operational conditions

System Quantity	Actual value
System frequency	50.0 Hz
System Voltage	66 kV
Total Net Generation	114.1 MW
System Load	114.1 MW – grid losses
Spinning Reserves	20.6 MW
Wind generation	41.5 MW
Cold reserve (stand-by)	31.2

The timeline of relevant events related to the second blackout at 02:56:11 on August 27, 2025 is shown in Table 3-3. The table includes a summary of events of the WOIS system, the protection system(s) and tripping of generation units wherever applicable. It must be noted that DNV used raw data from WOIS, SCADA, protection, etc, for the analysis of the sequence of events. Moreover, the events below do not include Operator handling during the events. These will be discussed in Chapter 4.

Table 3-3 Timeline of relevant events at the time of the blackout on 27 August 2025 at 02:56:11

Time	Unit	event	description
02:42:28	DG14	start oscillation/derating	large active power swings DG14. minor impact
02:43:28	DG9	switch to kW manual	no major impact
02:43:48	DG14	switch to kW / pf mode	large increase in reactive power output
02:44:07	DG11	switch to kW mode manual, at 2:46:47 switched back	no major impact
02:44:13	DG5	switch to isochronous mode	
02:45:03	DG5	switch to kW mode	not available for frequency/voltage support
02:45:06	DG14	switch to kW / pf mode	major increase in reactive power output, DG11/12/15 more underexcited
02:46:45	NDPP transformer	tap changing	major increase in reactive power NDPP units
02:46:47	D9	switch from power factor to voltage droop	increase reactive power output, DG11/12/15 more underexcited
02:47:19	DG4	start command and start failure	
02:48:01	D15	operator increasing reactive output	major increase in reactive power output, DG11/12 more underexcited
02:48:42	D9	switched to voltage droop	major increase in reactive power output, DG11/12 slightly more underexcited
02:49:01	DG11	trip	underexcitation
02:49:01	DG12	trip	underexcitation
02:49:02	load shedding	start load shedding	
02:49:45	NDPP transformer	tap changing	major increase in reactive power NDPP units
02:49:47	DG15	trip	underexcitation

Time	Unit	event	description
02:49:48	DG 9	trip	underexcitation
02:50:02	DG13	trip	underexcitation
02:50:47	NDPP transformer	tap changing	major increase in reactive power NDPP units
02:50:48	DG3	online	
02:50:49	DG10	trip	underexcitation
02:50:50	WF TC 1	disconnect	
02:50:54	DG14	trip	underexcitation
02:50:58	DKW 2B	trip step-up and auxiliary transformers	trip on over voltage
02:50:59	DG7	disconnect	not clear why DG7 breaker opened
02:50:59	DKW 2A	trip step-up and auxiliary transformers	trip on under frequency
02:51:51	DG3	switch to isochronous mode	available for frequency/voltage support
02:53:14	DG3	switch to kW mode	not available for frequency/voltage support
02:55:07	DG2	online	
02:56:04	WF TC 2	disconnect	
02:56:04	WF PC	disconnect	
02:56:04	WF KT	disconnect	
02:56:11	DE2	disconnect	not clear, freq. 45 Hz, voltage 10 kV
02:56:11	DE1	disconnect	not clear, freq. 45 Hz, voltage 10 kV
02:56:11	DE3	disconnect	not clear, freq. 45 Hz, voltage 10 kV
02:56:11	DE4	disconnect	not clear, freq. 45 Hz, voltage 10 kV
02:56:11	DG2	disconnect	STB, Engine shut down alarm active
02:56:11	DG6	disconnect	STB, Engine shut down alarm active
02:56:11	DG5	disconnect	breaker open from speed controller
02:56:11	DG3	disconnect	breaker open from speed controller

The sequence of events leading to the power supply disturbances began with a significant drop in active power output from the wind farms. Between 02:30 and 02:43, the output declined by approximately 22.4 MW. This imbalance in active power was compensated by diesel generating units operating under frequency-droop control, primarily at the Dokweg 2A and 2B power plants. Figure 3-3 shows the event 1 conditions. It is noted Only the most significant events are depicted in the figures below, while further relevant events are detailed in the accompanying explanation.

Sequence of Events

Large Wind fluctuation

1 Event: Absolute time: 02:43:00

- In 13 min the wind energy dropped by **22.4 MW (54%)**
- Spinning reserve: 20.6 MW
- Cold reserve: 31.2 MW

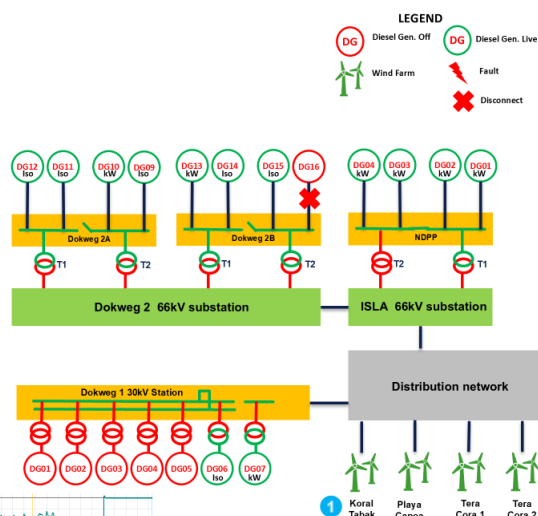
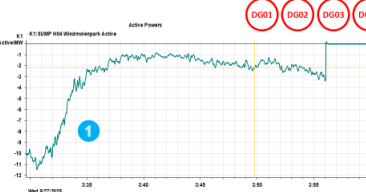
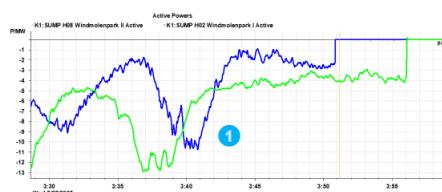


Figure 3-3 Event 1 – significant wind energy drops due to wind fluctuation

At 02:42:28 the operating mode of DG9 was changed from Isochronous-mode (Iso-mode) to KW-mode for unknown reasons to DNV. At the same time DG14 experienced elevated cylinder temperature deviations due to a rapid increase in power output. In response, the unit's control system reduced its output before ramping it up again, this occurred several times in the span of several minutes. To stabilize DG14, the operator switched its control mode from frequency-droop to fixed kW control. This change automatically altered the generator's voltage control from voltage-droop to power factor control. In this mode, reactive power is supplied proportionally to active power, regardless of grid voltage. This has caused DG14 to produce excessive reactive power. This disrupted the system's reactive power balance, prompting other units—primarily at Dokweg 2A/2B operating in voltage-droop mode—to absorb the surplus.

At 02:44:07, the operator changed DG11's operating mode from Iso-mode to kW-mode and then back to Iso-mode for reasons unknown to DNV. Similarly, at 02:44:13, DG05 was switched from kW-mode to Iso-mode and then returned to kW-mode at 02:45:03. This sequence was part of the machine's startup and synchronisation process with the grid.

Sequence of Events

Units operational mode change

2 Event: Absolute time: 02:43:48

- In 10 min, DG14 had derated 5 times due to an exhaust temperature issue (reaching maximum output), and derating was automatically activated.
- DG14 changed from Iso-mode to kW / pF mode by the operator. This resulted in a sudden increase in reactive power of DG14
- DG9 changed from Iso-mode to kW-mode

3 Event: Absolute time: 02:44:13

- DG05 Online and changed to Iso-mode and at 02:45:03 back to kW mode.

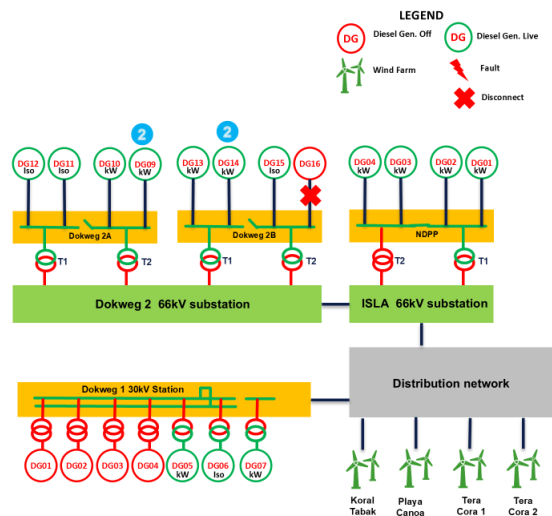
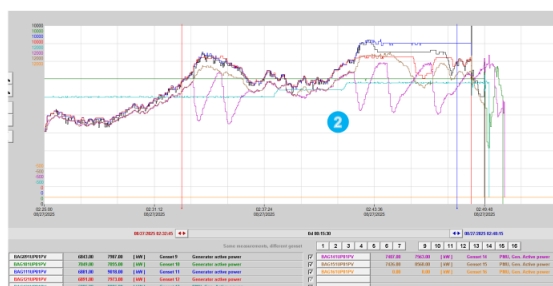


Figure 3-4 Event 2 and 3 with time stamps and an explanation of the events

At 02:45:06 DG11, DG12, and DG15 were absorbing excess reactive power in the system, with DG15 reaching the limits of its capability.

At 02:46:47 the next event occurred when DG9 was switched from automatic to manual control mode by the operator. Although still in voltage-droop mode, the unit responded with an increase in reactive power.

Notably, DG11, DG12 and DG15 continued to absorb high levels of reactive power, while other units remained unresponsive—either because they were operating in power factor control mode or were already beyond their critical limits.

Sequence of Events

Reactive Power imbalance

- 4 Event: Absolute time: 02:45:06
 - Due to DG14 Major increase reactive power output. DG11/12/15 increased reactive power absorption
- 5 Event: Absolute time: 02:46:47
 - The operator manually switched DG9 from power factor to voltage droop, The resulted in increasing reactive power output of DG9. DG11/12/15 further increased reactive power absorption

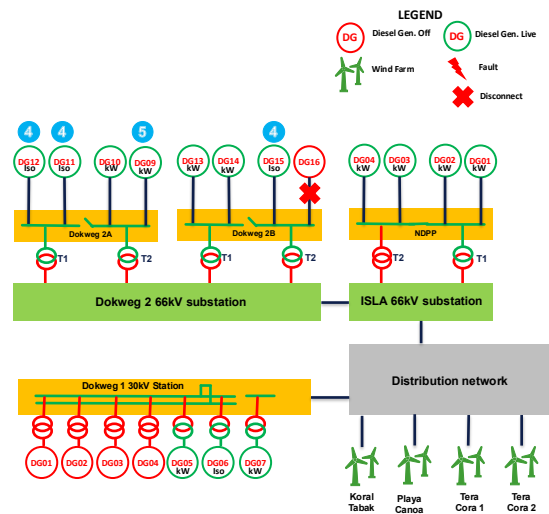
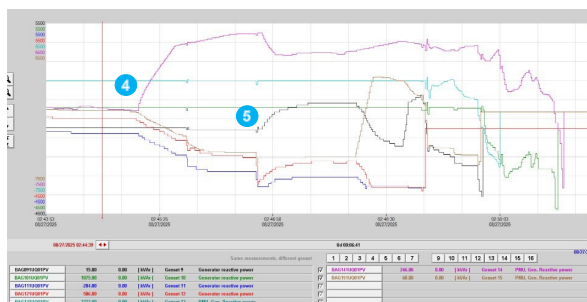


Figure 3-5 Events 4 and 5 – increased reactive power absorption by DG11, DG12 and DG15 and a change of DG9 operating mode.

At 02:48:01, operators reduced DG15's reactive power absorption to prevent instability, bringing it back within safe operating limits. However, this adjustment triggered a compensatory response from other units operating in voltage-droop control, which worked to restore reactive power balance.

At 02:46:42, DG9 suddenly increased its reactive power output. This event is not recorded in the event logs, but the unit's output data shows a sharp rise for reasons unknown to DNV.

At 02:49:01, when the reactive power imbalance pushed DG11 and DG12 below their minimum excitation limits. Their under-excitation protection systems tripped, causing both units to disconnect from the grid and triggering the under-frequency load shedding scheme.

-



At 02:49:45 a major disruption in reactive power balance caused a sharp rise in the 66 kV grid voltage. The NDPP units, operating in voltage-droop mode, detected this increase at their 11 kV terminals and began absorbing reactive power. However, their terminal voltage was influenced not only by the units' automatic voltage regulators but also by the automatic voltage controller on the NDPP 66/11 kV transformer. This transformer controller reacted approximately 40 seconds later, reducing the terminal voltage and triggering a sudden surge in reactive power output from the NDPP units.

Between 02:49:47 and 02:50:02, The reactive power disturbance was absorbed by Dokweg 2A/2B units—specifically DG15, DG9, and DG13—which exceeded their minimum excitation limits. As a result, their under-excitation protection systems tripped, disconnecting the DG9, DG13 and DG15 units from the grid.

Sequence of Events

Automatic Voltage Control & Units tripping

- 10 Event: Absolute time: 02:49:45
 - NDPP Step-up Transformer automatic voltage control activated. As a result NDPP units major increase in reactive power output.
- 11 Event: Absolute time: 02:49:47
 - DG15 tripped on underexcitation
- 12 Event: Absolute time: 02:49:48
 - DG9 tripped on underexcitation
- 13 Event: Absolute time: 02:50:02
 - DG13 tripped on underexcitation
- 14 Event: Absolute time: 02:50:47
 - NDPP Step-up Transformer automatic voltage control activated. As a result NDPP units major increase in reactive power output.

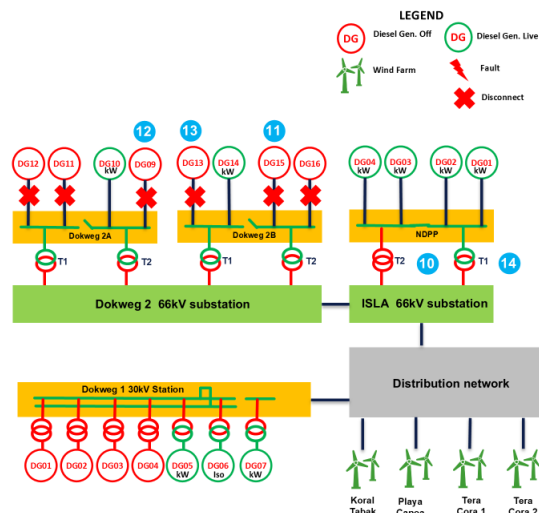
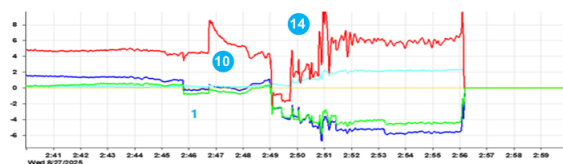
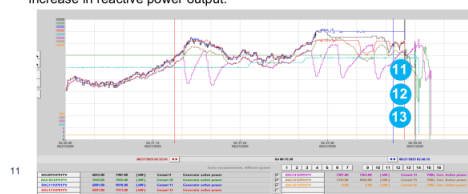


Figure 3-7 Events 10 to 14. NDPP Transformers automatic voltage control and tripping of DG9, DG13 and DG15 by under-excitation protection systems to trip

Just before 02:50:49, only DG10 and DG14 at Dokweg 2A/2B remained in operation. DG10, initially in power factor control mode, switched to voltage-droop mode and responded to the earlier trips of other Dokweg units. However, one minute later, the automatic voltage controller of the NDPP 66/11 kV transformer reduced the terminal voltage of the NDPP units, prompting a sharp increase in their reactive power output.

At 02:50:49 and 02:50:54, In response, DG10 and DG14 increased their reactive power absorption and were subsequently tripped by their under-excitation protection systems.

At 02:50:50 Windfarm Tera Cora 1 tripped. At this point, no units at Dokweg 2A/2B were operational.

Sequence of Events

Reactive Power imbalance & System collapse

- 15 Event: Absolute time: 02:50:48
 - DG3 online
- 16 Event: Absolute time: 02:50:49
 - DG10 tripped on underexcitation
- 17 Event: Absolute time: 02:50:50
 - Wind farm TC1 disconnected
- 18 Event: Absolute time: 02:50:54
 - DG14 tripped on underexcitation
- 19 Event: Absolute time: 02:50:58
 - Dokweg 2B Step-up Transformer tripped on overvoltage at 11kV side

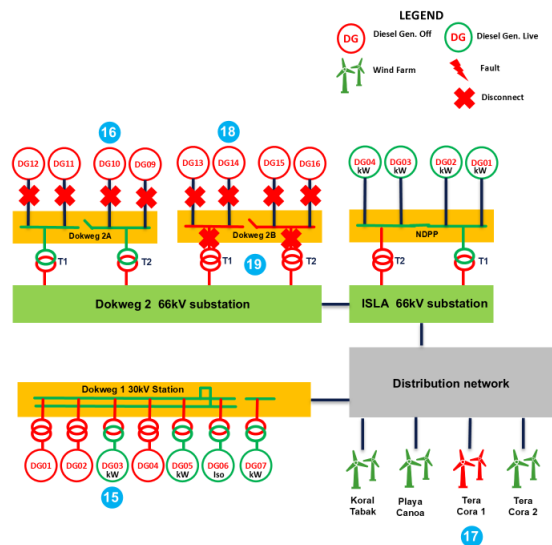
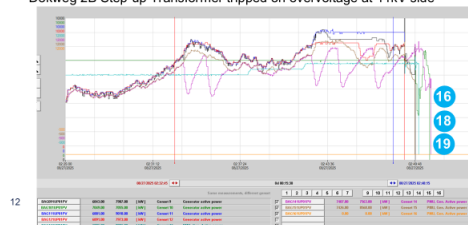


Figure 3-8 Events 16 to 19 – Tripping of DG10, DG14 and windfarm TC1

The system was temporarily sustained by four NDPP units, three units at Dokweg 1, and wind farms Tera Cora 2, Playa Canoa, and Koral Tabak (note: Tera Cora 1 had already tripped). These sources managed to keep the grid operational for approximately five minutes, until all three remaining wind farms also tripped. During this period, the system frequency dropped to 47.5 Hz, significantly below the normal operating range, indicating severe grid instability.

