AQUALECTRA

Report

Root cause analysis Blackout events

December 2020

February 1, 2021

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Ref nr. 2021-4027

Preface

In the wake of the recent black-out events - hereinafter referred to as the Events - and our corporate and social responsibility Aqualectra N.V. ("AQ") would like to objectively inform the community of Curacao with respect to the parameters that influenced the stability of the grid and consequently the Events.

This report will elaborate on the following items:

- The sequence of events;
- Terminologies;
- Technical parameters of the production and distribution system;
- Operational actions taken by the Plant Operators;
- How to safeguard the system for potential future events.

The purpose of this white paper is therefore to objectively inform the community of Curacao not only about the root-cause of the Events and the decision-making process for the long-term solutions to safeguard the grid, but also to create a level playing field for future qualitative debates.

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1. Context

Aqualectra N.V. ('AQ') a full subsidiary of Integrated Utility Holding N.V. is Curaçao's utility company responsible for the production and distribution of Power and Water as well as for the delivery of accompanying services. Since 2004 to 2019 Curacao has not observed any black-out event in the power supply grid. Nonetheless, in November 2019, a blackout event was observed and 2020 initiated with one black-out in February and finalized the year with a total of 3 additional black-outs in the period of one week in December. On the 4th of January 2021, Curacao experienced another black-out bringing the total to 5 blackouts in a period of 1-year.

This document elaborates on the 2020 and 2021 black-out events and explains the sequence of events leading up to the blackouts. AQ is working to continue to implement both technical and operational solutions to mitigate further Black-out events.

1.1 Terminologies

The following chapter describes the different terminologies used in this document. It serves the purpose to provide the reader with a crash-course in the electrical power system. Furthermore, the explanation of the sequence of events can be conceived better.

Active Power
measured in Mega Watts ('MW') is also called "real Power." Active Power is the electrical power consumed by a client due to its resistive Load (i.e., active power is the actual power which is dissipated in the circuit). It is generated by an electrical power Generating Unit which can be either a Diesel Power Plant, a Windmill or Wind farm system, Solar System, Gas turbine, etc.

Active Power is equal to the average value of Voltage times Current times the Power Factor.

Alternating Current ('AC')
is produced by Generation Units by means of electromagnetic induction. An alternation electromagnetic force is induced in a loop of conducting with by rotating the loop of wire in a uniform magnetic field. The alternating electromotive forces are of the sinusoidal form. The voltage varies with time from positive to negative at a rate given by the angular frequency. The angular frequency within a specific period equates to the Frequency of the Voltage.

The AQ grid is based on three-phases at which the AC-Voltages are offset in time by one-third of the period. By doing this, AQ can provide different voltages across the phases (e.g., 220/380V at which 220V is achieved between neutral and phase, and 380V is achieved between any two phases).

Apparent Power
measured in volt amps ('VA') is the power the grid must be able to withstand and is dependent on the ratio of Active Power and Reactive Power and is the product of Voltage and Current. For the grid of Curacao mostly mega volt amps ('MVA') is used.

Black-out

is a total loss of energy of the power grid due to an imbalance between Power generation and/or production and power demand and/or consumption. A common misconception of Black-outs is that they occur because of a lack of Power generation, however it is always caused by the imbalance (e.g., if the Power produced by Generating Units exceeds the Power demand, Over-Voltage and subsequently high Grid Frequencies are observed that can also lead to Black-outs. At these moments Protection Systems engage to protect the Grid and its Generating Units.)

Brown-out

is a selective power cut – initiated by the Grid Operators and / or by the Under-Frequency Load-Shedding Scheme ('UFLS')- in a given area to avoid a overloading he power generation system which may lead to a Black-out. A Brown-out reduces the Power demand consequently reducing the imbalance between the Power demand and supply.

Grid operators in the SCADA-room can trigger localized power outages to reduce the Power demand to meet the instantaneous Power output.

Capacitive Load

for Capacitive Load, the current lead the voltage and therefore has a leading Power Factor. This term is viewed from the perspective of the point which is supplying the active power.

Capacity

measured in Mega Watts ('MW') is the amount of electricity a Generation Unit can produce at maximum Power output. The reliability of a Generation Unit is measured by its capacity factor. The capacity factor is used to measure how often a Generation Unit is operating at full capacity.

The total available Capacity of the Generation Units is projected daily against the projected daily demand for production planning and/or Load Shedding planning.

The capacity factor for the gas turbine and diesel engines in the AQ-Grid is not utilized, because these Generation Units often run at lower Power Outputs to maintain a buffer to Ramp-up and/or Ramp-down. The capacity factor must not be confused with the Power Factor.

Current

measured in ampere ('Amp') is the stream of electrons moving through an electrical conductor (i.e., transmission and distribution cables). Current is derived from the electrical potential ('Volts') and the resistance ('R').

Distributed Energy Resources ('DER')

are electric Generation Units located within the distribution Grid or near consumer / Load, that produces Power outside of the utility Grid of AQ. They are also called stand-alone units. On Curacao, DER consist mostly of renewable energy technologies - such as household solar PV-systems ranging from 1-10kW_p, commercial PV-system of up to 1MW_p and wind turbines.

Frequency

measured in Hertz ('Hz') is the measure of the number of electric cycles of an AC per unit of time. Typical average Frequencies are 60Hz (used in the United States) and 50Hz (used in Europe and Asia).

Electrical appliances are designed to work on specific Frequencies. The life of an appliance can be negatively affected if it does not coincide with the Frequency of the Grid.

The average frequency of the AQ Grid is 50Hz. The Grid-Frequency is determined by the balance between the instantaneous sum of the Power-output of the Generation Units and the simultaneous Active Power demand of all the Loads plus Grid losses. The Frequencies must be kept between specific bandwidths to mitigate the activation of the Protection Systems and / or Load Shedding.

Frequency control

Grid and Plant operators are responsible for maintaining the real-time balance between production and demand. Frequency control takes place during the operating period, but also beforehand by means of demand forecasting and production forecasting based on the weather.

AQ performs weekly forecasts to quantify and map the available Generation Units. By doing this, preventive maintenance can be planned accordingly to avoid the possibility of deficiency of available Capacity of Generation Units.

During the operation period, Generation Units work mostly in Synchronous-mode.

Generation Units

are used for the generation of energy over time which is measured in Watt-hours ('Wh'). For large Generation Units – such as the Generation Units used by AQ – Mega Watt-hours ('MWh') is used as the measure of the amount of electricity produced. Generations Units can also be called Power plants.

The maximum level of electric Power that the Generation Units can supply is defined as the Capacity of the Generation Unit - measured in MW.

The following Generation Units are used by AQ (see table 1 and 2):

- Diesel Engines located at the Dokweg Power Plants;
- Gas turbine located at Mundo Nobo;
- Wind Mills located at Playa Canoa and Hato;
- Distributed Solar PV-systems;
- Gas turbines as well as stem units located at CRU (formerly the BOO plant).

Grid

also called the electrical Grid, electric Grid, Power Grid, is used to transport the electricity produced by the Generation Units to the Loads. The Grid consists out of the following components (see Figure 2 for a simplified version of the AQ Grid):

- The Generation Units;
- Transmission Network of above-ground cables for High Voltage (i.e., 66kV, 30kV and 12kV);
- Distribution Network of above-ground cables for High Voltage (i.e., 440V, 220kV and 127V);
- Transformers (Step-up / Step-down);
- Transmission sub-stations;
- Distribution power stations;
- Protection Systems;
- Regulator banks (i.e., capacitor banks the Reactive Power within the Grid);
- Switching gears and switching locations; and
- Electrical meters.

Inductive Load

For Inductive Load, the current lags the voltage and therefore has a lagging Power Factor. This term is viewed from the perspective of the point which is supplying the Active Power.

Isochronous mode

is a quick response mode between paralleled Generation Units in a Power plant to adjust to Load changes without causing Frequency variations in the Grid.

Load-shedding

also refers to Brown-outs. It is a methodology used to distribute the Load within a Grid across multiple Generation Units. Load shedding is used to relieve stress on a Generation Units when demand is greater than Power supply. A method to adjust for the imbalance between demand and Power-supply.

Load shedding is triggered automatically by the Under-Frequency Load-shedding Scheme('UFLS'), but also manually by the Grid-operators within the SCADA-system.

Manual-mode

During Manual-mode, Power plant operators can manually adjust the Power output of designated Generation Units. Generation units have a large list of Power and Voltage control grouping fields. One of which is the Constant-mode. The switch from Synchronous-mode to Manual-mode can trigger a Generation Unit to return to its setpoint values and function withing the Constant-mode.

During Constant-mode, the Reactive Power output becomes a function of Active Power Output and Power Factor. If the Power Plant Operator adjusts the Active Power output subsequently the Reactive Power output also increases and the other way around (knowingly or unknowingly). Thus, Generation Units can behave differently compared to during Synchronous mode.

Over-Voltage

occurs when the root mean square value of the AC-Voltage rises (i.e., the average value of the AC-Voltage), exceeding 10% of the PU and lasts longer than 1 minute. Over-Voltage is usually a result of the change in the imbalance between the Load and the Power-supply.

Overload

occurs when there is too much current passing through the conductor (e.g., cables). Cables heat up and can melt (i.e., cable failure), with the risk of starting an electrical fire. Overload in Generation Units can cause irreparable damage.

Current thresholds are set for Protection Systems to mitigate the risk of cable failures and / or high Currents in Generation Units.

Overload can occur during Under-Voltage moments at which the Voltage drops and the Current increases to maintain the same Power.

Per unit

Per Unit ('PU') is the expression of system quantities as fractions of a defined base unit quantity. In the Power supply system, some of these per-unit values are used:

- Frequency ('f'), f_{base}= 50Hz = 1 PU
- 66kV Voltage ('V'), $V_{66kV,base}$ = 66kV = 1PU
- 30kV Voltage ('V'), $V_{30kV,base}$ = 30kV = 1PU
- 12kV Voltage (V'), $V_{12kV,base}$ = 12.2kV = 1PU

Power factor
is the cosine angle between the voltage and current. It can be expressed by the power triangle in which the Power Factor is the ratio of Active Power to Apparent Power (see Figure 1). Power factor defines the efficiency of the Power supply system. A Power Factor of 1 can be considered as the optimal efficiency of a Power supply system. The four Power quadrants illustrate the base definition of Power and the direction of the Power flows.

Power factor is always a value between 0 and 1 and can be determined by the Lead or Lag of current regarding voltage (see Capacitive Load and Inductive Load).

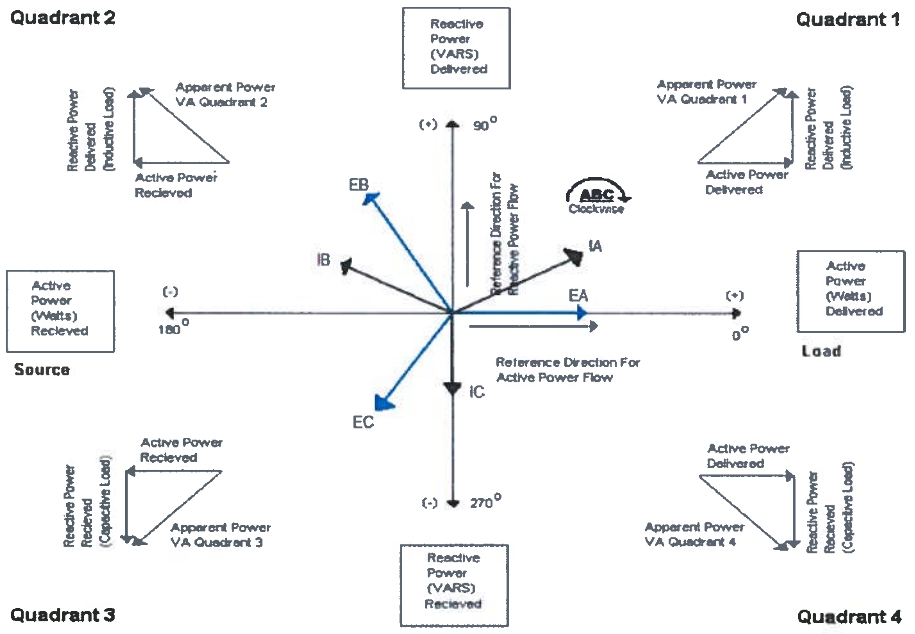

Figure 1 Power quadrants is used to define the direction of Power flows.

AQ applies a Power Factor between 0.97-0.99. The Loads in the AQ grid are considered Inductive Loads.

Protection systems
are required to protect both different components and stakeholders within the Power supply system. These systems are in place to protect the consumers ('Loads') but also the AQ's Grid itself from any faults. Power system fault is defined as the undesirable condition that occurs in the Power supply system that can cause damage to e.g., electrical appliances, Generation Units, Transformers, cables. Some faults include the following:

- Short circuit at which Current flows along an unintended path and causes Overloading;
- Ground (earth) fault;
- Over- and Under-Voltage;
- Overloading;
- Over- and Under-Frequency;

Protection systems – consist out of fuses, protective relays, and circuit breakers – with specific boundary conditions react to faults in the Grid.

Reactive Power

measured in Volt Ampere Reactive ('VAR') is the power that travels back and forth in the circuit or line without being consumed by the Load (i.e., a non-active Power). Reactive Power can be either negative or positive because it depends on the Power Factor of the Load.

The amount of Reactive Power in the Grid affects the Power Factor. Thus, if there is an excess amount of Reactive Power in the System the Power Factor is reduced consequently leading to lower operating efficiencies and higher operational costs.

Reactive Power is not always bad as it is useful for generating the necessary magnetic fields for the operation of inductive devices such as transformers and AC-motors, but also helps regulate the Voltage in large Generation Units.

Renewable Energy Sources ('RES')

Energy produced from RES are produced from natural sources or processes that are constantly replenished (e.g., sunlight or wind keep shining and blowing, even if their availability depends on time and weather. It cannot be instantaneously affected by humans). The concept of generating electricity from RES has been developed to solve the problems raised by environmental pollution and diminishing fossil fuel resources. Integration of clean renewable generation into existing Power supply systems has been proven to benefit both power system operators and customers. However, RES are intermittent by nature consequently leading to key challenges with higher penetrations in the Grid.

AQ achieves an average RES-penetration of around 39% on annual basis. For comparison purposes, the European Union achieved a RES-penetration of 18% in 2018.

SCADA-system

Supervisory control and data acquisition (SCADA) is a control system architecture comprising computers, networked data communications and graphical user interfaces (GUI) for high-level process supervisory management. From the SCADA-room, Grid operators can manage the Loads and the Grid remotely.

Synchronous Grid

A wide-area Synchronous Grid is an interconnection of different Power supply systems of different countries and/ or states. The general requirement of such a Grid is the Power supply system's share the same nominal Frequency. Electricity grid interconnections increase the Grids inertia, meaning that a change in the Power supply system of a specific country has limited effect on the Synchronous Grid's inertia.

Transformers

are used to transfer the electricity from one circuit to another by changing the Voltage without changing the Frequency. Transformers can either be used to step-up the Voltage or step-down the Voltage. Step-up transformers are mostly used to increase the voltage produced at the Generation Unit for transmission purposes, while step-down Transformers are used to reduce the Voltage to be used by the Load at appropriate Voltages.

Under-Voltage

also called Brown-out occurs when the average Voltage of a three-phase power system drops below a threshold value. Inductive devices such as three-phase motors and pumps, transformers, Generation Units are designed operate within a specific Voltage bandwidth to protect the devices against high Currents.

An increase in the Current causes increased heat in the windings and coils of the equipment consequently leading to damage of critical components. Operating in Under-voltage conditions can drastically reduce the life of the Generation Units.

Voltage
measured in Volts is the electric potential difference in electric potential between two points. It is defined as the work needed per unit of charge to move a specific charge between the two points (i.e., the source and the load).

On Curacao the typical AC-voltage for low Voltage systems is 380-220V and 220-127V. For high voltage, the typical AC-voltage is 66kV, 30kV and 12kV.

High voltage is used for transmission purposes (i.e., long distances) and low voltage is used for distribution purposes (i.e., short distances). The clear difference between high and low voltage is to reduce Power losses in the grid which is caused by the resistance of the conductor. The losses of transmission are often called copper loss is a function of the Current squared and the resistance ('R') of the conductor. Thus, the efficiency of transmission is increased four times by lowering the Current by 50%.

Voltage / Power control
is a system – integrating in the control systems of the Generation Units located at the Dokweg power plant- used for adjusting the Voltage / Reactive Power output of the Generating Units in response to the changes in the Load. The Generating Units Ramp-up or Ramp-down depending on the Balance between production and demand which can be judged by the Grid-frequency.

Generation Units have the following key grouping fields for the Power Control systems (the following are just the key grouping fields):

- Active Power output (MW);
- Active Power output Setpoint (MW);
- Min and Max Active Power output (MW);
- Participation factor;
- Automatic generation Control;
- Loss sensitivity.

Generation Units have the following key grouping fields for the Voltage Control systems (the following are just the key grouping fields):

- Reactive Power output (MVAR);
- Min and Max Reactive Power output (MVAR);
- Automatic Voltage regulation;
- Set point Voltage;
- Constant Mode;
- Participation factor;
- Loss sensitivity.
-

1.2 Description of the Curacao Grid and its parameters

The Curacao Power grid can be considered very complex compared to most of the Caribbean islands. The reason for this being the fact that from the late 1990 to the early 2000 the local economy was growing, and the demand forecast projected a necessary growth which would overload the energy transport system at 30-kV level. This resulted in the deployment of a 66-kV grid complementing the existing 30kV grid (see figure 2).

Furthermore, with the strategic choice of including renewables, the Grid management became even more complex and was requiring further automation. Altogether it was decided to further automate the grid management by implementing a SCADA-system (2005 / 2006).

The complexity of the grid is found in balancing the 4-quadrands in the power supply system (figure 1) by managing not only the power plants, but also the RES and the load fluctuations during the supply period. It should be noted that there are the following parameters to control:

i. **Voltage**
Should be held steady within the preset supply boundaries.

ii. **Amperes (Load)**
Fluctuates due to the demand of customers. It should be noted that not only the active power demand fluctuates but also the Apparent (reactive) Power demand.

iii. **Frequency**
Fluctuates due to the balancing of the load in the system and the availability of capacity. With overcapacity comes over-frequency. With capacity shortage comes under-frequency.

iv. **Reactive power**
Fluctuates due to the demand of customers. It should be noted that not only the active power demand fluctuated but also the apparent (reactive) power demand.

v. **Renewable supply fluctuations**
Renewable sources mostly generate active energy (Watts per hour) and the not generate apparent power. Other (fossil) units are to compensate for this lack of reactive power supply from the RES.

These parameters are controllable in a steady state situation. In a dynamic state (short circuit, generation failure etc.) human interaction is not able to react fast enough to be able to (re)establish the balance of the five (5) parameters. Automated systems should be keenly programmed to address this imbalance.

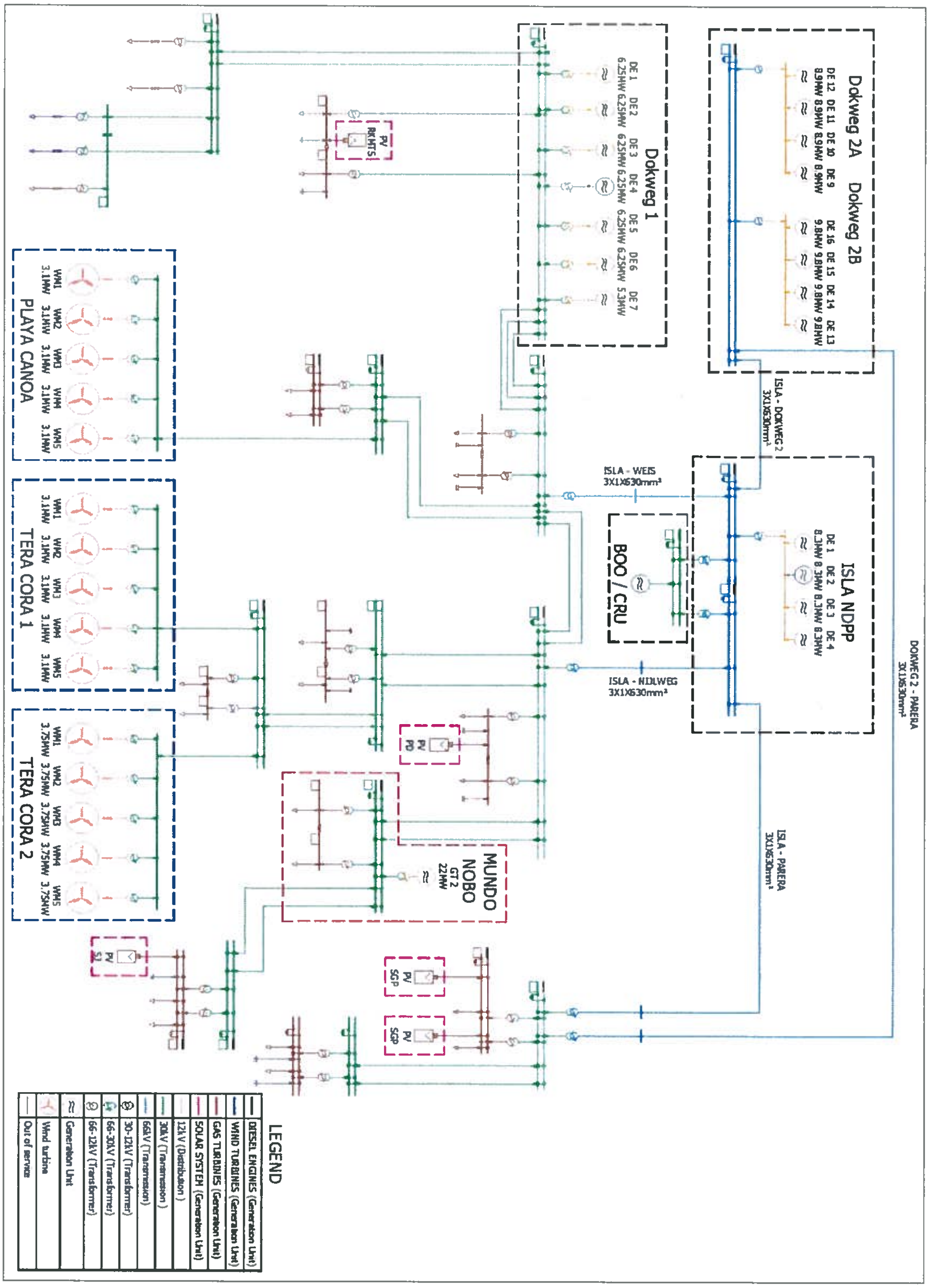

Figure 2: Single-line diagram of Power Grid

Based on the complexity of Grid management, especially with respect to the Frequency management, AQ started and commissioned an Isochronous management system supplied by Wärtsilä (the engine manufacturer) in September 2018.

This system aids in the Grid Frequency management ensuring the stability of the grid by neutralizing the effects of the intermittency of the RES.

