RAC Blackout Investigation Review

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2.0	04/06/2026	Updated report	Customer feedback.
1.0	13/02/2026	New report.	NA

Prepared for
The Regulatory Authority of Curacao

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Executive summary

The 2025 RAC Final Report reviews the implementation status of corrective actions following the 2019–2023 Curacao blackouts and evaluates the 2025 blackout investigation and restoration reports. Overall, the electrical system shows clear progress, with most previously recommended actions implemented or underway, though some remain informal or insufficiently documented.

Protection systems, historically responsible for many blackouts, have seen substantial updates in methodology, testing, and implementation plans, but formal procedures and verification are still incomplete.

Work on generation and system stability has advanced, and DNV’s 2025 blackout review confirms improved operator understanding and sound investigation methods. However, control-mode switching logic, reactive power management, and procedural clarity remain areas requiring reinforcement.

Organizationally, Aqualectra has enhanced governance and internal processes, though consistent application of formal procedures is still needed to ensure long-term robustness.

Conclusion: The system is evolving positively—technically, procedurally, and organizationally. Progress is real, but sustained effort is required to close remaining gaps and achieve a resilient islanded grid with increasing renewable penetration.

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1. Purpose and structure of the report

Purpose of the study:

The Regulatory Authority of Curacao appointed Laborelec on the following scope of work:

- Follow-up on the previously identified action list (from the previous blackouts) and evaluate their implementation status
- Provide expert opinion on the 2025 blackout investigation and restoration reports

For this study, the relevant technical reports were made available by Aqualectra. In addition, a 2-day site visit (including discussions with relevant experts) was organised. For more information, the site visit is summarized in Appendix B.

Purpose of the report:

The main purpose of the report is to provide an overview of the follow-up actions taken by Aqualectra after the 2019-2023 blackouts, as well as the actions identified after the 2025 blackout. The report provides an overview of progress rather than a detailed description of each action, and includes an high-level expert assessment of the measures undertaken.

Structure of the report:

It is important to note that there are fundamental differences between the series of blackouts that occurred between 2019 and 2023, and the last blackout of 2025. Therefore, the report is structured into two main parts:

- Part 1: Follow-up actions from 2019-2023 blackout events

For this part, it is proposed to keep the same three sections as in the 2024 report from Laborelec[1]. Therefore, the first section focuses on the actions on “system protection”. The second section focuses on “power generation and system stability” while the last section is about “organization and procedure”.

- Part 2: Review of 2025 blackout investigations

This second part provides an expert opinion on the 2025 blackout investigation report but also on the “evaluation of the restoration process” report. It is worth noting that it is the first time a dedicated analysis on the restoration process has been carried out, in line with a recommendation made in 2024.

Disclaimer:

Some reports made available are confidential. This report summarizes some of the information in these reports and should not be published without review of confidential aspects by Aqualectra.

[1] *https://rac.cw/wp-content/uploads/2024/05/Curacao-Investigations-Review-Report-Final-LBE39731734344672.pdf*

2. Part 1: follow-up actions blackouts 2019-2023

2.1. Methodology

The following methodology has been used for reviewing the follow-up actions identified in the previous blackout investigation reports and other relevant studies shared by Aqualectra. This methodology focuses on the analysis of documentation, verification of assumptions, and discussions with relevant Aqualectra staff.

This methodology ensures that reliability improvements are supported by credible analyses and that follow-up actions are progressing as intended. It combines technical rigor with practical considerations, fostering confidence in the process while maintaining a clear focus on system reliability. No additional simulations or tests have been performed.

The approach also included a site visit and can be divided into three main steps:

- **Step 1: Verification of available and up-to-date documentation**

The initial step consists of confirming the availability and completeness of all relevant reports. These include reliability assessments, incident analyses, and action plans prepared by the network operators. Ensuring that these documents are up to date and accessible is essential, as they form the basis for subsequent evaluation activities.

- **Step 2: Implementation status**

In parallel with the technical review, the implementation status of recommended actions is assessed. This evaluation is based on progress reports and interviews with network operators rather than physical verification of each device. The approach emphasizes trust and transparency, recognizing that exhaustive field checks would be resource-intensive and beyond the scope of this review.

- **Step 3: Technical Assessment**

Once the existence of the documentation is verified, the underlying assumptions and limitations are critically reviewed. This involves checking whether the assumptions are made according to engineering best practices and/or relevant standards. The final step is to challenge the content of the reports through targeted technical checks. It is important to note that no additional testing, or simulations have been performed. Therefore, the comments are mainly based on Laborelec's experience and best practices.

Aqualectra provided relevant reports from the last 5 years. From each of these reports, recommendations were translated into actions, and a summary table (shown in Table 1) presents the progress made on these actions.

In the scope of this study, the list of actions was reanalysed and grouped into categories and subcategories, (as shown in Appendix A and in the following sections).

Row Labels	Average of % progress	Count of Recommendation #
2020	**100.00%**	**13**
Digsilent Blackout 11 Feb. 2020	100.00%	8
Digsilent blackout 7 Dec. 2020	100.00%	3
Wärtsilä Blackout 7 Dec. 2020	100.00%	2
2021	**88.97%**	**33**
Digsilent Blackout 12 Dec. 2020	100.00%	1
Digsilent Blackout 10 Dec. 2020	100.00%	2
Fabbro, Blom and Gomez findings regarding blackouts	96.43%	21
K-Line blackouts 10 & 12 Dec 2020 and 4 Jan 2021	50.00%	2
Schneider Blackout 10 & 12 Dec 2020 and 4 Jan 2021	60.00%	5
Wärtsilä Blackout 10 & 12 Dec and 4 Jan 2021	100.00%	2
2023	**100.00%**	**26**
Digilent Blackout 15 June 2023	100.00%	1
Digsilent Blackout 8 June 2023	100.00%	2
DNV Blackout 14 Nov. 2023	100.00%	7
DNV Blackout 8 and 15 June 2023	100.00%	10
DNV Brownout 27 July 2023	100.00%	4
Isochronous load sharing system calibration and testing	100.00%	2
2024	**100.00%**	**3**
Uitkomst onderzoek "Curacao Blackout Investigations Review" BTPU	100.00%	3
Grand Total	**95.00%**	**75**

Table 1: Summary of actions and progress (table provided by Aqualectra)

2.2. Protection

2.2.1. Reminder on the key concept of protection systems

Protection systems ensure safety of people and equipment while maintaining system integrity during faults. Their role in system security is critical: fast and selective fault clearing prevents cascading outages and stabilizes the system after disturbances. Inadequate protection can compromise reliability by causing unnecessary disconnections or failing to isolate faults, which is especially risky in an island grid with limited redundancy.

2.2.2. Main recommendations from 2019 - 2023 blackouts

In this 2019-2023 period, the predominant causes of the blackout events were associated with protection. Aqualectra stated that "10 blackouts in the period 2019 – 2023 were due to the grid protection system"[2].

Based on the technical reports and blackout investigations reports, Aqualectra compiled a list of actions to be carried out. This list includes 75 actions, among which 29 are associated the protection system. It is worth mentioning that all actions are not equal in terms of impact and time required to be performed. This number should therefore only be seen as indicative.

[2] https://ser.cw/wp-content/uploads/sites/280/2025/03/Presentation-SER-NL_20250307.pdf

For the sake of clarity, we decided to group the “protection system” actions into several subcategories.

The first one is related to the protection philosophy, which can be defined (non-official definition) as *the main concept that governs the desired functionalities and coordination of the protection devices. It establishes the principles to detect, isolate, and mitigate faults or abnormal conditions in a manner that preserves:*

- *Safety of personnel and equipment*
- *System integrity and stability (via selectivity and discrimination between protection zones)*
- *Continuity and reliability of service*

The second group of actions concerns protection coordination. After defining the protection philosophy, a dedicated coordination study is needed to ensure proper selectivity and correct operation of both main and backup protection devices. It is important to note that protection coordination studies have to be performed regularly in an evolving electrical grid (e.g. every 1 or 2 years and after a significant network change).

The third action group concerns training for the relevant staff, while the fourth focuses on the physical wiring and testing of protection devices in the cabinets.

A set of actions to ensure the proper functioning of the monitoring devices (PFM) is also included in the “Protection” group. Finally, the group “Other” includes small quick-win actions that couldn’t be assigned to any of the five groups mentioned.

An overview of these topics and associated number of actions can be seen in Table 2.

	Topic	Number of actions in the list (75 in total)
Protection & monitoring (29 actions)	Protection Philosophy	3
	Protection Coordination Study	12
	Training	1
	Wiring checks and testing of protection bays	5
	PFM (Power Factory Monitoring)	5
	Other	3

Table 2: Overview of actions related to protection system

2.2.3. Work performed in 2024 and 2025

It is worth noting that protection settings changes have been performed in July 2023 at Tera Cora, Nijlweg, Dokweg 2 and Isla. These have been done according to recommendations from DNV as “Quick-win” follow-up actions from the June 2023 blackouts. This has proven to be a satisfactory short-term measure.