Sequence of Events

Reactive Power imbalance & System collapse

- 20 Event: Absolute time: 02:50:59
 - DG7 tripped on underexcitation
- 21 Event: Absolute time: 02:50:59
 - Dokweg 2A Step-up Transformer tripped on under frequency at 11kV side
- 22 Event: Absolute time: 02:55:07
 - DG2 online and DG3 switched to Iso-mode and back to kW mode
- 23 Event: Absolute time: 02:56:04
 - Wind farm TC2, PC and KT disconnected

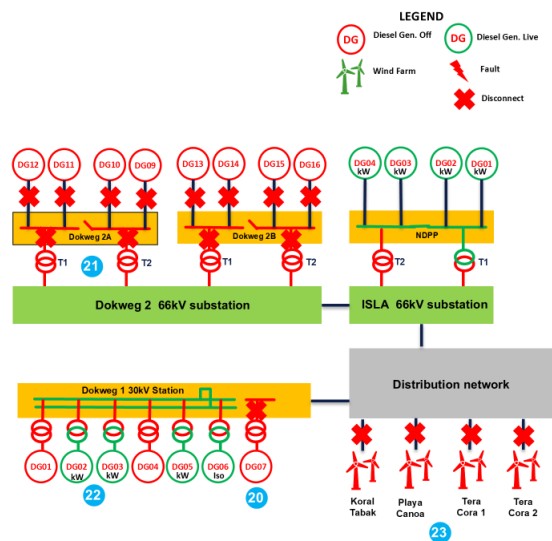
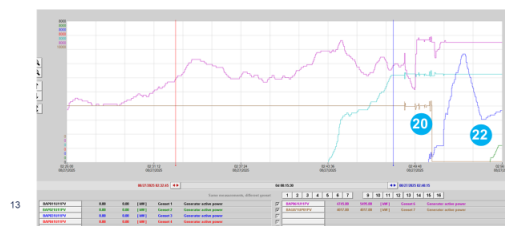


Figure 3-9 Events 20 to 23 – Tripping of DG7 and all remaining windfarms (TC2, PC and KT)

The extensive load shedding, initiated by the first unit trips at Dokweg 2, also played a role in temporarily sustaining the system. However, the combination of very low frequency and insufficient frequency control capabilities at Dokweg 1 and NDPP ultimately led to system instability. This resulted in a complete collapse of the grid and triggered a full system blackout.

Sequence of Events Blackout

24 Event: Absolute time: 02:56:11

- DG1, DG2, DG3, DG4 from NDPP tripped on underfrequency

25 Event: Absolute time: 02:56:11

- DG2, DG3, DG5 and DG6 from Dokweg 1 tripped on underexcitation

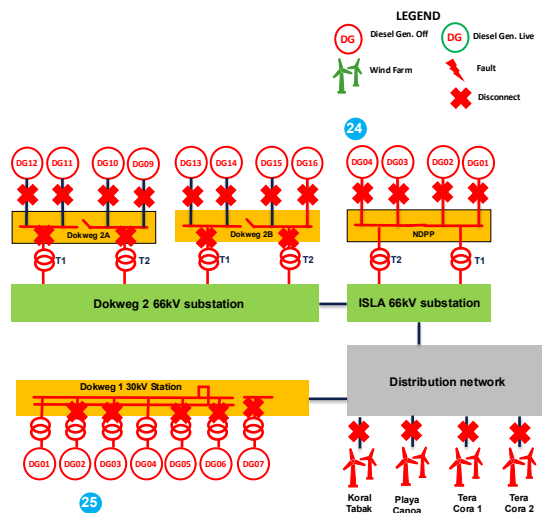
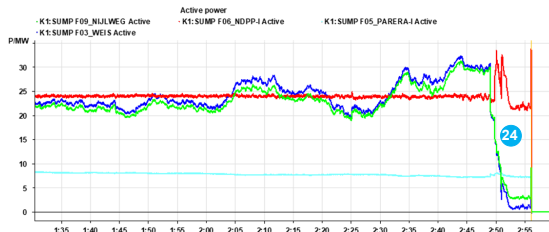


Figure 3-10 Events 24 and 25 – tripping of last remaining generation resulting in a full system blackout

3.3 Power system behaviour and diesel generation

3.3.1 Active power

The active and reactive power in the system were relatively stable until the power from the wind farms dropped at 2:30 from 46 MW down to 20 MW at 2:43, see Figure 3-11.

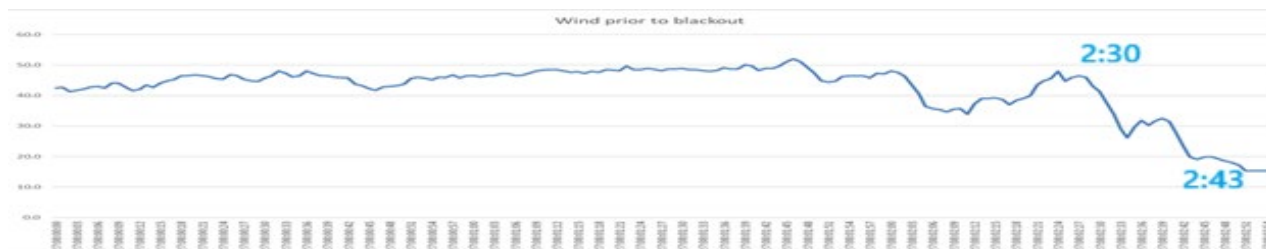


Figure 3-11 Active power wind farms 27-08-2025 from 0:00 until blackout at 02:56

The drop in wind power was mainly balanced by the Dokweg 2A/2B units, which were set to support the grid frequency, see Figure 3-12. This figure shows the active power output at the 66 kV connections of the 4 step-up transformers. The output increased from 42 MW at 2:30 to 59 MW at 2:43 by units DG9, 11, 12, 14, 15. Units 10,13 were in kW mode at fixed output. At Dokweg 1 increased the active power output (DG 6, while DG5 was started) while NDPP output remained unchanged because these units are operated in base load, not responding to frequency changes.

Unit DG 14 at Dokweg 2B experienced temperature issues because of the steep increase of power output at 2:33 and automatic output reduction was activated several times, see red curve in Figure 3-12. At 2:45 this unit was set to kW

operation mode by the operator to stabilize the power output. A few minutes before unit DG9 was set to kW mode by the operator because of exhaust gas temperature alarm.

Although the units of Dokweg 2A/2B were operating near maximum output, the frequency was maintained without load shedding, see Figure 3-13, until units DG 11, 12 tripped at 2:49 because of too high absorption of reactive power.

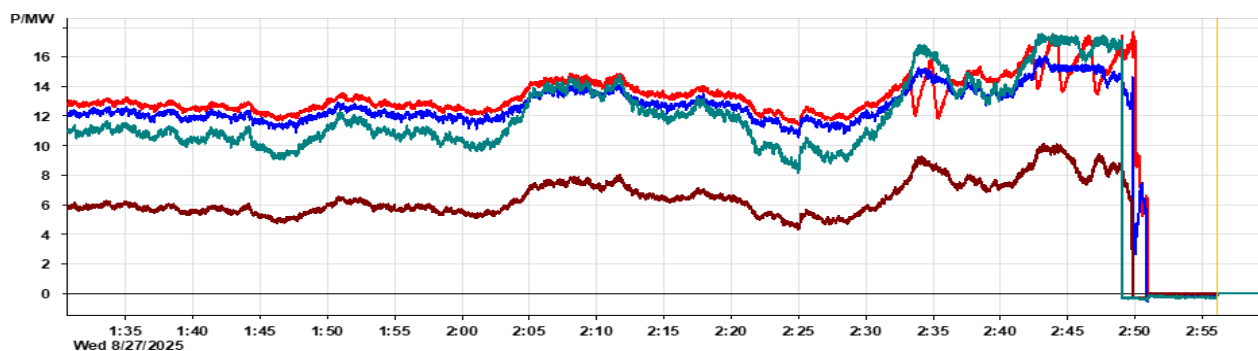


Figure 3-12 Active power DKW 2A/2B power plants at 66 kV connection step-up transformers. Blue: DKW 2A-T2 (DG 9/10); Green: DKW 2A-T1 (DG 11/12); Red: DKW 2B-T1 (DG 13/14); Brown DKW 2B-T2 (DG15/16)

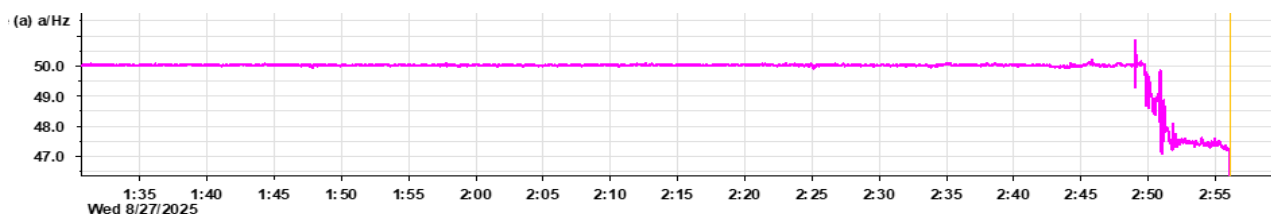


Figure 3-13 Grid frequency

After the trip of all units at Dokweg 2A/2B, the 4 units at NDPP and 4 units at Dokweg 1 were online. None of the units was able to control the frequency: the 4 units at NDPP were in base load (kW mode) and only 1 of the 4 units in Dokweg DG 6 was in frequency control mode (frequency droop). However, this unit was at maximum output and not able to control. DG 3 was just synchronized seconds before and building up load, DG 7 tripped only 5 seconds after the last Dokweg 2A/2B unit tripped.

Massive load shedding in load center Nijlweg-Weis, starting at 2:49, and power surges of the NDPP units at 2:50, see Figure 3-14, helped the power system to survive, however the frequency could not be maintained and dropped to 47.5 Hz, see Figure 3-13. When the remaining 3 wind farms tripped at 2:56 (wind farm Tera Cora 1 tripped already at 2:51), all remaining diesel generating units tripped and the system blacked out.

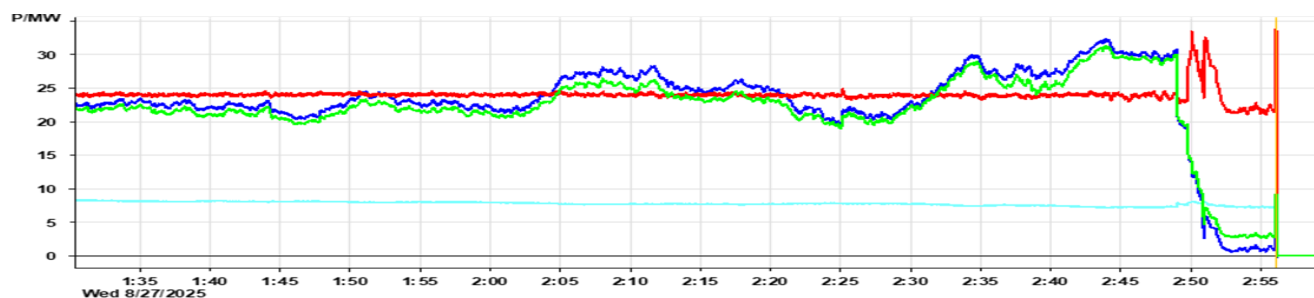


Figure 3-14 Active power NDPP and net demand Nijlweg-Weis (gross demand-generation DKW 1/ wind farms) RED: NDPP-I (NDPPII offline); Green: Nijlweg feeder; Blue: Weis feeder

Zooming in on the active power output of the Dokweg 1 units, see Figure 3-15, indicates poor frequency support. After the trip of the last Dokweg 2A/2B units and DG 7 at 2:51, only DG 3 had frequency support capability when the control

was switched to isochronous control just before 2:51. But at 2:53 it was switched back to kW mode with deactivated frequency control. The start-up of DG 2 at 2:55 was too late to save the system

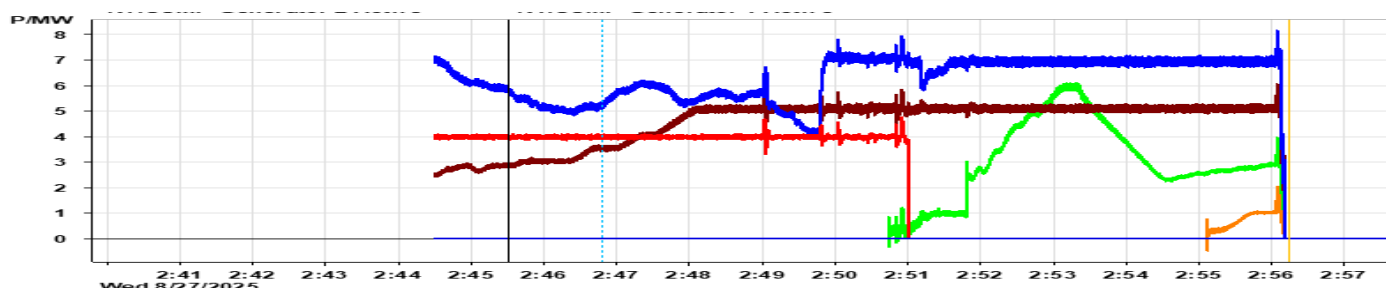


Figure 3-15 Active power output Dokweg 1 units during the last 12 minutes before blackout

Blue: DG 6, Brown: DG 5, Red: DG 7, Green DG 3, Orange: DG 2

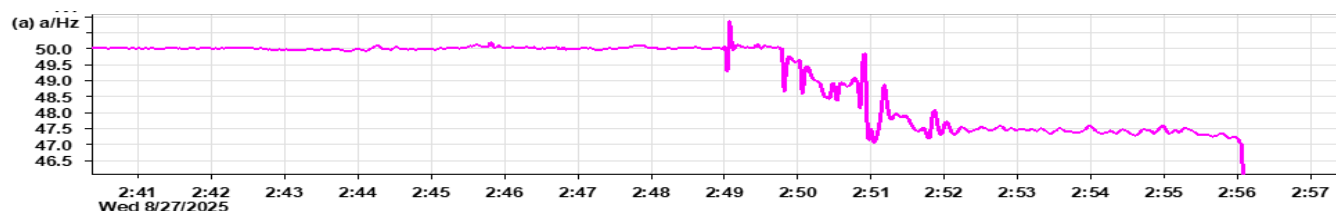


Figure 3-16 Grid frequency

For detailed analysis of the active power balancing and frequency behaviour, see ANNEX 1.

3.3.2 Reactive power

The reactive power of the units at Dokweg 2A/2B was stable and near zero until unit DG 14 was switched to kW mode. As a consequence of this, the generator voltage control switched automatically from voltage droop mode (supporting grid voltage and reactive power balancing) to power factor control (not supporting voltage and reactive power balancing). It appeared that the internal preset power factor setpoint was at 0.85 lagging (supplying large amount of reactive power), see red curve in Figure 3-17. The units in voltage droop mode (DG 11, 12, 15), responded by absorbing this large amount of reactive power of DG 14.

But when operators increased the reactive power output of DG 15 (brown curve) to bring that unit out of the danger zone of instability or tripping, units DG 11, 12 were automatically forced to absorb even more reactive power. Then at 2:48 DG 9 (blue curve) was switched to manual mode and the reactive power output of this unit increased. This pushed DG 11, 12 over the edge of their capacity of maximum reactive power absorption and their underexcitation protection tripped these units.

The loss of reactive power absorption by these 2 units was balanced by, DG 9 and 15 at Dokweg 2A/2B, the 4 units at NDPP, see Figure 3-19, and DG 6 at Dokweg 1, see Figure 3-20. However, the 4 units at NDPP increased 45 seconds later suddenly their reactive power output because their generator voltage was automatically increased by the automatic voltage regulation on the NDPP step-up transformer. DG 15, 9, 13 responded by absorbing more reactive power and were tripped by their underexcitation protection.

Then one minute later, at 2:50:49 again a decrease of generator voltage at NDPP because of the automatic voltage regulation on the step-up transformer. The subsequent increase of reactive power supply by the 4 units at NDPP caused the two remaining units at Dokweg 2A/2B, DG 10 and 14, to trip at underexcitation.