The following is a block schematic of the Curacao electrical grid:

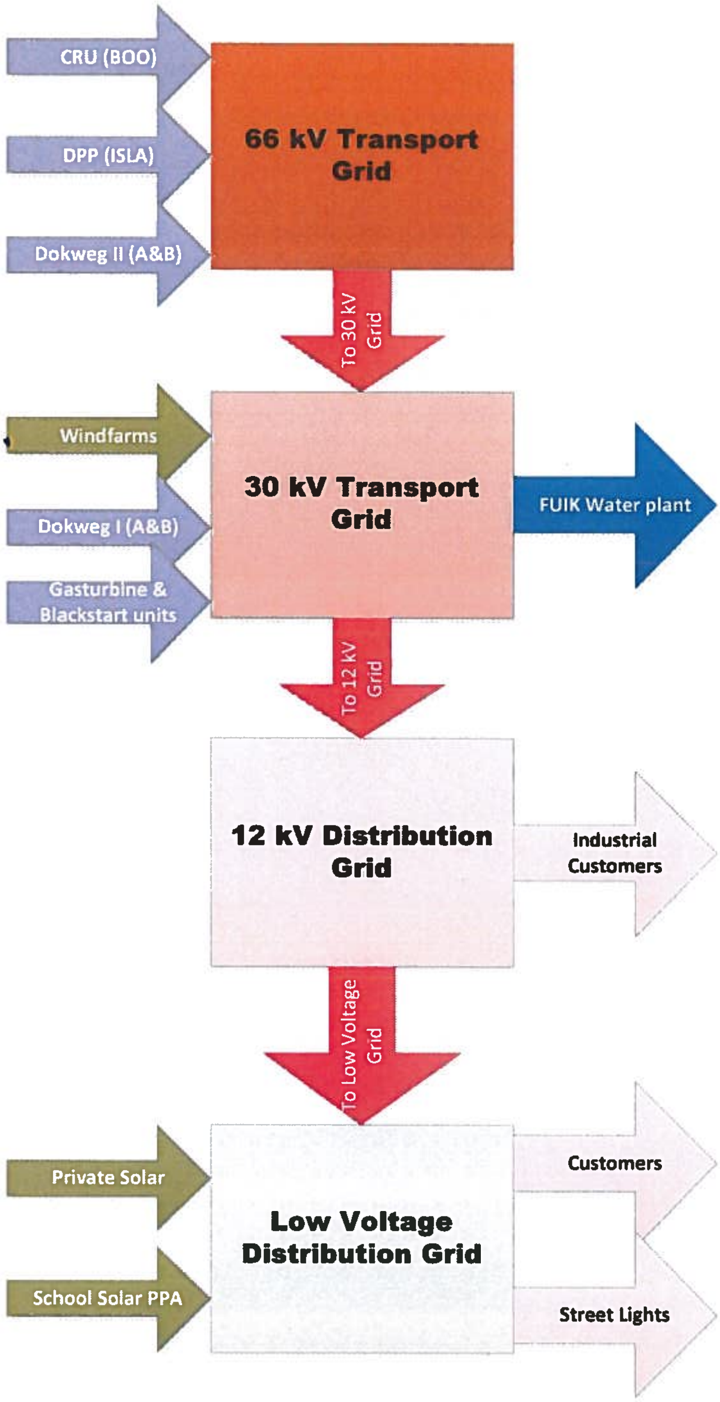

Figure 3: Electrical system block-diagram

The AQ Generation Units for Fossil-based generation (see table1) and for Renewable – based generations (see table 2) are comprised as follows:

Generation Unit	Denomination	Capacity [MW]
Fossil generation		
DW1	Dokweg 1	43.8
DW2A	Dokweg 2A	35.6
DW2B	Dokweg 2B	39.2
ISLA NDPP	MAN Diesel	33.6
GT2	GT (Mundo Nobo)	22.0
Total installed capacity		**174.2**

Table 1: Fossil Generation systems

Generation Unit	Denomination	Capacity [MW]
TK1	Windfarm Tera Kora 1	15.50
TK2	Windfarm Tera Kora 2	18.75
PC1	Windfarm Playa Canoa	15.50
Solar systems	School Solar PPA	2.90
Total installed capacity		**52.65**

Table 2: Renewable Generation units

The distribution grid infrastructure can be parametrized as follows:

Asset type	Voltage	Count	Unit
Cables underground	66 kV	52	km
	30 kV	260	km
	12 kV-H	315	km
	Low voltage	727	km
Cables Overhead	Various	321	km
Voltage transformers	66 / 30 kV	6	Transformers
	66 / 11 kV	4	Transformers
	30 / 12 kV	20	Transformers
	12 kV/ Low Voltage	1,662	Transformer station / box
	12 kV/ Low Voltage	788	Pole mounted
Public Lighting Poles	Conical	13,056	pcs
Public Lighting Poles	Iron	10,920	pcs
	Wooden	9,500	pcs

Table 3: Power distribution grid assets

1.3 Key challenges on Curacao

Power supply systems for island nations such as Curacao must cope with key technical challenges. The main challenge of island Power systems is the balance between Power supply and demand. Wide area Synchronous Grids on the other hand – such as Europe and the United States – are electric Power Grids that has regional scale or greater that operate at a synchronized utility frequency and is electrically tied together across state and country lines.

The loss of Capacity due to a failure and / or disconnection of a Generation Unit in country "A" – which is connected to a Synchronous Grid – is instantaneously supplemented by the Power supply system of a neighboring country "B." Thus, the loss of supply Capacity is replaced to maintain the potential imbalance in the Power supply system. The Grid Capacity is therefore much more robust to cope with sudden changes in the imbalance of Power supply and demand. For Curacao, the disconnection of a Power plant cannot be instantaneously supplemented by other Generation Units as the available Grid Capacity is fixed.

An additional technical challenge arises with regards to effective integration and optimal utilization of RES in the Power supply system of Curacao. RES is intermittent by nature and have non-dispatchable characteristics (e.g., wind and solar energy directly connected to the Grid are not dispatched by the Plant operators, but by the prevailing winds and solar irradiation at specific moments). The intermittent nature of RES – because they are directly connected to the Grid - can have detrimental effects on Grid performance, its reliability and Power and Voltage quality.

Another key challenge with respect to RES – especially with respect to solar energy – is that they are considered Distributed Energy Resources (DER). Therefore, there can be a discrepancy between the total installed Capacity and the Active Power production at specific moments.

Challenges with respect to RES are reduced by supply and demand planning but are always subjected to discrepancies (i.e., the climate and weather can be predicted to a certain degree of certainty).

2. The Blackout events

AQ experienced a sequence of blackouts during 2020 and lastly on January 4th, 2021. Upon experiencing a Blackout, AQ's approach (steps to be adhered to) can be summarized as follows:

1. Do a preliminary assessment of the situation and safeguard what needs to be safeguarded
2. Setup personnel at:
    a. SCADA (crisis center, Grid Operations Manager in control);
    b. Powerplants (Plant Manager in control);
    c. 30/12 kV substations;
    d. Black start unit(s) (Field Services manager in control);
    e. Crisis Communications team (Communications advisor in control).
3. After Approval of the Power Supply Chain Manager in consultation with the Technical Director the black start procedure is started and restauration process is initiated.
4. After the power restauration is completed, the grid stability (Voltage, Frequency, Power and Apparent Power) is monitored for the next 24 – 48 hours (about 1 to 2 days) to ensure proper grid operation.
5. Data analysis is started the next working day of the blackout using all available data sources (WISE/WOIS, PFM and SCADA) to determine the exact root cause of the event.

Summarizing the events the following impact can be attributed to the blackout events:

Description	February 11th	December 7th	December 10th	December 12th	January 4th	Total(s)
Start time	09:15 AM	8:30 AM	15:15 PM	19:02 PM	14:15 PM	-
End time (last feeder connection)	20:00 PM	20:18 PM	21:23 PM	21.21 PM	19:00PM	-
Total duration [hrs.]	10.85	11.88	6.08	26.19	4.85	**59.85**
Estimated loss of GWh to be sold [GWh]	0.94	1.02	0.53	2.29	0.453	**5.233**

Table 4: Duration of the blackout events

The estimated cost impact of the Black-out events can be summarized within the following table. The description within this table is the result of the analysis performed in step 5 of the approach for dealing with a blackout event at AQ (see table 5).

Description	Amount [NAf]
Total loss of revenues (estimated) @ Avg 0.5591	2,907,320
Total projected claims pay-out	250,000
Overtime and out-of-pocket expenses (approx.)	150,000
Investigations (estimated)	250,000
Expert hire (approx.)	100,000
Compensation scheme	1,900,000
Total estimated financial impact	**5,557,320**

Table 5: Total cost impact blackouts

AQ has engaged the following Subject Matter Experts ('SME's) for analyzing the cause(s) of the event(s):

AQ internal SME's:

Personnel	Job Title	Job description
D. Jonis, MSc. MBA	Chief Executive Officer	Has the primary responsibility to - including, but not limited to- make major corporate decisions, manage the overall operations and resources of AQ, act as the main point of communication between the Board of Directors ('BOD') and corporate operations and being the public face of the company.
R. Garmes	Manager Power Supply Chain	Manages the different departments within the Power Supply Chain such as the Transmission & Distribution, Power Plants and Maintenance Power departments guaranteeing efficient and reliable Power production, transmission, and distribution.
J. Granger	Head of Department Power Plants	Responsible for the operation and management of the Power Plants to meet the standards and requirements with respect to availability, reliability, safety and quality of Power production.
J. Smit	Head of Department Transmission & distribution	Responsible for the operation and management of the Power transmission and distribution Grid to meet the standards and requirements of availability, reliability of supply, safety, and quality of Power supply.
A. Guillermo	Coordinator protection and testing	Responsible for the preparation and implementation of inspection and operational work on Protection systems, instrumentations, communication tools and data networks to ensure the safety and optimal availability of the Power Grid.

Table 6: Aqualectra internal Subject Matter Experts

External companies providing SME's for the following reports and memo's:

	Brief description
DIgSILENT GmbH	Provided in depth analysis of transient activities of the instances prior to and after the blackout. The findings are based on the information recorded by the PFM as well as the input from the Aqualectra SME.

Wärtsilä	Provided in depth reporting and analysis of plant operating conditions and alarms of the instances prior to and after the blackout. The findings are based on the information recorded by the PFM as well as the input from the Aqualectra SME.
BWSC	Provided in depth reporting and analysis of plant operating conditions and alarms of the instances prior to and after the blackout. The findings are based on the information recorded by the PFM as well as the input from the Aqualectra SME.
K-line	Supplier of the 66-kV switchgear at Dokweg II. which provided supporting analysis of the 66kV Protection system (circuit breaker) of AQ.
DNV-GL	Designer of the current 66 kV grid and SCADA system. Provided overall analysis of the grid management philosophy and possible root cause findings.
Schneider Electric	Supplier of the 66-kV protection system. Provided overall analysis of the protection system alarms and functioning of the protection system.

Table 7: Companies providing analysis support.

Based on the result of the analysis of the SME's the root cause is found and actions could be taken.

2.1 The isolated events

Based on the obtained data and the analysis of the internal as well as external subject matter experts, the events of February 11th and December 7th can be typified as isolated events, there is no correlation between the cause of both event except the handling of the operators.

For the events of December 10th, 12th and January 4th a correlation is established which is explained in paragraph 2.2.

February 11th, 2020

The first Black-out event was initiated due to a gradual change from over- to under-excited of the Generation Units at the ISLA NDPP. The change from over- to under-exited caused transient Voltage drops in the Grid which led to instabilities in the Grid (DIgSILENT: Analysis of Grid events -11.02.2020).

The change from Over- to Under-excited which is a change from a positive to a negative Power Factor, was inadvertently initiated by the Plant operator which led to a change in the Power quadrant (BWSC: email dd January 9th 16:44 PM from Henrik Stolberg). Consequently, the sudden imbalance in the Grid tripped the Protection system of windfarms (PC and TC1) due to the Under-Voltage conditions. This led to the UFLS to activate and the stabilization process was initiated. During the stabilization process (voltage levels recovered) the sudden reconnecting and ramping-up of Wind turbines introduced an instability in the frequency due to the availability of excess capacity in the grid. This led to a 2nd phase of instability in the grid causing a blackout.

December 7th, 2020
The second Black-out event – on December 7th – occurred after Plant operators switched the Diesel Engines in Dokweg 2 from I-synchronous mode to Manual-mode (DIgSILENT: Analysis of Grid events -07.12.2020). The sudden change in operating modes caused a sudden drop in active and reactive power impacting the voltage level consequently leading to Under-Voltage.

Protection systems of the Windfarms triggered sudden cut-offs of the windfarms even though this was to be avoided after the blackout event of February 11th. The frequency control system embedded in the operation of the Dokweg 2 plant provides primary frequency regulation in the system. As these plants are in Manual-mode they cannot participate in stabilizing the system. The sudden switch in operation modes cause the DE to return to a Set-point lower than the output prior to changing the setting, leading to a loss in Reactive Power and consequently a loss in system Voltage.

Upon the disconnection of the windfarms together with the loss of frequency control resulted in the destabilization of the system. Upon the tripping of the power generation units, the loss of power resulted in low frequency. At this point the operators at Dokweg II (re)started the tripped units and connected these units to the grid. This additional capacity together with the reconnection of the windfarm resulted in instability in the grid leading to the blackout event.

December 10th and 12th, 2020 and 4th of January 2021
The remaining Black-out events are not considered isolated events and have the same root-cause which can be traced back to the December 7th Black-out. The root cause of these events is described in the following chapter (DIgSILENT: Analysis of Grid events -10.12.2020 & DIgSILENT: Analysis of Grid events -12.12.2020).

2.2 Relationship between the blackout events 2021

Despite the challenges in managing the Curacao electrical distribution grid, it has never before happened that 3 blackout events occurred in one week and 4 in one month. As a first action after such events, analysts would seek to find out if there is a (causal) relationship between the events. This analysis was also performed for the "December events." This analysis yielded the following results:

As a common factor between the December 10th, 12th, and January 4th event was found to be the disconnection of bay F04 at the Dokweg 66 kV substation (DIgSILENT: Analysis of Grid events -10.12.2020 & DIgSILENT: Analysis of Grid events -12.12.2020). This disconnection resulted in the Dokweg II A&B plant to be fully disconnected from the grid hence leading to the loss of frequency control in the grid. Since the UFLS could not deal properly with the sudden loss of load, this resulted in a series of blackouts.

Preliminary investigation by DNV-GL based on information obtained from AQ indicated that the cable protection system (P521) triggered the disconnection of bay FS04 (DNV-GL Memo dd 09.01.2021). Since there was no probable cause for the P521 to trigger, AQ requested Schneider to perform a local investigation of the protection system of the 66 kV substation. Schneider is the supplier of the protection system of the 66-kV switchgear which was supplied by K-Line. Further investigation of the root cause of the disconnection of the FS04 bay (Scheider Electric: Aqualectra Blackout investigation report, 14.01.2021) indicates that the protection system P139 was triggering and causing the bay FS04 to disconnect.

As stated in the Schneider report, the P139 was starting the disconnect sequence at $0.88I_n$ which was calculated at 528 Amps. Figure 4 shows the load on the cable connecting Dokweg II substation with the ISLA substation. To confirm the analysis by Schneider, AQ analyzed the load of the cable and can conclude that:

a) The event of December 7th is visible in the load of the cable
b) The event of December 10th is visible, and it coincides with a load exceeding the 528 Amps
c) The event of December 12th is visible, and it coincides with a load exceeding the 528 Amps
d) On December 22nd there was a "near" miss since the load exceeded the 528 Amps, but the "overloading" did not last enough to cause a trip event
e) On December 28th there was a "near" miss since the load exceeded the 528 Amps, but the "overloading" did not last enough to cause a trip event
f) The event of January 4th is visible, and it coincides with a load exceeding the 528 Amps

The setting of the P139 (overcurrent protection) which is programmed to trigger at 528 AMP is an erroneous setting. This setting is derived from the I_{ref} (reference current) that is set in the protection system logic. This I_{ref} is set at 0.88 which allows the cable to be loaded up to a maximum of 88% of the capacity. The cable has a nominal load capacity of 600 Amp but can be loaded to a maximum of 528 Amp.

The question remains why now? What is causing the cable to be overloaded?
Referring to figure 2, it can be noted that the only production plants feeding in to the 66kV grid are the CRU plant, DPP plant at ISLA and the Dokweg II plants. From figure 2 it can be deducted that the supply of energy to the grid from the Dokweg plant occurs trough:

- 66/30 kV transformer at load center Weis
- 66/30 kV transformer at load center Parera.

When performing a blackstart in the Curacao power grid, the energizing of the 66kV grid starts by blackstarting the 66kV transformers at DPP at ISLA and the Parera. This was not done during the December 7th blackstart. Reason for this being that the root-cause of the December 7th event was not known at the time of the blackstart. For this, it was opted not to soft start the Loadcenter Parera. This caused all the generated capacity from the Dokweg II plant to flow through the ISLA 66 kV substation to the island grid. This caused the load on the cable to increase.

As can be concluded from figure 4, the load of the ISLA – Dokweg cable before December 7th and after January 10th (when the Parera transformer was soft started) are considerably less than in the period between December 7th and January 4th.

After the root cause analysis by Schneider (Scheider Electric: Aqualectra Blackout investigation report, 14.01.2021), the Parera transformer was soft started on January 10th, 2021 (in the morning hours). With this the first step of the correction of the root cause of the repeated blackouts of December 10th, 12th and January 4th was corrected. Still remains the protection system analysis to set the protection system of both the P139 and the P521.

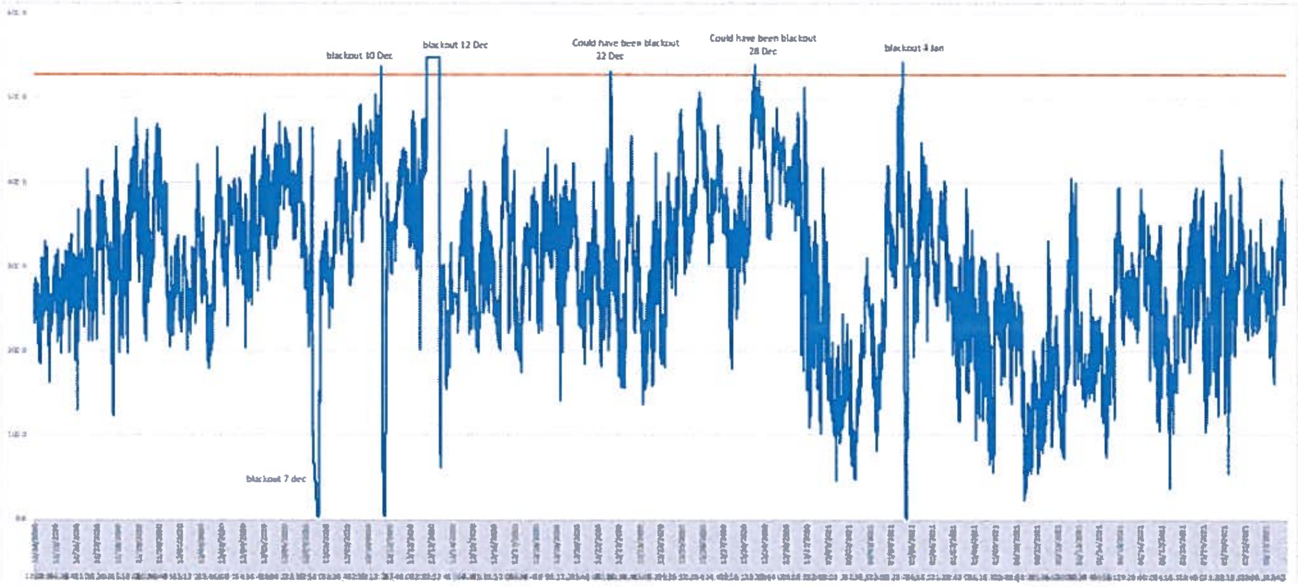

Figure 4: ISLA - DOKWEG 66kV cable load

3. Recommendations and actions taken

AQ has set out a clear path towards addressing the grid instabilities which caused the black-out stemming from the event of February 11th and the last event of January 4th, 2021 events. This path is mostly based on the recommendation of the various expert analysis made based on data obtained from system recorders (PFM-systems) and other internal analysis made by AQ.

An approach to guiding the realization of all the required actions resulting from the blackout events is reflected in figure 5. Based on these analyses by the various internal and external subject matter experts the following recommendations have been issued and the corresponding action has been taken based there on:

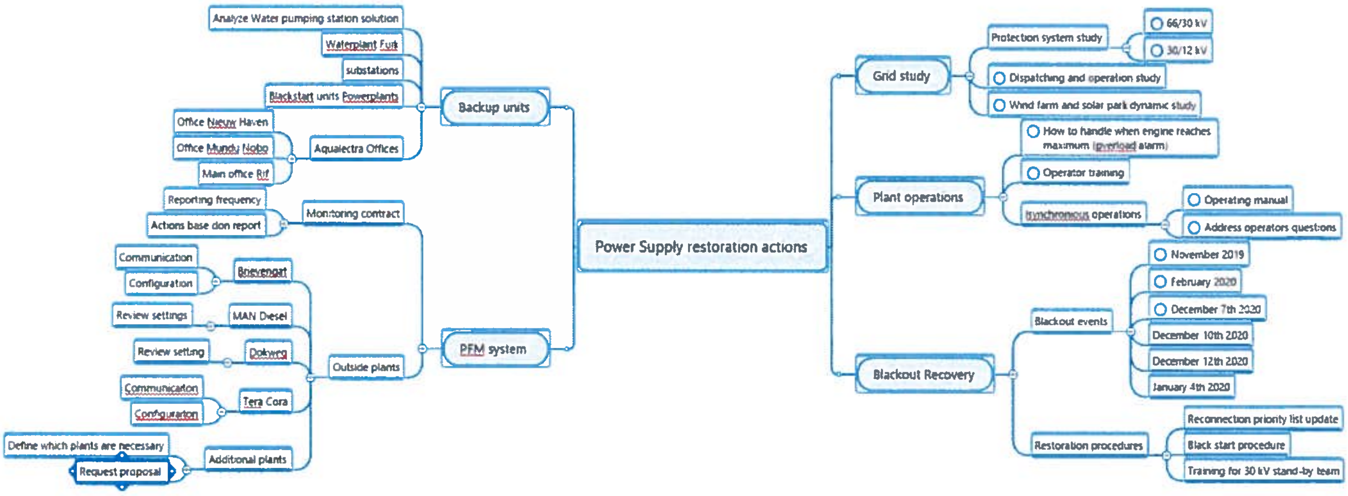

Figure 5: Mind Map Blackout restauration events

The actions are categorized based on the following principles:

1) Short-term actions
These actions are based on "firefighting" and preventing repeat of the Blackout events and addressing other shortcomings during the restoration process.

2) Mid-term actions
These actions are based on the recommendations of the external subject matter experts and are to be completed in a time span of 3 to 5 months.