While not specifying explicitly a time horizon, reviewing the protection philosophy, performing a protection coordination study and implementing the new settings (according to the updated philosophy) were considered as “long term plan”. The review of the protection philosophy has been performed in 2024, followed directly by the updated protection coordination study. This can be considered as fully in line with the recommendations.

Protection philosophy study

Earlier protection studies performed by DIgSILENT in 2021, focusing on the 66/30 kV grids and using overcurrent protection as back-up, did not fully cover the entire 66 kV and 30 kV systems. In particular, they did not adequately address coordination with the generator protection systems. In addition, relying on overcurrent protection can’t ensure selectivity of the back-up protection in a meshed network.

The philosophy proposed by DNV recommends to split the network in different areas:

- In area 1, if a fault is not selectively cleared by the protection system, a full black-out could occur. Therefore, the protection system must isolate only one network element in 100ms, even if malfunctioning of one main protection (e.g. via a second and independent main protection).
- In area 2, if a fault is not selectively cleared by the protection system, a limited loss of load could occur but will not lead to black-out. Therefore, the protection system can be slower in case of malfunction of the main protection (e.g. via a back-up protection).

Therefore, DNV recommends having two main protections in area 1 and one main protection in area 2. For example, for the 66kV grid, the proposed philosophy relies on the existing main protection (differential) and proposes to have a second main protection (distance) using different measurement techniques. These two mains operate independently and ensure redundancy while clearing only the faulty element in 100 ms.

Protection coordination study 66 and 30 kV grid

According to the new protection philosophy, a dedicated protection coordination study has been performed. This study proposes settings for all protection devices. These settings have been verified in simulations based on extreme scenarios (low demand high renewable and high demand no renewables). N-1 simulations have also been performed. It is important to note that the study does not include the BESS plant nor the future Salu power plant.

Wiring checks and tests of protection relays

These recommendations focused on the Dokweg 2 substations, on specific bays. While some work has been done, it is understood that there are some actions pending on bays 3 and 10.

Power System Monitoring

Aqualectra uses DIgSILENT PFM devices to monitor its systems. The main actions carried out included updating the PFM monitoring system, replacing older PFMs, and verifying PFM measurements. A reliable monitoring system is essential for investigating events and confirming the proper performance of voltage and frequency control, as well as protection systems.

2.2.4. Current status & implementation plan

Dedicated studies have been performed by DNV and provide the necessary information for the full implementation. The new protection philosophy follows best practices and is more robust. However, it requires new protection relay functionalities and potentially new devices. This explains why the full implementation has not yet been completed. A comprehensive inventory of the protection devices is planned for early 2026, which should provide a clear view of the components that may need replacement.

The implementation of the updated settings is as follows:

- Phased roll-out starting at lower voltage levels (i.e. 12kV, 30 kV and then 66kV)
- For each asset: schedule outage, update protection relay settings, and perform functional tests via Omicron injection box.
- For the 66kV, some prerequisites are required:
  - Outage planning is constrained by asset criticality; scheduling must be coordinated carefully.
  - Establish redundancy on the 66 kV cable before applying new settings.
  - Distance protection was not used on 66kV protection relays in the past, most likely requiring new devices. Explaining the long implementation time on the 66kV.

In terms of implementation, it was also recommended to begin with the 12 and 30kV levels before moving to the 66kV, which has been done by Aqualectra. Until the full implementation is completed, there remains a temporary risk of non-selectivity in the event of a 66 kV cable failure and potential malfunction of the differential relays. Aqualectra considers this risk to be acceptable for the time being.

It is important to note that significant changes are expected on the 66kV grid (BESS and Salu plant, as well as a new 66kV substation), the settings will have to be updated taking into consideration these changes. It has been confirmed by Aqualectra on 22nd May 2026 that an updated protection study has been performed in December 2025 (including BESS and Salut Plants) and already implemented.

It must also be noted that the follow-up of protection settings change is done in an Excel sheet. It is considered that the use of a centralized database with versioning is beneficial and less prone to errors. It was confirmed by Aqualectra that the implementation in a centralized databased software “StationWare” is ongoing, which when implemented will reduce the risk of error.

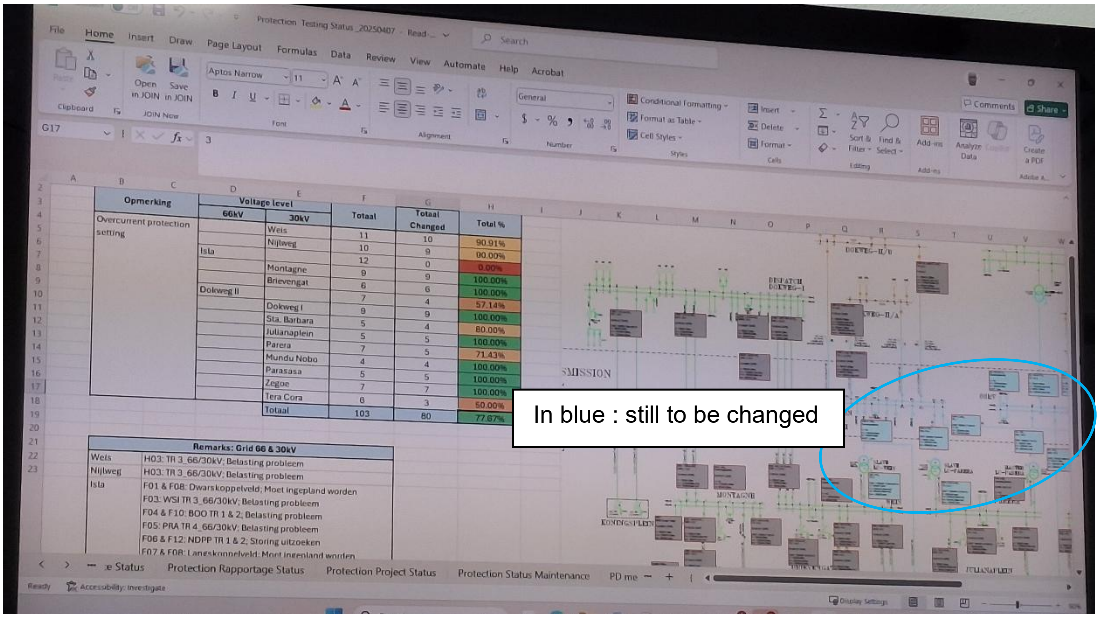

Figure 1: Overview of implementation status of new protection philosophy

In addition, the following points were mentioned by Aqualectra (which are in line with industry best practice):

- Review of the protection settings every 2 years; test each relay annually.
- Data management: settings are currently in Excel, this is prone to errors unless very carefully handled. The StationWare software was mentioned several times with, recently confirmed, concrete plans to migrate to Stationware for centralized management. The use of softwares like StationWare is good practice and would facilitate tracking settings changes and reduce the risk of errors. As of May 2026, StationWare has been procured and is currently being populated with the required data (during the implementation of the updated protection settings).
- Aqualectra could not commit to a full implementation date because dependent on cable work and outage planning on the 66kV grid. It was mentioned several times that the work to make the 66kV Isla – Dokweg can take some time, and is a pre-requisite. This work was recommended in a “Risk Assessment”[3] study done by DNV A best estimation for 100% completion could be around 2027.
- For under frequency load shedding, the frequency thresholds and adjustments are based on expert knowledge from Aqualectra’s staff. It is noted that there is a rotation in the loads to be tripped per threshold (to avoid that the tripping at the first threshold always affects the same customers).

2.2.5. Expert opinion on the work performed (including also feedback from site visits)

Protection coordination has historically been a critical vulnerability in the distribution network, with several past blackouts linked to inadequate and non-selective protection settings. These incidents highlighted the importance of robust protection schemes to ensure effective fault isolation and system reliability. In response, Aqualectra addressed the issue by adopting a new protection philosophy and by updating the protection coordination study.

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[3] *This study was not shared by Aqualectra*

Despite these significant steps forward, full implementation of the revised protection philosophy is still ongoing. After full implementation of the protection philosophy on the 66kV, the reliability of the system will be further increased.

In addition to the implementation of the new protection philosophy, attention must be given to wiring integrity, as past incidents revealed incorrect wiring in the Dokweg substation. It is strongly recommended to thoroughly test and verify protection device functionalities after any modifications.

Finally, protection coordination is not a one-time exercise. The distribution network is undergoing continuous changes, including increased load demand, integration of new assets, and modifications of the topology. Therefore, the protection coordination study has to be regularly updated (ideally yearly or bi-yearly).

Points of attention:

- Wiring checks to be performed on some bays.
- Future modifications of the 66kV grid, such as the new Salu Power Plants, and the implementation of a redundant path between Isla and Dokweg. These modifications have been considered in the latest protection settings, as confirmed by Aqualectra in May 2026.
- Proper training and transition period for implementation of the protection settings in a centralized database for protection settings.