The 66 kV grid voltage increased rapidly to 74 kV after all Dokweg 2A/2B were tripped at 2:51, see Figure 3-18

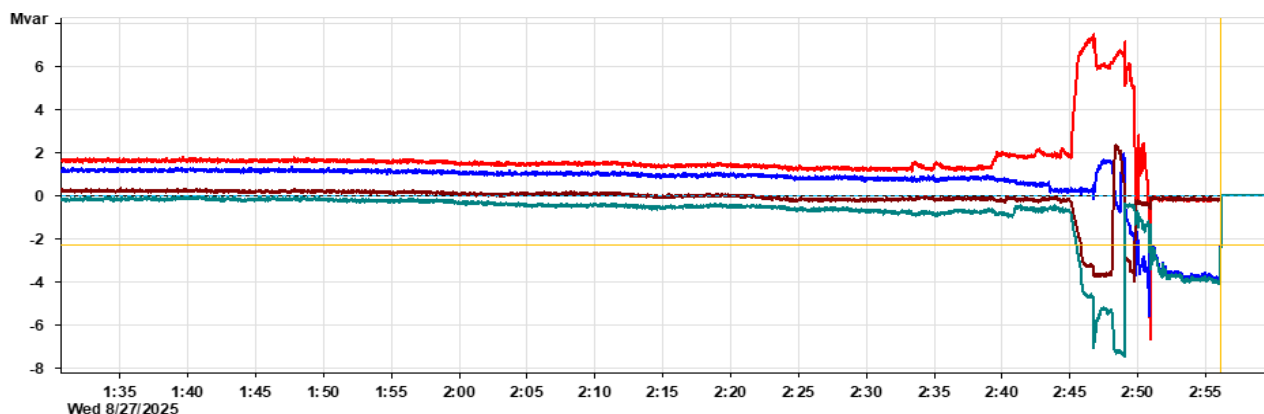


Figure 3-17 Reactive power DKW 2A/2B power plants at 66 kV connection step-up transformers.
DKW 2A-T2 (DG 9/10); Green: DKW 2A-T1 (DG 11/12); Red: DKW 2B-T1 (DG 13/14); Brown DKW 2B-T2 (DG15/16)

Blue:

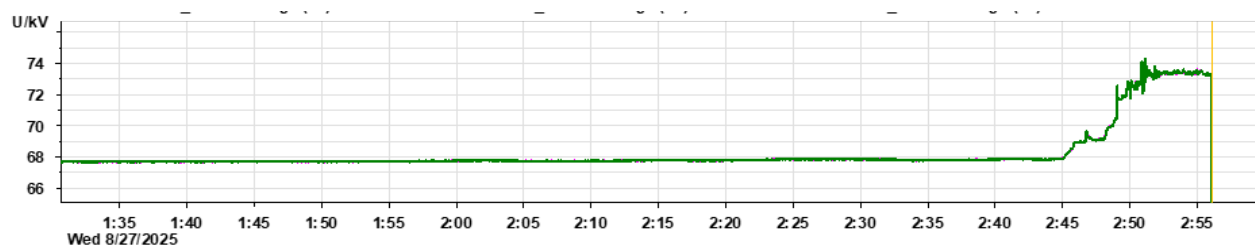


Figure 3-18 66 kV grid voltage

While Dokweg 2A/2B were struggling with the increase of reactive power of DG 14, DG 15 and DG 9

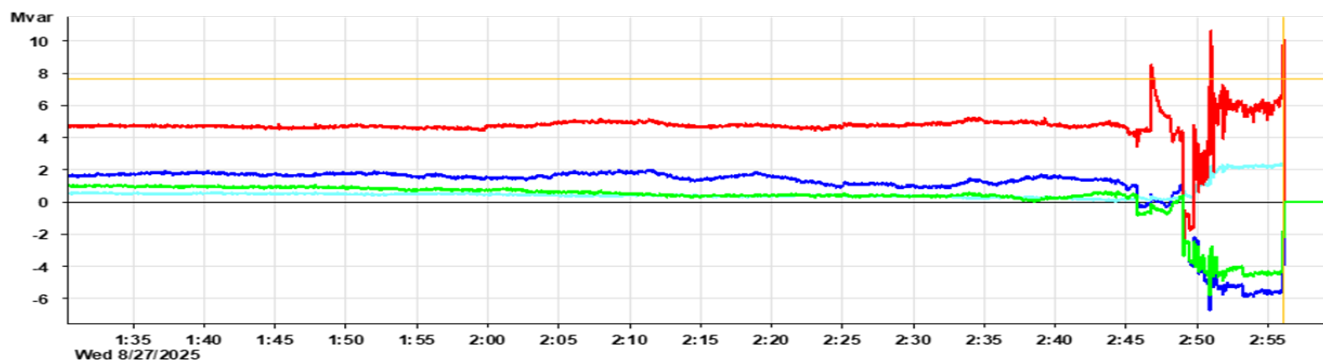


Figure 3-19 Reactive power NDPP and net demand Nijlweg-Weis(gross demand-generation DKW 1/ wind farms)

The reactive power output of the unit in voltage control at Dokweg 1, DG 6, was interfered by the automatic voltage regulation of the Nijlweg-Weis transformers. Because of increasing 66 kV voltage also the 30 kV voltage increased and the 30 kV automatic voltage control instructed a tap change of the Nijlweg-Weis transformers between 2:45-2:46, between 2:49-2:50 and between 2:51-2:52, see Figure 3-21. This disruption by the automatic tap changing made the voltage support by the Dokweg 1 units ineffective

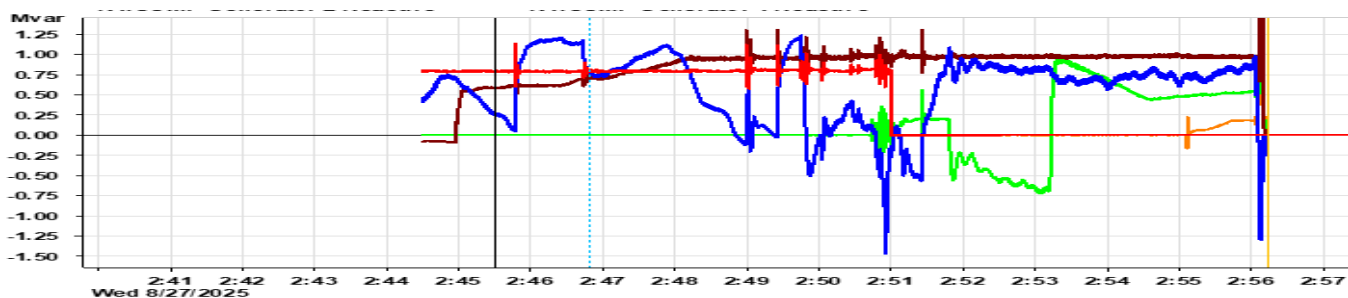


Figure 3-20 reactive power Dokweg 1 units during the last 12 minutes before blackout. Blue: DG 6, Brown: DG 5, Red: DG 7, Green DG 3, Orange: DG 2

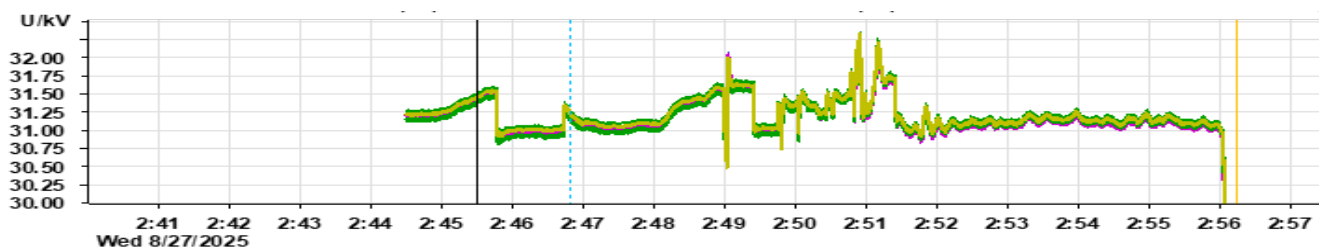


Figure 3-21 30 kV Dokweg 1 voltage recording

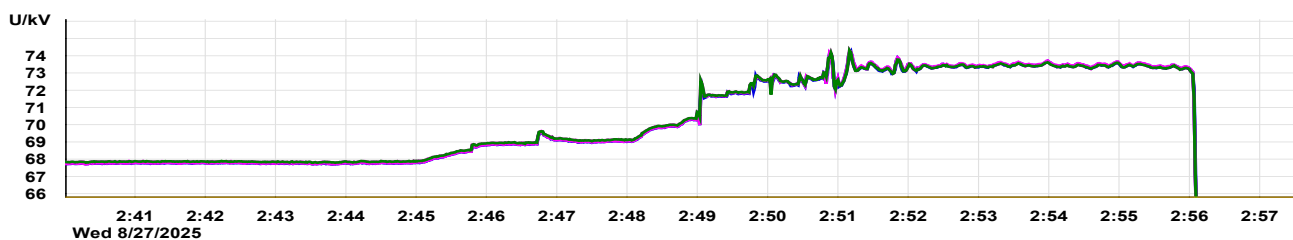


Figure 3-22 66 kV grid voltage recording

For detailed analysis of the reactive power balancing and voltage behaviour see ANNEX 1.

3.4 Protection performance assessment

All generators at Dokweg 2A/2B were tripped by their under-excitation protection systems. Just prior to tripping, these units were absorbing a substantial amount of reactive power, making the activation of under-excitation protection both expected and justified. However, it remains unclear whether the units' Automatic Voltage Regulators (AVRs) were equipped with under-excitation limiters, which could have mitigated the risk and potentially prevented the trips.

The subsequent trips of units at NDPP and Dokweg 1 were unavoidable due to the critically low grid frequency, which occurred following the disconnection of the wind farms—likely triggered by low-frequency protection mechanisms.

Unexpectedly, the step-up and auxiliary transformers at Dokweg 2A/2B also tripped. The Dokweg 2B transformers disconnected due to overvoltage, while the Dokweg 2A transformers tripped on underfrequency. These transformer trips were not anticipated and contributed further to the system instability.

Given the sequence of events and the system's response to voltage and frequency disturbances, a thorough review of the voltage and frequency protection settings for all units, transformers, and busbars across the affected power plants is essential. This review should assess whether current settings are appropriate and resilient enough to handle similar disturbances in the future, and whether coordination between protection systems can be improved to prevent cascading failures.

4 ROOT CAUSE ANALYSIS

This chapter describes the results of Step 1 and 2 as described in chapter 2.4. The investigation results are visualized in an incident map, evaluated for cause-consequence scenarios and technical barriers that should have prevented the blackout and avoid unwanted consequences.

4.1 Main events

At ~02:30–02:43, wind farm output fell by ~22 MW. Diesel generators at Dokweg 2A/2B (on frequency-droop) picked up the deficit; spinning reserve was sufficient.

DG14 ramped quickly and showed high cylinder temperature deviations. Operators shifted it from frequency-droop (speed governing) to kW control. This automatically changed the generator from voltage-droop (normal for grid voltage support and reactive sharing) to power-factor (PF) control. The operator actions are justified to avoid tripping of the DG14. Because the PF setpoint was much lower than the unit's pre-change PF, DG14 increased reactive power output significantly, upsetting the system's reactive balance.

Units still on voltage-droop—primarily at Dokweg 2A/2B—reacted by absorbing the surplus reactive power (operating under-excited), pushing several machines toward their stability limits. DG15 bore the largest absorption and approached the danger zone; operators reduced its absorption to restore the margin. That action shifted the burden to other droop-controlled units, notably DG11 and DG12, which then absorbed heavily. One should note that the operators should have noticed the reactive power change of DG14 and should have adjusted it. This action was not performed due to sudden stress and distraction from abundant alarms.

A further disturbance occurred when DG9 was moved from automatic to manual control. Although it remained in voltage-droop, it increased reactive power, the final nudge that pushed DG11 and DG12 past their minimum excitation limits, tripping on under-excitation protection. The reason behind this operational action by the operator remains unclear to DNV.

This large disruption in reactive power balance caused a steep increase in 66 kV grid voltage. NDPP units (in voltage-droop) sensed high voltage at their 11 kV terminals and absorbed reactive power. About 40 s later, the automatic voltage controller (OLTC) on the NDPP 66/11 kV transformer lowered the terminal voltage, which forced a step increase in NDPP reactive power. Dokweg 2A/2B units DG15, DG9, and DG13 absorbed that disturbance, crossed their UEL limits, and tripped.

At this moment only DG10 and DG14 at Dokweg 2A/2B remained. DG10 switched from PF to droop to respond, but ~1 min later the NDPP transformer AVC again decreased terminal voltage, provoking another NDPP reactive increase. DG10 and DG14 responded and tripped on UEL.

With Dokweg 2A/2B offline, four NDPP units and three Dokweg 1 units continued, supported by wind farms Tera Cora 2, Playa Canoa, and Koral Tabak (Tera Cora 1 had already tripped). The system survived ~5 minutes more, but frequency hovered near 47.5 Hz, significantly below the normal operating range, indicating severe grid instability. Progressive load shedding helped keep it alive temporarily; however, the very low frequency and insufficient primary frequency control at Dokweg 1 and NDPP led to tripping of the remaining generation and windfarms, leading to system collapse and total blackout.

4.2 Incident Map and Root Cause(s)

For the most probable scenario the cause-consequence relations are presented in Figure 4-1. The presentation is in the form of an incident map according to the Kepner-Tregoe method. The corresponding legend is provided within the same figure. The subsequent sections explain the cause-consequence relations in detail along the corresponding part of this incident map for each phase.

NOTE: The sequence of events in the incident map evolves over time from the bottom to the top. The time scales between the various events can differ significantly. As such it is important to notice that an event placed at a higher position in the graph does not necessarily have to happen after an event placed at a lower position in case they are not connected by a causal line.

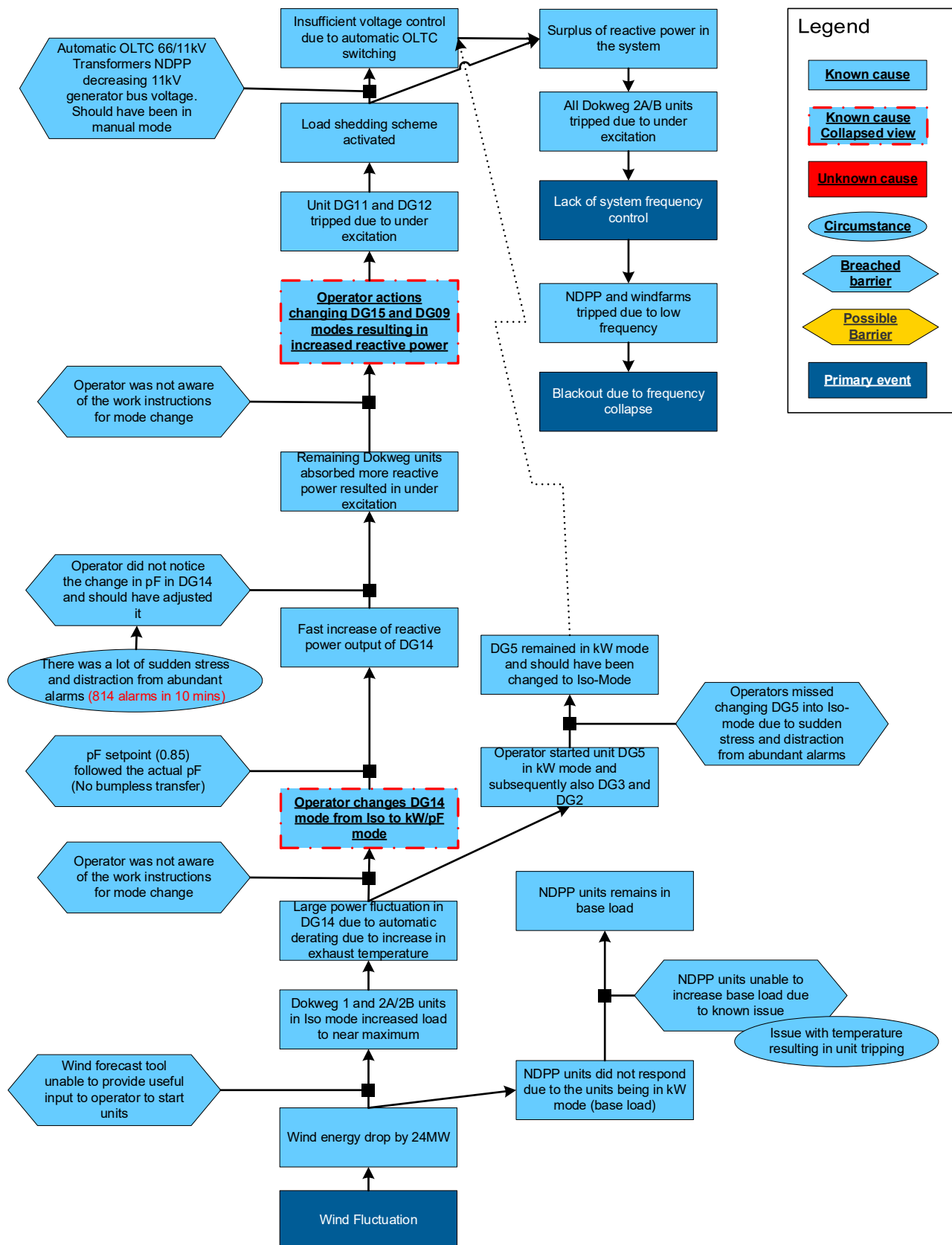


Figure 4-1 Total incident map of the blackout that occurred on 27 August 2025

4.3 Root Cause

The fundamental technical root cause of the blackout was a severe imbalance in reactive power sharing among diesel generating units, which triggered a cascade of under-excitation trips and ultimately led to a full system collapse. This imbalance was not a single-point failure but the result of interacting technical factors and operational decisions under stress. The key contributing elements are detailed below:

- **Control Mode Change of DG14:** DG14 was shifted from frequency-droop to kW control to prevent thermal overload due to rapid load pickup. This was a justified action to avoid tripping the unit. This change automatically switched the generator from voltage-droop (essential for reactive power sharing and grid voltage support) to power factor (PF) control. The PF setpoint was significantly lower than the unit's previous operating point, causing DG14 to suddenly inject a large amount of reactive power. This disrupted the delicate reactive power balance and forced other units in voltage-droop mode to absorb excessive reactive power, pushing them toward their minimum excitation limits.
- **Lack of Immediate Reactive Power Correction:** Operators did not adjust DG14's reactive output after the control mode change, likely due to alarm flooding and operational stress (total 814 Alarms in 10 mins), this critical adjustment was overlooked. The prolonged high reactive output from DG14 amplified system imbalance and accelerated the progression toward instability.
- **DG15 Reactive Power Adjustment:** Operators manually reduced DG15's reactive absorption to bring it out of the danger zone. While this protected DG15, it shifted the reactive absorption burden to other droop-controlled units, notably DG11 and DG12, which then operated deep under-excited and closer to their stability limits.
- **DG9 Mode Change:** DG9 was switched from automatic to manual control for unclear reasons (as noted by DNV). Although still in voltage-droop, it increased reactive power output, further disturbing the system. This was the final trigger that pushed DG11 and DG12 beyond their minimum excitation limits, causing them to trip on under-excitation protection.
- **NDPP Transformer AVC Actions:** The automatic voltage controller (Step-up transformers OLTC) on the NDPP 66/11 kV transformer responded with delayed voltage reductions (40 s and again ~1 min later). Each voltage reduction caused NDPP units to increase reactive power absorption sharply, which in turn forced remaining Dokweg units (DG15, DG9, DG13, later DG10 and DG14) to absorb even more reactive power. This repeated stress drove them past their UEL limits, leading to sequential trips. The NDPP transformer's automatic changing OLTC resulted in voltage adjustments acted as a secondary disturbance amplifier, worsening the reactive imbalance at critical moments.
- **Reactive Power Control Philosophy:** The system relied heavily on voltage-droop control for reactive sharing, but operator interventions without full knowledge of applicable work instruction for unit mode change, introduced inconsistent control strategies (droop vs PF vs manual), creating instability. High stress and numerous alarms likely impaired situational awareness, delaying corrective actions.