Attachment II provided an outline of the recommendations issued by DigiSilent based on their analysis. The realization of these actions is also included in this table.

3.1 Short-term actions

The short-term actions are aimed at restoring Power and ensure grid stability for the coming months and years. These actions are to uphold the power generation and distribution to be able to finalize the mid-term actions and ensure continuity and reliability of power supply. These actions should also, in case of a repeat blackout event, shorten the restoration period as well as enable critical data analysis. The identified short-term actions are:

Actions related to the powerplant(s) operations
One of the identified challenges leading to the blackout of February 11th and December 7th and December 10th were the operator handling of the power plant. For this reason, the following actions need to be taken on short term:

a) Finalize the implementation of the Isochronous project and document the working of the system.
b) (Re)Train the operators in:
    a) Plant operations
    b) Operations of the Isochronous operating system
    c) Transport grid understanding and management
    d) Calculating and maintain spinning reserve capacity
c) Blackstart unit at DPP (blackstart location)
   The connection of this unit to the plans should be revised/ replaced as well as the capacity of the unit should be increased to be able to load up the plan as well perform soft-start of the transformers Weis and Parera simultaneously
d) Backup generators at each powerplant
   All the backup generators at Dokweg I&II as well as Mundu Nobo (GT-II) should be revised and kept in optimal running condition at all times.

Actions related to the grid operations
The following actions should be taken to ensure proper reestablishment and operation after grid preventing blackout and ensuring easy restoration:

a) Determine the blackout restauration policies and procedures
    i. Redefine the blackstart procedure
    ii. Redefine the reconnection priority list
    iii. Train the grid dispatchers and powerplant operators in blackstart procedure and restauration policies
b) Reestablish the proper functioning of the PFM recording system and ensure online access and monitoring by DigiSilent

c) Blackstart units and backup units for the standard functionalities
The following blackstart and backup units need to be tested and replaced for proposer functioning:
All the backup generators at Main office Rif and Nieuwe Haven should be revised and kept in optimal running condition at all times.

These actions should be completed before March 31st, 2021.

3.2 Midterm actions

First priority should be realization of the short-term actions. During the realization of the short-term actions, the mid-term action should also be pursued. The following actions should be realized as mid-term actions:

a) Grid protection study
An extensive grid protection study should be realized at the 66 / 30/12 kV level. This in order to be able to set the protection systems at the correct level for preventing occurrences in the plant and grid which can lead to blackout events
b) Grid stability study
With the upcoming expansion of wind and solar, a static grid stability study has been performed. The dynamic study needs to be finalized. Based on this study
c) Determine the dispatch and operations philosophy
It is required to determine the dispatching priorities (which units) of the active and reactive power to the grid

d) Installing PFM monitoring system in the power substations
Aqualectra has engaged with DigiSilent for a continuous monitoring of the plants and grid transient activities. In order to be able to analyze and prevent inadvertent occurrence, it is necessary to monitor the system transient. Installing additional monitoring systems is necessary to obtain an optimal dataset for analysis.

These actions should be completed before July 31st, 2021.

4. Conclusion

Prior to the sequence of Black-outs Curacao has been experiencing after the November 4th, 2019 blackout, no other Black-out events occurred since November of 2006. During 2020 Curacao has experienced 4 blackout events whilst in the first week of January 2021, (on January 4th, 2021) another blackout event occurred. This totaling five (5) black-outs events in a period of one (1) year.

Aqualectra has not taken these events lightly and analyzed the root cause(s) of the events together with the following AQ SME's:

1) D. Jonis, MSC, MBE
2) R. Garmes,
3) J. Granger
4) J. Smit
5) Guillermo

External companies providing SME's are:

1) DigiSilent GMbH
2) Wärtsilä
3) BWSC
4) DNV-GL
5) K-Line
6) Schneider

The following conclusions can be drawn from the investigations:

Root-cause:

- The February 11th event was caused by the Generation Units at NDP plant at ISLA to change form over exited to under excited. Reason therefore being operator induced. This caused a Voltage instability leading to disconnection of the windfarms. Upon the grid almost being stabilized, the wind farms inadvertently reconnected causing an increased instability.
- The December 7th event was caused by the Generation Units at Dokweg II plant being changed from operation mode by the operators. This caused a Voltage instability leading to disconnection of the windfarms amongst others. Upon the grid almost being stabilized, the wind farms inadvertently reconnected causing an increased instability. Also, it is noted that the operators started the three (3) tripped Dokweg II units in a short timeframe and connected these to the grid without the grid having the required load for these units.
- The events of 10th, 12th and January 4th were caused by "Overloading" of the cable connecting the Dokweg II plant to the Grid. This Overloading was not a true Overloading but was caused by the I_{ref} of the Protection system being programmed at 88% of the $I_{nominal}$.

Actions taken:

- The first action after the analysis was to unload the Dokweg-ISLA cable by soft starting the 66/30 kV transformer at Parera
- Another action was to (re)establish the functioning of all PFM's. Up till now all PFM's are working but the Brievengat PFM needs to be connected online. This is work in progress
- DigiSilent has been engaged for performing the grid-protection study as well as the grid stability study. DNV-GL is also engaged in supporting in this study
- Two (2) other independent studies, triggered by the Board of Supervisory Directors are ongoing and are being supplied with information.

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References / Attachment

	Date	Document	Brief description
DIgSILENT GmbH	19/05/2020, Rev2	Security of Supply in Curaçao's Electricity System Analysis of Grid Events - 11.02.2020	This report includes an analysis of the sequence of events and the results of the preliminary investigations of the Black-out event of February 11th.
DIgSILENT GmbH	21/12/2020, Rev1	Security of Supply in Curaçao's Electricity System Analysis of Grid Events - 07.12.2020	This report includes an analysis of the sequence of events and the results of the preliminary investigations of the Black-out event of December 7th.
DIgSILENT GmbH	23/12/2020, Rev1	Security of Supply in Curaçao's Electricity System Analysis of Grid Events - 10.12.2020	This report includes an analysis of the sequence of events and the results of the preliminary investigations of the Black-out event of December 10th.
DIgSILENT GmbH	28/01/2021, Rev1	Security of Supply in Curaçao's Electricity System Analysis of Grid Events - 12.12.2020	This report includes an analysis of the sequence of events and the results of the preliminary investigations of the Black-out event of December 12th.
Wärtsilä	15/01/2021, Rev B	Analysis of Grid Event on 7th of December 2020	This report includes an analysis of the various events that took place in the power system of AQ which eventually led to a blackout in the power system on the 7th of December.
Wärtsilä	15/01/2021, Rev A	Analysis of Grid Event on 10th of December 2020	This report includes an analysis of the various events that took place in the power system of AQ which eventually led to a blackout in the power system on the 10th of December.
Wärtsilä	15/01/2021, Rev A	Analysis of Grid Event on 12th of December 2020	This report includes an analysis of the various events that took place in the power system of AQ which eventually led to a blackout in the power system on the 12th of December.

Wärtsilä	15/01/2021, Rev A	Analysis of Grid Event on 4th of January 2021	This report includes an analysis of the various events that took place in the power system of AQ which eventually led to a blackout in the power system on the 4th of January.
K-line	14/01/2021	Dokweg 66kV Substation – Testing Report	This report includes an analysis of the 66kV Protection system (circuit breaker) of AQ which eventually led to the blackout events on the 10th, 12th of December and the 4th of January.
DNV•GL	09/01/2021	Samenvatting stand van zaken met betrekking tot het onderzoek naar de black-outs.	This memo provides an impartial perspective from DNV•GL on short-term solutions to prevent future blackout events based on reports by 3rd parties.
DNV•GL	12/01/2021	Planning van de inzet van de productie-eenheden en bepaling van bijbehorende MW- en Mvar regelstrategie	This memo goes more in-depth with respect to the short-term solution "Planning of the Generation Units."
Schneider Electric	14/01/2021	Aqualectra – Blackout investigation report (this study covers the 10,12th December 2020 and 4th January 2020 events)	This report provides an overview of the investigations carried out on the circuit breakers of Bay 03, Bay 04 and Bay 10 which were assumed to have triggered the Blackout events of on the 10th, 12th of December and the 4th of January. The report further elaborates on the actions undertaken and further recommendations to reduce potential future events.
BWSC	09/01/2021	Email correspondence from Mr. Hendrik Stoberg	In this email an explanation is given how the units at DPP ISLA can change from over excitement to under excitement and back
		Overview of Status of the recommendations by DIgSILENT	From a Smartsheet all actions related to the recommendations in the DIgSILENT report are tracked

P1960
Security of Supply in Curaçao's Electricity System

Report on Trip Events in February 2020

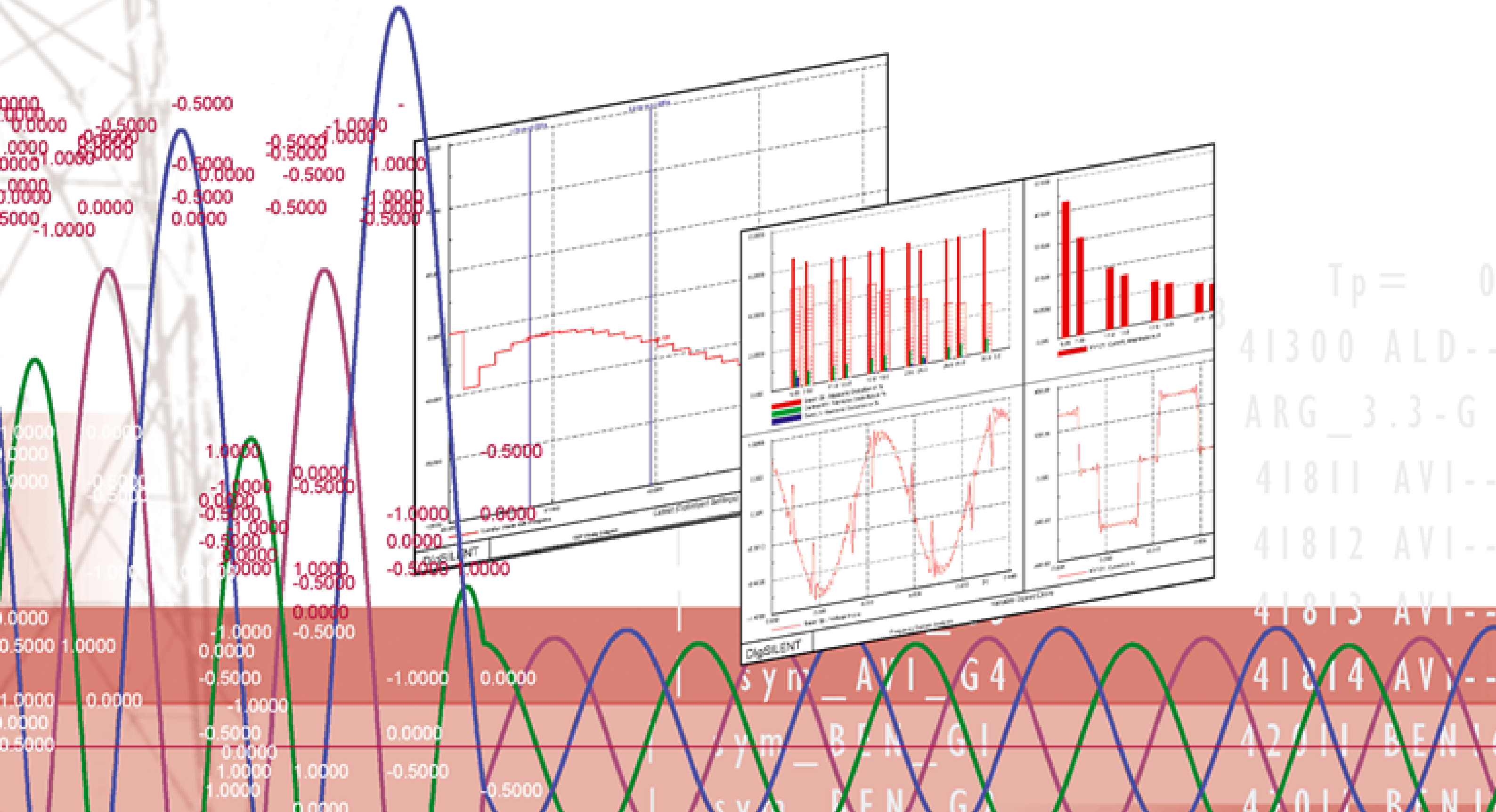
Prepared for:

Aqualectra

Curaçao - Netherland Antilles

Publisher:

DIgSILENT GmbH, May 2020



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Document Revision History

Version	Status	File	Issued	Prepared by
01	First Version	P1960_Aqualectra_Security-of-Supply_REPTRIP01_R02_V01.docx	02.04.2020	M. Schmieg J. Gómez
02	Second Version	P1960_Aqualectra_Security-of-Supply_REPTRIP01_R01_V02.docx	19.05.2020	J. Gómez

Table of Contents

List of Abbreviations

PFM	DIgSILENT Monitoring System
SCADA	Supervisory Control and Data Acquisition
UFLS	Under-Frequency Load-Shedding

1 Introduction

On the 10th and 11th of February 2020, several events occurred in the power system of Aqualectra in Curaçao which led to complete or partial blackouts. This report includes the analysis of the sequence of events and the results of the preliminary investigations.

2 Monitoring Systems

2.1 SCADA

The SCADA system used by Aqualectra monitors, among others, voltage, frequency, active and reactive power in multiple locations in the power system.

The recordings provided by Aqualectra [1] [2] correspond to February, and they include measurement for all days and hours of this month with a 1-minute resolution (average values).

2.2 PFM

Several PFM monitoring systems are installed in the main substations of Aqualectra. Figure 2-1 provides an overview of their location in the power system.

The preliminary analysis of the PFM monitoring systems reveals the following issues:

- Some of the PFM systems are **not accessible and/or did not record the events of interest** due to malfunctioning caused by lack of periodic maintenance. Table 2-1 shows an overview of the current status of each of them.

Table 2-1: DIgSILENT Monitoring systems – Aqualectra - Curaçao

#	Substation	Type	Status (13.03.2020)
1	Isla NDPP	PFM300	Available, but with wrong high current trigger settings -> results in a huge amount of recordings, so due to storage limitations, the data from the blackouts are already overwritten.
2	Isla 66 kV	PFM300	Available, but with limited records form the blackouts since power supply was interrupted during that time
3	Dokweg 1	PFM300	Not accessible
4	Dokweg 2	PFM300	Not accessible
5	Dokweg 66 kV	PFM300	Available, with all records from the blackouts
6	Mundo Nobo	PFM2	Out of service
7	Tera Cora	PFM2	Not accessible
8	Playa Canoa	PFM2	Not accessible

- The configuration of the PFM systems has not been updated considering the latest changes in the network topology. Therefore, the signals available in each of the PFM systems **reflect the configuration at the time of commissioning, but not necessarily the actual status**. As an example, the PFM located in substation Isla 66 kV has recordings corresponding to two feeders with transformers (Dokweg II-T1 and Dokweg II-T2), whereas current network topology shows that in the same substation there are four transformers in total. Subsequent discussions with Aqualectra [3] have determined that the other two transformers correspond to signals

"Wartsila" and "Spare CT 1". On the other hand, the PFM configuration includes signals for BOO, NDPP, Weis, Niljweg and Isla 2, whereas in current network topology there are just two lines from Isla 66 kV: to substations Isla and Parera. Again, subsequent discussions with Aqualectra [3] have determined that some of these signals are "spare", hence not connected.

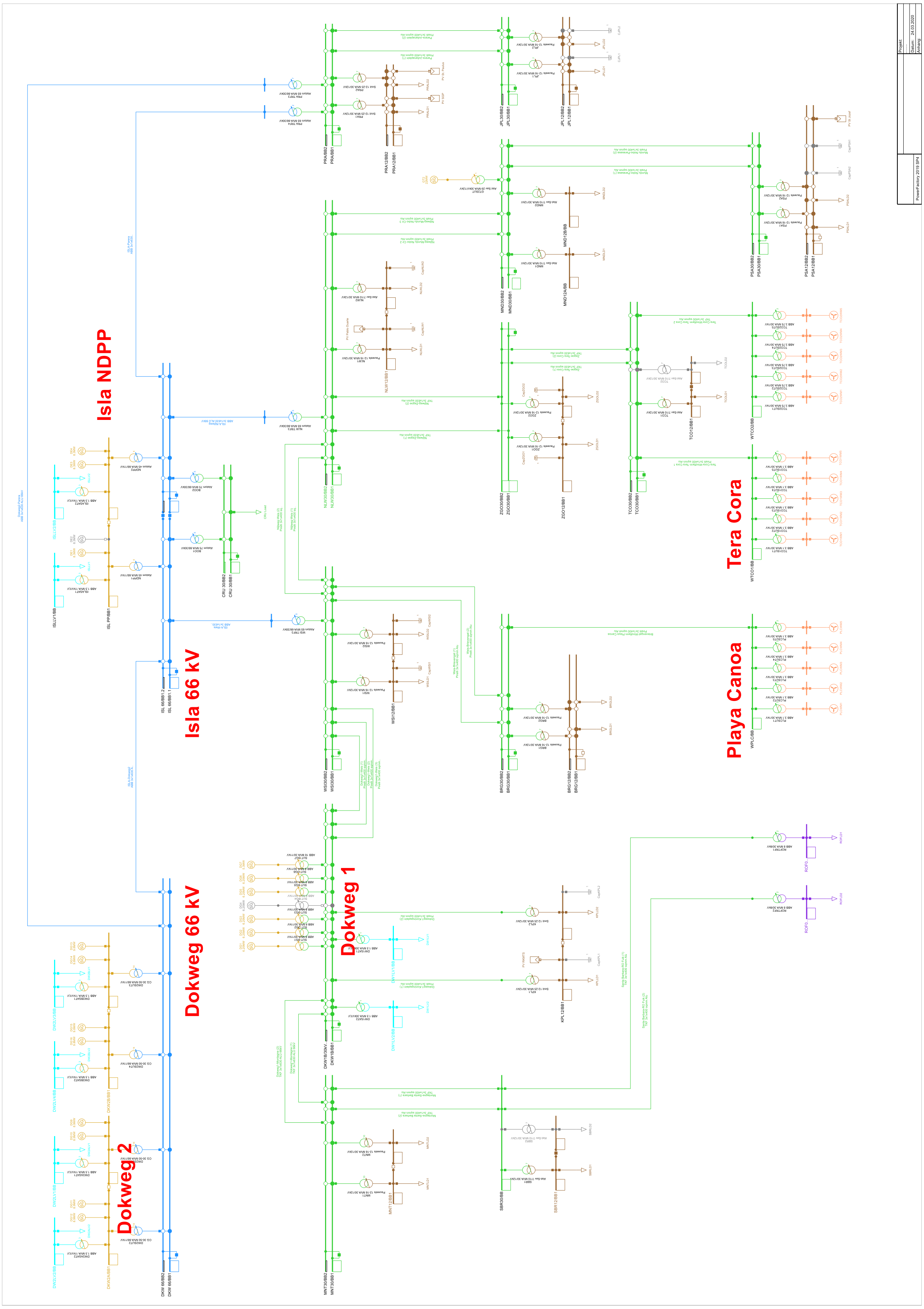


Figure 2-1: Single-Line-Diagram – Aqualectra - Curaçao

2.2.1 PFM Dokweg 66 kV

Table 2-2 shows the measurement signals available in the PFM located at substation Isla 66 kV [3], as well as its corresponding location in the PF simulation model (Figure 2-1).

Table 2-2: Measurement signals in the PFM Dokweg 66 kV

Signal	Enabled	Feeder connection	PF Model
BUS-A	X		DKW66/BB1
BUS-B	X		DKW66/BB2
Spare VT		-	-
Bus coupler	X	-	DKW66/CB0
BOO	X	No cable connected yet (spare)	-
NDPP	X	No cable connected yet (spare)	-
Wartsila	X	Feeder F03	66/11 kV Transformer DW2SUT4 (Dokweg 2B - Units 15 and 16)
Isla 1	X	Feeder F04	ISLA-Dokweg2
Dokweg II-T1	X	Feeder F05	66/11 kV Transformer DW2SUT1 (Dokweg 2A - Units 09 and 10)
Parera	X	Feeder F07	Dokweg2-Parera
Weis	X	No cable connected yet (spare)	-
Nijlweg	X	No cable connected yet (spare)	-
Spare CT 1		Feeder F10	66/11 kV Transformer DW2SUT3 (Dokweg 2B - Units 13 and 14)
Isla 2	X	No cable connected yet (spare)	-
Dokweg II-T2	X	Feeder F12	66/11 kV Transformer DW2SUT2 (Dokweg 2A - Units 11 and 12)
Spare CT 2		-	-
Spare CT 3		-	-
Spare CT 4		-	-
Digital Input 1	X	-	-

2.2.2 PFM Isla 66 kV

Table 2-3 shows the measurement signals available in the PFM located at substation Isla 66 kV [3], as well as its corresponding location in the PF simulation model (Figure 2-1).

Table 2-3: Measurement signals in the PFM Isla 66 kV

Signal	**Enabled**	**Feeder connection**	**PF Model**
Dwarskoppelveld sec.	X	1	ISL 66/CB.L0
spare		2	-
Weis	X	3	ISLA-Weis
BOO	X	4	66/30 kV Transformer BOO1
Parera	X	5	ISLA-Parera
NDPP	X	6	66/11 kV Transformer NDPP1 (Units DE1 and DE2)
Langskoppelveld sec.	X	7	-
Langskoppelveld sec.	X	8	-
Nijlweg	X	9	ISLA-Nijlweg
BOO	X	10	66/30 kV Transformer BOO2
Parera	X	11	ISLA-Dokweg2
NDPP	X	12	66/11 kV Transformer NDPP2 (Units DE3 and DE4)
Dwarskoppelveld sec.	X	13	ISL 66/CB.R0

3 Events on 10th of February 2020

Recording: Monitor_2020.02.10 23.59.59.cfg

Location: Dokweg 66 kV

As shown in Figure 3-1, voltage and frequency drop significantly (voltage drops down to ~0,9 p.u.) twice in a time frame of four hours.