2.3. Generation and system stability

2.3.1. Reminder on key concepts and definitions

This section provides a reminder of key concepts and terminology used in the subsequent sections. These elements are summarized below.

A **governor** is the control system that regulates the mechanical power delivered to a generator by adjusting the turbine input (steam, water, gas) to keep the rotational speed and frequency stable. In frequency-droop control, it reacts to frequency deviations by adapting the generator's active power output.

An **Automatic Voltage Regulator (AVR)** controls the generator excitation to maintain a stable terminal voltage and regulate reactive power.

The **Under-Excitation Limiter (UEL)** is a protection and stability function within a generator's excitation system designed to prevent the machine from operating in dangerously under-excited conditions

If the UEL fails, **Under-Excitation Protection** trips the machine to protect it.

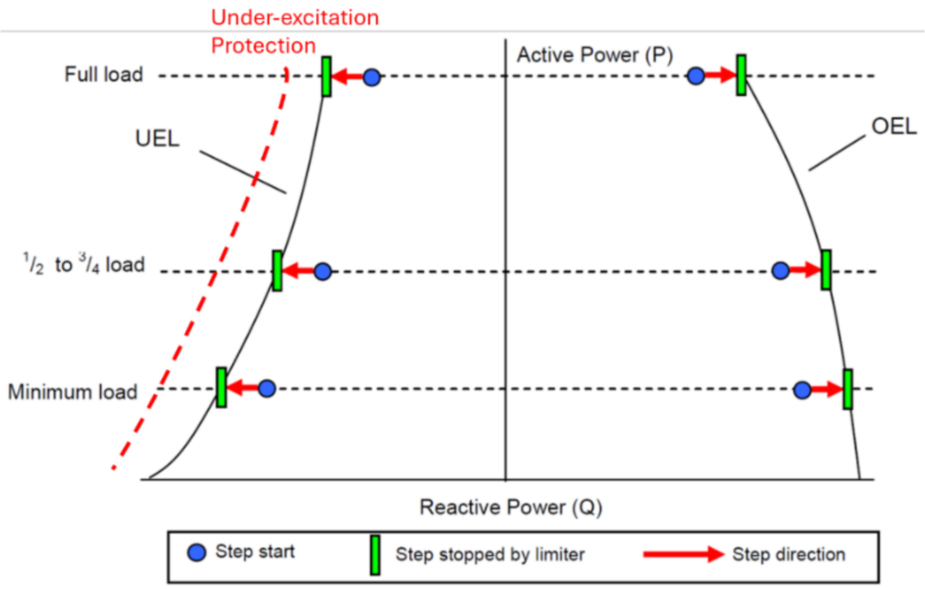


Figure 2: Generator capability curve and illustration of recommended testing for limiters[4]. The under-excitation protection is also shown (for illustrative purpose only, this is not based on real settings)

The withstand capability of a generating unit can be categorized into "static" and "dynamic".

The static withstand capability is typically represented by the generator capability curve. For the sake of simplicity, two axis are represented in the capability curve shown in Figure 2:

- Active Power (P) which goes from the technical minimum to the maximum continuous rating

[4] *https://www.aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2024/iess-rule-terminology-changes-to-national-connection-documents/dynamic-model-acceptance-test-dmat-guideline-v30.pdf?la=en&hash=D2FCA072C47E9EB094A7C94C48924B81*

- Reactive Power (Q) which typically ranges from around 50% in reactive power production to around -30% in reactive power absorption (these values depends on the design of each machine and can therefore differ).
- External parameters such as voltages or external temperatures also influence the capability curve (but are not represented here)

Ideally, the machine operating points are defined based on grid needs and technical capabilities of the machine. When the operating points go outside the secure operating area, it is allowed for the machine controllers to first ‘limit’ (i.e. pushing back the operating point into the secure zone via action of the limiter) and ultimately disconnect to prevent material damages (which is the role of the protection devices). Ideally, there is a margin between the limiter and the protection. The IEEE Std. C37.102-2023 recommends that “*A properly coordinated loss of field protection allows the UEL to act first before operating to alarm or trip the unit*[5].” To be noted that the coordination between UEL and protection is difficult to achieve for all operating points. This coordination can be done by applying a margin to the threshold value and/or by using time discrimination.

The dynamic withstand capability refers to how the generator behaves during and immediately after grid disturbances, such as voltage dips (or rises). Modern grid codes require generators to remain connected and support the system during these events—known as Fault-Ride-Through (FRT). Dynamic withstand capability was an issue for the windfarms at Playa Canoa and Tera Cora but was solved. This stays an important aspect to consider for future connected assets.

2.3.2. Main recommendations from 2019 - 2023 blackouts

From the technical reports and blackout investigations reports, Aqualectra extracted a list with the actions to perform. This list includes 75 actions, among which 36 are related to generation and system stability. It is worth mentioning that all actions are not equal in terms of impact and time required to be performed. This number should therefore only be seen as indicative.

For the sake of clarity, we decided to group the actions into several subcategories.

- **Frequency and voltage control**, which groups mainly the tasks related to evaluating the control characteristics in all power plants, as well as generating quarterly reports on voltage and frequency.
- **Governor and AVR settings** (control, protection, and limiters), which groups the tasks related to control verification of the generating units.
- **Security analysis**, which is the assessment of whether the electrical network can withstand disturbances without violating operational limits such as voltage, frequency, or line loading.
- **Windfarms disconnection**, which groups the tasks related to disconnection and automatic reconnection of wind turbines.
- **Withstand capabilities**, which include all actions linked to tripping of diesel generation and wind turbines.
- **Training**, mainly for power plant operators.

[5] *IEEE Std. C37.102-2023*

	Topic	Number of actions in the list (75 in total)
Generation and System Stability (36 actions)	Frequency and voltage control	6
	Governor and AVR settings (control, protection and limiters)	6
	WindFarms (disconnection&reconnection)	6
	Withstand capabilities	6
	Security analysis	3
	Other	2
	Training	7

Table 3: Overview of actions related to Generation and System Stability

Voltage and frequency control

An important recommendation in the action list was about frequency stability and about the impact of the diesel generating units' control mode. From the study performed by DIgSILENT, it was recommended to have the maximum number of units on droop control in order to share the active power reserve amongst these units.

This study also recommended the installation of a BESS plant for improving frequency and voltage stability of the network. In order to quantify the benefits of the new BESS installation, quarterly reports and statistical analysis of grid frequency and voltage can be used as a good indicator.

Generator controls: Governor and AVR settings

The recommendations focused mainly on frequency control of diesel unit. The constant power mode does not provide any stabilizing effect on the grid during frequency variations while the isochronous and droop modes provide clear system stability benefits. The normal operation control modes are currently always isochronous or droop controls.

With regards to the AVR settings, the main aspect was to ensure coordination between excitation limiters and generator protections.

Windfarm disconnection and reconnection

During the 2020 grid events, the wind farms at Playa Canoa and Tera Cora experienced multiple disconnections triggered by under-voltage protections, followed by reconnections that were not always optimally coordinated. These automatic reconnections introduced additional disturbances. The necessary actions have been taken by Aqualectra to prevent this.

Withstand capabilities (dynamic)

There were some recommendations to analyze how to maximize the fault-ride-through capabilities of the wind turbines and diesel generation plants, in particular during long voltage dips. Testing and validating asset withstand capabilities is essential to ensure they remain connected at their full technical potential during system disturbances.

Security analysis

The security analysis can be defined as the process of evaluating a power system's ability to withstand disturbances without violating operating limits or causing cascade failure. The main recommendation was to perform offline simulations (via PowerFactory) in order to evaluate the impact of a set of contingencies. This was performed by DigSilent and one of the conclusion identified the need to install a BESS. Security analysis should ideally be re-evaluated every year.

Training of operators

It was recommended to train operators on (i) control modes of diesel units and (ii) on grid behaviour and protection settings.

2.3.3. Work performed in 2024 and 2025

Voltage and frequency control, and security analysis

Security analysis has been addressed through external studies performed by DIgSILENT. The reports included steady-state and dynamic (RMS) simulations. The N-1 contingency analysis was performed for several operating scenarios in a time horizon 2021-2024. One of the main outcomes of the study is the recommendation for the installation of BESS plant.

Aqualectra put a high priority on the BESS installation and commissioning, and interfacing with GEMS Digital Energy Platform from Wärtsilä.

In addition, a prototype synchronous compensator project (~6 MW, from Wartsila) is in discussion with Wärtsilä. This prototype is a classical engine, equipped with a clutch between the alternator and the engine. This would allow synchronous condenser operation without the need to burn fuel. This is seen as a project with good potential because this type of technology will probably be needed to achieve higher and higher VRE penetration. Previous reports outlined the benefits of synchronous condensers for system stability.

Governor and AVR settings

The normal operating modes for units are now droop control, according to the recommendations. There was however no evidence of work performed to verify coordination of UEL and under-excitation protection, but recent discussions on this topic took place between Aqualectra and Wärtsilä in January 2026.