5 EVENT, SCENARIO & OPERATOR IMPACT ANALYSIS

DNV is tasked with the review of the Sequence of Events and to assess what might have occurred with appropriate operator intervention and/or hardware system settings.

The Sequence of Events as discussed in section 0 and mapped in section 4.2 has been evaluated for operator actions and crucial hardware system settings that may or may not have contributed to the load shedding and eventually the blackout. Obviously, these are not events with binary impacts, hence a quantitative model has been performed.

The events and corresponding What-If scenarios are:

1. What if the wind forecast tool was able to predict the large wind fluctuation? Not relevant as the focus is on operator action and hardware settings.
2. What if there was a procedure in place for changing the Generator operating mode? Not relevant if the next few barriers were in place. Later corresponding procedures and training can be implemented.
3. What if the DG14 Power Factor set point was higher (than 0.85) or set to follow the current Power Factor? To be modelled; model item 1.
4. What if DG5 operational mode after start-up in kW to Iso-mode and back to kW was not missed by the operator? DNV deems this to have a small impact on main sequence of events.
5. What if the operator had adjusted the DG14 Power Factor manually? To be modelled; model item 2.
6. What if the 66/30kV transformer OLTC's were set to manual mode? Not relevant; it is an additional factor but not decisive.
7. What if the operator had not changed the operating mode of DG9 and DG15? To be modelled; model item 3.
8. What if the 66/11kV transformer OLTC's were set to manual mode? To be modelled, model item 4.

Consequently, following the above rationales to select or deselect events, DNV has made the following selection for quantitative modelling:

Model item 1 What if the DG14 Power Factor set point was higher (than 0.85) or set to follow current Power Factor?

If this barrier was in place (meaning, if this setting was implemented) then DG14 would not have increased its reactive power output. This will be modelled with a likeness of W% resulting in no further issues.

Model item 2 What if the operator had adjusted the DG14 Power Factor manually?

If this barrier was in place (meaning, if this action was done – note that this is not necessarily following a procedure as there was no corresponding procedure) then DG14 would increase its reactive power output (causing instabilities) yet within due course this would have been limited resulting in less instabilities. This will be modelled with a likeness of X% resulting in no further issues.

Note that this action and model item is mutually exclusive with model item 1.

Model item 3 What if the operator had not changed the operating mode of DG9 and DG15?

If this barrier was in place (meaning the operator had not changed the operating mode of DG9 and DG15) then there would be less increase in reactive power output and with Y% likelihood that DG11 and DG12 would not have tripped on under-excitation and load shedding would not have occurred, even with the 66/11kV OLTCs in automatic mode.

Model item 4 What if the 66/11kV transformer OLTC's were set to manual mode?

If this barrier was in place (meaning the OLTC's were set to manual mode) then there would be less instabilities with Z% likelihood of limiting to experiencing load shedding only.

DNV has thoroughly discussed the assumptions W,X,Y and Z, the underlying physics and made best engineering assumptions for the values. A model has been developed to determine the likeliness of a not ending up with load shedding or Black Out following the assumptions, incorporating for uncertainties in their corresponding values. For instance, X is apt with uncertainty related to the time it would have taken for the operator to note the Power Factor going up (even with dynamic alarming providing a digest of critical alarms and actions only to avoid operators being drawn in numerous lower priority alarms), to determine what to do, execute the action and the time it would take for the system to respond.

Assumption W is modelled by a triangular distribution with between 85% and 99% with a mean value of 97%. This means that we expect a positive impact avoiding the start of the series of events by 97% as most expected value tapering off to 99% (avoiding 100% certainty) on the high-end and 85% on the low-end of the likeliness. In case of a set higher Power Factor to follow it depends on the value set being close to the Power Factor at the time of the incident.

Assumption X is modelled by a uniform distribution between 50% and 80%. This means that we expect a positive impact after start of the series events, limiting it from further trigger next events by 50% to 80%. The wide range is due to the physical factors discussed above. The uniform distribution is chosen as it typically represents operator action well.

Assumption Y is modelled by a minimum extreme distribution depicted in Figure 5-1. This means that we expect a positive impact of 90% mean value up to 100% and down to 64%. This type of distribution represent a double operator action with system responses well. As an alternative, a triangular distribution could be chosen.

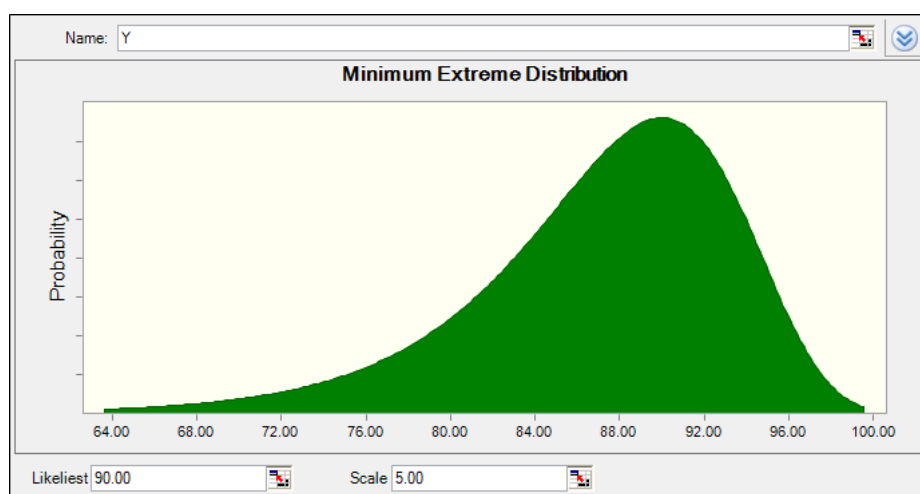


Figure 5-1 The minimum extreme distribution assumption for Y

Assumption Z is modelled by a triangular distribution with between 80% and 99% with a mean value of 95%. This means that we expect a positive impact by 95% as most expected value tapering off to 99% (avoiding 100% certainty) on the high-end and 80% on the low-end of the likeliness.

The model contains a mathematical formula representing the likeliness of the four events and assumed impacts as a parallel connection with W and X being mutually exclusive. While in time the events occurred in series, each of them could have lowered the likeliness following the What-If scenarios. The model then computes the total likeliness of not having experienced Load Shedding (with W,X,Y active), only Load Shedding (with only Z active) and the Black Out (with W,X,Y,Z active). It does so by computing the total likeliness 25,000 times (optimal point for granularity of results versus computation time) sampling from each of the four assumed distributions. The results of this so-called Monte Carlo simulation, are stored per computation and represent a distribution of expected values.

The model results in a distribution of expected values related to the likeliness of having avoided a Blackout as displayed in Figure 5-2. As model items 1 and 2 are mutually exclusive, there are two related graphs.

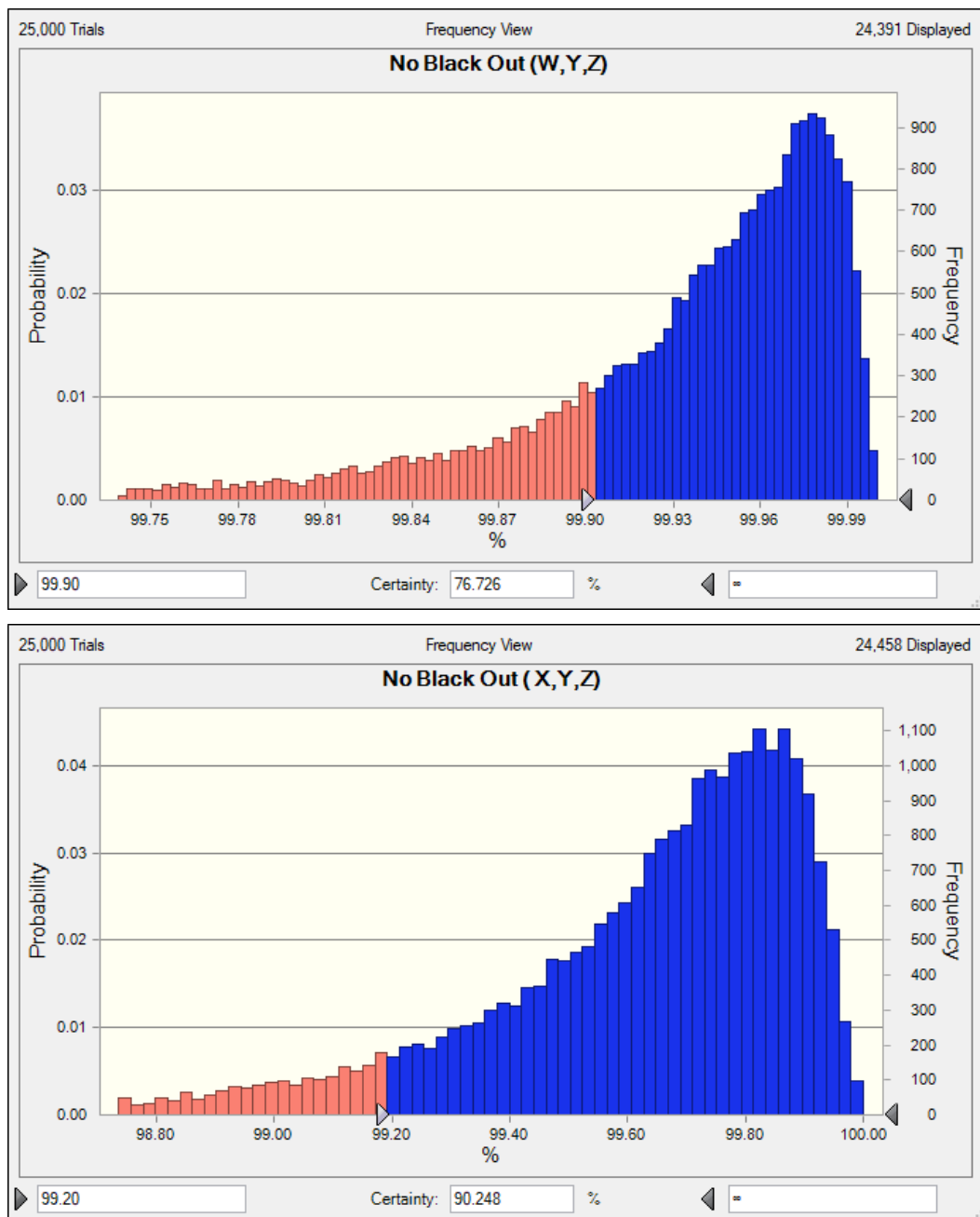


Figure 5-2 Distribution of expected values; likeliness of avoiding a Black Out for both potential sequences

The best results are obtained with model Item 1 (automatic following of the Power Factor or maintaining a set value higher than 0.85). The mean value is around 99.98%. In DNV's view high enough to consider implementing the consequential improvements related to the three involved model items. It can also be observed that with 76.7% certainty the likeliness of having avoided a Black Out exceeds 99.9%.

The lesser results, involving model item 2 with a dependence on operator action to adjust the Power Factor, still provide a mean of approximately 99.9% and a 90.2% certainty that the likeliness exceeds 99.2%.

With respect to the likeliness of avoiding Load Shedding, the model results in a distribution of expected values related as displayed in Figure 5-3.

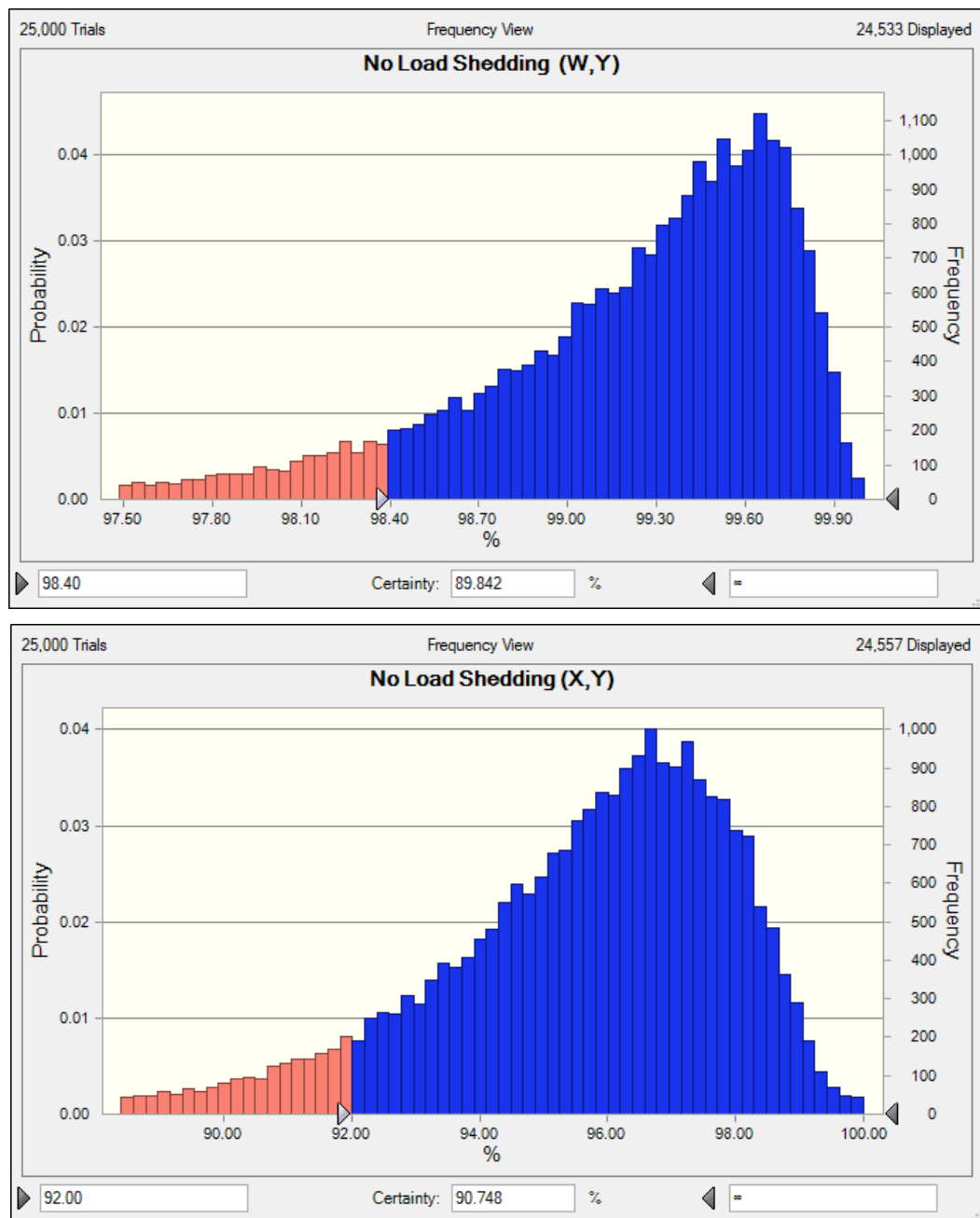


Figure 5-3 Distribution of expected values; likeliness of avoiding Load Shedding for both potential sequences

The best results are again obtained with model Item 1 (automatic following of the Power Factor or maintaining a set value higher than 0.85). The mean value is around 99.7% and it can be observed that with 89.8% certainty it will exceed 98.4%.

The lesser results, involving model item 2 with a dependence on operator action to adjust the Power Factor, provide a mean of approximately 97.0% and a 90.7% certainty that the likeliness exceeds 92.0%.

Lastly, the likeliness of restricting the incident to Load Shedding would involve model item 4 only; What-If the 66/11kV transformer OLTC's were set to manual mode.

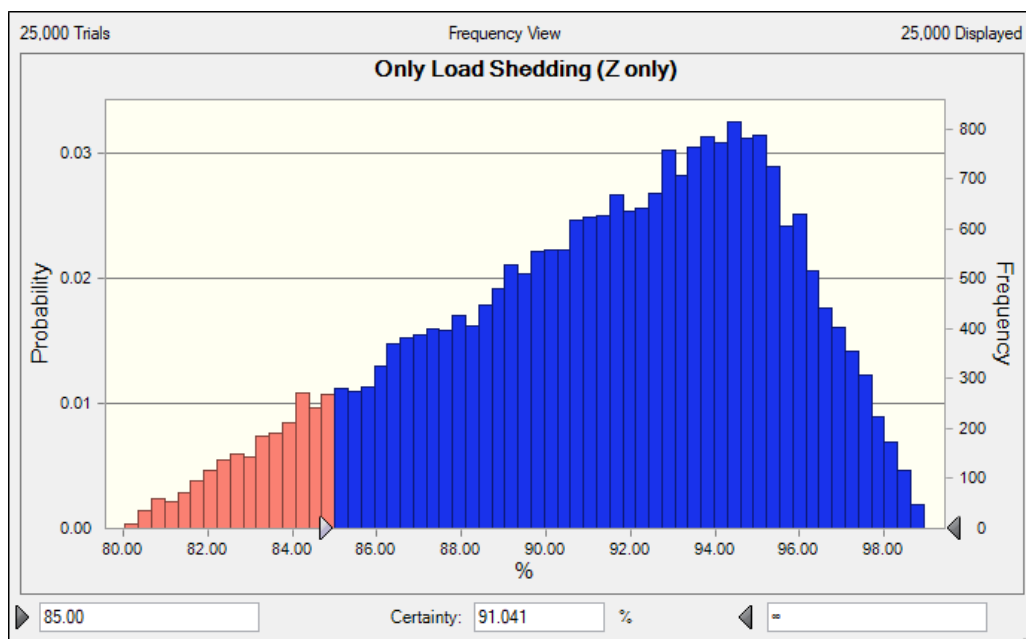


Figure 5-4 Distribution of expected values; likeliness of restricting the event to Load Shedding only

The models shows a likeliness with a mean value of approximately 95.0% and a 91.0% certainty that the likeliness exceeds 85.0%. Note that this results depends one-on-one on the assumption Z.