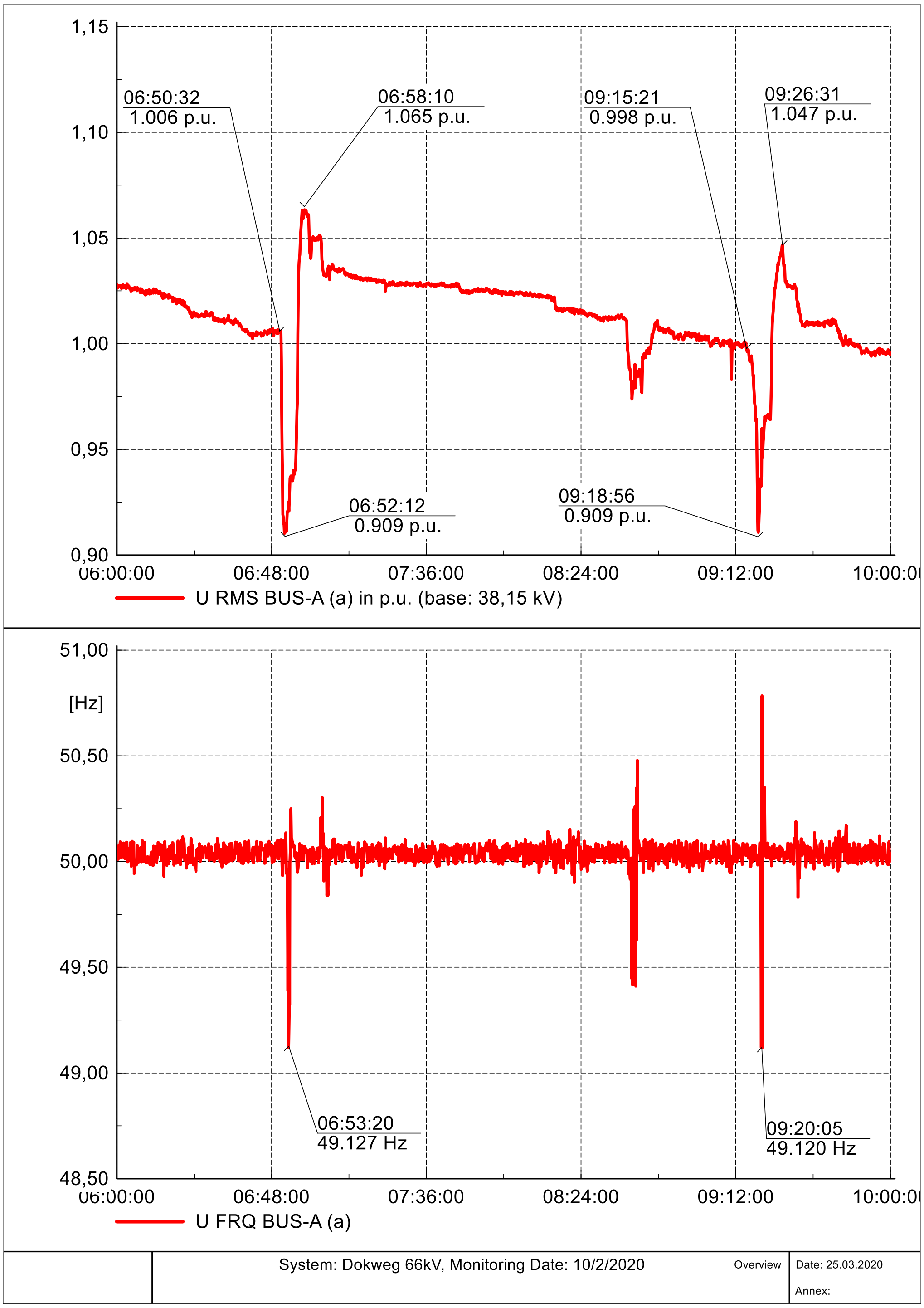


Figure 3-1: Overview of events on the 10th of February 2020 – Dokweg 66 kV – Voltage (up) and frequency (bottom)

3.1 1st Event

3.1.1 PFM Recording

Recording: Monitor_2020.02.10 23.59.59.cfg

Location: Dokweg 66 kV

Date: 10.02.2020

Time: 06:50:53

Plots:

- Figure 3-2: Voltage (top) and network frequency (bottom)
- Figure 3-3: Voltage (top) and reactive power in WARTSILA[1] and DOKWEG II-T1[2] (bottom)
- Figure 3-4: Network frequency (top) and active power in WARTSILA and DOKWEG II-T1 (bottom)

Remarks:

- Signal DOKWEG II-T2 shows a measured current of approximately zero, hence it is assumed that units 11 and 12 in Dokweg 2B are disconnected at the time of the event
- Signal Spare CT 1 shows no measurements, hence it is assumed that units 13 and 14 in Dokweg 2B are disconnected at the time of the event
- The bus coupler is closed at the time of the event
- Lines to substations Isla 66 kV and Parera are in operation at the time of the event

---

[1] WARTSILA corresponds to 66/11 kV Transformer DW2SUT4 in Figure 2-1, where units Dokweg 2B - Unit 15 and Dokweg 2B – Unit 16 are connected

[2] DOKWEG II-T1 corresponds to 66/11 kV Transformer DW2SUT1 in Figure 2-1, where units Dokweg 2A - Unit 09 and Dokweg 2B – Unit 10 are connected

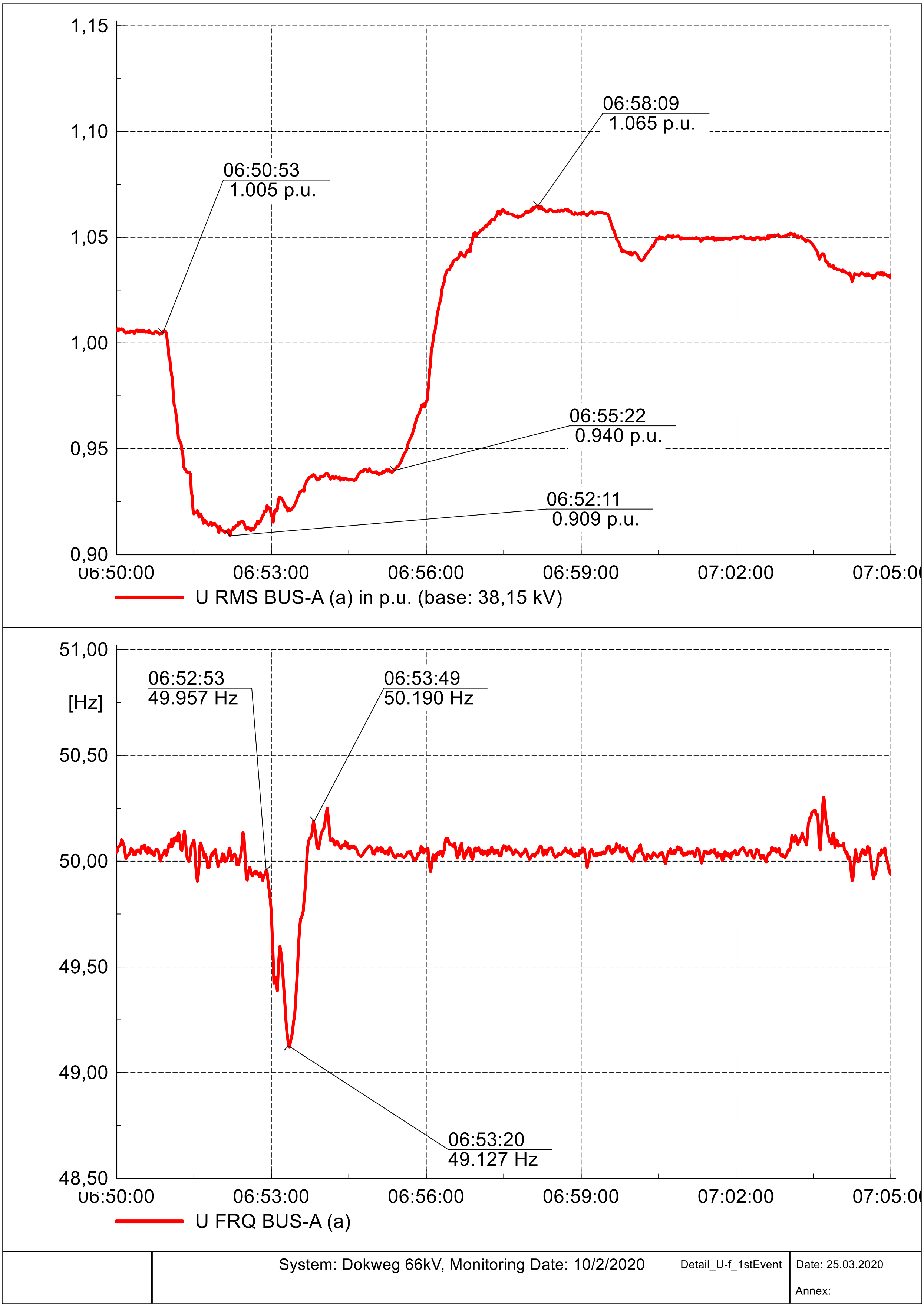


Figure 3-2: 1st event on the 10th of February 2020 – PFM Dokweg 66 kV – Voltage (up) and frequency (bottom)

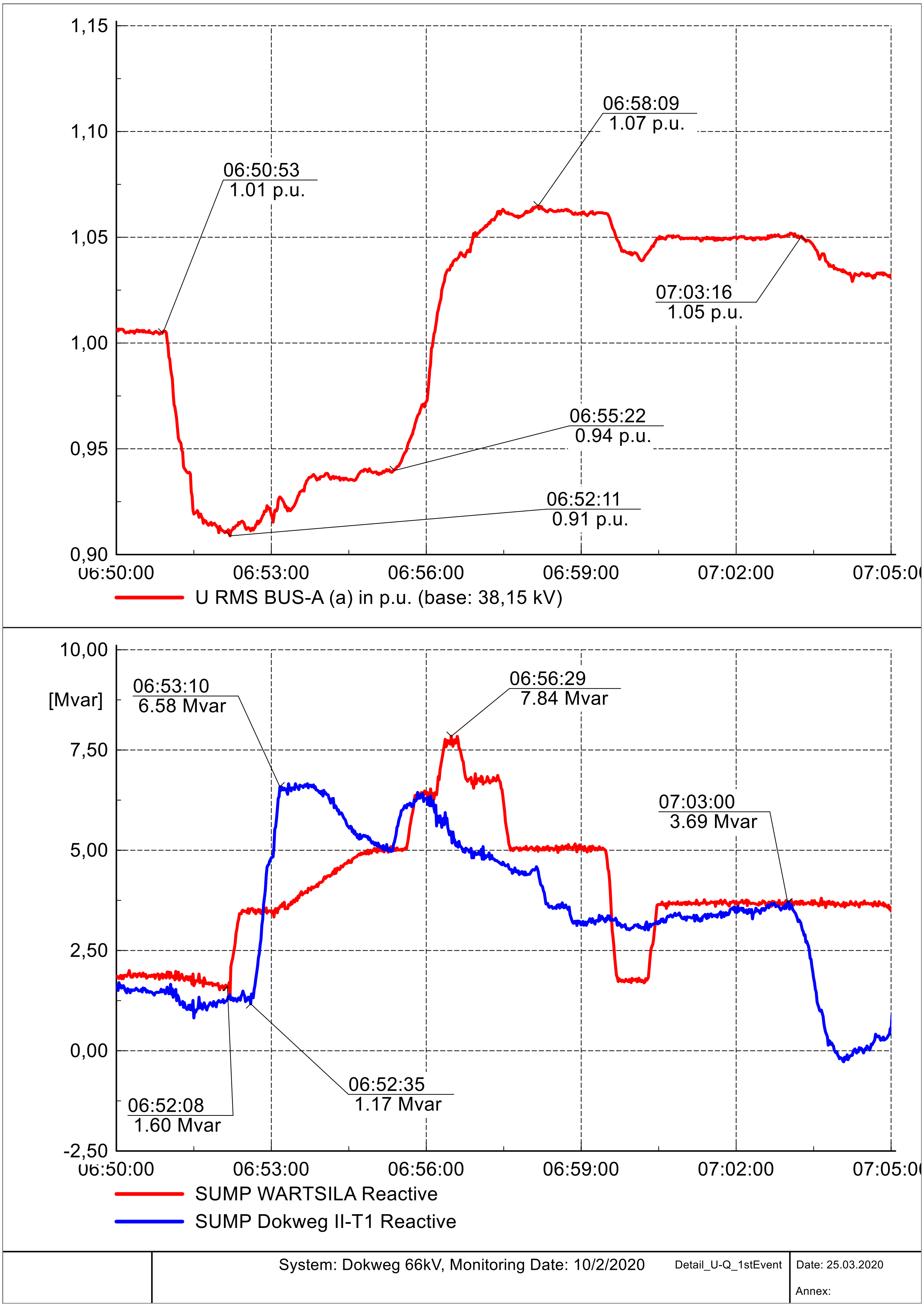


Figure 3-3: 1st event on the 10th of February 2020 – PFM Dokweg 66 kV – Voltage (up) and reactive power (bottom)

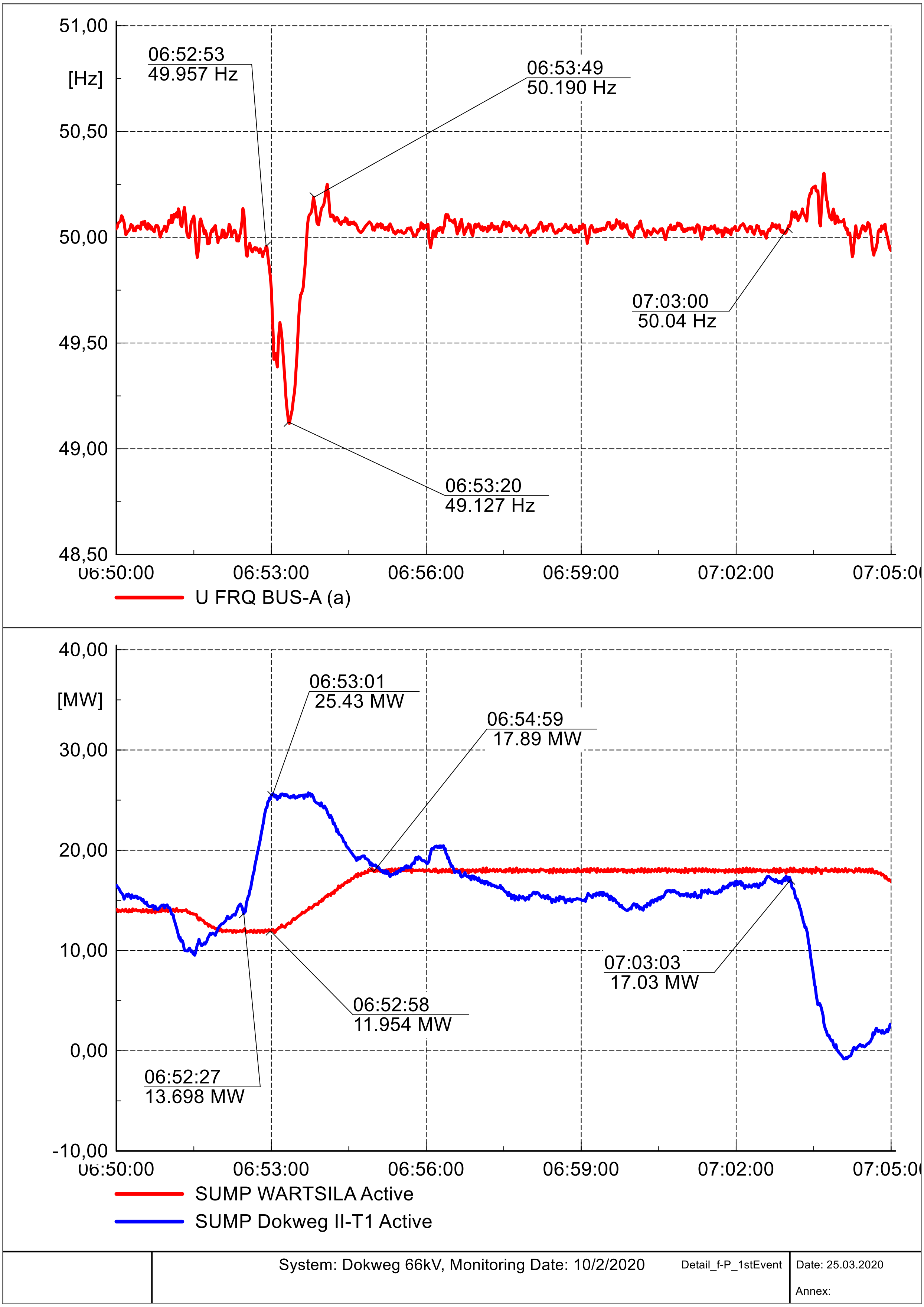


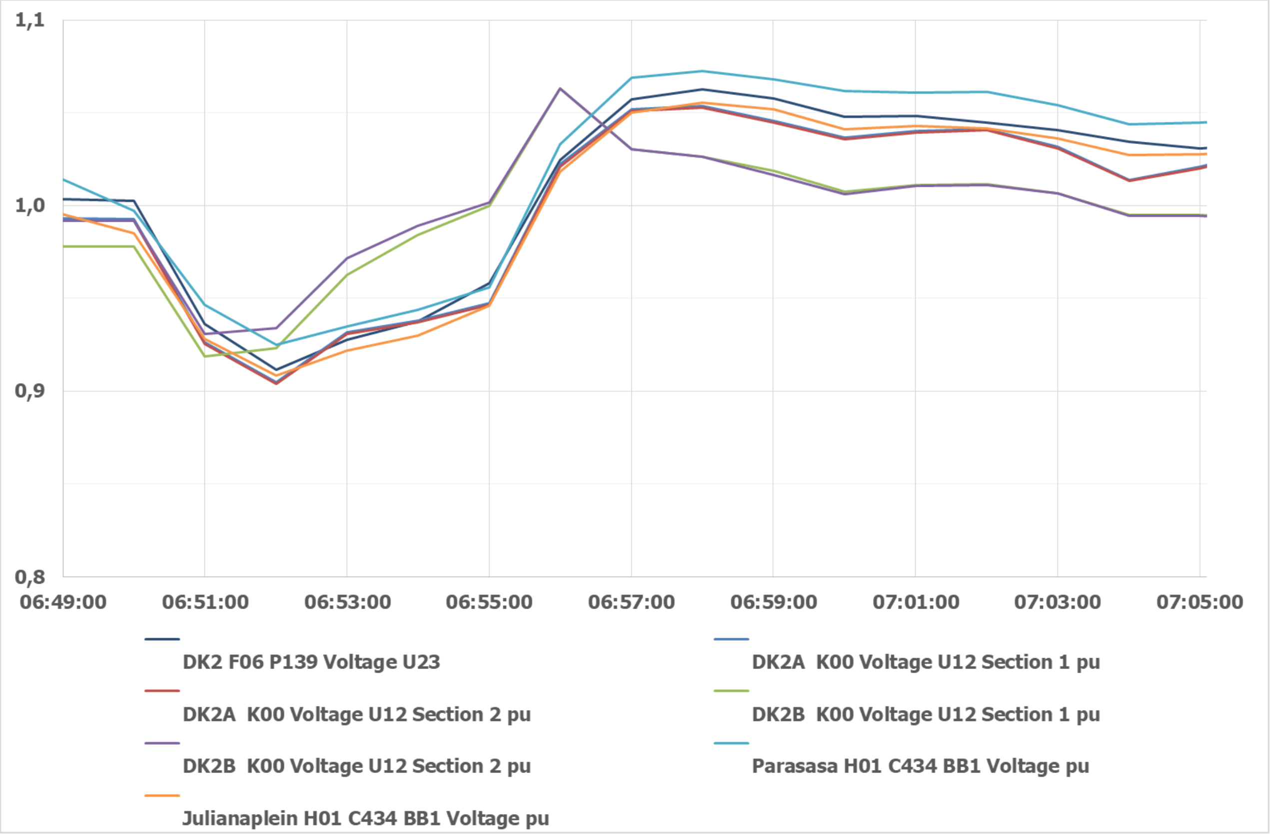
Figure 3-4: 1st event on the 10th of February 2020 – PFM Dokweg 66 kV –Frequency (up) and active power (bottom)

3.1.2 SCADA

Recording: Generation 202002.xlsx

Plots:

- Figure 3-5: Voltage (top) and reactive power in different network locations (bottom)
- Figure 3-6: Network frequency (top) and active power in different network locations (bottom)



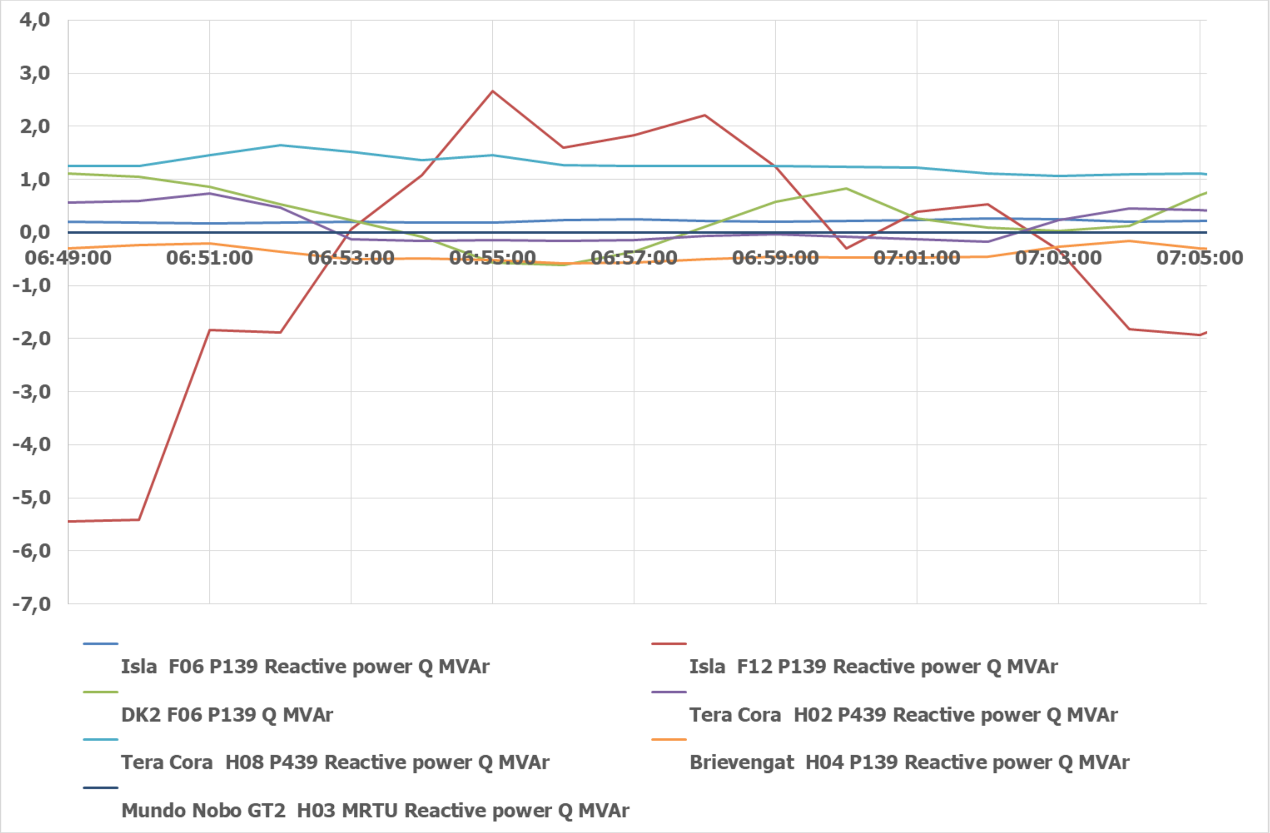


Figure 3-5: 1st event on the 10th of February 2020 – SCADA – Voltage (up) and reactive power (bottom)