Windfarm disconnection and reconnection

Actions at Playa Canoa and Tera Cora had been done already a few years ago in order to avoid automatic reconnection of several wind turbines.

Withstand capabilities

Analysis of the unit's behaviour during past events was performed. However, no concrete actions were defined on verification, testing or evaluation of potential enhancement of withstand capabilities of wind and diesel units. These could form part of further recommendations. It is also recommended to establish clear withstand capabilities requirements for future assets.

Training of operators

In terms of training, Wärtsilä provided training to the plant operators. This was also done by Wärtsilä in order to better understand the behaviour and control modes of the diesel generating units.

Selected staff members have also been trained in PowerFactory modelling, with the goal of eventually being able to challenge Consultants' results internally.

2.3.4. Current status & implementation plan

All actions mentioned in the previous section are closed.

2.3.5. Expert opinion on the work performed (including also feedback from site visits)

The BESS plant will significantly improve the reliability of the overall system. It has the capabilities to respond quickly to frequency variations and also to contribute to voltage regulation. The combination with a centralized island-wise controller (GEMS) should also be very beneficial. By monitoring the statistical values of voltage and frequency before and after BESS installation, significant differences will be observed, outlining the added value of the BESS. It is however important to understand well the limitations of the BESS and GEMS controls. Therefore, offline simulations (including fast-transient) are recommended, especially for faults close to the BESS plant and in scenarios with very few diesel units connected.

Proper coordination of generator limiters and protections is also recommended. In other words, a limiter should act by moving the unit operating point into a stable operating area. For slow variations, the normal expected behaviour would be that the limiter acts without impacting the protection. If not possible or if voltage variations are too fast, the unit is then allowed to trip via its protection to avoid damage. The recent discussion on this topic between Aqualectra and Wärtsilä is seen as a positive step and it is agreed that the recommendations from Wärtsilä should improve the situation during high-voltage conditions. In addition, it would be good to have better monitoring and archiving of the logs of the limiters and protection, in order to better understand their behavior. It is also recommended to study and define a desired voltage-ride-though envelope to establish a clear desired dynamic withstand capability, in particular for future generating units.

In the short-term, an updated topology of the 66kV grid is expected. Some weak points have been identified in a study performed by DNV[6] and it was recommended to increase redundancy on a specific path. It is understood that this study assessed and proposed mitigation actions. Also, the connection of the BESS and Salu Power Plants to new substations will impact the 66kV network.

The last steady-state and dynamic (RMS) studies were performed 2022 and it is now expected to see in the short-term future an update of this study. It is noted that the simulations are performed almost solely by DIgSILENT. Ideally, Aqualectra should be able

[6] *Study was not made available to the Consultant*

to use the model themselves and challenge even more the results from the Consultants. Aqualectra currently does not perform Power Factory simulations themselves. However, it is understood that selected staffs have been trained and have the skills to understand and/or perform the simulations.

Regarding the stability of the existing system, the BESS has a great potential to provide substantial benefits. This will definitely improve the frequency stability of the system. It must be noted though that the GEMS system is still in a testing phase and trial period is required in order for Aqualectra to understand the benefits and limitations of this new technology in the island.

The new engine power plant will also provide more flexibility in terms of outage planning for the generating units and is probably needed to cope with the expected load growth.

In an island system with increasing penetration of renewable energy, stability will be a continuous challenge both in terms of frequency and voltage, but also in terms of control interactions. In the short term, the wind farms repowering and connection of new new wind farms will need to be very carefully considered with regards to system stability.

In summary for the “Generation and System Stability”, Aqualectra has actively progressed on multiple fronts to enhance both generation reliability and system stability. These actions include:

- Strengthening operator competence.
- Power system simulations and stability analysis.
- Integrating new assets (BESS) with appropriate testing.
- Adapting and verifying generator frequency controls.

These efforts reflect a significant and structured response to recommendations made after recent blackouts.

2.4. Organization and procedure

The last group of actions focuses on the operational procedures and on the organization structure. From the 75 listed actions, 10 concern these aspects (as shown in Table 3).

	Topic	Number of actions in the list (75 in total)
Organization & operational procedures (10 actions)	Organisation change	1
	Operational procedures for control mode (e.g. isochronous vs droop vs kw)	8
	Operational rules for grid security (e.g. N-1 security constraints, spinning reserve)	1

Table 3: Overview of actions related to Organization and Procedure

2.4.1. Main recommendations until 2023 blackouts

Most of the recommendations were improving operational procedures.

From an organisational perspective, it was also highlighted that certain elements of the organisational structure may benefit from adjustments to ensure clearer allocation of responsibilities.

2.4.2. Work performed in 2024 and 2025

Operational procedures

There are clear improvements observed regarding the operational procedures mentioned in the action list. For example an updated procedure for control mode switching was clearly visible in the control rooms. Also, it is now clear that the normal operating mode of diesel unit is droop control.

It has to be noted that all procedures have not been reviewed one by one, and the review was limited to the ones mentioned in the action list. It is however expected that the GEMS will integrate the operating philosophy of the operators in order to optimize dispatch and reserve.

Organisation

First, the prior general manager power has been appointed CTO. Second, significant positive organization changes can be observed under the CTO:

- Clear split between Grid Management and Plant Management.
- For both the Grid and Plants, operation and maintenance have been split into separate responsibilities.
- The head of protection & testing reports directly to the Grid Manager Power

- In addition, it has been mentioned that each plant has a designated supervisor with clear accountability. There is a rotation between the plant supervisors among the different power plants.
- Grid and Plant Managers meet regularly in operational meetings with the Grid Manager Power to present highlights. Information is also exchanged using Chat Groups with the relevant people.
- The departments are located in Nieuwe Haven en Dokweg; a new campus is being built.
- Some vacancies remain to be filled. It has also been said that the HR department had been reorganized, with an extra focus on talent development and acquisition.

The updated organigrams, below the CTO, are shown here below. It is worth noting that other parts of the organization have also been changed but are less relevant for the topics discussed.

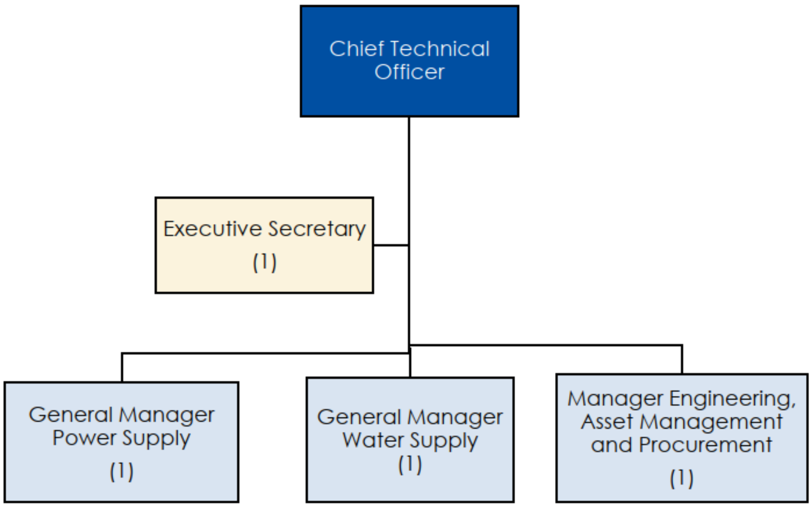


Figure 3: New organigram Aqualectra (1)

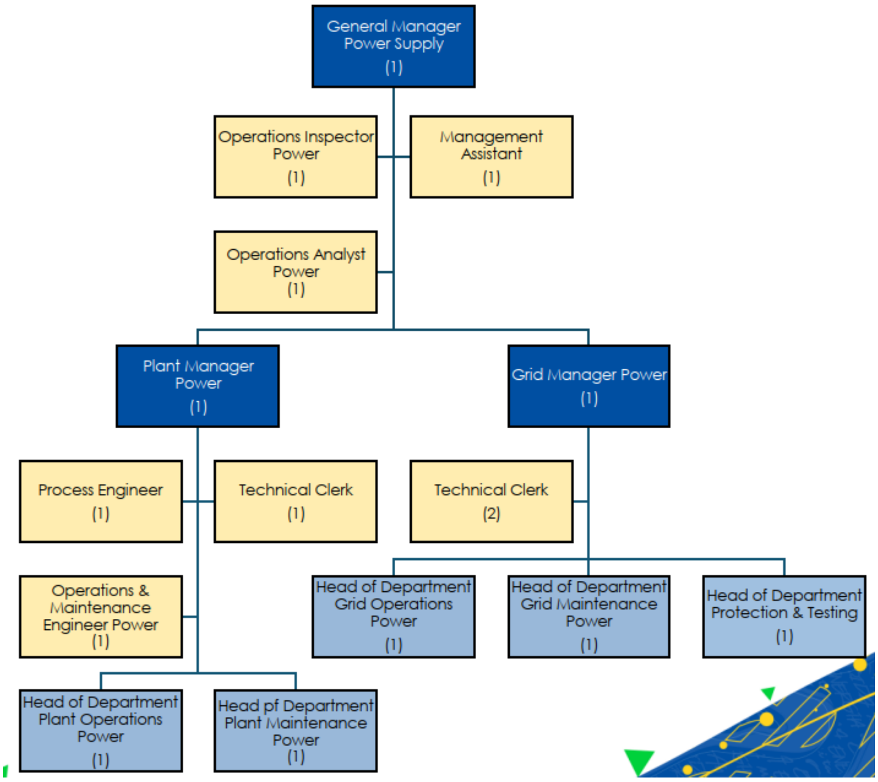


Figure 4: New organigram Aqualectra (2)

2.4.3. Current status & implementation plan

All actions mentioned in the previous section are closed.