In conclusion the model indicates that:

- 4) The Black Out could have been avoided with 99.98% and 99.90% certainty, respectively, with:
 - a. Automatic following the Power Factor (or higher set point), not having changed the operating mode of DG9/15 and the 66/11kV transformer OLTC's set to manual mode.
 - b. Manual operator Power Factor adjustment, not having changed the operating mode of DG9/15 and the 66/11kV transformer OLTC's set to manual mode.
- 5) The Load Shedding could have been avoided with 99.7% and 97.0% certainty, respectively, with:
 - a. Automatic following the Power Factor (or higher set point), not having changed the operating mode of DG9/15.
 - b. Manual operator Power Factor adjustment, not having changed the operating mode of DG9/15.
- 6) The incident could have been restricted to Load Shedding with 95.0% certainty with the 66/11kV transformer OLTC's set to manual mode.

6 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

The blackout on 27 August 2025 was triggered by significant wind fluctuations, which initiated a complex sequence of events related to unbalanced reactive power control. Importantly, this was not a single-point failure but rather the result of vulnerabilities in reactive power management amplified by justified yet uncoordinated operational actions and automatic voltage control responses.

A key disturbance was introduced when DG14 was manually switched to a different control mode to prevent thermal overload. While the action was technically justified, it led to a severe reactive power imbalance due to incorrect control mode settings and delayed corrective interventions—decisions made under operator stress (total 814 Alarms in 10 mins).

The lack of immediate adjustment to DG14's reactive output, combined with subsequent manual interventions on DG15 and DG9, further destabilized reactive power sharing among the DGs. These actions, though intended to protect individual units, increased the stress across the remaining generators, pushing several into deep under-excitation conditions.

Ultimately, the NDPP transformer's automatic voltage control action resulted in tripping of the remaining units due to the unbalanced reactive power.

To review What-If scenarios relevant to the events building up to the blackout, DNV has developed a quantitative model. The model outcome indicates that:

- 1) The blackout could have been avoided with 99.98% and 99.90% certainty, respectively, with:
 - a. Automatic following the Power Factor (or higher set point), not having changed the operating mode of DG9/DG15 and the 66/11kV transformer OLTCs set to manual mode.
 - b. Manual operator Power Factor adjustment of DG14, not having changed the operating mode of DG9/DG15 and the 66/11kV transformer OLTCs set to manual mode.
- 2) The Load Shedding could have been avoided with 99.7% and 97.0% certainty, respectively, with:
 - a. Automatic following the Power Factor (or higher set point), not having changed the operating mode of DG9/DG15.
 - b. Manual operator Power Factor adjustment, not having changed the operating mode of DG9/DG15.
- 3) The incident could have been restricted to Load Shedding with 95.0% certainty with the 66/11kV transformer OLTCs set to manual mode.

6.2 Recommendations

Based on the findings of this investigation, DNV recommends the following for implementation:

Short-term recommendations

Control Philosophy & Operating Modes

- Keep generators in voltage-droop control as the default, even when the diesel engine is run in kW (power) mode.
- Keep all units in frequency-droop by default; only exit droop if a unit is at credible risk of tripping at high output or during rapid ramps; maintain adequate spinning reserve.

- Reconsider with Wärtsilä the automatic transfer to PF control when entering kW mode; either disable the auto-switch or require operator confirmation, so the generator can remain in voltage-droop with appropriate ramp limits.
- NDPP units (operated at reduced continuous output): Investigate enabling frequency-droop or temporarily higher outputs with safeguards. Note these units will auto-return to pre-disturbance output when system frequency is restored to 50 Hz by Dokweg 1/2A/2B in isochronous mode.
- Test/activate bump less transfer automatic voltage regulators of generators when control mode switches from voltage-droop-power factor and vice versa

Transformer OLTC & Voltage Control

- Operate the 66 kV OLTCs at NDPP in manual mode in manual mode and ensure all tap changes are coordinated with power plant operators.
- Specifically for Nijlweg-Weis to investigate the conditions automatic voltage control by performing system studies.

Mid-term recommendations

Supervisory Control & Procedures

- Develop a comprehensive strategy and detailed procedures for reactive power balancing and voltage control, taking into account the generator, engine control modes and transformer automatic voltage control in applicable operational scenarios. This should include performing load flow studies to accurately model reactive power flows and system voltage profiles under major generation or network disturbances. The study should evaluate system voltage stability, reactive power interactions, and the coordination between transformer tap operations and generator voltage-droop control to ensure optimal system performance and prevent unintended voltage disturbances.
- Review and update comprehensive and clear SOPs for (a) control mode changes and (b) reactive power balancing
- Implement a two-person verification and interlocking for unit operating mode transitions and major reactive setpoint changes. Log all changes.

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/2/	Blackout August 27 2025
/3/	Event_Alarm list 27-08-2025
/4/	Engine Control modes
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/6/	sWOIS Operator Manual
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/8/	09072025 161849 Electrical system 2B Genset 9, 4 and 14 Control
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/10/	08272025 000000, 08272025 235959, System, 1_400
/11/	20250902_Frequentie trap
/12/	66KV-30KV2025Eduel2pdf
/13/	PFM data
/14/	MoM with Operators 090925 - FINAL
/15/	Operation Modes Aqualectra
/16/	Mechanical power to Electrical power
/17/	Active Reactive Power

ANNEX 1: DETAILED ASSESSMENT ON ACTIVE AND REACTIVE POWER BEHAVIOUR GENERATING UNITS

1 ACTIVE POWER BEHAVIOUR

1.1 Overall behaviour active power balancing / frequency support

DG 6, 9, 11, 12, 14, 15 were on isochronous mode, DG 7, 10, 13 and NDPP units on kW mode, DG 1, 2, 3, 4, 16 were offline.

The frequency control / active power balancing was mainly done by 5 DKW 2A/2B units. At DKW 1 only one unit out of 3 was supporting active power balancing / frequency. NDPP units are standard operated in kW mode and were on an output of 75% of rated capacity. Aqualectra limits the output because of a risk that these units trip at a higher output.

The units managed to balance the drop in active power from the wind farms without load shedding and keep frequency at 50 Hz. Load shedding occurred. after 2 units at DKW 2A/2B tripped. The load shedding of 20 MW compensated the loss of power from the 2 units and frequency was stable at 50.0 Hz

Only after another 3 units at DKW 2A/2B tripped, the frequency could not be maintained at 50 Hz and dropped to 49.0 Hz. Further load shedding stabilized the active power balance.

One minute later another 3 units tripped, the remaining 2 at Dokweg 2A/2B and one unit at DKW 1. The frequency dropped to 47.5 Hz but surprisingly was stable for 4 minutes before the system collapsed. The collapse occurred just after the wind farms Tera Cora 2, Playa Canoa and Koral Tabak disconnected (Tera Cora 1 disconnected already earlier), probably caused by the low frequency and insufficient frequency control capabilities of the units at NDPP and Dokweg 1.

Recommendations:

- Keep all units in frequency droop control, unless the units are expected to trip at high output or at fast output variations.
- The 4 NDPP units are operated at reduced continuous output. Investigate what is required to operate these unit in frequency droop control mode or run them for limited period of time at a higher output. Keep in mind that these units will automatically return to their pre-disturbance output when the frequency is restored to 50 Hz by the units of Dokweg 1, 2A, 2B in isochronous mode.

1.2 Dokweg 2A and 2B units active power

1.2.1 Overall observations

- Based on screenshots WOIS: DG 6, 9, 11, 12, 14, 15 on frequency droop at 2:40
- Until 2:30 steady operation with variations in active power output and sufficient spinning reserve
- At 2:30 steep increase of active power output by DG 11/12 and DG 15 because of wind power drop. The active power increase of DG 9/10 and 13/14 is only half of the increase of DG 11/12 and DG 15, indicating that one of DG 11/12 and DG 13/14 was in kW mode
- At 2:33 DG 14 is automatically derated by its control because of cylinder temperature unbalance due to steep increase of active power output. This happens twice between 2:33 and 2:35 and 3 times between 2:42 and 2:47.
- At 2:43 most units are near or on maximum output with very small margin for spinning reserve. However no load shedding until DG 11/12 trip at 2:49.
- 2:50:58: DKW 2B step-up and auxiliary transformers trip on overvoltage
- 2:50:59: DKW 2A step-up and auxiliary transformers trip on underfrequency

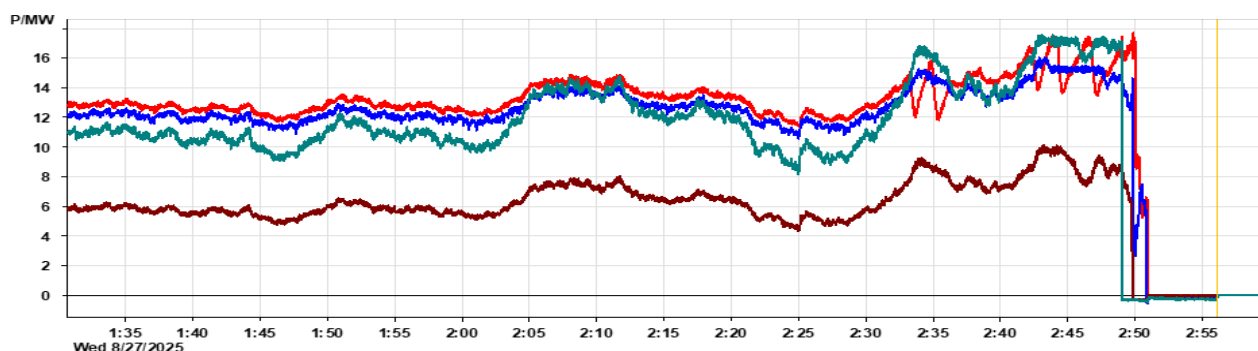


Figure 1-1 Active power DKW 2A/2B power plants at 66 kV connection step-up transformers. Blue: DKW 2A-T2 (DG 9/10); Green: DKW 2A-T1 (DG 11/12); Red: DKW 2B-T1 (DG 13/14); Brown DKW 2B-T2 (DG15/16)

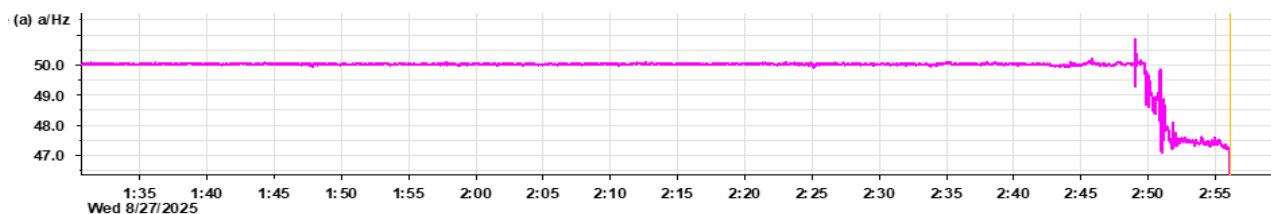
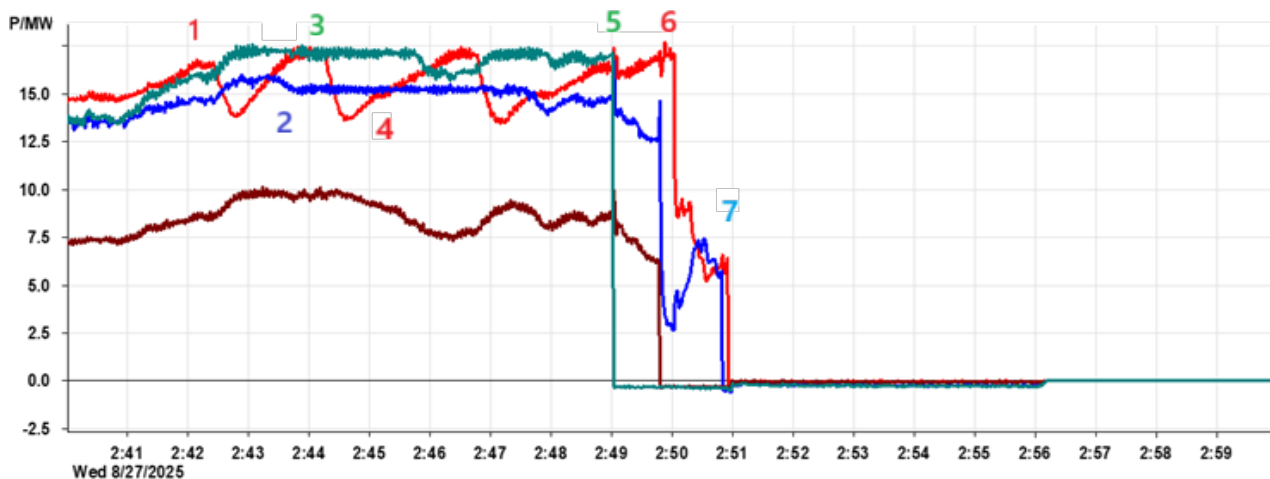


Figure 1-2 Grid frequency

1.2.2 Detailed observations

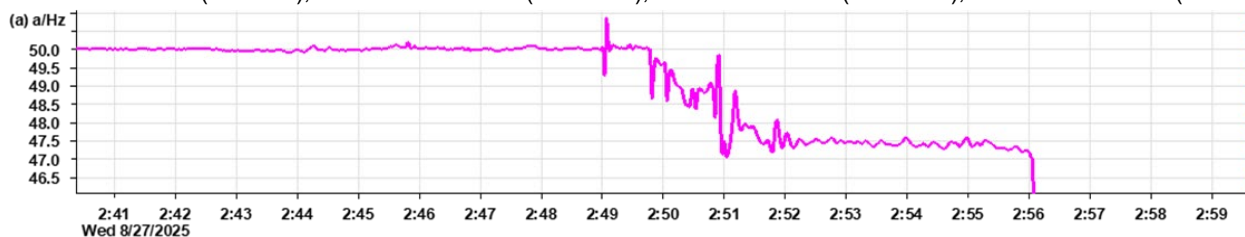
Coloured numbers refer to numbers in figure below.

- **1:** DG 13/14: oscillation output by DG 14
- **2:** at 2:43:28: DG 9 switched to kW mode manual, switched to isochronous mode at 2:46:47
- **3:** at 2:44:07: DG 11 switched to kW control manual
- At 2:44 to 2:47: DG 9/10 at 15 MW, not participating in frequency support while not at rated output
- At 2:43 to 2:46: DG 11/12 at 17.5 MW
- **4:** at 2:45:06: DG 14 switched to kW mode and switched to isochronous mode at 2:46:59 Again, switch to kW mode at 2:47:54 and to droop mode at 2:48:39. The at 2:49:16 switch to kW mode.
- **5:** at 2:49: trip of 2 units (DG 11, 12), frequency transient
- **6:** at 2:50: drop frequency after trip of 3 units (DG 15, 9, 13) to 49.0 Hz
- **7:** at 2:51 onwards: further decrease of frequency to 47.5 Hz after trip of the remaining DKW 2A and 2B units DG 10, 14. Now only 4 NDPP and 3 DKW 1 units online.



Active power DKW 2A/2B power plants at 66 kV connection step-up transformers

Blue: DKW 2A-T2 (DG 9/10); Green: DKW 2A-T1 (DG 11/12); Red: DKW 2B-T1 (DG 13/14); Brown DKW 2B-T2 (DG15/16)



Grid frequency

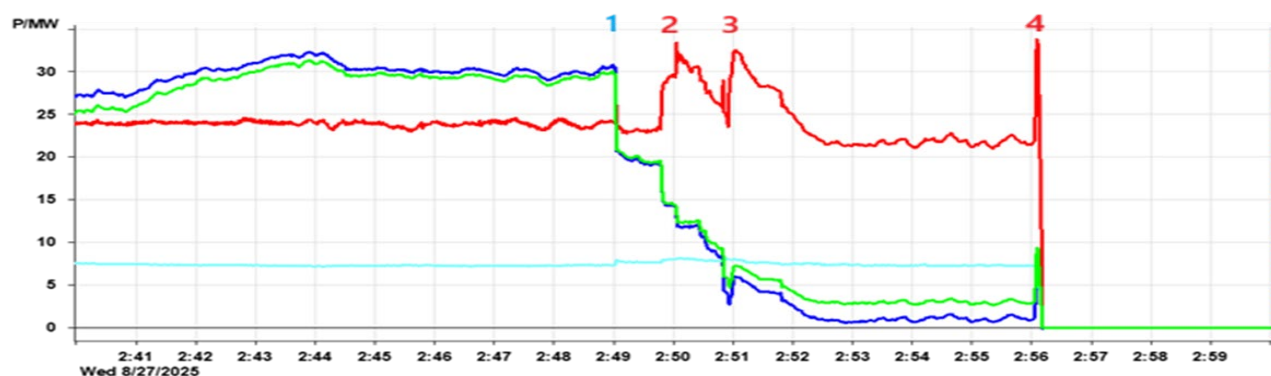
1.3 NDPP units active power and net demand Nijlweg-Weis load center

1.3.1 Observations

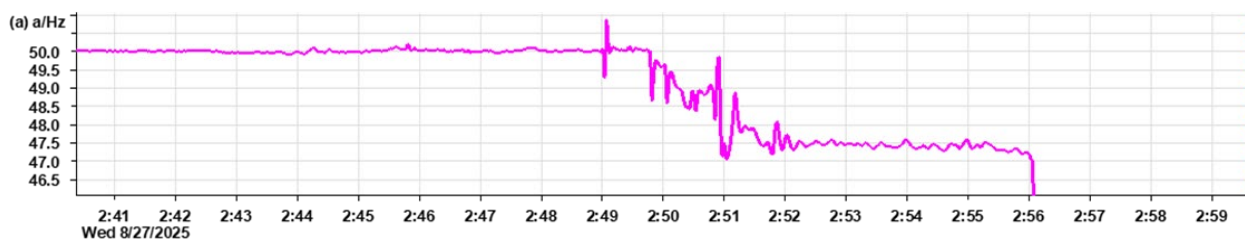
The active power demand of Nijlweg-Weis load center is included in the figure below to show the load shedding in the network. The net demand of Nijlweg-Weis is the demand of all consumers connected to this load center minus the active power generated by Dokweg 1 and the 4 wind farms which are connected to this load center.