Figure 3-6: 1st event on the 10th of February 2020 – SCADA – Frequency (up) and active power (bottom)

3.2 2nd Event

3.2.1 PFM Recording

Recording: Monitor_2020.02.10 23.59.59.cfg

Location: Dokweg 66 kV

Date: 10.02.2020

Time: 09:16:56

Plots:

- Figure 3-7: Voltage (top) and network frequency (bottom)
- Figure 3-8: Voltage (top) and reactive power in WARTSILA and DOKWEG II-T1 (bottom)
- Figure 3-9: Network frequency (top) and active power in WARTSILA and DOKWEG II-T1 (bottom)

Remarks:

- Signal DOKWEG II-T2 shows a measured current of approximately zero, hence it is assumed that units 11 and 12 in Dokweg 2B are disconnected at the time of the event
- Signal Spare CT 1 shows no measurements, hence it is assumed that units 13 and 14 in Dokweg 2B are disconnected at the time of the event
- The bus coupler is closed at the time of the event
- Lines to substations Isla 66 kV and Parera are in operation at the time of the event _pu

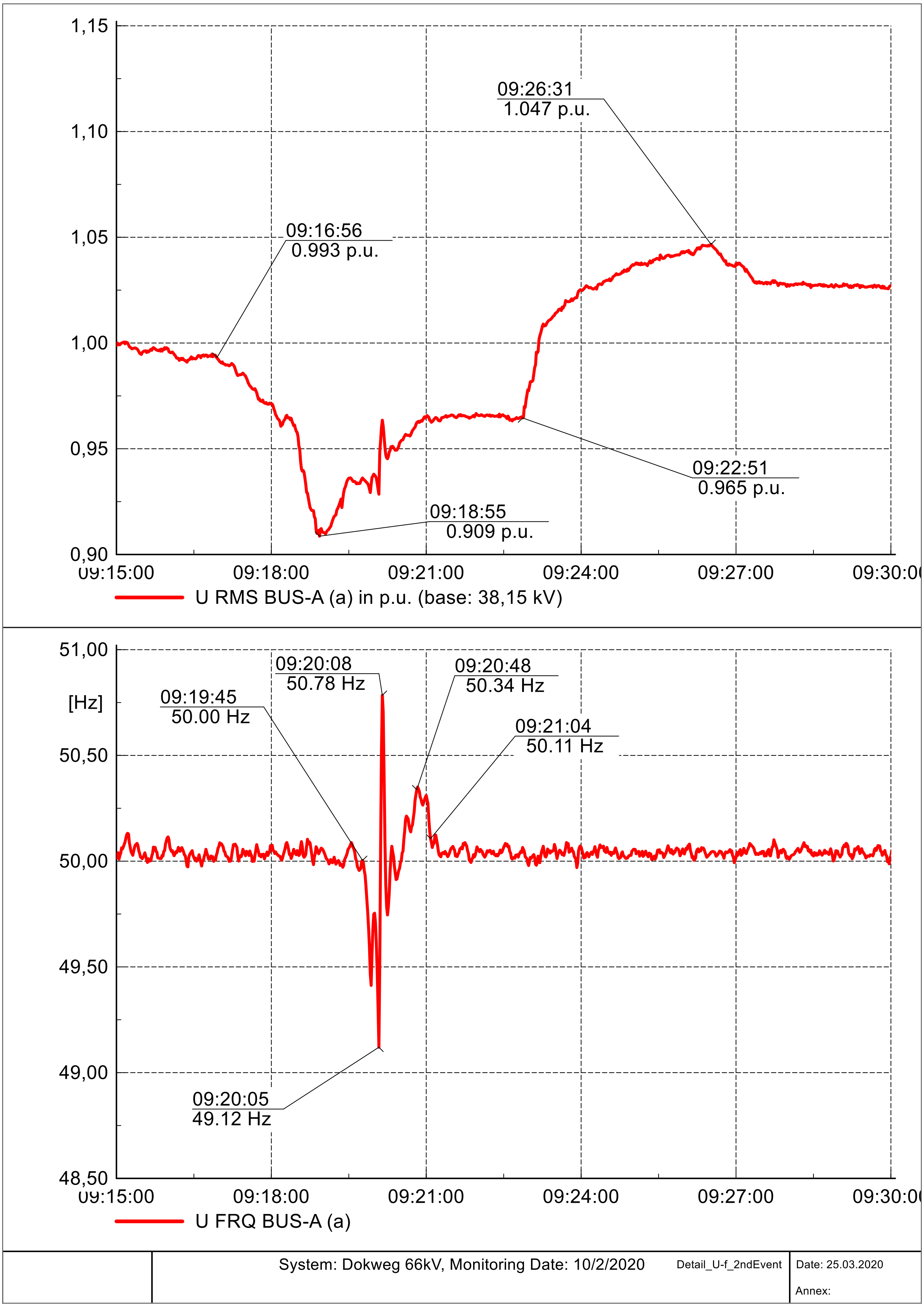


Figure 3-7: 2nd event on the 10th of February 2020 – PFM Dokweg 66 kV – Voltage (up) and frequency (bottom)

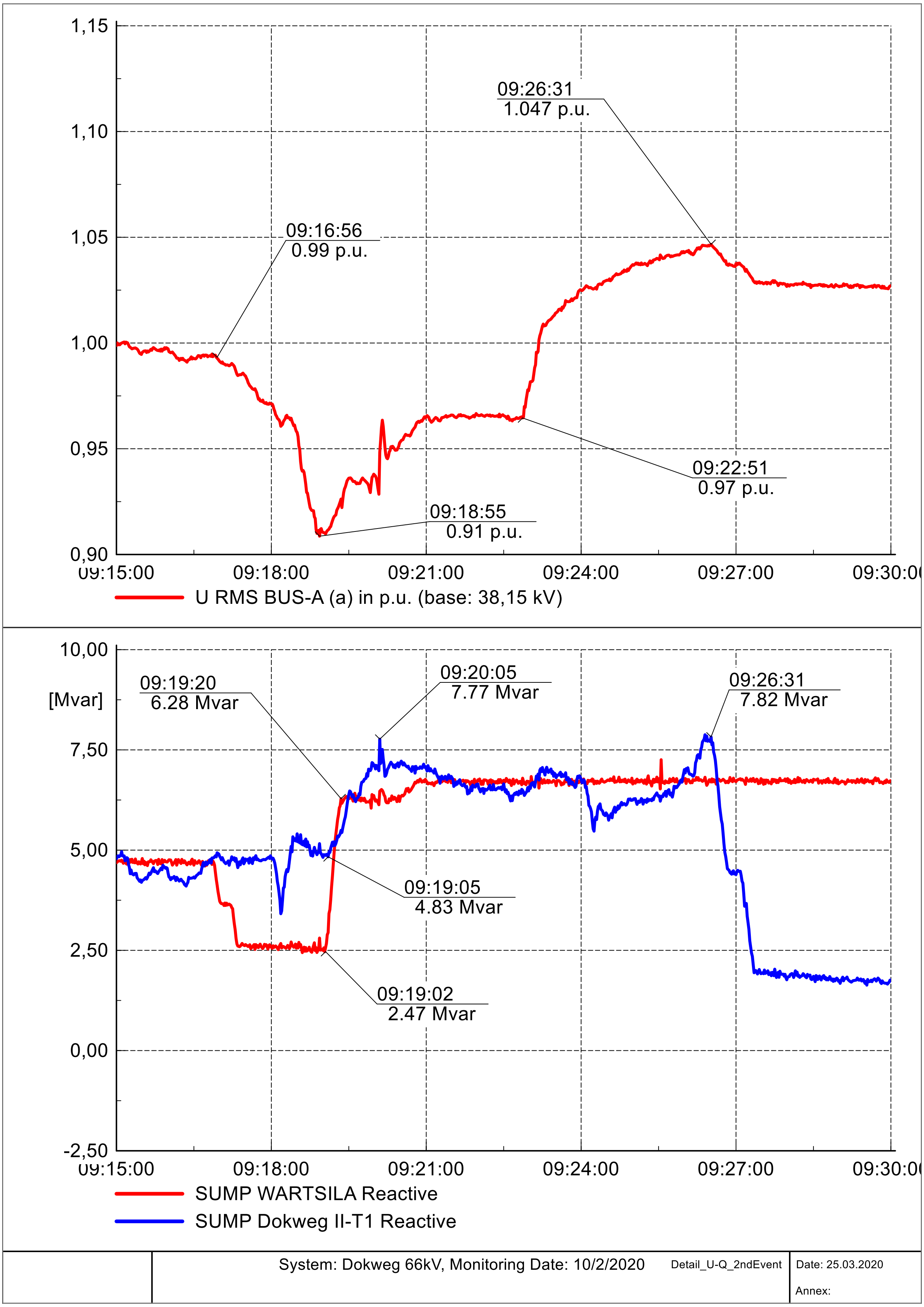


Figure 3-8: 2nd event on the 10th of February 2020 – PFM Dokweg 66 kV – Voltage (up) and reactive power (bottom)

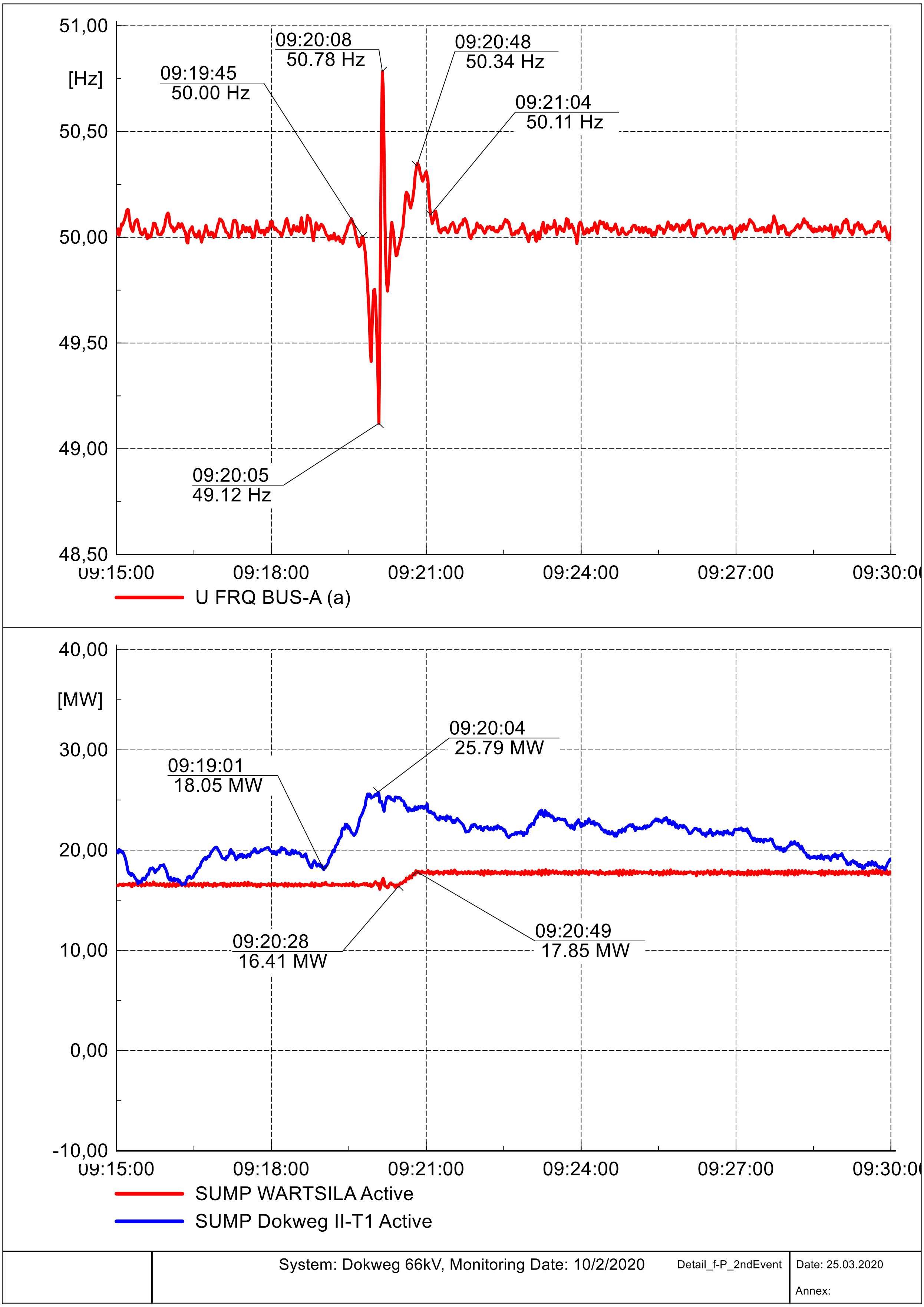


Figure 3-9: 2nd event on the 10th of February 2020 – PFM Dokweg 66 kV –Frequency (up) and active power (bottom)

3.2.2 SCADA

Recording: Generation 202002.xlsx

Remarks

- The SCADA recordings do not show the voltage drop at the 33 kV voltage level. Since the correspondence with the PFM measurement cannot be confirmed completely, no SCADA measurements are considered in the analysis, hence not included in the report.

3.3 Observations and Preliminary Conclusions

1. Based on the information available, the most probable sequence of events is the following:
    a. Generating units DE3 and/or DE4 in NDPP power plant gradually change the operation from over- to under-excited in a time frame of approximately five minutes. As a result, voltage drops in all network locations by approximately 10%.
        i. The change in the reactive power generation in units DE3 and/or DE4 does not seem justified due to any voltage deviations.
        ii. There is not sufficient information to determine which generating unit (DE3 or DE4, or both) is responsible for the observed behavior. According to Aqualectra [4], this behaviour has been observed in the past in unit DE3. According to the same source, this behaviour was not triggered by an action of the plant or network operator.
        iii. After the initial voltage drop, voltage control in other generating units (e.g. in Dokweg 2A and 2B) is able to stabilise voltage and initiate recovery.
        iv. Approximately eight minutes after the initial voltage drop, generating units in NDPP power plant (DE3 and/or DE4) gradually return to their initial reactive power (over-excited).
    b. Approximately 2 minutes after the initial event in NDPP power plant (a), wind farms "Playa Canoa" and "Tera Cora 1" reduce their output power down to zero in a time frame of less than one minute. As a result, frequency decreases down to approximately 49,1 Hz.
        i. SCADA measurements suggest that there is no sudden disconnection of the wind farms, but a sustained output power reduction. It is possible that not all wind turbines in the park disconnect at the same time, which would also lead to a more or less gradual decrease in the output power of the wind park. However, there is not sufficient information to confirm this hypothesis completely.
        ii. The disconnection of both wind farms is triggered by the voltage decrease in the network. According to [5], the undervoltage protection in the wind farms is set at 0,9 p.u. and 2,5 seconds (measured at the 33 kV busbar at the POC). The SCADA measurement shows that the minimum voltage during the event is slightly above 0,9 p.u. but since the value represents a one-minute average, it is highly possible that the voltage drops transiently below 0,9 p.u., thus activating the under-voltage protection of the wind turbines.

        iii. Unlike the other wind farms, wind farm "Tera Cora 2" maintains the same output power with no reduction. Therefore, it can be assumed that the under-voltage protection settings are different than in wind farms "Playa Canoa" and "Tera Cora 1".

        iv. After the disconnection of the wind farms, frequency control in other generating units (e.g. in Dokweg 2A and 2B) is able to contain frequency decay and to recover it up to nominal values in less than 60 seconds since the initial drop.

        v. Approximately 10 minutes after the disconnection of the wind farms, when voltage has already recovered close to nominal values, wind farms "Playa Canoa" and "Tera Cora 1" start increasing their output power back to the "pre-event" value, which causes a slight over-frequency in the network (50,25 Hz).

2. During the event, generating units in WARTSILA and Dokweg II-T1 provide voltage control by increasing reactive power contribution when voltage drops. However, it appears as if voltage control occurs only after a certain deadband is exceeded.

    a. Voltage controllers from WARTSILA and Dokweg II-T1 show important differences. WARTSILA seems to control output following an external setpoint that changes periodically, which might suggest some type of power plant controller. On the other hand, Dokweg II-T1 shows a more continuous type of control which suggests a decentralised voltage controller. In general, Dokweg II-T1 adapts faster to changes in the voltage.

2. Generating units in WARTSILA and Dokweg II-T1 also provide frequency control by changing their output power to limit frequency excursion and to stabilise it afterwards.

    a. Similarly as for voltage controllers, frequency controllers from WARTSILA and Dokweg II-T1 show important differences. WARTSILA seems to control output following an external setpoint that changes periodically, which might suggest some type of power plant controller. On the other hand, Dokweg II-T1 shows a more continuous type of control which suggests a decentralised frequency controller. In general, Dokweg II-T1 adapts faster to changes in the frequency.

4 Events on 11th of February 2020

Recording: Monitor_2020.02.11 23.59.59.cfg

Location: Dokweg 66 kV

As shown in Figure 4-1, a drop in voltage occurs at approximately 08:24 hours. After 08:36 hours, system starts to show instabilities in both voltage and frequency, and eventually system collapses (09:13 hours)

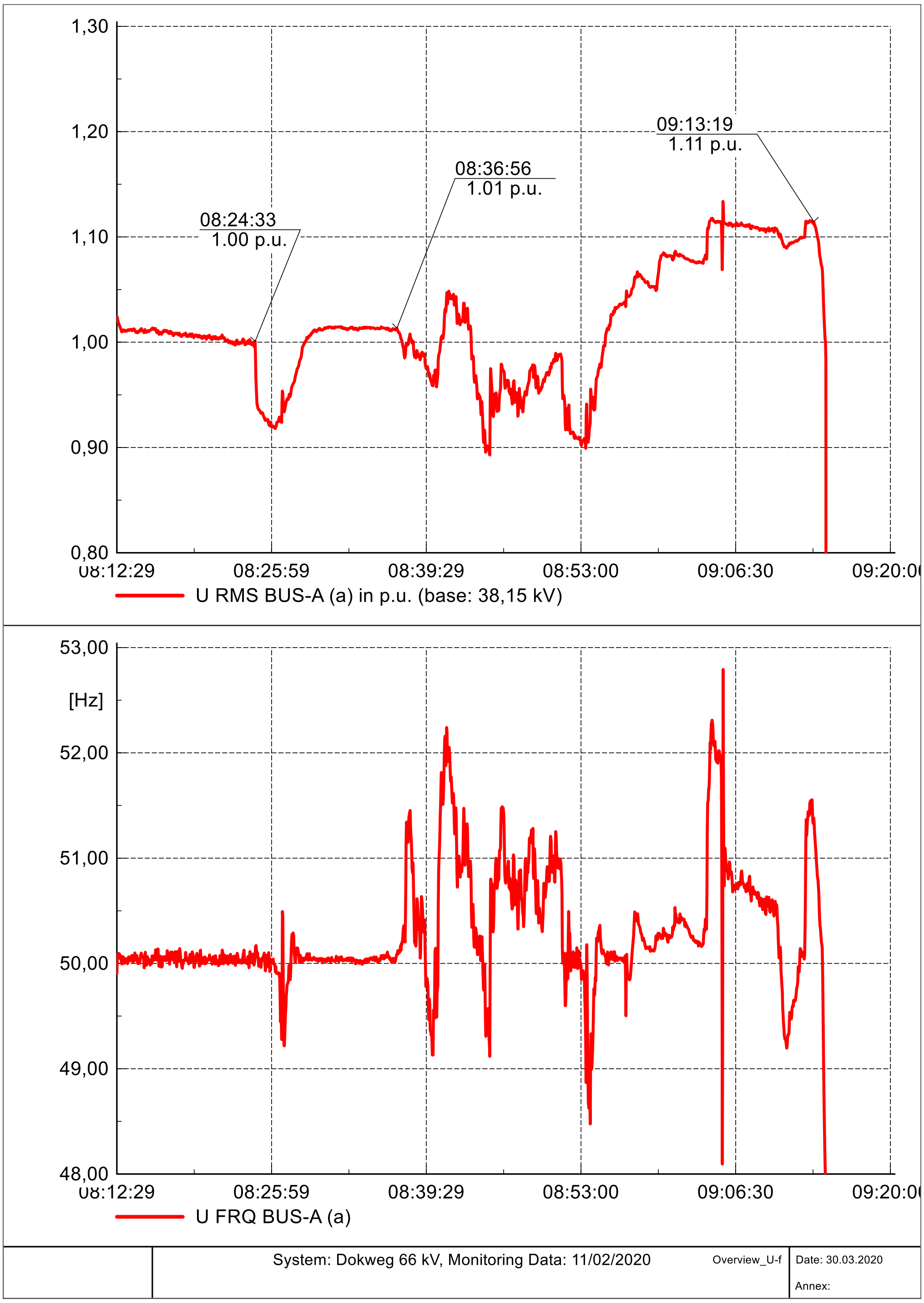


Figure 4-1: Overview of events on the 11th of February 2020 – Dokweg 66 kV – Voltage (up) and frequency (bottom)

4.1 1st Event

4.1.1 PFM Recording

Recording: Monitor_2020.02.11 23.59.59.cfg

Location: Dokweg 66 kV

Date: 11.02.2020

Time: 08:24:33

Plots:

- Figure 4-2: Voltage (top) and network frequency (bottom)
- Figure 4-3: Voltage (top) and reactive power in WARTSILA and DOKWEG II-T1 (bottom)
- Figure 4-4: Network frequency (top) and active power in WARTSILA and DOKWEG II-T1 (bottom)

Remarks:

- Signal DOKWEG II-T2 shows a measured current of approximately zero, hence it is assumed that units 11 and 12 in Dokweg 2B are disconnected at the time of the event
- Signal Spare CT 1 shows no measurements, hence it is assumed that units 13 and 14 in Dokweg 2B are disconnected at the time of the event
- The bus coupler is closed at the time of the event
- Lines to substations Isla 66 kV and Parera are in operation at the time of the event