2.4.4. Expert opinion on the work performed (including also feedback from site visits)

In terms of operational procedures, it has been identified in several reports (including in the 2025 blackout report) that there is generally a lack of formal procedures. However, the specific operational procedures mentioned in the action lists are now implemented.

While it is not within the scope of work to provide opinions on the organizational structure of Aqualectra, it is agreed that the updated organization will provide benefits for system reliability. For example, the split between grid management and plant management ensures that each domain can focus on its core mission with dedicated expertise. Also, separating operation and maintenance roles increases accountability, and improves the daily decision-making process. The position of the protection department can also be noted. The head of protection and testing reports directly to the Grid Manager, which provides more visibility and transparency on the protection tasks.

2.5. Conclusions

Over the past two to three years, Aqualectra has demonstrated substantial and measurable progress across several technical and organizational dimensions. The review of the follow-up actions shows that many of the recommendations identified in earlier assessments have been addressed. This includes clearer operational procedures, strengthened coordination with external consultants such as DNV and DIgSILENT, and key projects such as the BESS plant, allowing to mitigate challenges linked to high renewable penetration while enhancing system reliability. These improvements reflect significant effort and commitment from the teams involved and deserve to be formally acknowledged.

That said, important areas could be identified where continued attention and follow-up are necessary. Several actions identified in earlier investigations remain ongoing or are not fully implemented, such as:

- Coordination between UEL and generator protections to avoid units tripping. As first step, a discussion on UEL settings between Aqualectra and Wärtsilä took place. In addition, it is highly recommended to monitor UEL and protections' logs, and test the coordination of the limiters and protections (similarly to what is proposed by AEMO[7] in Australia). It also outlines the need to model excitation limiters and generator protections in PowerFactory when performing security analysis.
- Finalize the implementation of the protection philosophy on the 66kV
- Considering to define clear requirements on withstand capabilities for existing and new generating units (including inverter-based assets such as wind, solar and BESS)
- Continue to perform regularly (e.g. yearly) protection coordination studies, as well as security analysis.

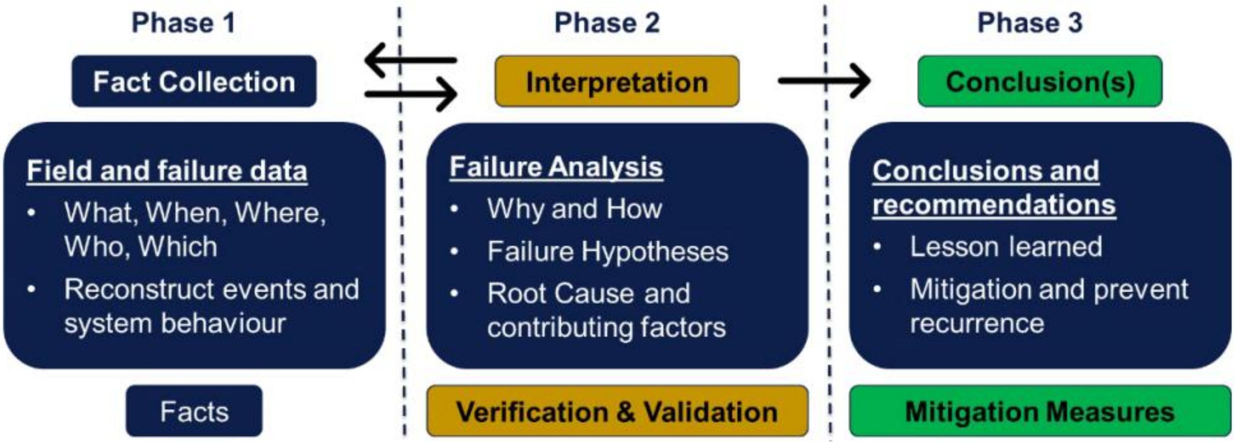
The progress is real and measurable, but the remaining actions are essential to consolidate these gains and cope with future challenges.

[7] *https://www.aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2024/iess-rule-terminology-changes-to-national-connection-documents/dynamic-model-acceptance-test-dmat-guideline-v30.pdf?la=en&hash=D2FCA072C47E9EB094A7C94C48924B81*

3. Part 2: Analysis of recently published DNV reports

3.1. Backout report 27 August 2025

As in the previous blackout investigations, DNV was appointed to conduct the investigations of the 27th August 2025 blackout. Senior experts from DNV were made available via Teams to answer any questions on the methodology and on the reports results. The general methodology followed by DNV in the blackout investigation report (shown here below) is clear and well-proven.



The initial contributor to the blackout event of August 2025 was a large wind variation. As expected, the generating units at Dokweg reacted to the frequency change by increasing their active power output. One unit reached temperature limits and automatically entered derating mode for five times in a row. The operator therefore decided to change the operating mode of the machine to constant active power. By changing the operating mode from droop to constant kW, the unit went also to constant power factor. This caused (i) the unit to stop contributing to voltage support and (ii) to contribute negatively to the reactive power balance by being on an inadequate MVar setpoint.

It has to be noted that most of the points mentioned in the reports were discussed in detail with Aqualectra's staff during the site visit. This illustrates that Aqualectra's staff followed closely these studies.

The sequence of events leading to the 2025 blackout is well described in the report and it is also agreed that the operator intervention was understandable. However, the unclear procedure for control mode change and the internal logic of the engines were major contributors in the blackout. The logic for control mode switching has been updated and procedure for control mode change is now updated (the updated procedures were clearly visible on the operators' desk at Dokweg). In their report, DNV also presented a "what-if" analysis to evaluate what could have happened if, for example, the control mode of the machine was changed smoothly. DNV explained that this was performed using a Monte-Carlo approach with probability and distribution assumed based on expert knowledge. While the probability provided in this analysis can be challenged, the "what-if" methodology and incidence map are considered as very useful because they allow to identify the main contributing events.

Another important aspect mentioned in the DNV report is the voltage control. The main action after the blackout was to set the MAN on-load tap changer (OLTC) transformers to manual mode.

In summary, the methodology followed by DNV in the blackout investigation is appropriate and the incidence map has been proven very useful. The recommendations from the report are clear and some have already been implemented by Aqualectra (e.g. system operator procedure and engine control mode change).

It has to be noted that the automatic derating and also the behaviour of the AVR were not discussed in detail. Ideally, limiters should be properly tuned to put the units back in the safe operating zones. Another aspect mentioned in the DNV reports was the need to review the settings of the voltage and frequency protections.

The coordination between limiters and protection is not a straightforward task but allows the system to be more robust against disturbances. These points were already mentioned in the previous section as well as in the previous report from Laborelec[8]:

- *Diesel units control: robustness of control parameters shall be further analysed via simulations or field tests. Moreover, switching of control mode should be included in a dedicated procedure.*
- *Diesel units protections: it is preferred to have the units limiting their output in case of overloading (rather than disconnecting). Generally, it is important to keep critical units as long as possible connected to the grid.* This point was not mentioned in any of the report but was discuss orally during the visit. Aqualectra confirmed that this aspect is included in the dynamic reactive power study (currently ongoing).

The AVR settings were made available and by only looking at the thresholds, there should be good coordination between limiter and protection. Recent recommendations from Wärtsilä proposed to adapt the “voltage dependence” parameter. It is agreed that this would improve the situation during high-voltage scenarios. However, it is still recommended to have field tests or monitoring/logs validating the behavior of the AVR and limiters.

The same reasoning is followed for the temperature derating: is it expected that a unit can enter the derating zone several times? It should be feasible to better coordinate the limiter and the droop control mode to avoid this.

To conclude on the blackout investigation report from DNV, the analysis provides clear recommendations on (i) Control Philosophy & Operating Modes, (ii) Transformer OLTC & Voltage Control and (iii) Supervisory Control & Procedures. It is agreed that if these recommendations are followed, the blackout event would have been avoided. And during the site-visit, some key actions were already implemented (such as operating procedure, blocking of OLTC and update of logic during control mode switch). It is also worth noting that if the BESS was fully commissioned on the day of the event, the blackout would have very likely been avoided. However, for the sake of completeness, we insist on the recommendations to perform field tests of the excitation systems of diesel units.

[8] Curacao Blackout Investigations Review

3.2. Restoration report

Regarding restoration, this is the first time that the process has been formally analysed, following a recommendation made in 2024. It is positive to see that this recommendation has now been followed.