Coloured numbers refer to numbers in figure below.

- Until 2:50 steady output of 4 units at 24 MW total.
- **1**: 2:49: load shedding Nijlweg-Weis load center when DG 11, 12 tripped
- **2**: 2:50: sudden power surge from 24 to 30 MW 45 when DG 15, 9, 13 tripped. Further load shedding
- **3**: 2:51: sudden power surge from 24 to 32 MW when DG 10, 14 tripped. Further load shedding
- 2:53: output stabilized at 22 MW until system collapsed
- **4**: 2:56 all units trip after wind farms trip



Active power NDPP power plant and net demand load center Nijlweg-Weis at 66 kV connection transformers
RED: NDPP-I (NDPP-II offline); Green: Nijlweg feeder; Blue: Weis feeder



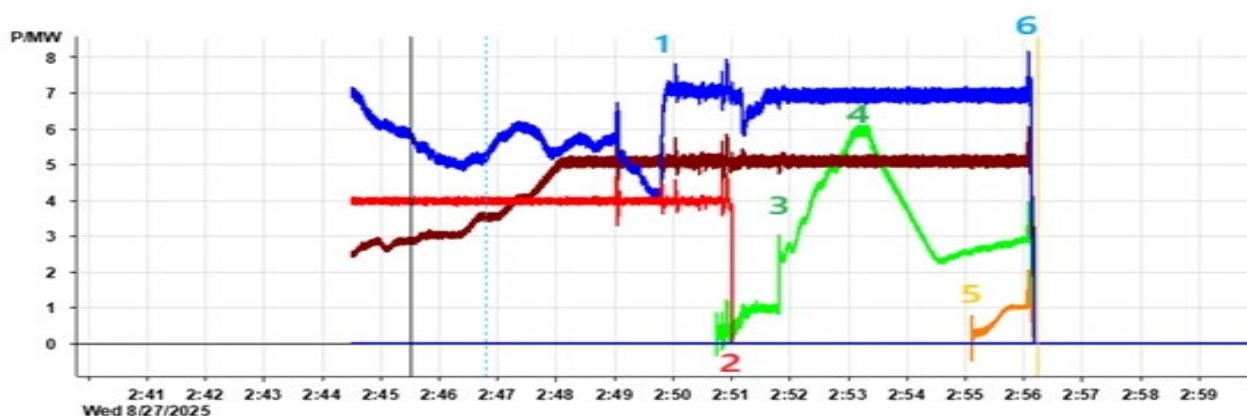
Grid frequency

1.4 Dokweg 1 units active power

1.4.1 Observations

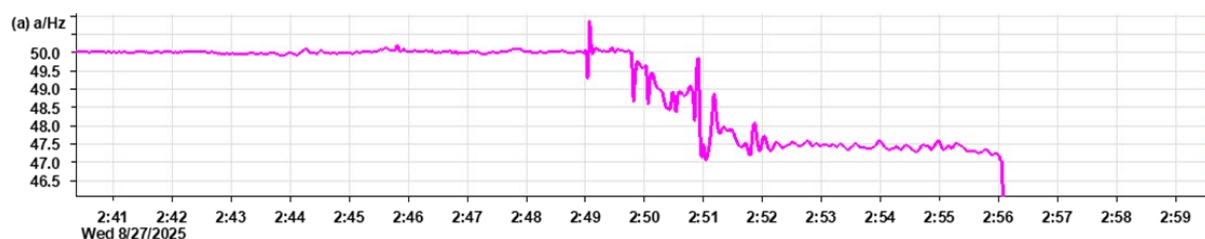
Coloured numbers refer to numbers in figure below.

- In service at 2:45 are DG 5 (resynchronised at 2:43:36), DG 6, DG 7.
- 2:44:13: DG5 is switched to isochronous mode but at 2:45:03 back to kW mode. DG6 is in isochronous mode, DG7 in kW mode
- DG6 active power varies because of isochronous mode. DG5 is loaded after synchronisation, DG7 is at constant output of 4 MW
- **1:** 2:49:49 sudden jump in active power output DG6 up to maximum power when DG 15, 9, 13 trip. No change in power output DG 5, 7
- **2:** 2:50:59 trip of DG7, cause not clear yet. Near the same time, DG 10 and 14 trip, NDPP units power surge and load shedding occur. DG3 is synchronised
- **3:** 2:51:51: DG 3 switched to isochronous mode, picking up load. DG 6 remains at maximum output and DG 5 at constant output.
- **4:** 2:53:14 DG 3 switched to kW / pf mode, ramping down power output after alarm "P>Pmax, reduce load". DG 6 and 7 output do not change. No units in service controlling frequency?!
- **5:** 2:55:07 DG 2 synchronised.
- **6:** 2:56 trip of all 4 DKW 1 units after wind farms trip



Active power Dokweg 1 units

Blue: DG 6; Red: DG 7; Brown: DG 5; Green: DG 3; Orange: DG 2



Grid frequency

2 REACTIVE POWER BEHAVIOUR

2.1 Overall behaviour reactive power balancing / voltage support

Units DG 6, 11, 12, 15 and the 4 NDPP units were on voltage droop supporting reactive power balancing, adjusting their reactive power output when the reactive demand of the network demand changes.

The voltage control / reactive power balancing was mainly done by the 4 DKW 2A/2B units. DKW 1 and NDPP units, although on voltage droop control, can only shortly contribute. Because of the automatic voltage control on the Nijlweg-Weis and NDPP 66 kV transformers, which controls the voltage at the units connected at Dokweg 1 and NDPP with some delay, this contribution will only last until the transformer control restores the normal voltage. The changes caused by the automatic voltage control give an additional reactive power disturbance on the DKW 2A/2B units.

The changes in reactive power because of active power changes of wind farms was negligible.

The high reactive power increase of DG 14, when its control was changed to kW (Power Factor) mode, had to be compensated by the units in voltage droop by absorbing this additional reactive power. It became worse when the reactive power output of DG 15 was increased by the operator to take DG15 out of the under-excitation danger zone. It forced DG 11/12 further into their under-excitation danger zone.

Finally, DG 11/12 tripped on under excitation when DG 9 reactive power increased when it was switched to manual control. As a consequence, remaining units at Dokweg 2A/2B had to compensate by importing additional reactive power and tripped on under excitation.

The voltage in the system increased during this period from 68 to 74 kV. This was caused by the increase of reactive power absorption of the units at Dokweg 2A/2B in the beginning and later also by the load shedding and tripping of units. The system collapsed because of wind farms tripping and insufficient frequency control capabilities of the units at NDPP and Dokweg 1.

Recommendation:

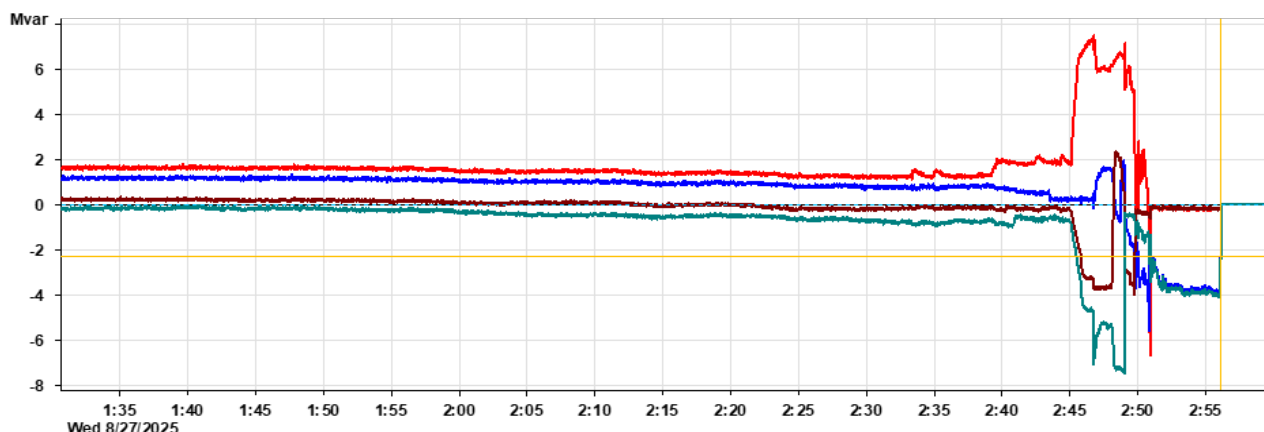
- Keep all units in voltage droop control as much as possible, even when the diesel engine needs to run in kW mode.
- Reconsider with Wärtsilä the automatic transfer to power factor control when in kW mode. When there are issues with the diesel engine which require kW mode, the generator can still operate in voltage droop mode
- Put 66 kV transformers at NDPP and Nijlweg-Weis at manual control tap changer. The automatic voltage control of these transformers overrides the voltage droop control. Adjusting the tap has an impact on the reactive power balance and shall be coordinated with the power plant operators.
- Prepare a strategy and procedure for reactive power balancing and voltage control. Load flow calculations will be required to determine reactive power flows and system voltages during large disturbances in generation and network.

2.2 Dokweg 2A and 2B units reactive power

2.2.1 Overall observations

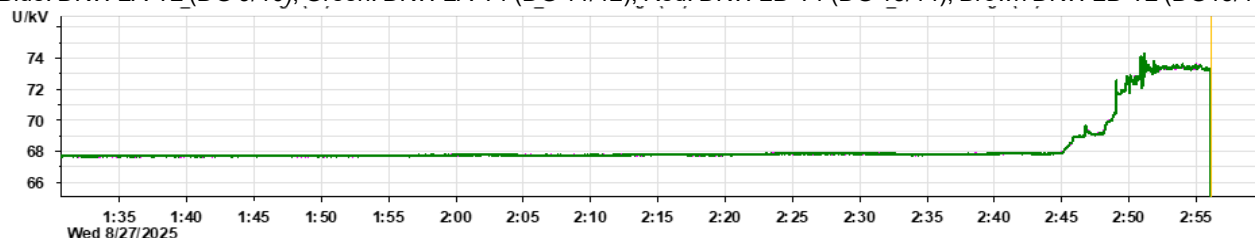
Based on screenshots of the WOIS system, units DG 6, 11, 12, 15 and NDPP units were on voltage droop at 2:45.

- Until 2:40 steady reactive power output of all DKW 2A/2B units
- At 2:40 small increase reactive power output of DG 13/14 by operator voltage control actions without impact on system voltage
- At 2:45 steep increase in reactive output DG 14 when it was switched to power factor control mode. Response of other units, which import large amount of reactive power (under excitation) and increase of system voltage. This event is the first trigger that led to the blackout.
- At 2:48 steep increase in reactive power output of DG 15 by operator voltage control actions with major increase on system voltage and further increase of reactive power import of DG 11/12. This event is the second trigger that led to the blackout.
- At 2:49 trip of DG 11, 12 on under excitation and response of other units at DHKW 2A/2B to balance the system reactive power
- At 2:50 trip of DG 15, 9, 13 on under excitation because of response to balancing reactive power caused by trip DG 11, 12 and increase reactive power output of DG 15 before.
- At 2:51 trip of DG 10, 14 on under excitation because of response to balancing reactive power caused by trip DG 11, 12, 15, 9, 13 before.
- 2:50:58: DKW 2B step-up and auxiliary transformers trip on overvoltage
- 2:50:59: DKW 2A step-up and auxiliary transformers trip on underfrequency
- 2:49 onward: the 66 kV system voltage increases rapidly after tripping of units and load shedding



Reactive power DKW 2A/2B power plants at 66 kV connection step-up transformers

Blue: DKW 2A-T2 (DG 9/10); Green: DKW 2A-T1 (DG 11/12); Red: DKW 2B-T1 (DG 13/14); Brown DKW 2B-T2 (DG15/16)



Voltage 66 kV grid

2.2.2 Detailed observations

Coloured numbers refer to numbers in figure below.

- **1:** at 2:45:06 DG 13/14 steep increase in reactive power. DG 14 switched to kW mode and automatically to Power Factor mode. Power factor setpoint was at 0.85. DG 11/12 and DG 15 responded, but DG 9/10 did not respond. DG 9 switched to PF mode at 2:43:28, DG 10 switched to droop mode at 2:49:49, so probably was in power factor mode before.
- **2:** At 2:46:47 D9 switched from PF to voltage droop. An increase in reactive power of D 9/10, but no bumpy transfer
- **3:** 2:47: steep peak import reactive power DG 11/12. At the same moment steep increase reactive power NDPP units because of tap change of their step-up transformer. It appears that DG 13/14 respond. DG 13 did not switch modes in this period, so assumed to be in voltage droop. DG 14 was in PF mode before but switched to voltage droop mode at 2:47:00
- **4:** 2:48: steep increase reactive power DG 15, by manual increase command operator. DG 11/12 and DG 9/10 respond. DG 13/14 did not respond and maintained high reactive power output. DG 14 was just before switched to PF mode .
- **5:** At 2:48:42: DG 9/10 steep increase reactive output. DG 9 switched from voltage droop Hz mode to voltage droop manual mode (tracking issue or manual controlling setpoint or operator adjustments which are not in event log?)
- **6:** 2:49:01 trip of DG 11/12 by underexcitation protection at -7.7 Mvar at 66 kV. DG 15 responded to absorb reactive power and also minor contribution from DG 13/14, 9/10 and NDPP units.
- **7:** 2:50: trip of DG 15 (2:49:47), 9 (2:49:48), 13 (2:50:02) on underexcitation. DG 10, 14 still online together with 4 units at NDPP, 3 units at DKW 1.
- **8:** 2:51: trip of DG 10, 14 on underexcitation while both importing high reactive power
- 2:51 onwards: while DG 9, 10, 11, 12 were tripped, their step-up transformers import 4 Mvar reactive power continuously until blackout. Even when step-up transformers 11 kV breaker tripped at 2:50:58 on overvoltage.
- Voltage 66 kV: the voltage started to increase from the moment DG 14 was switched to power factor control with the high, sudden increase of reactive power injection. The voltage increased further when DG 15 switched to power factor control. A voltage jump occurred at the moment when units tripped at underexcitation and load shedding started at 2:49. Strangely enough the voltage stabilized at 73.5 kV while all DKW 2A and 2B were already tripped. The 4 NDPP units together with 2 DKW 1 units managed to control the voltage.



Reactive power DKW 2A/2B power plants at 66 kV connection step-up transformers

Blue: DKW 2A-T2 (DG 9/10); Green: DKW 2A-T1 (DG 11/12); Red: DKW 2B-T1 (DG 13/14); Brown DKW 2B-T2 (DG15/16)



Voltage 66 kV grid

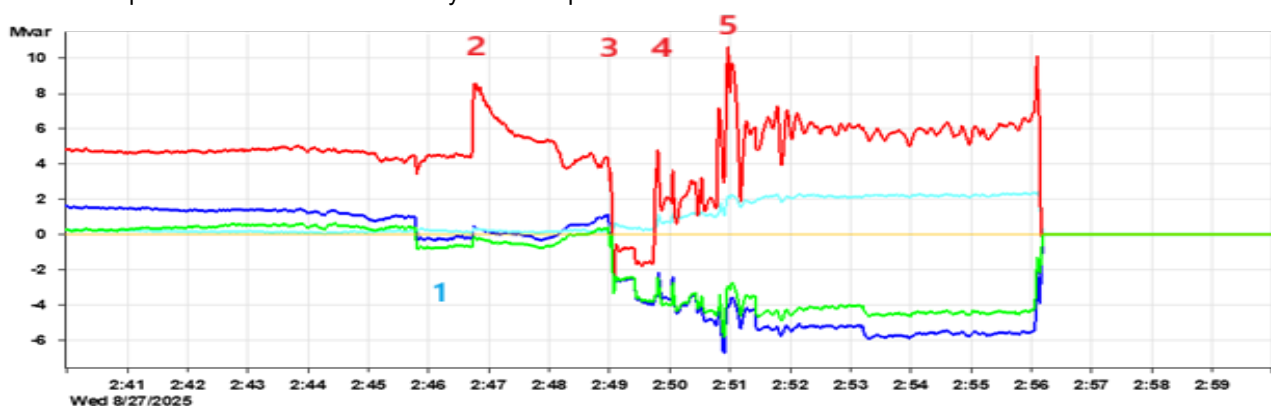
2.1 NDPP units reactive power and net demand Nijlweg-Weis load center

2.1.1 Observations

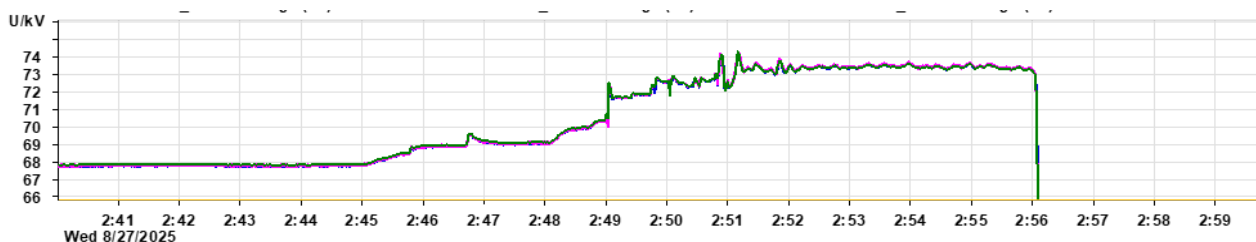
The reactive power demand of Nijlweg-Weis load center is included in the figure below to show the load shedding in the network. The net reactive power demand of Nijlweg-Weis is the demand of all consumers connected to this load center minus the reactive power from the Dokweg 1 and the 4 wind farms which are connected to this load center.

Coloured numbers refer to numbers in figure below.