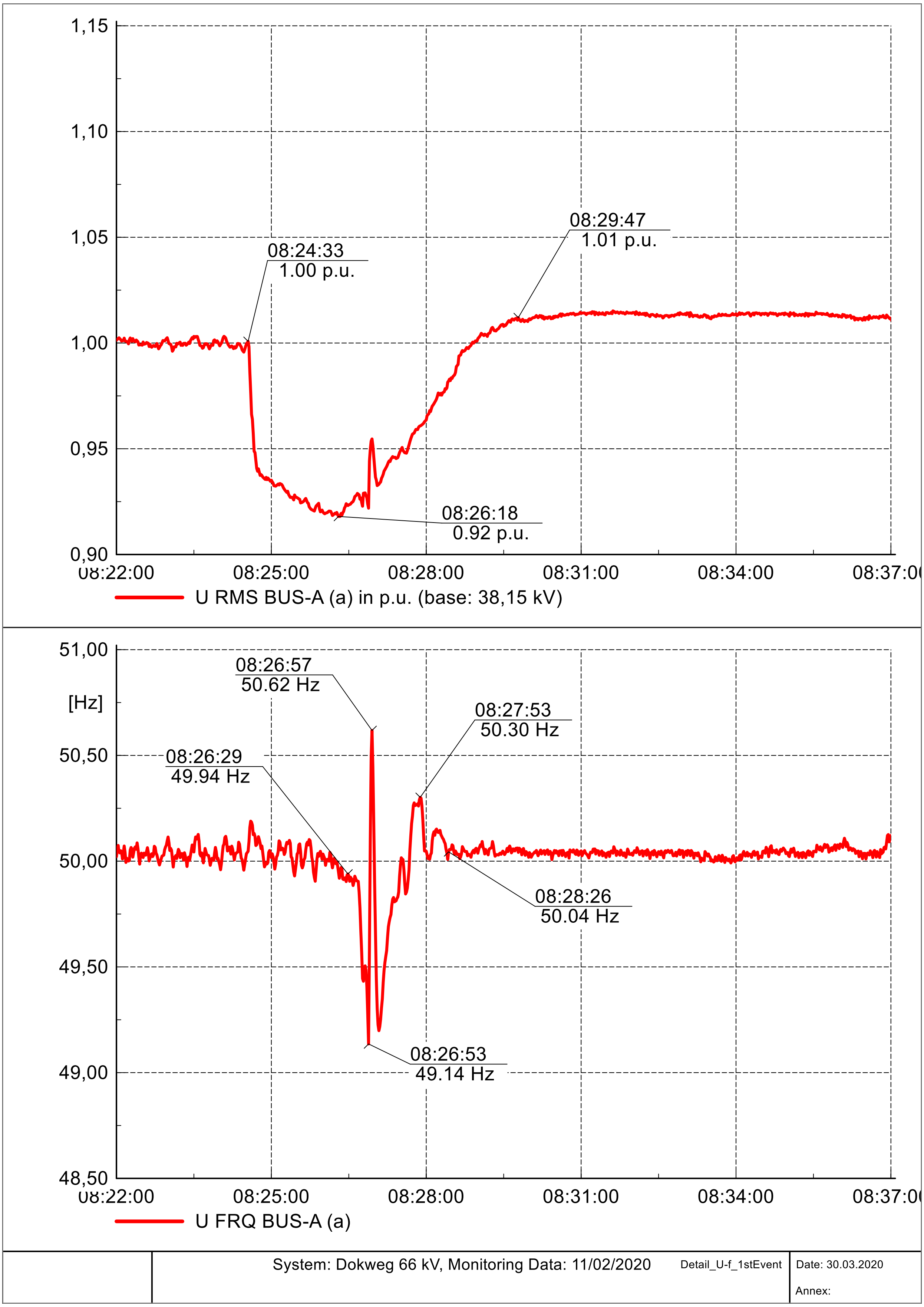


Figure 4-2: 1st event on the 11th of February 2020 – PFM Dokweg 66 kV – Voltage (up) and frequency (bottom)

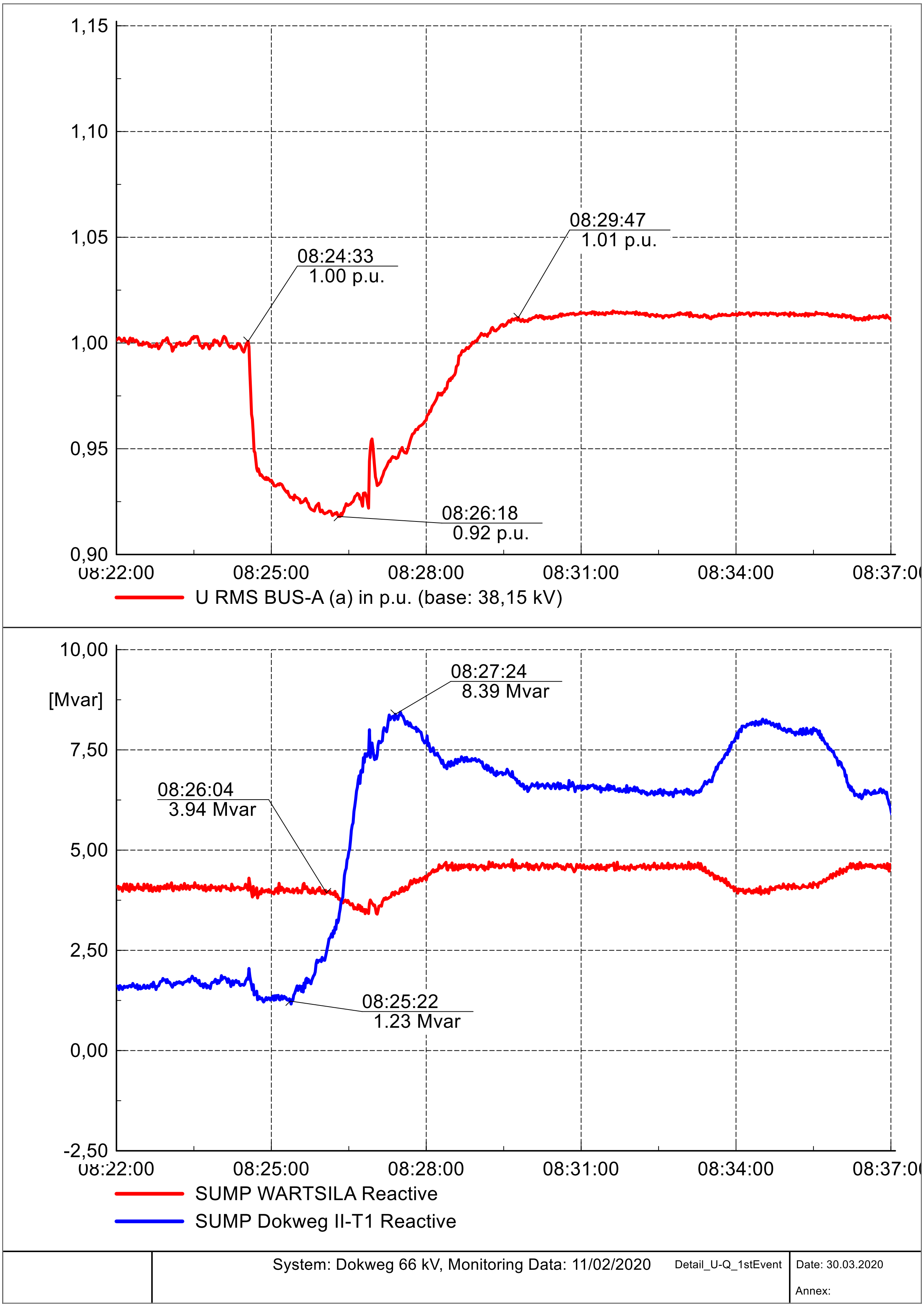


Figure 4-3: 1st event on the 11th of February 2020 – PFM Dokweg 66 kV – Voltage (up) and reactive power (bottom)

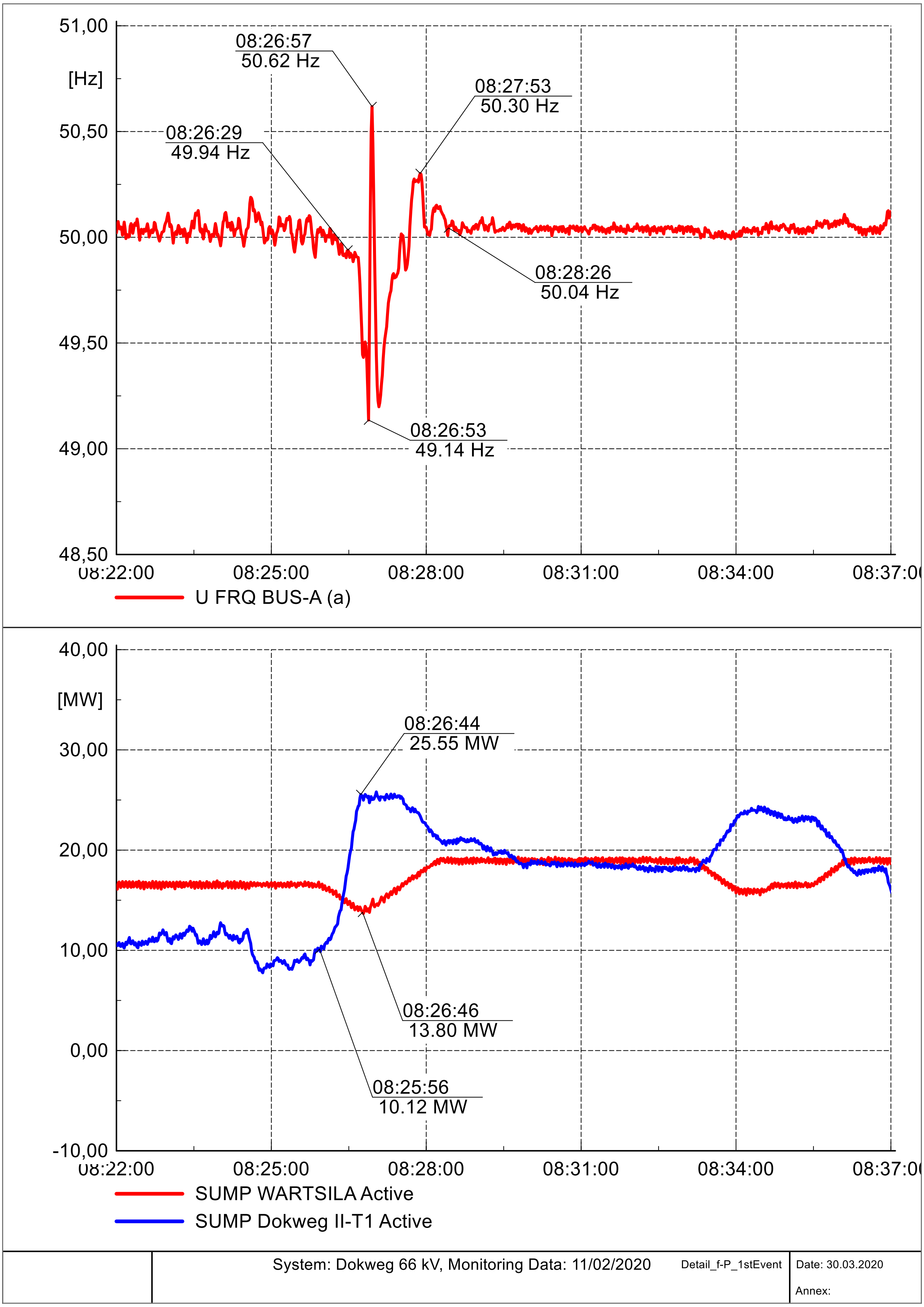


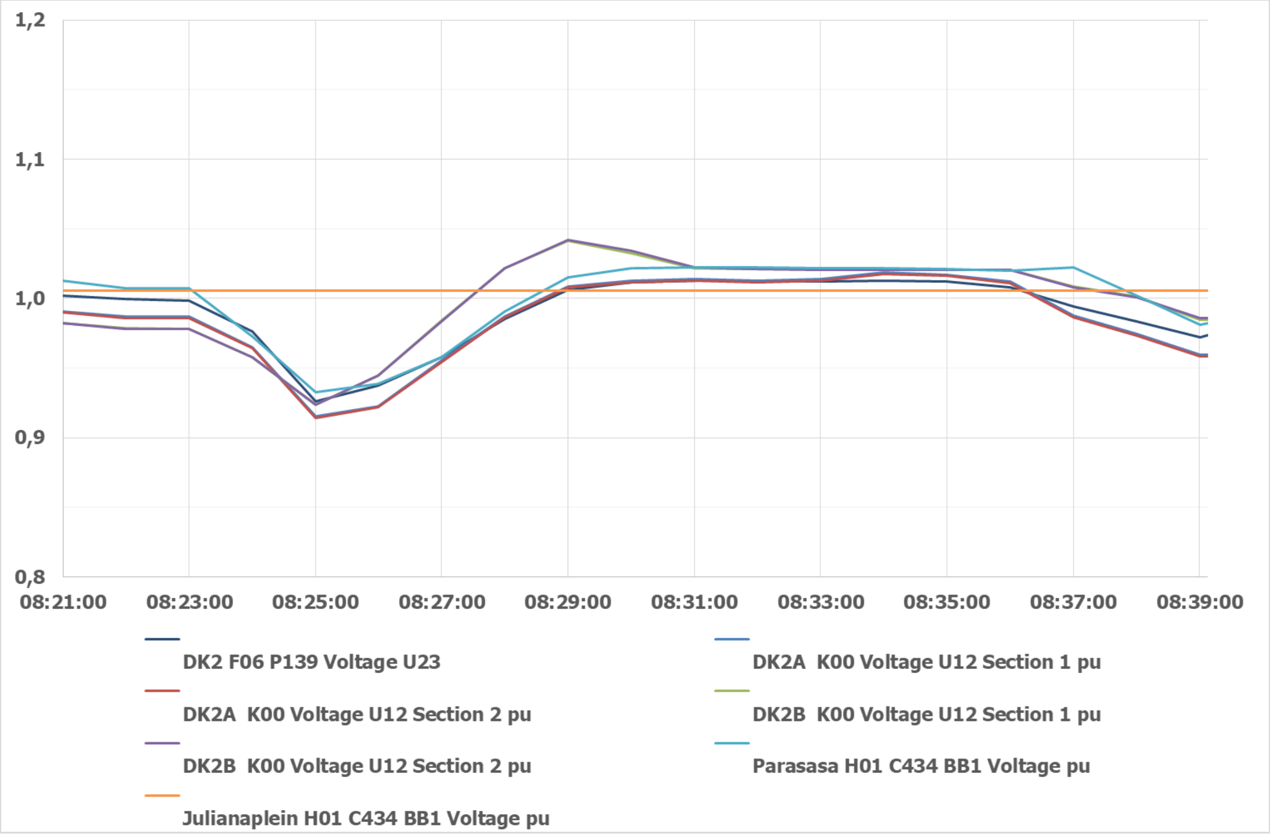
Figure 4-4: 1st event on the 11th of February 2020 – PFM Dokweg 66 kV –Frequency (up) and active power (bottom)

4.1.2 SCADA

Recording: Generation 202002.xlsx

Plots:

- Figure 4-5: Voltage (top) and reactive power in different network locations (bottom)
- Figure 4-6: Network frequency (top) and active power in different network locations (bottom)



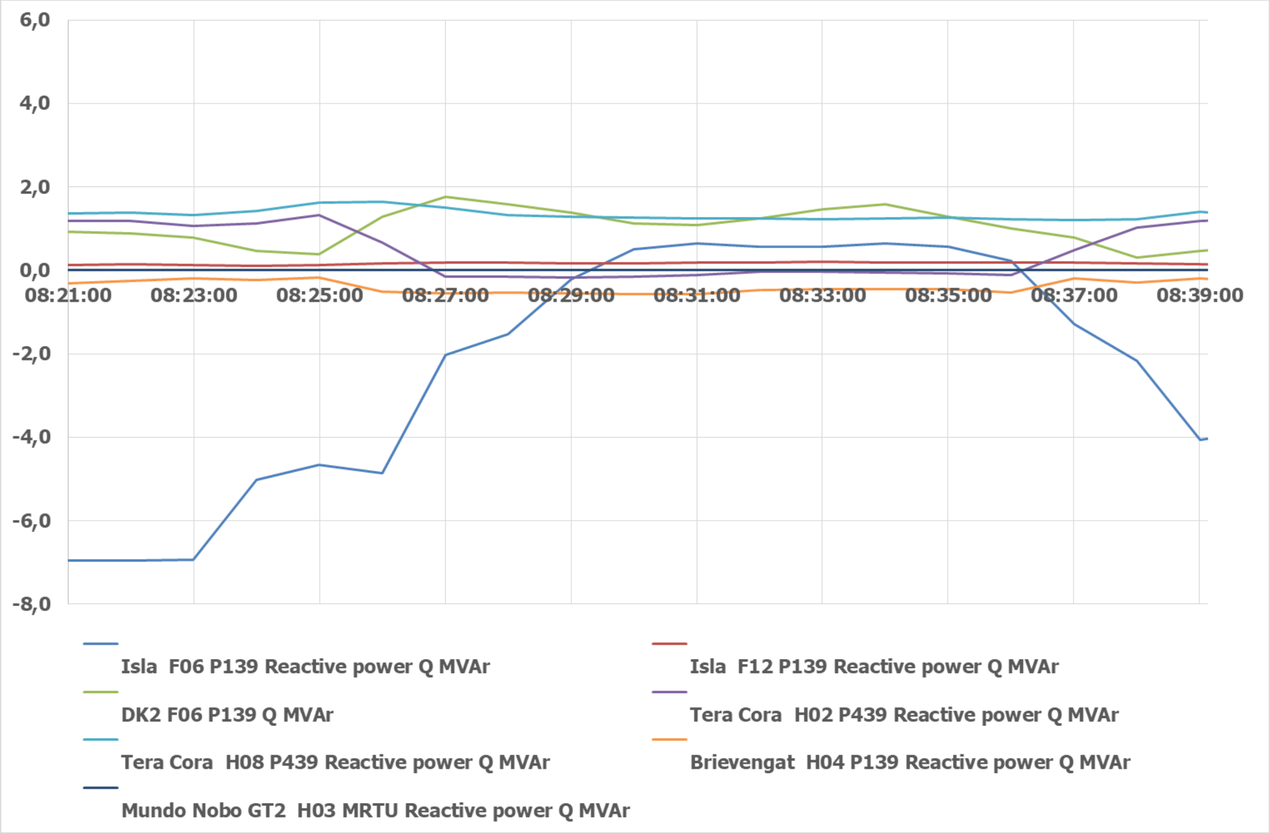
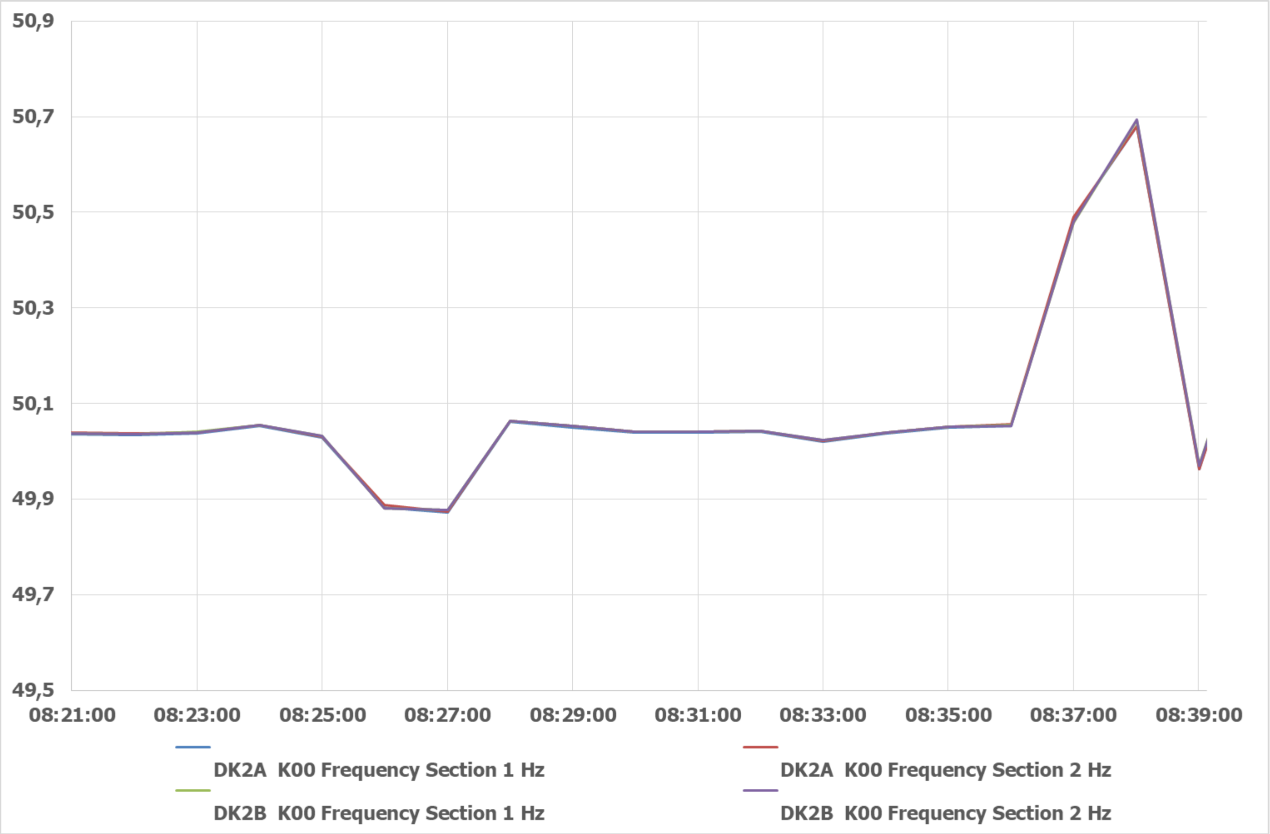


Figure 4-5: 1st event on the 11th of February 2020 – SCADA – Voltage (up) and reactive power (bottom)



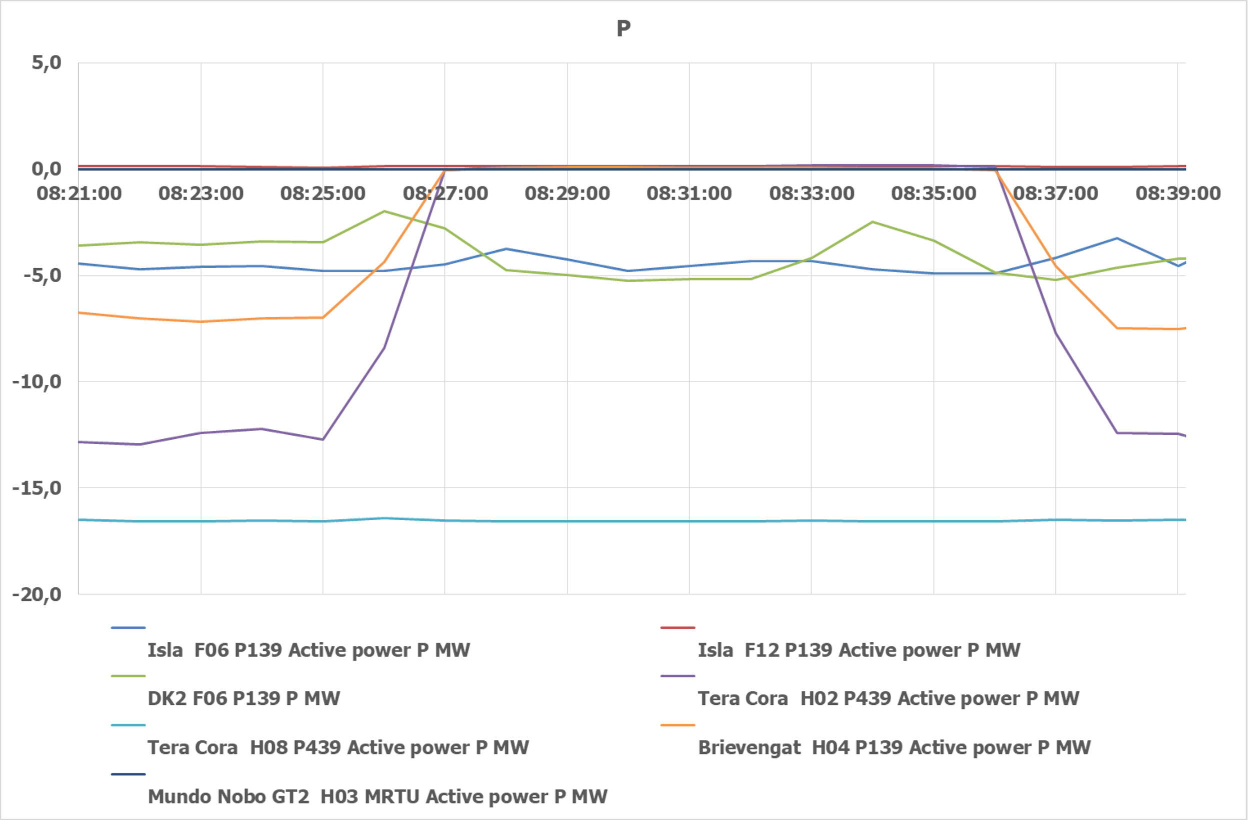


Figure 4-6: 1st event on the 11th of February 2020 – SCADA – Frequency (up) and active power (bottom)