The report from DNV is again very clear and improvement points have been identified. These points are categorized into short-term and medium term actions, and should allow to restore the system in a much faster way than what was realized on August 27th.

One point discussed with Aqualectra was the UPS at Dokweg, which should provide back-up supply for around 8 hours and lasted less than 1 hour during the blackout. It was mentioned by Aqualectra that this was solved after the blackout and that UPS are tested yearly. From our experience, UPS in hot environment sometimes may have a significantly reduced lifetime, it is therefore highly recommended to ensure that the UPS are properly tested at regular interval (good practice suggests once per year).

It has been observed in the blackout restoration process that the amount of MVar to absorb was too high during the 7 first restoration attempts while this amount was much smaller in the 8th (successful) attempt. This probably outlines the lack of formal procedures and alternative restoration paths in case the preferred path is not possible to re-energize. Also, a new restoration sequence, including the BESS plant, should be studied and formalized in a procedure. Using the BESS in the restoration process will stabilize the system during the early stages. All of these recommendations are present in the DNV report.

The only comment that can be done on the recommendations is on the system simulations. The report mentioned that simulations have to be performed in a mid-term horizon, and it is correct that, in order to validate a restoration path, detailed simulations have to be performed. However, it is recommended to also perform simplified simulations such as steady-state reactive power balance for the soft-energized path in the very short-term. These simplified simulations will allow the plant operators to anticipate the amount of MVar required at each restoration step (a rule of thumb is that 66kV cables, see CIGRE TB338, would generate around 0.2 MVar per km (to be confirmed with exact cable type in Curacao)). It has to be outlined that DNV has already been appointed by Aqualectra to further investigate the reactive power contribution during restoration.

Apart from that comment, all recommendations from DNV on the restoration report are clear and very relevant. In addition, it is agreed that analyzing alternative scenarios for system restoration will take time but the main short-term benefits would probably be to use the BESS as for stabilizing the grid after the soft energization step. With the help of the BESS, the engine will be more stable and it will also help for voltage and frequency control.

4. Conclusions and recommendations

Across the four components reviewed - protection, generation and system stability, organizational structure and procedures, and the 2025 blackout investigation with associated restoration analysis - a consistent picture emerges: Aqualectra has made substantial progress in addressing the recommendations while still facing several challenges that require continued follow-up.

From a protection standpoint, the introduction of a revised protection philosophy, the updated coordination study, and the phased implementation of new relay settings is a significant improvement compared to the situation prior to 2023. The system is clearly moving toward more selective, robust, and fault-tolerant protection schemes, even if full implementation - particularly at 66 kV - remains pending. Wiring integrity issues and the absence of centralized settings management still pose risks and require systematic, disciplined follow-up. It is understood that there are some advanced discussions with DIgSILENT regarding this last point.

In terms of generation and system stability, the commissioning of the BESS and improvements in control strategies is beneficial for both the frequency and voltage stability. However, deeper work remains necessary regarding the tuning and coordination of the excitation limiters and generator protections. This was already initiated in January 2026 by Aqualectra in discussion with Wärtsilä. The expected evolution of the grid (new Salu plant, higher VRE penetration) will further accentuate the need for robust control settings and field testing.

The updated organizational structure provides an adequate and clear framework. The clear split between grid and plant responsibilities, and the position of the protection and testing department allows a better focus of each department on its core activities. Remaining gaps relate mainly to ensuring that formal operating procedures exist for all critical activities and are consistently applied.

Finally, the 2025 blackout analysis and restoration review confirms both the progress and the remaining weaknesses in the system. While the methodology used by DNV was sound and many recommendations were addressed promptly (e.g., improved procedures for control-mode switching), the event also revealed areas where operator actions, control logic, and reactive power management still need reinforcement. Restoration performance showed that with structured procedures, BESS support, and improved reactive power planning, future events should be restored in a more timely manner. However, achieving this objective will require the continuation and consolidation of the significant efforts already underway.

Overall, Sections 2.1 through 2.4 show a system that is evolving in the right direction—technically, procedurally, and organizationally. The progress is real and measurable, but the follow-up of the remaining actions is essential to consolidate these gains. In particular, it is important for the Regulatory Authority of Curacao to stay aware of the progress of following items:

- Implementation status of the protection settings on the 66kV,
- Return of experience of the BESS plant and GEMS,

- Have a list of the topics studied by DNV and DIgSILENT (e.g. protection coordination study, grid expansion plan, impact of windfarm repowering, voltage stability study, review of restoration procedure)
- Timeline and impact for commissioning of the Salu plant, as well as high-level test plan of the generating units (frequency and voltage control, limiters, protections)
- Required withstand capabilities of new wind turbines and new diesel engines
- Any planned upgrade on the 66kV or 30kV grid.

Appendix A. Follow-up action plan (Excel file)

	Topic	Number of actions in the list (76 in total)	Level 1 assessment			Level 2 assessment (implementation & follow-up)		Level 3 assessment (Quality and verification)	
			Do the reports/documents exist?	**Author**	**Date of last version**	**Implementation status**	**Additional remark**	**Document Review**	**Verification of assumptions & methodology**
Protection & monitoring	Protection Philosophy	3	Yes	DNV	7-Feb-25	Ongoing	The new philosophy requires installation of new relays which explain the time before full implementation	Yes	Methodology according to best industry practice
	Protection Coordination Study	12	Yes, 2021 and 2024, next updated expected in 2026	DIgSILENT DNV	27-Mar-25	Full implementation on 12 and 33kV Not on the whole 66kV grid, wait for cable redundancy, relays are tested (orally confirmed)	Still use of excel for implemetation follow-up, instead of centralized database	Yes	DNV study with new philosophy ensure selectivity, which was not the case with the DIgSILENT study.
	Training	1	Orally mentioned that training took place with DNV or DIgSILENT				Aqualectra staff well aware of the DNV reports, which outlines their implication and understanding during these studies	Orally confirmed	
	Wiring checks and testing of protection bays	5	Recommendation from 2021 report from Schneider	Schneider	14-Jan-21	Ongoing, listed as priority in task list	No specific target date for completion has been discussed	Yes	Schneider document of good quality. Procedures for wiring checks and relay testing not verified.
	PFM (Power Factory Monitoring)	5	Orally mentioned			Completed according to excel file	Important to do regular check to confirm that PFMs monitor properly	No	
	Other	3	Small other actions			Implemented		No	
System Stability	Frequency and voltage control	6	Included in stability study from reports: Unit Commitment and Generation Dispatch Dynamic simulations	DIgSILENT	17-Feb-22	Studies performed based on simulation model	Validation of the offline models (controls, limiters and protections) based on testing and monitoring highly recommended.	Yes	Sound methodology Assumptions and scenarios to be udpated with more recent values Simulation models to be updated if discrepancies with actual controls
	Operational rules (e.g. N-1 security constraints, spinning reserve)	1	ISLAND+ FUNCTIONAL SPECIFICATION	Wartsila	24-Jun-25	Process via operational procedures until BESS commissioning Constraints will be considered by BESS GEMS as described in Functional Specification report	Automatic process via BESS GEMS should improve reliability of the system Some remarks: (i)No explicit definition of spinning reserve nor reserve requirements forecast, (ii) no time-domain simulations with BESS GEMS control logic included	Yes	DIgSILENT reports is for offline simulations Wartsila functional specifications do not provide details on the control logic
	Security analysis	3	Unit Commitment and Generation Dispatch Dynamic simulations	DIgSILENT	17-Feb-22	BESS installed Synchronous condenser under pilot project No foreseen adaptations of UFLS Withstand capabilities of wind turbines not tested	Cover the period 2021-2024 Provide justifications for the need of spinning reserve, increased system strength, update UFLS scheme and withstand capabilities of wind turbines	Yes	Sound methodology Assumptions and scenarios to be udpated with more recent values
	Training	1	Orally mentioned				Aqualectra staff well aware of the DNV reports, which outlines their implication and understanding during these studies		
Generation & operational procedures	Governor and AVR settings (control, protection and limiters)	6	Settings check performed at Dokweg 1 (from Excel file) Dokweg 2A-2B for 2020 and 2021 blackouts	Aqualectra Wartsila	6-Aug-2024 15-Jan-2021	No specific study/reports on tuning of governor and AVR settings. Detailed reports on actual settings made available.	BESS and operation rules should further reduce the occurrences of hitting the limiters. However, it is recommend to monitor and test potential control interactions, as well as coordination limiters/protections.	Yes	UEL and UE protection settings are at first sight are set according to best practice. Logs or tests would be useful to verify this.
	Operational rules (e.g. isochronous vs droop vs kw)	8	New procedure in place for changing operating mode Logic updated	Aqualectra Wartsila	Sep-25	Operational mode is speed droop and voltage droop mode	Use of BESS GEMS should theoretically further ease the work of operators New procedure and logic updated in 2025.	Yes	Procedure for change of operating mode is clear and concise.
	WindFarms (disconnection&reconnection)	5	Done in 2021			Implemented	Satisfactory for installed wind turbines.	No	
	Withstand capabilities	2	Covered in "Risk assessment report" from DNV	DNV		For all assets, settings for under- and over-voltage protection and, under- and over-frequency protection should be verified and available in a centralized database.	It is recommed to assess whether requirements should be more stringent, with stricter compliance process (for example: for repowering, BESS and new wind turbines) in the future. Testing and monitoring of withstand capabilities also recommended for combustion engines.	No, report not made available	
	Training of operators	6	Orally mentioned						