- Until 2:47 steady output of 4 units at 5 Mvar export total.
- **1**: 2:46: reactive power reduction Nijlweg-Weis because of tap change Nijlweg-Weis transformer, which was on automatic voltage control.
- **2**: 2:47: reactive power surge NDPP units because of tap change step up transformer, which was on automatic voltage control.
- **3**: 2:49: sudden reactive power drop when 66 kV voltage increased because of trip DG 11, 12.
- **4**: 2:50: sudden reactive power increase because of tap change step up transformer.
- **5**: 2:51: sudden reactive power increase because of tap change step up transformer
- output stabilized at 22 MW until system collapsed



Reactive power NDPP power plant and net demand load center Nijlweg-Weis at 66 kV connection transformers
RED: NDPP-I (NDPPII offline); Green: Nijlweg feeder; Blue: Weis feeder



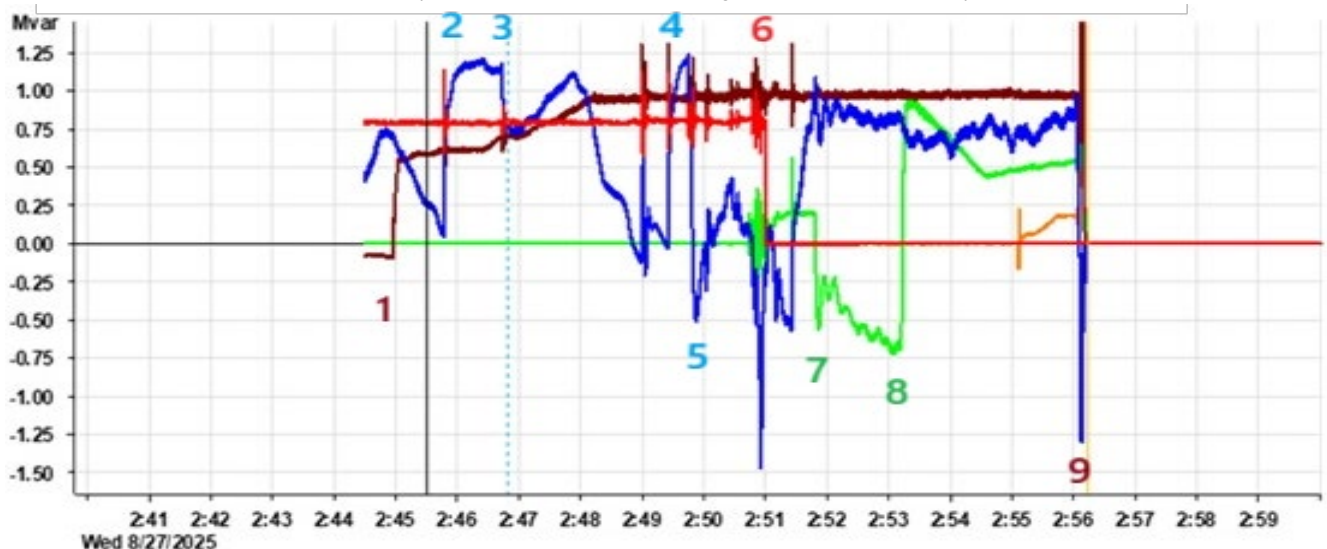
Voltage 66 kV grid

2.2 Dokweg 1 units reactive power

2.2.1 Observations

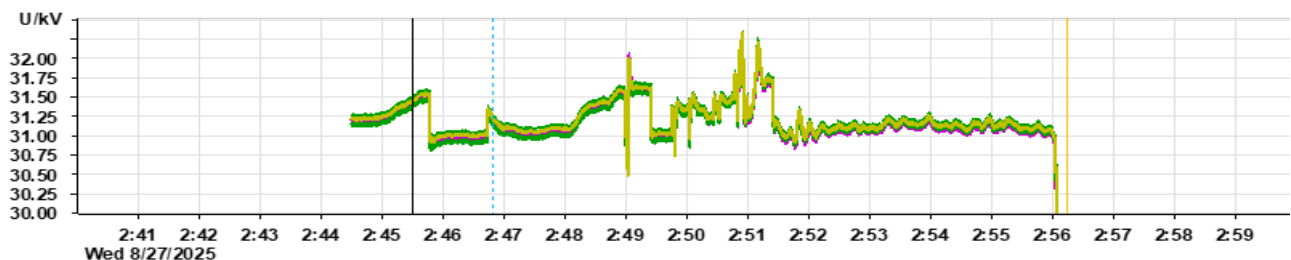
Coloured numbers refer to numbers in figure below.

- In service at 2:45 are DG 5 (resynchronised at 2:43:36), DG 6, DG 7.
- DG6 reactive power varies because of isochronous mode. DG 5 is loaded after synchronisation, DG7 is at constant output of 0.8 Mvar because in PF mode
- **1**: 2:45:00 sudden jump in reactive power output DG 5, which was switched to kW / PF control.
- **2**: 2:45:46 sudden jump in reactive power output DG 6 caused by tap change of 66 kV transformers Nijlweg-Weis, which were on automatic voltage control.
- **3**: 2:46:45 sudden reduction reactive power DG 6 caused by reactive power surge NDPP units which responded to tap change of 66 kV transformer NDPP which was on automatic voltage control.
- **4**: 2:49:25 sudden jump in reactive power output DG 6 caused by tap change of 66 kV transformers Nijlweg-Weis, which were on automatic voltage control.
- **5**: 2:49:44 sudden reduction reactive power DG 6 caused by reactive power surge NDPP units which responded to tap change of 66 kV transformer NDPP which was on automatic voltage control
- **6**: 2:50:59 trip DG 7, not clear why
- **7**: 2:51:51 DG 3 importing reactive power after switch to isochronous (voltage droop)
- **8**: 2:53:14 DG 3 steep increase reactive power after switch to kW / PF mode
- **9**: 2:56:12 trip of all 4 DKW 1 (low lubrication oil pressure, generator excitation off) units after wind farms trip



Active power Dokweg 1 units

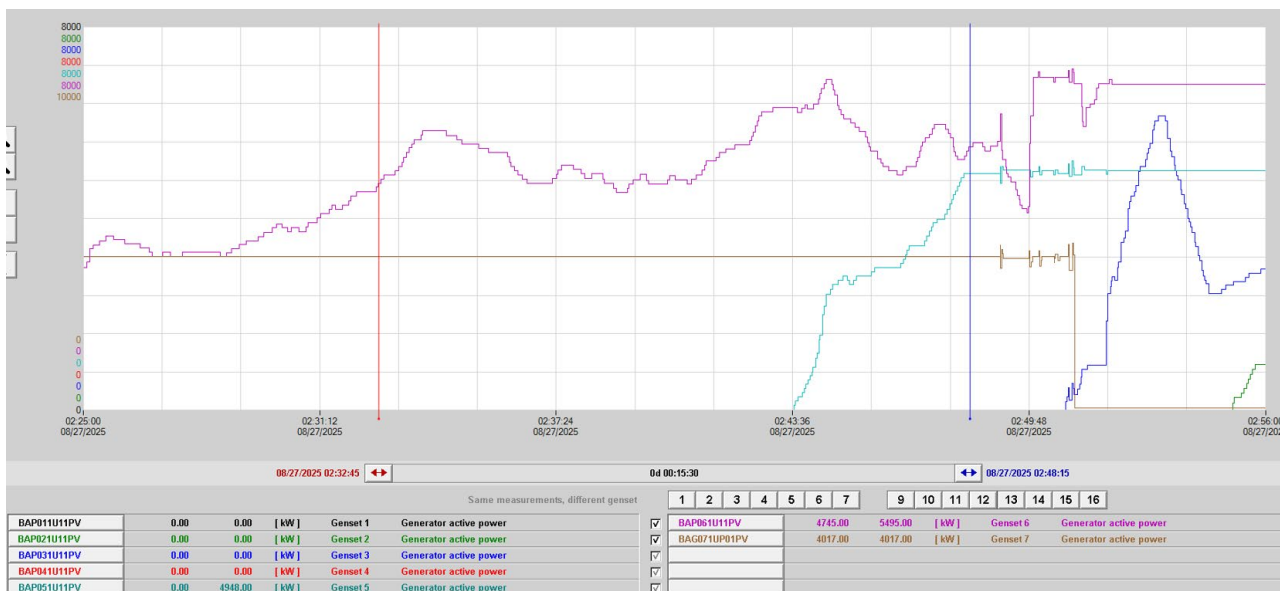
Blue: DG 6; Red: DG 7; Brown: DG 5; Green: DG 3; Orange: DG 2



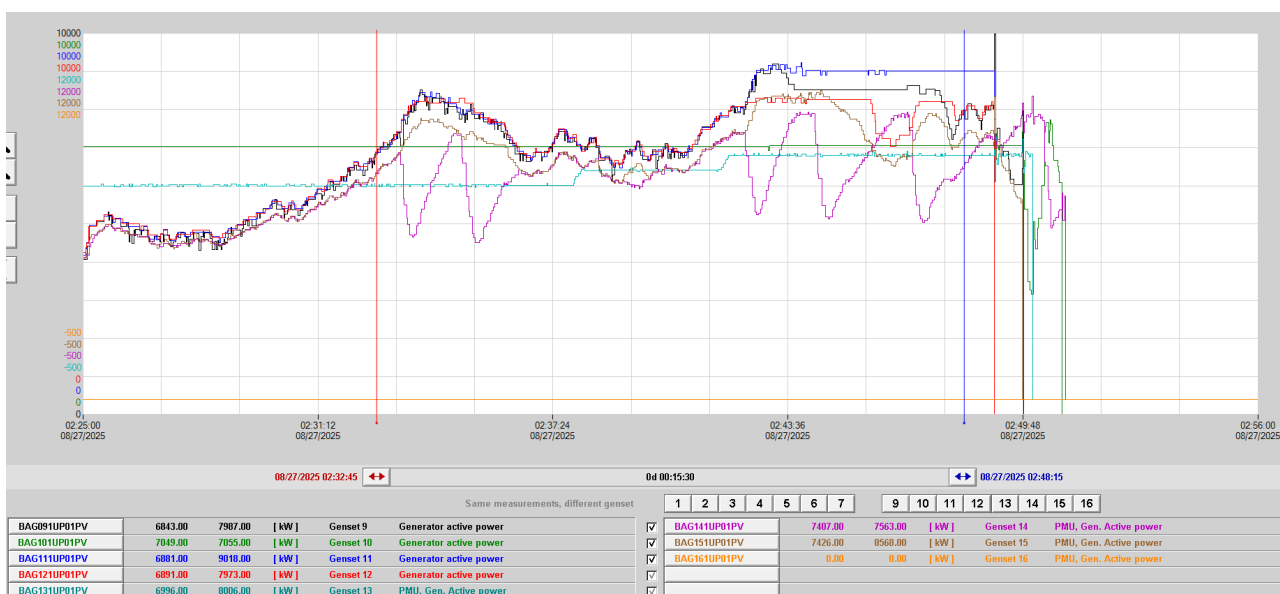
Voltage at 30 kV Dokweg 1

ANNEX 2: SCREENSHOTS DOKWEG 1, 2A AND 2B FOR INFORMATION

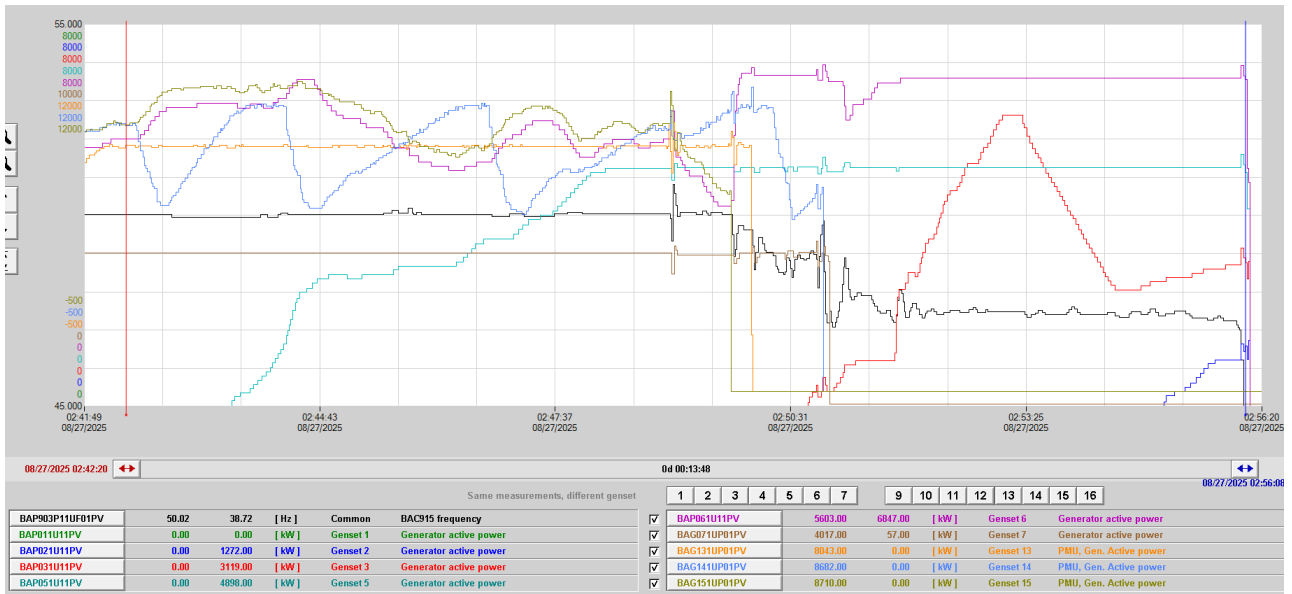
1 ACTIVE POWER BEHAVIOUR



Active power Dokweg 1 units during last 30 minutes before blackout



Active power Dokweg 2A, 2B units during last 30 minutes before blackout

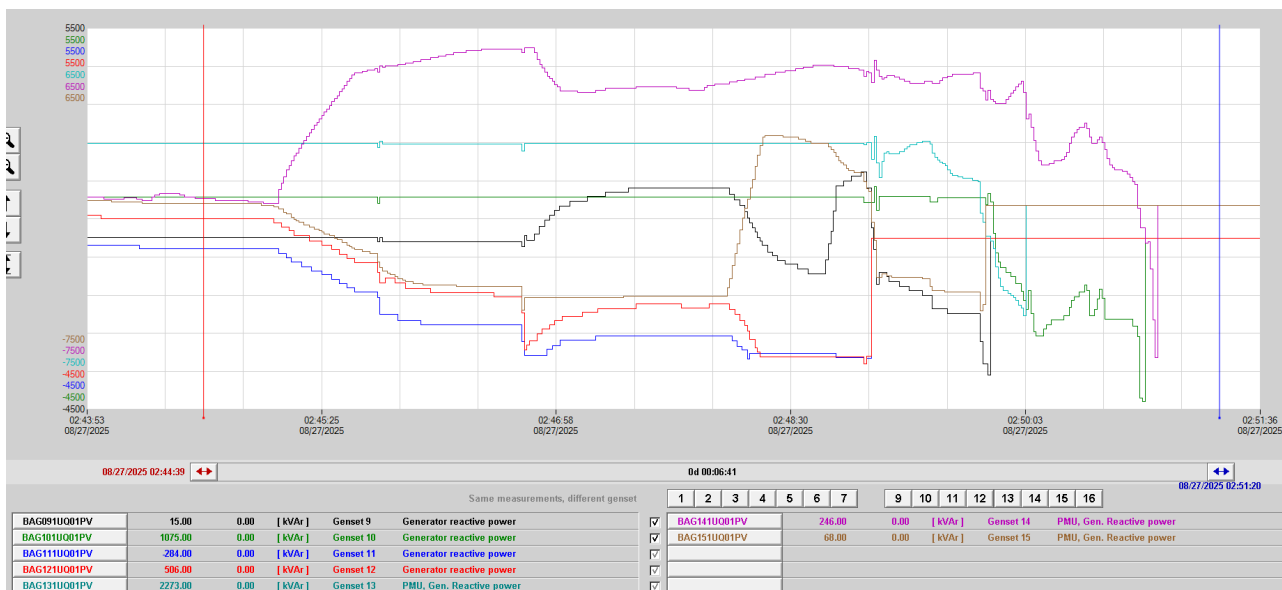


Active power and frequency Dokweg 1, 2A, 2B units during last 15 minutes before blackout