4.2 2nd Event

4.2.1 PFM Recording

Recording: Monitor_2020.02.11 23.59.59.cfg

Location: Dokweg 66 kV

Date: 11.02.2020

Time: 09:16:56

Plots:

Time frame 08:00 – 09:20 hours

- Figure 4-7: Voltage (top) and network frequency (bottom)
- Figure 4-8: Voltage (top) and reactive power in WARTSILA and DOKWEG II-T1 (bottom)
- Figure 4-9: Network frequency (top) and active power in WARTSILA and DOKWEG II-T1 (bottom)

Time frame 09:10 – 09:15 hours

- Figure 4-10: Voltage (top) and network frequency (bottom)
- Figure 4-11: Voltage (top) and reactive power in WARTSILA and DOKWEG II-T1 (bottom)
- Figure 4-12: Network frequency (top) and active power in WARTSILA and DOKWEG II-T1 (bottom)

Remarks:

- Signal DOKWEG II-T2 shows a measured current of approximately zero, hence it is assumed that units 11 and 12 in Dokweg 2B are disconnected at the time of the event
- Signal Spare CT 1 shows no measurements, hence it is assumed that units 13 and 14 in Dokweg 2B are disconnected at the time of the event
- The bus coupler is closed at the time of the event
- Lines to substations Isla 66 kV and Parera are in operation at the time of the event

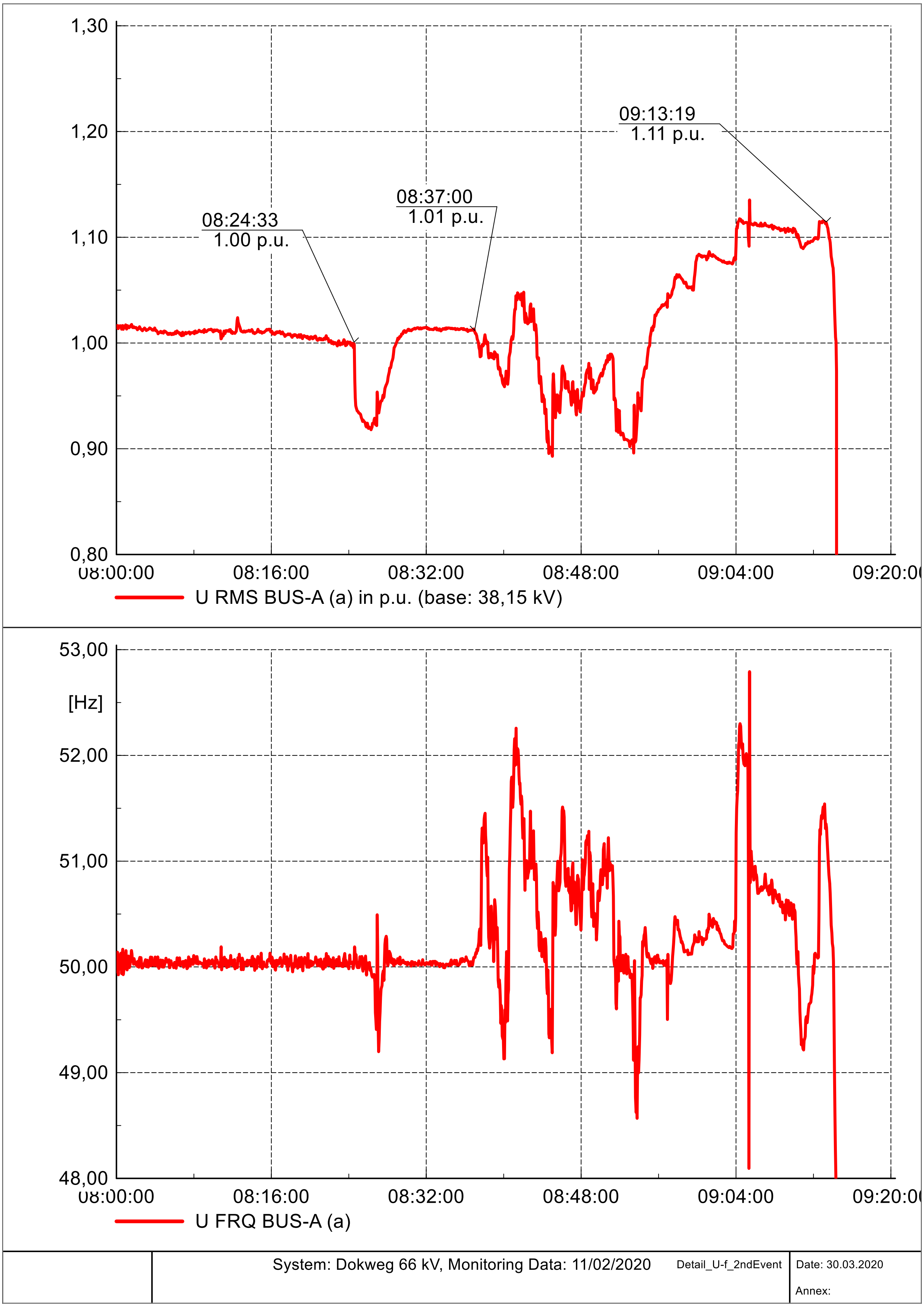


Figure 4-7: 2nd event on the 11th of February 2020 – PFM Dokweg 66 kV – Voltage (up) and frequency (bottom)

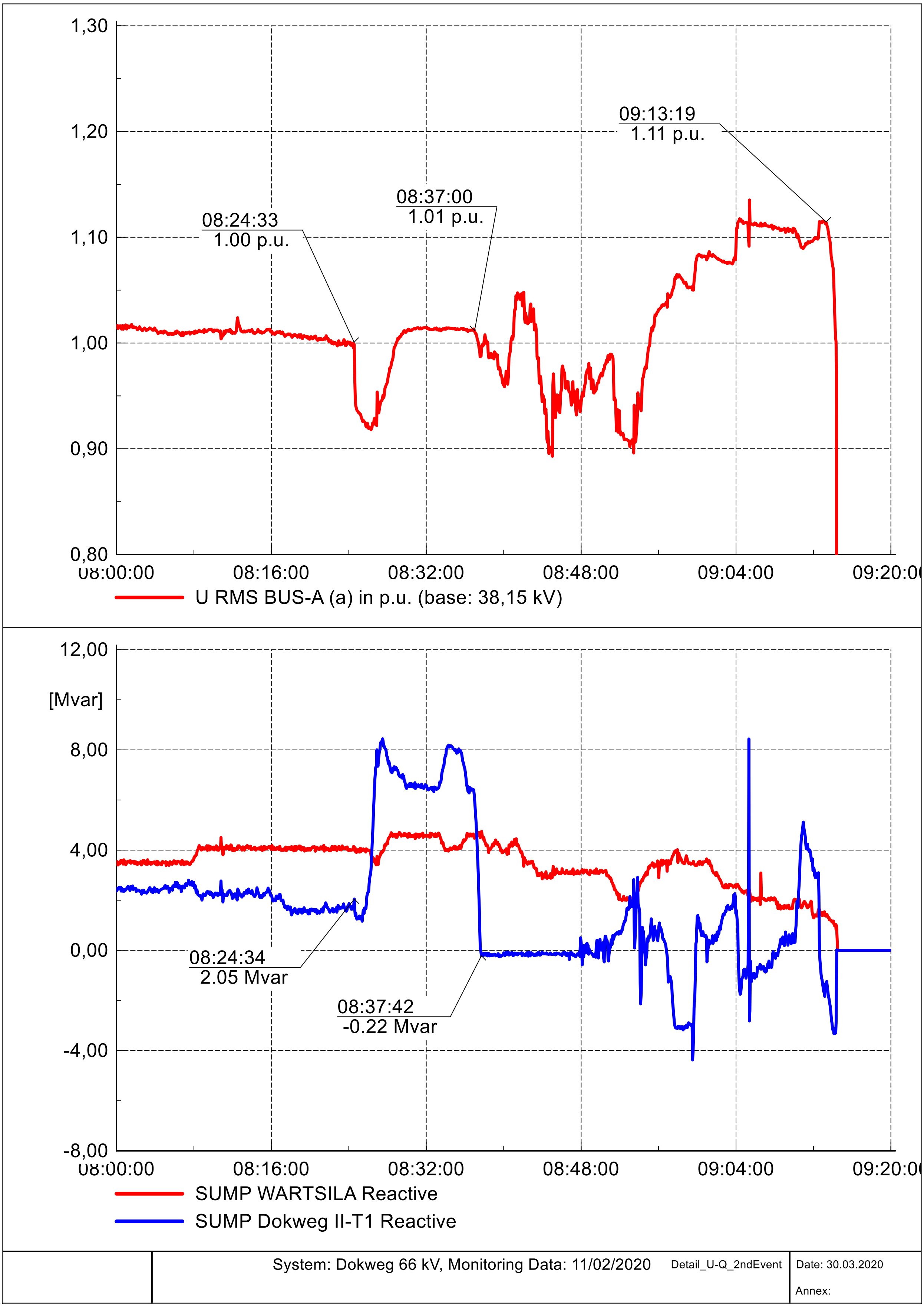


Figure 4-8: 2nd event on the 11th of February 2020 – PFM Dokweg 66 kV – Voltage (up) and reactive power (bottom)

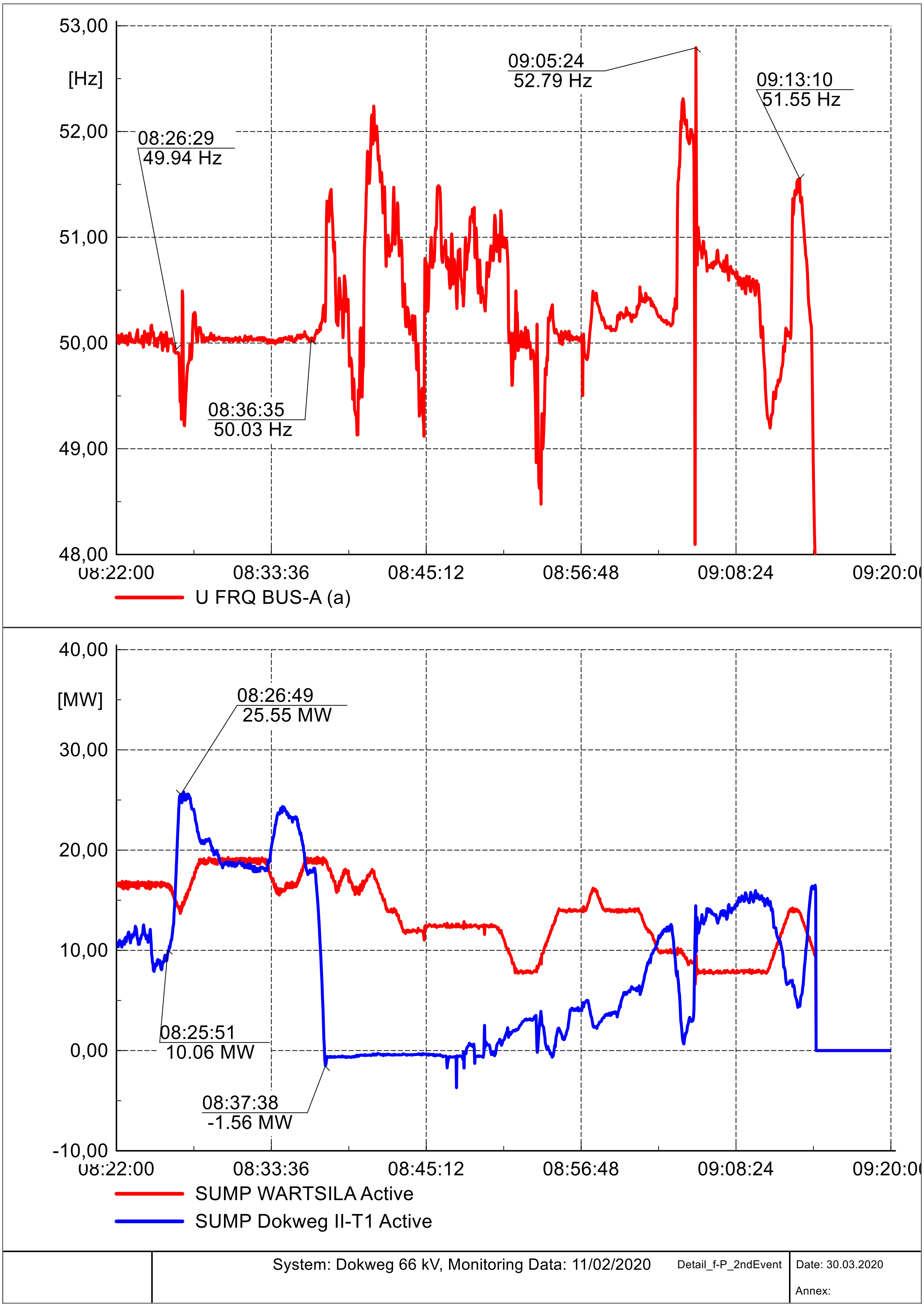


Figure 4-9: 2nd event on the 11th of February 2020 – PFM Dokweg 66 kV –Frequency (up) and active power (bottom)

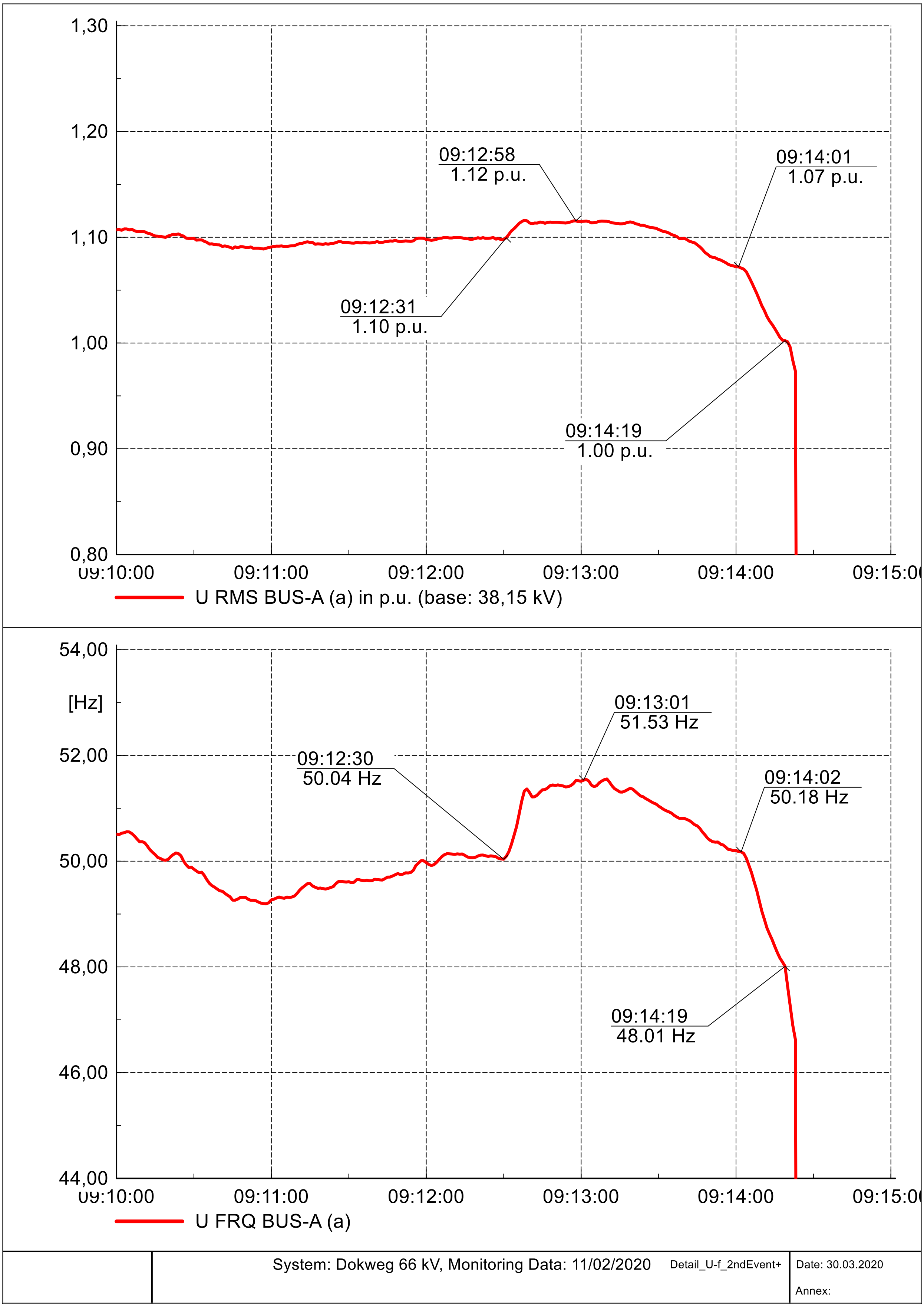


Figure 4-10: 2nd event on the 11th of February 2020 – PFM Dokweg 66 kV – Voltage (up) and frequency (bottom)

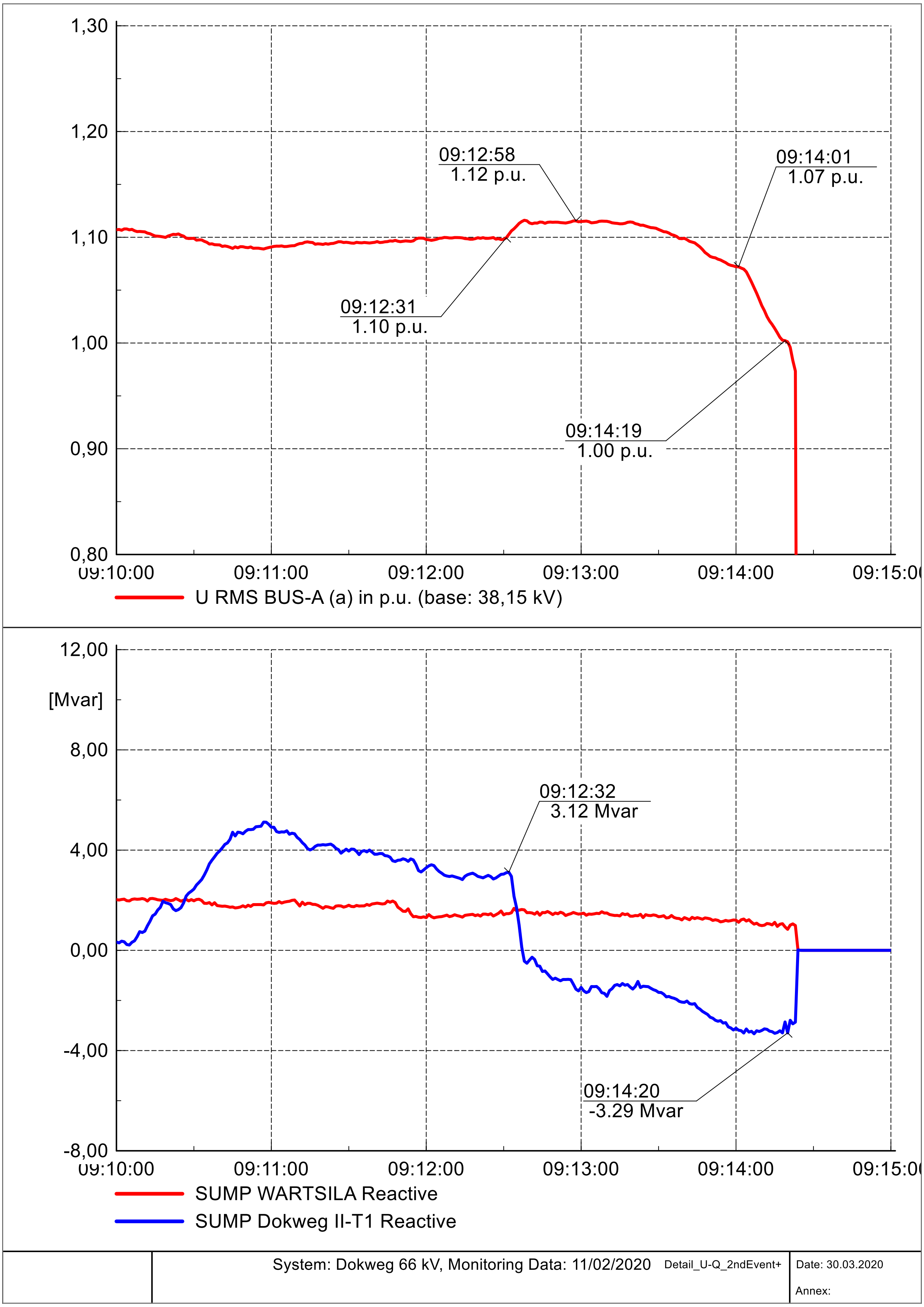


Figure 4-11: 2nd event on the 11th of February 2020 – PFM Dokweg 66 kV – Voltage (up) and reactive power (bottom)