Appendix B. Site visit Report

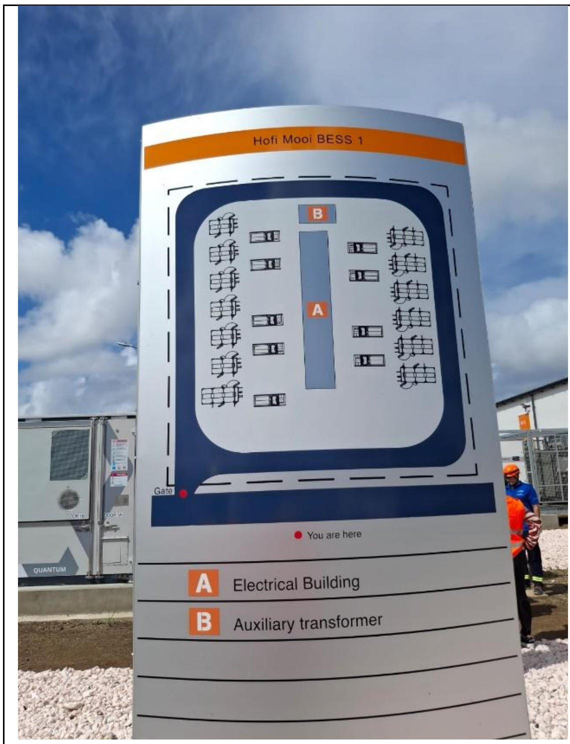
Appendix B.1. Grid Control Centre

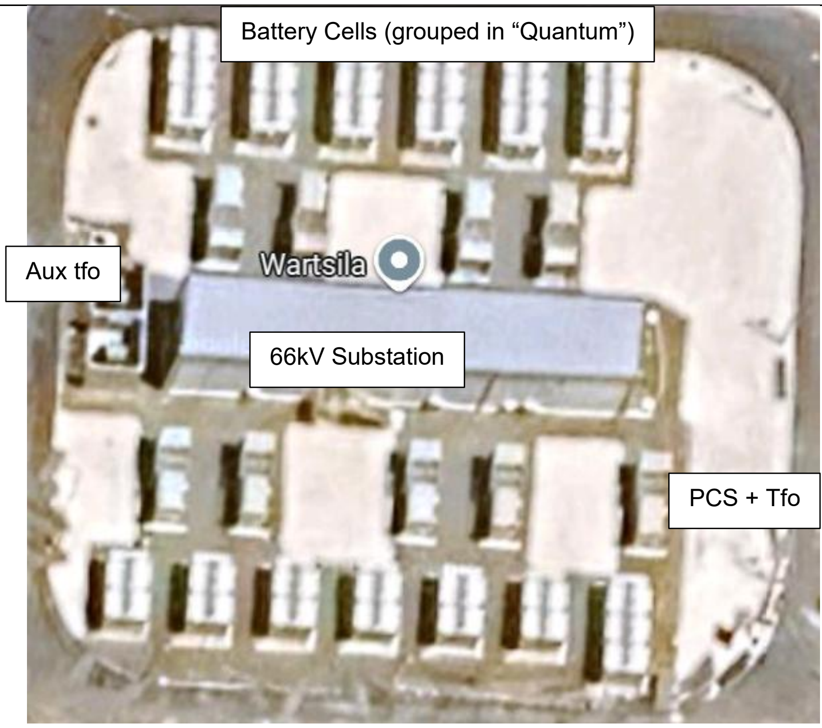
- The control centre is located in Nieuwe Haven and is very new. It consists on several desks split between Water and Electricity Network Operations. There are enough screens to have a clear view on the water and electricity networks. An interactive touch screen is also installed in the middle of the room, allowing easy and fast switch between applications.
- The Grid Operators can observe via the ABB SCADA systems the grid from 12kV to 66kV. There are limited observability in the LV grid, which is common among distribution grid operators. It has to be noted that data from smart meters can be accessed via another software (not SCADA) and provide useful information for fault locations.
- It is understood that there is a project for upgrading the SCADA system. This has not been discussed in details.
- There are several softwares that can be used in parallel in the control room. For example, PFM for monitoring and disturbance investigations, visualization of smart meter data. While only the SCADA will typically be needed by operators, having access to additional information might be useful in some applications.
- The main function of the Grid Control Center is crew management and grid reconfiguration in case of outages. A GIS interface allows easier guidance of the crew for faster intervention. In the future, it is also expected that the use of smart meters will allow a quicker detection of the faults (current approach is to wait for customer complaints for LV grid) and ideally reduce the average interruption duration time.
- For the MV grids, faults are automatically identified and isolated. During interventions Fault Current Indicators (FCI) are used on overhead lines to help locating the fault, but their signals are not observables from the control centre—site visits are required. Fault location on underground cables typically requires specific measurements, this is standard practice.
- No system simulations are performed in (near) real-time. The SCADA essentially consists of measurements. This could be an area of improvement, the following functionalities[9] could definitely bring values: state estimation, load flow & contingency analysis modules, grid snapshot (grid operating points) export and potentially volt/var .
- Voltage and frequency are observable from the control centre but controlled in the power plants control room. This is not standard practice to have voltage and frequency control at the plant level rather than at the grid level, but this is understandable considering Aqualectra's scope of activities.

[9] *Exact names of the functionalities depend on the SCADA version and vendor.*

- The grid includes capacitor banks totalling 2 Mvar, and specific rules for cos(φ) at the customer level are not enforced.
- Backup control centres exist at plant sites.
- In case of blackout, operations take the lead.

Appendix B.2. BESS Power Plant





The 25MW/45MWh BESS plant has been operational since September, with the fully automated GEMS system in commissioning, (will be fully operational in January).

The BESS plant consists of:

- 9 x 4.2 MVA SMA PCS SCS 3600 UP-XT (2 Grid Forming and 7 Grid Following)
- 33 Quantum Battery Containers
- 13 Quantum Containers composed of 8 to 12 racks (8 CATL modules per rack)
- Two auxiliary transformers
- A 30kV AIS substation in the central building

The main purpose of the BESS is to maximize the share of renewables in the system, while increasing grid resilience and stability. Therefore, charge/discharge will be used to maintain grid frequency (and mitigate wind fluctuations). Also, a special attention was paid to the speed of response of the BESS in order to ensure a stable grid in case of sudden active power deviation. The BESS plant will also contribute to voltage regulation.

The BESS capabilities include black start and soft starting for grid restoration after blackout. The black start functionality has been successfully tested.

The BESS is controlled by the GEMS logic. The GEMS will act as an optimizer for dispatching, voltage and frequency control. The GEMS site acceptance testing includes testing of primary, secondary and tertiary control loops. For example, the sudden loss of one power unit (up to 10MW) has been tested with very limited impact on grid frequency. During that test, the frequency went down to 49.6Hz after 100-150ms (while without batteries the same event would have likley led to some load shedding). A video recording of this test has been shown during the visit.

Additional notes:

- To our understanding, there are currently no detailed power system simulations which include the GEMS control logic as well as the frequency and voltage controls of the engines. To be noted that the GEMS control logic for dispatching has been used in a Plexos study.
- Aqualectra mentioned explicitly the importance of maintaining manual competence in case of GEMS regulation system failures. This will be done be deactivating the GEMS at regular intervals.
- The BESS was tendered jointly with an Energy Management System. Wärtsilä won the bid and could easily interface their GEMS with the BESS plant and Dokweg engine plants (also from Wärtsilä). The wind farms are also interfaced and the interface with the MAN plant is ongoing.


Quantum Battery Container
BSB 009-01-02-02
BSB 009-01-02-01
Rack
Module
WARNING
NOTICE

Appendix B.3. Isla site

At the Isla site, Aqualectra operates the MAN Power Plant and the installation of a new power plant is ongoing. The MAN plant is connected to two 11/66kV 45MVA transformers to the 66kV Isla substation. There are also two 30/66kV 75MVA transformers connecting Isla substation to the refinery.

The new power plant will be connected to a new 66kV substation. However, there will be very likely a transition period (e.g. for commissioning) during which the Salu plant will be connected to the existing Isla 66kV substation.

Appendix B.3.1. MAN Power Plant

- The MAN Power Plant has been commissioned in 2002 and has 4x8.3MW units.
- These units, even if older than Dokweg 2 plant units, are used for blackstart due to their better reactive power capability.