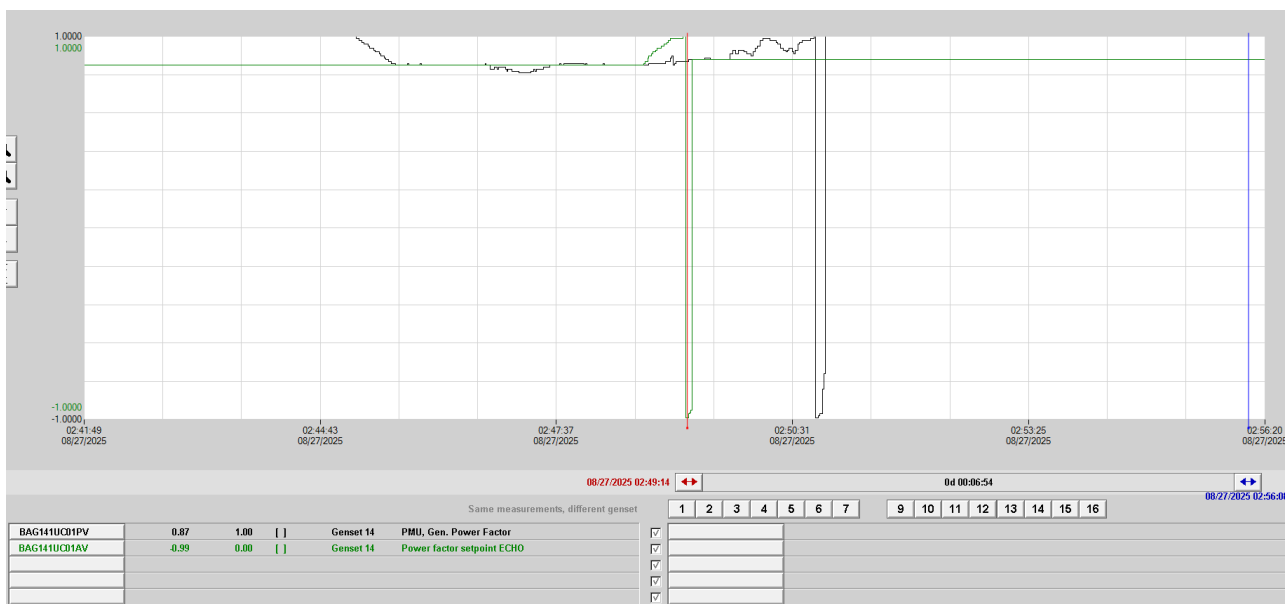
2 REACTIVE POWER BEHAVIOUR



Reactive power Dokweg 1 units during last 30 minutes before blackout



Reactive power Dokweg 2A, 2B units during last 23 minutes before blackout



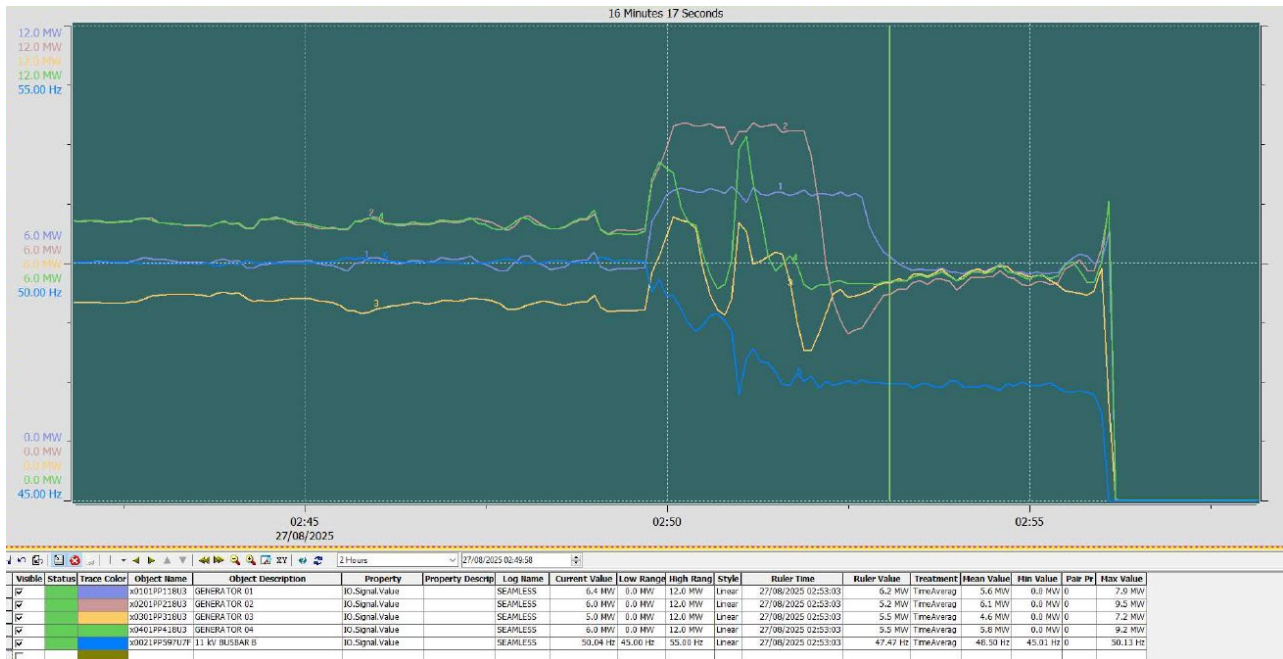
Power factor setpoint and actual power factor DG 14 (black=actual power factor, green =power factor setpoint)



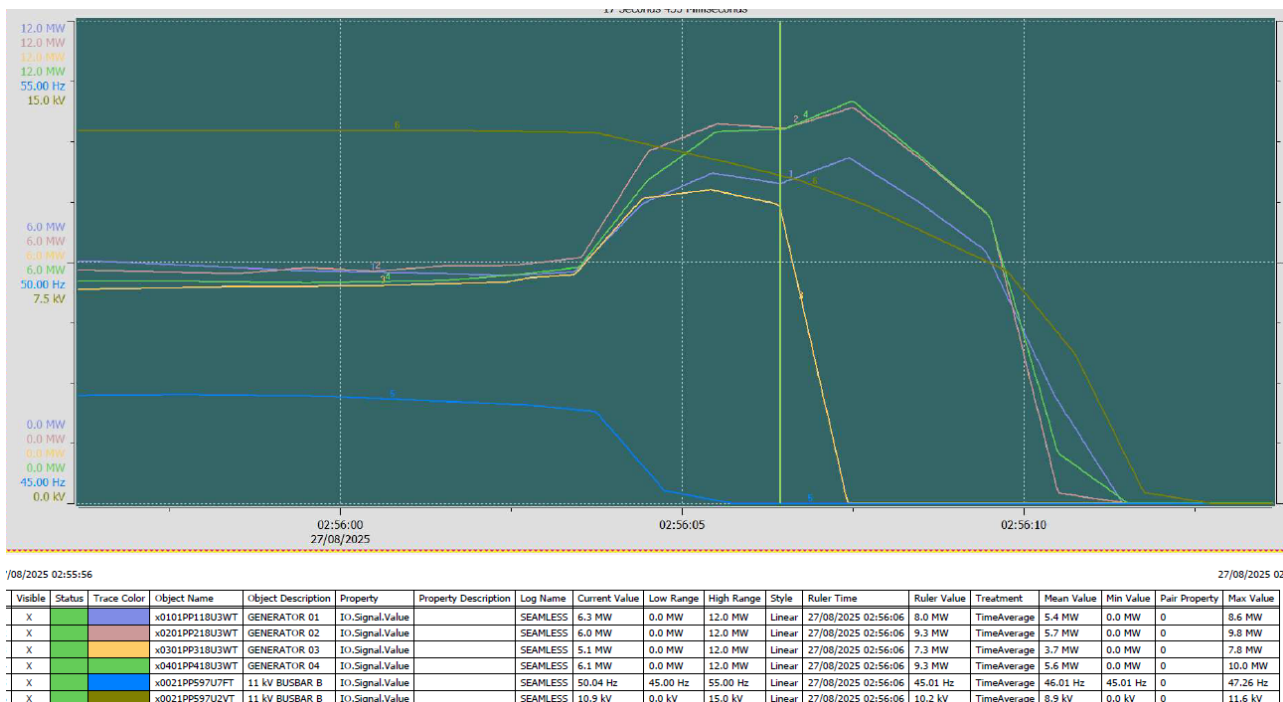
Busbar voltages Dokweg 1, 2A, 2B (black=DKW 1, green=DKW2A, blue=DKW2B)

ANNEX 3: SCREENSHOTS NDPP

3 ACTIVE POWER NDPP

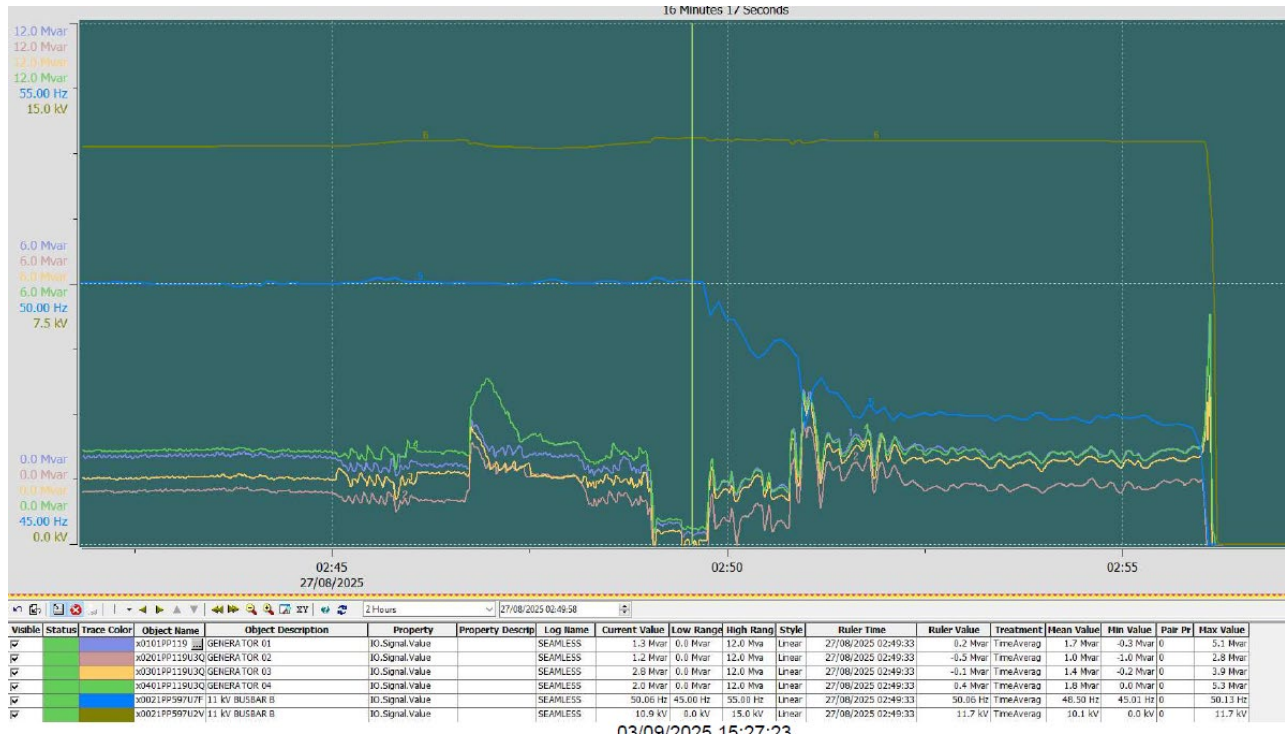


Active power output NDPP units during last 15 minutes before blackout

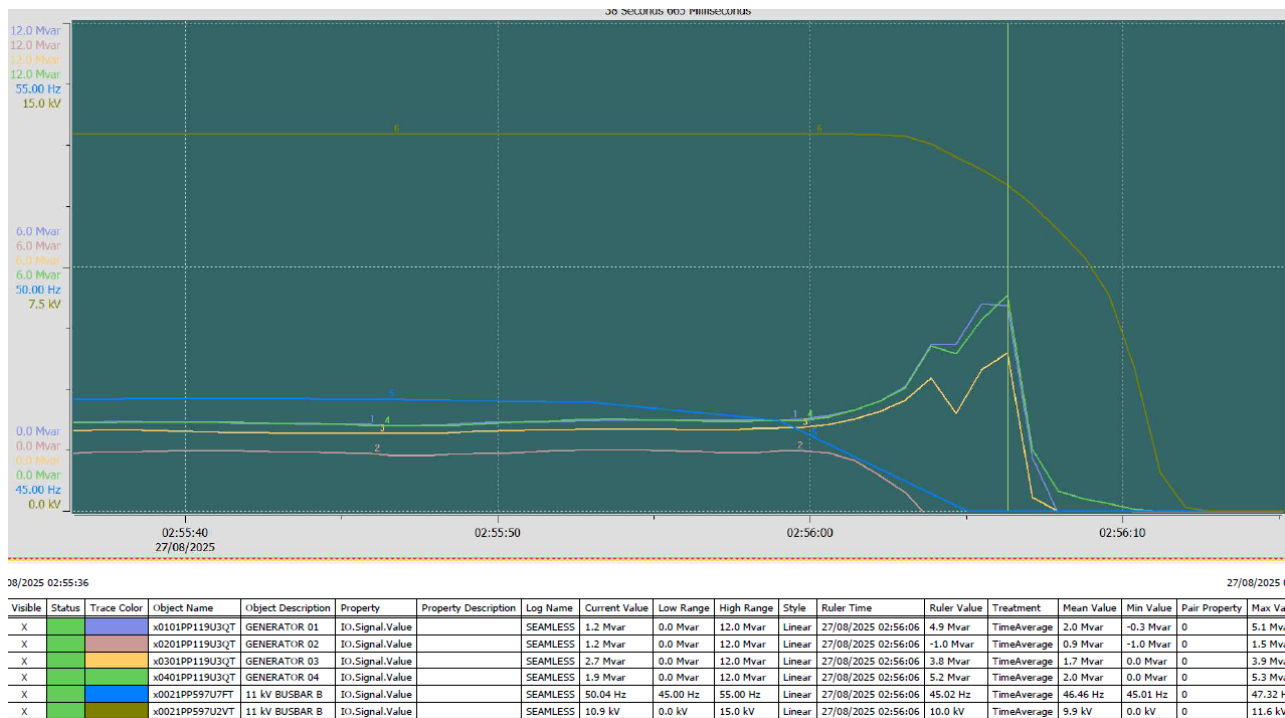


Active power output NDPP units during last 15 seconds before blackout

4 REACTIVE POWER NDPP



Reactive power output NDPP units during last 15 minutes before blackout



Reactive power output NDPP units (no negative scale Mvar available) during last 15 seconds before blackout

ANNEX 5: SETTINGS DOKWEG 2A, 2B UNITS FOR INFORMATION

1 AUTOMATIC VOLTAGE REGULATOR

3.4.11.1 System Data

```
[SYSTEM DATA]
Ie Nominal = 8.3A
Potential Transformer = Three_Phase
UM Nominal = 11.000kV
UM Primary = 11.000kV
UM Secondary = 110.0V
UNet Nominal = 11.00kV
UNet Primary = 11.00kV
UNet Secondary = 110.0V
IM2 Nominal = 642A
IM2 Primary = 800A
IM2Secondary = 1.000A
CT Phase = 0
Ie No Load = 47.0%
Kceiling = 9.57V/V
Xq = 0.82
f Nominal = 50.00Hz
Single Phase Machine = FALSE
```

Nominal excitation current:	Ie Nominal [A]
Measuring voltage three- or single-phase:	PT [Single_Phase] [Three_Phase] [Three_ph_gnd]
Nominal voltage of the Machine:	UM Nominal [kV]
Potent. transformer, prim. voltage:	UM Primary [kV]
Potent. transformer, sec. voltage:	UM Secondary [V]
Nominal voltage of the Network:	UNet Nominal [kV]
Potent. transformer, prim. voltage:	UNet Primary [kV]
Potent. transformer, sec. voltage:	UNet Secondary [V]
Nominal machine current	IM2 Nominal [A]
Current transformer primary:	IM2 Primary [A]
Current transformer secondary:	IM2 Secondary [A]
No load excitation current:	Ie No Load [%]
Ceiling factor:	Kceil [V/V]
Machine reactance:	Xq [p.u.]
Frequency nominal:	f Nominal [Hz]

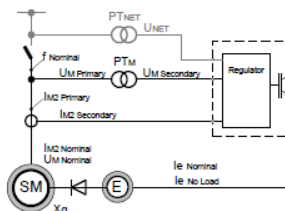


Figure system data settings AVR DG 14 (left) and explanation (right)

```
[IeMin LIMITER]
Minimum = 0.0%
Active = FALSE

[IeMax LIMITER]
Maximum = 160.0%
Maximum Hold Time = 10.0s
Delayed = 120.0%
Delayed Hold Time = 60.0s
Continuous = 105.0%
Active = TRUE

[PQ LIMITER]
Minimum Q (P @ 0%) = -25.0%
Minimum Q (P @ 25%) = -25.0%
Minimum Q (P @ 50%) = -25.0%
Minimum Q (P @ 75%) = -25.0%
Minimum Q (P @ 100%) = -25.0%
Voltage Dependency = TRUE
Active = TRUE
UELpriority = FALSE
Voltage Dependency Factor = 0.0

[UM LIMITER]
Minimum = 90.0%
Maximum = 110.0%
Minimum Active = TRUE
Maximum Active = TRUE
UMLim FRT Hold = FALSE
```

PQ Limiter

The characteristic is determined by 5 points

- Q limit at P = 0%	Minimum Q(P @ 0%) [%]
- Q limit at P = 25%	Minimum Q(P @ 25%) [%]
- Q limit at P = 50%	Minimum Q(P @ 50%) [%]
- Q limit at P = 75%	Minimum Q(P @ 75%) [%]
- Q limit at P = 100%	Minimum Q(P @ 100%) [%]
- Voltage dependency active	Volt.Dependency: True/False
- Limiter active	Active = True/False

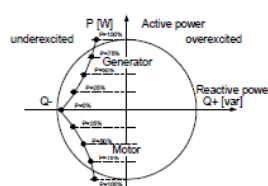


Figure limiter settings AVR DG 14 (left) and explanation (right)

2 UNDER EXCITATION PROTECTION

UNDER EXCITATION STAGE Q< (40)							ON
Underexcitation stage Q<	Q@P0%	-0.05 ... -1.0 x P _m	-3347	kVAr	-30	%*Sn	
Underexcitation stage Q<	Q@P80%	-0.05 ... -1.0 x P _m	-3347	kVAr	-30	%*Sn	
Operating time of stage Q<	t<	0.1 ... 300 s			2.00	s	
Release delay	t<	0.1 ... 300 s			0.5	s	

Under excitation protection setting Dokweg 2A units. Setting is -3347 kVar

UNDER EXCITATION STAGE Q< (40)							ON
Underexcitation stage Q<	Q@P0%	-0.05 ... -1.0 x P _m	-3668	kVAr	-30	%*Sn	
Underexcitation stage Q<	Q@P80%	-0.05 ... -1.0 x P _m	-3668	kVAr	-30	%*Sn	
Operating time of stage Q<	t<	0.1 ... 300 s			2.00	s	
Release delay	t<	0.1 ... 300 s			0.5	s	

Under excitation protection setting Dokweg 2B units. Setting is -3668 kVar



About DNV

DNV is the independent expert in risk management and assurance, operating in more than 100 countries. Through its broad experience and deep expertise DNV advances safety and sustainable performance, sets industry benchmarks, and inspires and invents solutions.

Whether assessing a new ship design, optimizing the performance of a wind farm, analyzing sensor data from a gas pipeline or certifying a food company's supply chain, DNV enables its customers and their stakeholders to make critical decisions with confidence.

Driven by its purpose, to safeguard life, property, and the environment, DNV helps tackle the challenges and global transformations facing its customers and the world today and is a trusted voice for many of the world's most successful and forward-thinking companies.