- It has been mentioned that the plant availability was lower than normal recently but this has been improved and plant has now high availability.
- The machines are usually operated in kW modes and manually adjusted when needed. The frequency is controlled by the Dokweg units, in droop or isochronous modes.
- There is a manned control center on the site.

Appendix B.3.2. Salu – New Machines & Control Center

- Four new Wärtsilä 20V32 8 MW machines will be installed at ISLA. It has been mentioned that this new power plant includes improvements based on HAZOP studies and return-of-experience (REX) from other engine plants (Dokweg and MAN). For example, the design of the new plant incorporates compressor redundancy to avoid single points of failure with significant consequences.
- Initially, two control centers will operate, but eventually, a single center will manage all existing and new machines.
- The soil has been prepared and the machines are already on the island.

Wärtsilä 20V32 engines for Salu power plant (~10MVA)

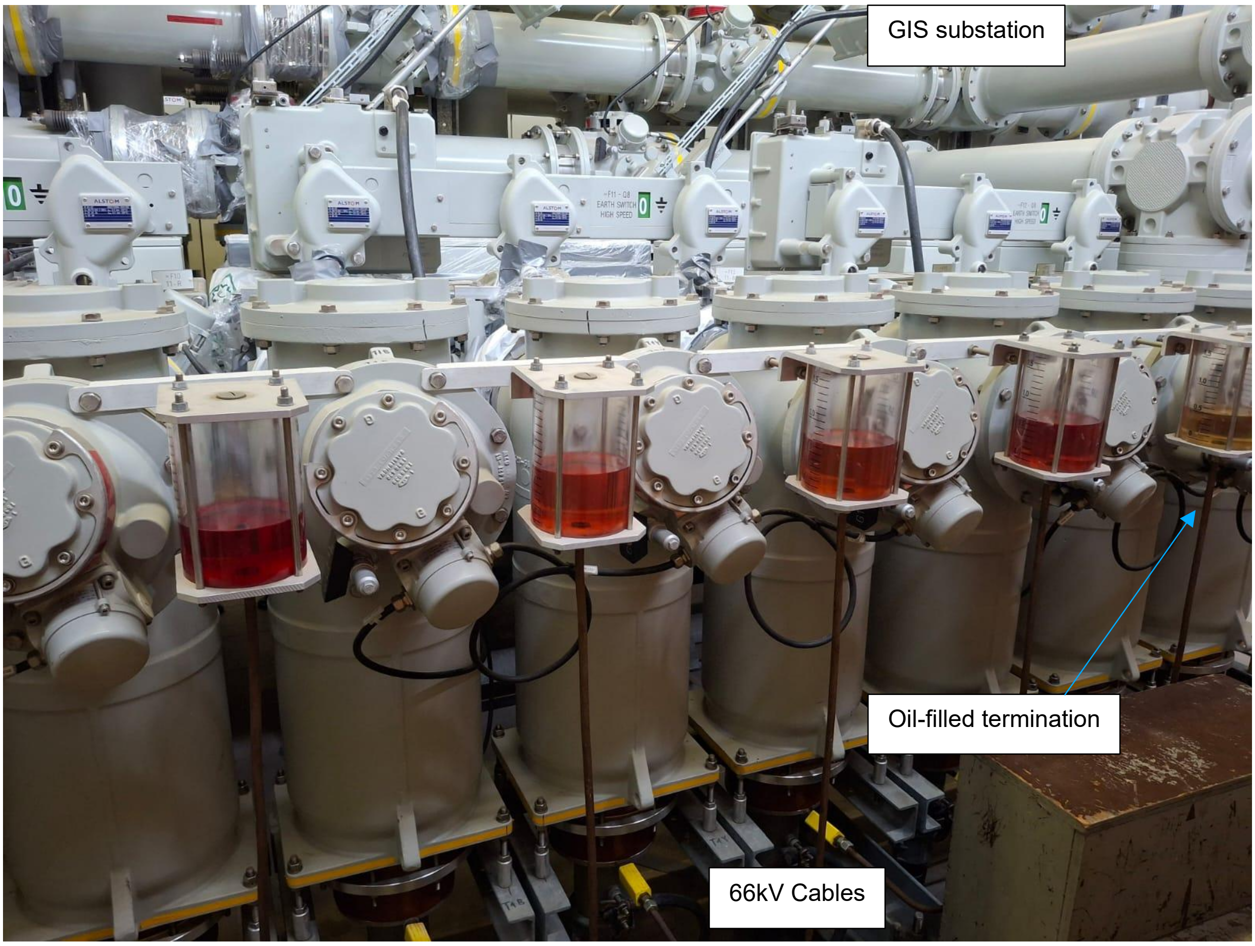
Appendix B.3.3. 66 kV GIS Substation (built 2002, 4 transformers)

- Substation overall condition is good; minor SF6 leakage observed requiring maintenance. First maintenance is scheduled for 2026.
- There is an air condition in the main building and good ventilation in the UPS room.
- Transformer oil samples are taken annually for health assessment. This is good practice.
- There are 4 transformers:

    - 2 x 11/66kV step-up transformers between MAN machines terminal and 66kV Isla substation
    - 2 x 30/66kV transformers between the 30kV BOO substation (refinery) and the 66kV Isla substation

- New protection cabinets are planned for installation and already present in the substation.
- The cable terminations are oil-filled type with the three first termination having oil of a much lighter colour. Aqualectra confirmed that there was no failure of this cable, and no repair was carried out
- Electrolyte lead-acid batteries provide back-up supply in case of blackout; it was mentioned that batteries are tested annually.


MAN Power Plant
11/66kV Tfo


GIS substation
Oil-filled termination
66kV Cables

Appendix B.4. Main impressions from the site visit

Appendix B.4.1. People

It is acknowledged that the relevant people were made available by Aqualectra and were present at the table for the discussion and visit. In addition, senior experts from DNV were also remotely available to answer specific questions on the 2025 blackout and restoration investigations. During the discussion with DNV, it was observed that the people from Aqualectra followed closely the DNV study and were very aware of the technical content.

It was also seen that a few very knowledgeable people at Aqualectra cover a wide range of responsibilities (from engine power plant, installations, commissioning, FAT, blackstart, frequency & voltage controls, etc.) which outlines that formal procedures are needed to delegate/distribute their tasks. This point was also recognized by Aqualectra which is confident that the new organisation is better fitted for these types of challenges.

It also has to be noted that Aqualectra seems very proud of their achievements over the last couple of years, which includes review of protection settings, installation new BESS, etc. It is agreed that the amount of work performed is significant and represents a clear improvement compared to 2023.

Appendix B.4.2. Overall

The Curacao electrical system is improving, many projects are ongoing or were performed recently. If we strictly stick to the action list from previous reports, most of our questions have been answered and we agree that most of the actions are implemented or are being implemented (confirmation of implementation of some actions rather discussed orally that formally proven), with probably sometimes a lack of formal procedure. It was also noted that the assets installed by Aqualectra (BESS, Protection Cabinets, substations, transformers, engine, etc.) are provided by well-known and qualified vendors. The same observation can be done on the softwares.

Appendix C. Indicative figures for the reactive power produced by transmission circuits under no load

Table C1. Indicative figures for the reactive power produced by transmission circuits under no load.

V [kV]	Transmission	Conductor	C [μF/km]	L [mH/km]	Q_C [Mvar/km]
66	Overhead	524 Al	0.010	1.440	0.01
66	Underground	300 Cu	0.178	0.768	0.2
150	Overhead	Steel/Al 52/591	0.011	1.115	0.1
150	Underground	1200 Al	0.191	0.592	1.3
400	Overhead	Steel/Al 92/591	0.015	0.800	0.7
400	Underground	2000 Cu	0.200	0.756	10.0
400	Underground	2500 Cu	0.240	0.724	12.1

(from CIGRE TB338, 2007)

Appendix D. List of Acronyms

Acronym	Definition
AVR	Automatic Voltage Regulator
BESS	Battery Energy Storage System
CTO	Chief Technical Officer
FCI	Fault Current Indicator
FAT	Factory Acceptance Test
FRT	Fault Ride-Through
GEMS	Grid Energy Management System (Wärtsilä)
GIS	Gas-Insulated Substation
HAZOP	Hazard and Operability Study
HR	Human Resources
LV	Low Voltage
MVar	Mega-Volt-Ampere reactive
MW	Megawatt
MVA	Mega-Volt-Ampere
N-1	Contingency criterion (loss of single element)
PCS	Power Conversion System (SMA PCS)
PFM	PowerFactory Monitor (DIgSILENT)
RAC	Regulatory Authority of Curaçao
REX	Return of Experience
RMS	Root-Mean-Square (dynamic simulation)
SCADA	Supervisory Control and Data Acquisition
Tfo / Tfos	Transformer(s)
UEL	Under-Excitation Limiter
UPS	Uninterruptible Power Supply
VRE	Variable Renewable Energy

Appendix E. Distribution list

Electronic format

as PDF to:

Zariona Martijn	The Regulatory Authority of Curaçao	z.martijn@rac.cw
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as SD link to:

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