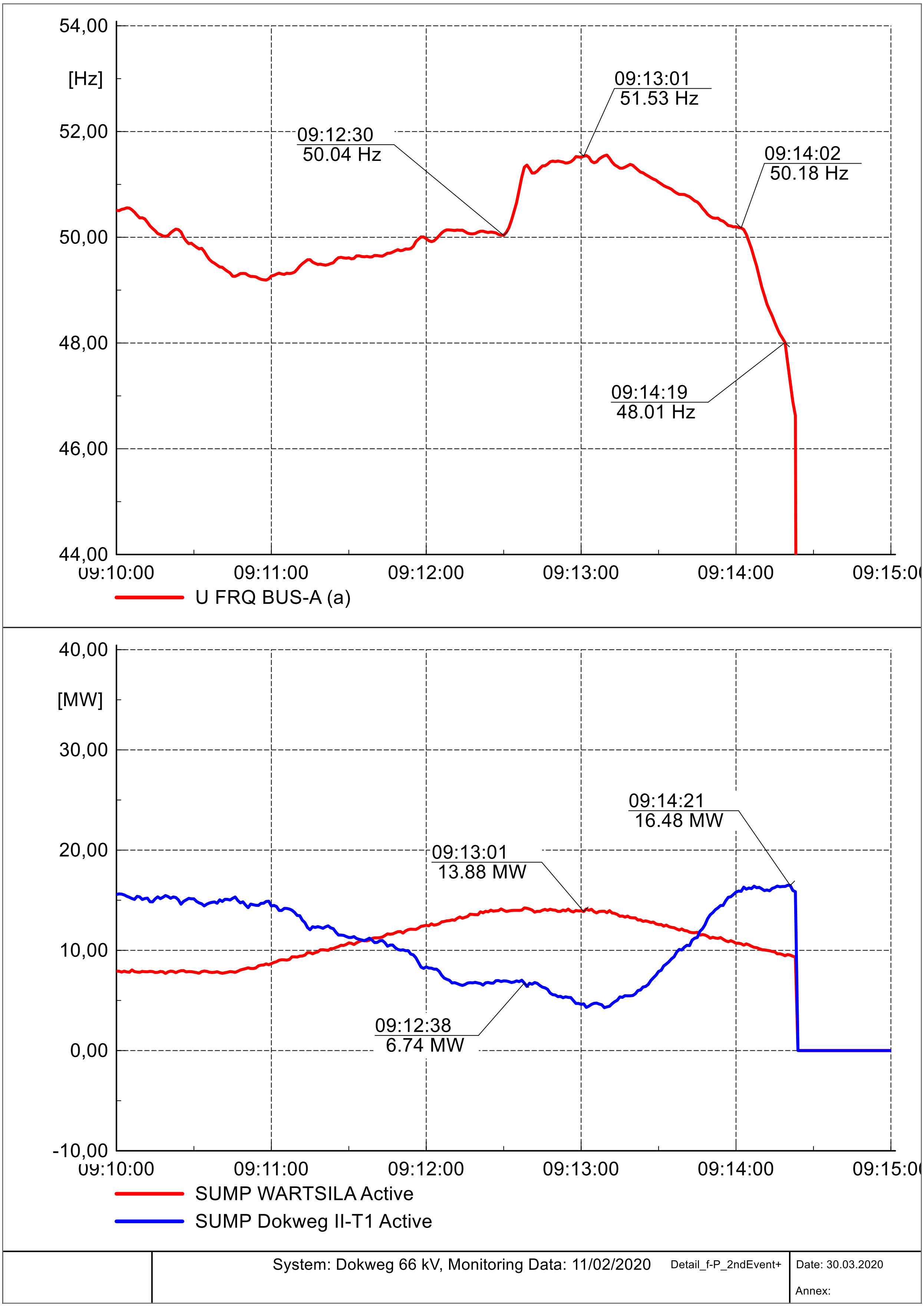


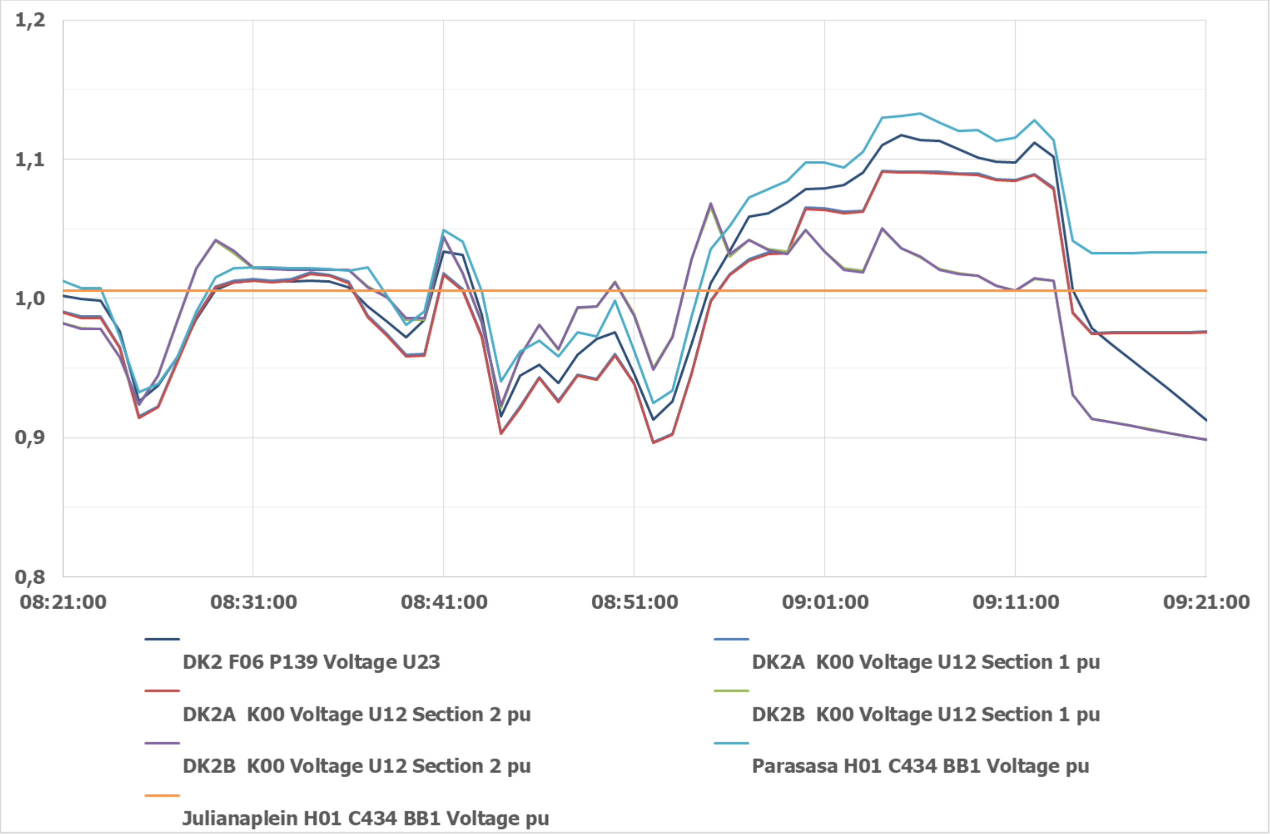
Figure 4-12: 2nd event on the 11th of February 2020 – PFM Dokweg 66 kV –Frequency (up) and active power (bottom)

4.2.2 SCADA

Recording: Generation 202002.xlsx

Plots:

- Figure 4-13: Voltage (top) and reactive power in different network locations (bottom)
- Figure 4-14: Network frequency (top) and active power in different network locations (bottom)



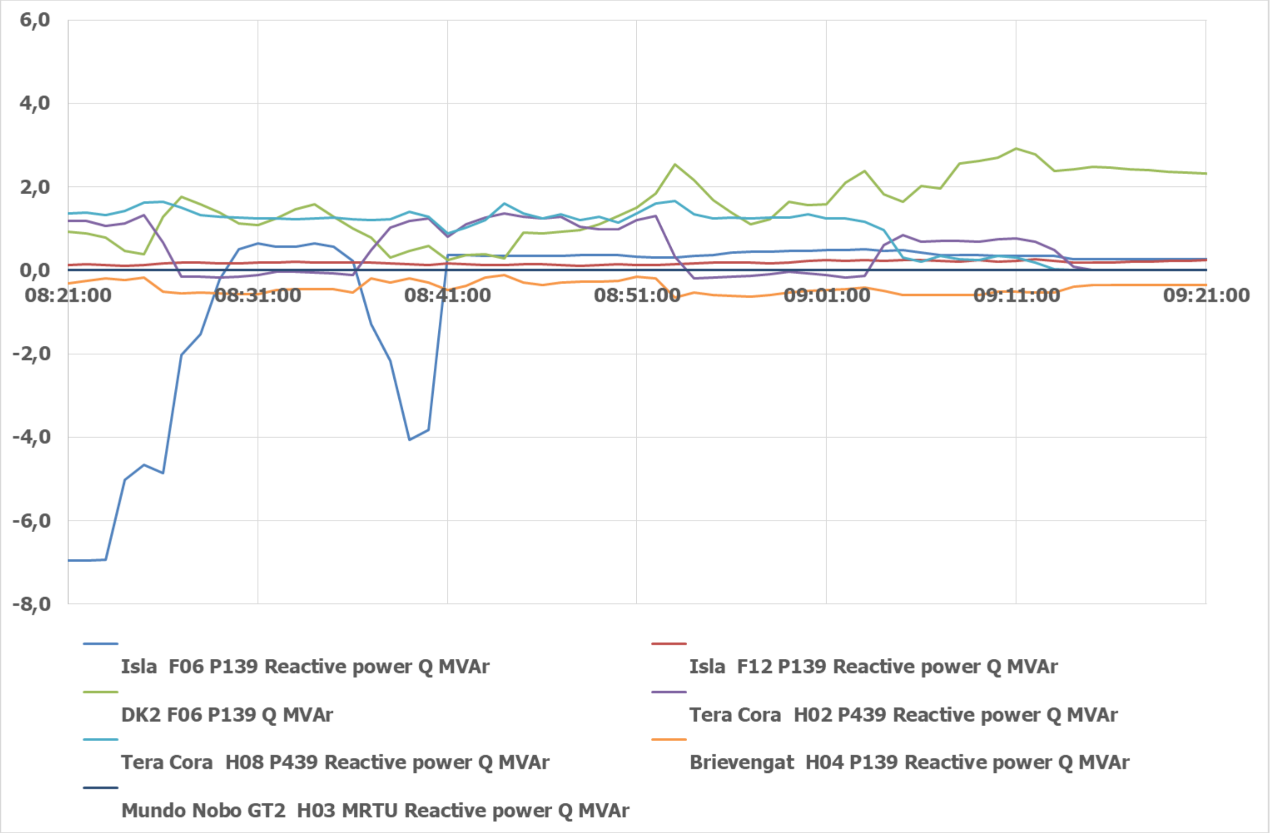
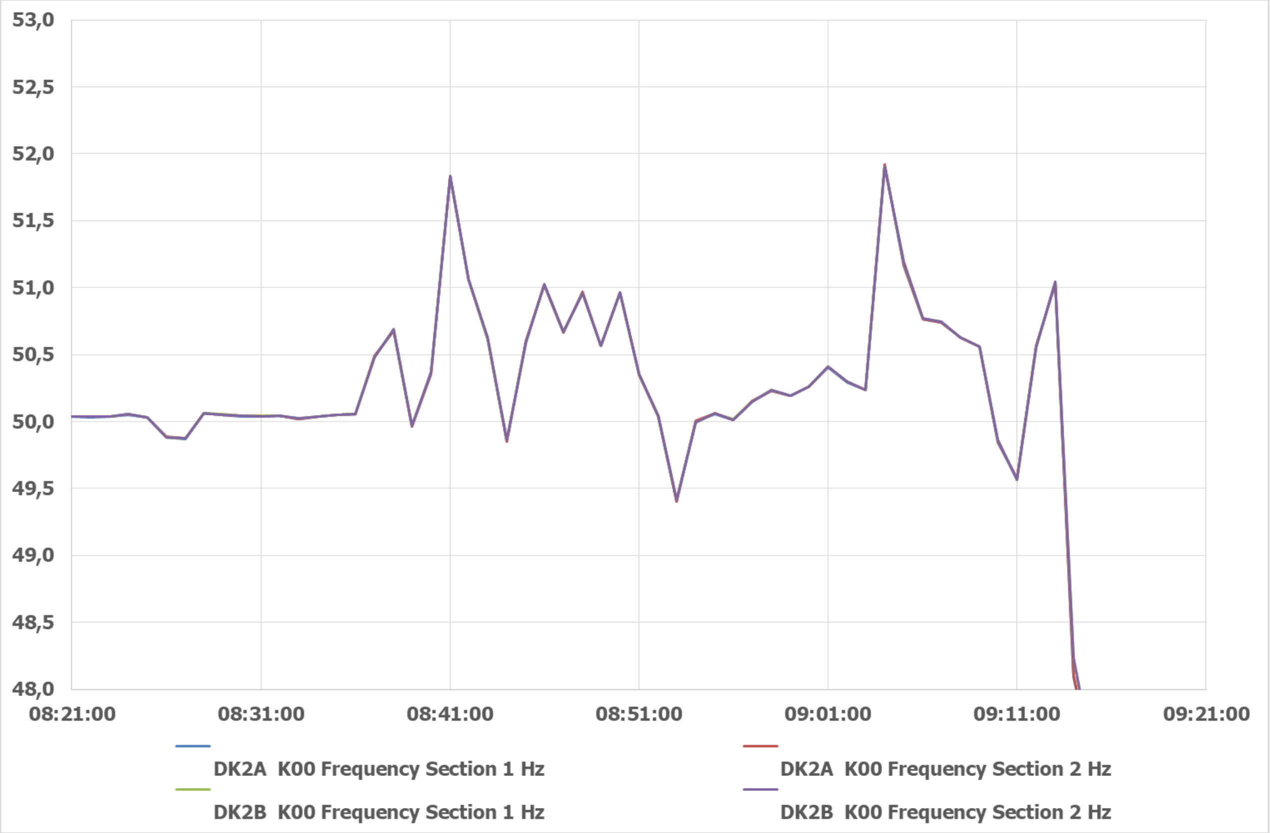


Figure 4-13: 2nd event on the 11th of February 2020 – SCADA – Voltage (up) and reactive power (bottom)



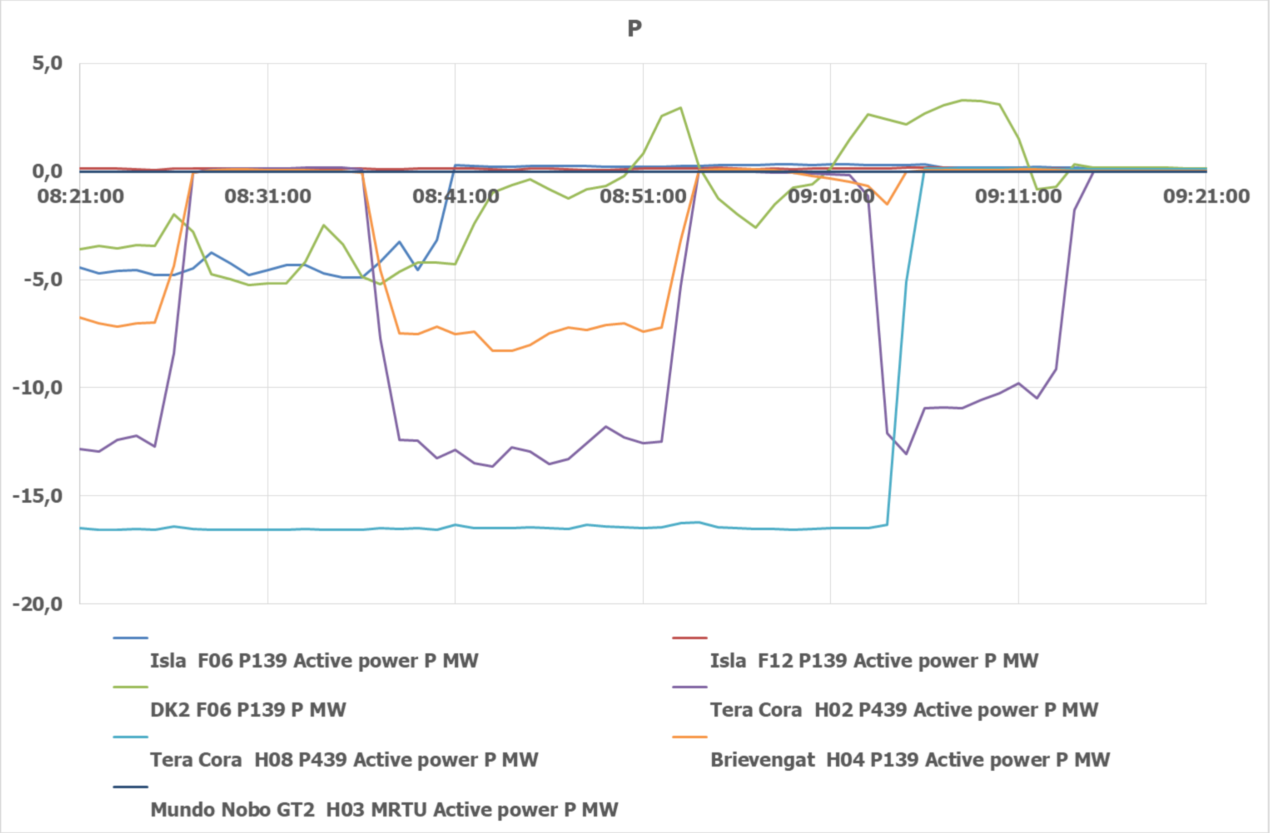


Figure 4-14: 2nd event on the 11th of February 2020 – SCADA – Frequency (up) and active power (bottom)

4.3 Observations and Preliminary Conclusions

1. The analysis of the first event on the 10th of February (see chapter 3.1), including the root cause investigations, is also applicable for the first event on the 11th of February. The only difference is that on the 11th of February, the change the operation from over- to under-excited occurs in units DE1 and/or DE2, while on the 10th of February it corresponds to units DE3 and/or DE4. In both cases, the generating units are located in power plant NDPP.
2. Some minutes after the 1st event occurs, and once system has stabilised, frequency and voltage begin to show an unstable behaviour which eventually leads to a blackout.
    a. There is a correlation between the beginning of the instabilities and the disconnection of the generators in Dokweg II-T1. It seems like these generators provide primary frequency regulation in the system which cannot be substituted (at least not by the generating units online at that moment).

    b. After the disconnection of the generators in Dokweg II-T1, voltage starts deviating and reaches values below 0,9 p.u. and above 1,1 p.u. Frequency deviates as well, reaching minimum and maximum values (before the blackout) of 48 Hz and 52,5 Hz, respectively.

        i. Prior to the blackout, wind farms "Playa Canoa" and "Tera Cora 1" disconnect once again due to undervoltage, reconnecting again (only wind farm "Tera Cora 1") some minutes afterwards. This contributes to increasing the variations in voltage and frequency.

        ii. Wind farm "Tera Cora 2", which remained connected during the first event (voltage drop), disconnects during one of the frequency or voltage excursions. Measurements show how frequency reaches values above 52 Hz and voltages above 1,1 p.u. According to [6], overfrequency protection of the wind turbines is adjusted at 52,5 Hz for 1 second, while overvoltage protection is adjusted at 1,1 p.u. and three seconds.

    c. The blackout seems to be initiated by overvoltage conditions (above 1,1 p.u.), sustained for more than one minute, which eventually causes the disconnection of generation that leads to a frequency decrease.

    d. Frequency drop is not contained (at least not effectively) by the primary frequency regulation of the generating units or by the action of the under-frequency load-shedding scheme (UFLS). When frequency reaches 48 Hz, more generation disconnects and the RoCoF increases even more, eventually causing the blackout.
3. The behaviour of generating units in WARTSILA and Dokweg II-T1 is not always the optimum to stabilise the system:

a. In overvoltage conditions, generators in Dokweg II-T1 increase the reactive power production, when it is exactly the opposite what would have been expected (see Figure 4-11 at 09:10 hours)

b. Frequency regulation of generators in WARTSILA show a delay in the response which causes that, in case of fast frequency variations, the actual response is counter-productive: increase of output power when frequency increases and vice versa (see Figure 4-12).

c. Generators in Dokweg II-T1 increase their output power even when frequency is above nominal (see Figure 4-12 at 09:13 hours).

5 Conclusions and Recommendations

The analysis of the network events on the 10th and 11th of February in 2020 leads to the main conclusions and recommendations summarised in the following table:

Table 5-1: Summary of conclusions and recommendations

#	Conclusions	Recommendations
1	Generating units in power plant NDPP occasionally and unexpectedly changed their operation from over-excited to under-excited, causing transient voltage drops down to approximately 0,9 p.u. in all network locations	Detailed investigation in power plant NDPP to determine the root cause for the observed behaviour. Definition of mitigation measures to assure a stable operation.
2	Wind farms "Playa Canoa" and "Tera Cora 1" disconnected during the events, most probably due to the undervoltage protection settings, which are currently adjusted at 0,9 p.u. and 3 seconds. However, wind farm "Tera Cora 2" did not disconnect during the same events.	Assessment to determine if the protection settings in wind farms "Playa Canoa" and "Tera Cora 1" can be modified to resemble those in wind farm "Tera Cora 2", with the objective of a more robust and uninterrupted operation in case of grid faults.
3	Reconnection of wind farms "Playa Canoa" and "Tera Cora 1" and the subsequent output power ramp-up leads to transient overfrequency in the network.	Reduction of the ramp-up gradient in wind farms "Playa Canoa" and "Tera Cora 1" to minimize the impact on network frequency
4	Generators in Dokweg 2A disconnected unexpectedly on the 11th of February, right after one of the voltage drop events occurred. However, for the same event the day before, those generators remained connected.	Further investigation to determine the root cause of the disconnection.
5	Generators in Dokweg 2A seem to be critical for system stability: their disconnection on the 11th of February led to significant voltage and frequency variations which eventually caused the blackout.	Further investigation to review the overall system concept for frequency and voltage regulation.
6	Generators in Dokweg 2A and Dokweg 2B show differences in their dynamic behavior for frequency and voltage control. Units in Dokweg 2B seem to have a superseded controller (e.g. power plant controller) which leads to a delayed response in case of fast frequency and/or voltage variations due to e.g. grid faults.	Detailed investigation to determine frequency and voltage control characteristics in all power plants. Assessment of unit performance with respect to overall system control strategy, i.e. if performance criteria are fulfilled.
7	PFM configuration is not completely consistent with current network topology (e.g. signal IDs, spare signals)	Update of PFM monitoring systems, so that the configuration is consistent with current network topology. Definition of procedure to update them in case of modifications in network topology.
8	PFM not accessible and/or did not capable of recording all events of interest	PFM shall be accessible remotely and configured to assure that all relevant events in the system are recorded, which will support the analysis of future events.

6 References

[1] Aqualectra, “Generation 202002.xlsx”.

[2] Aqualectra, “Load 202002.xlsx”.

[3] Aqualectra, “Email from jsmit@aqualectra.com with subject: RE: Teleconference with Aqualectra, 2020.04.15,” 07.05.2020 15:47.

[4] Aqualectra, “Email from jsmit@aqualectra.com - Subject: RE: Teleconference with Aqualectra, 2020.04.15,” 13.05.2020 21:28.

[5] Aqualectra, “wind voltage range.jpg”.

[6] Aqualectra, “Wind frequency range.jpg”.

P2029
Security of Supply in Curaçao's Electricity System

Analysis of Grid Events - 07.12.2020

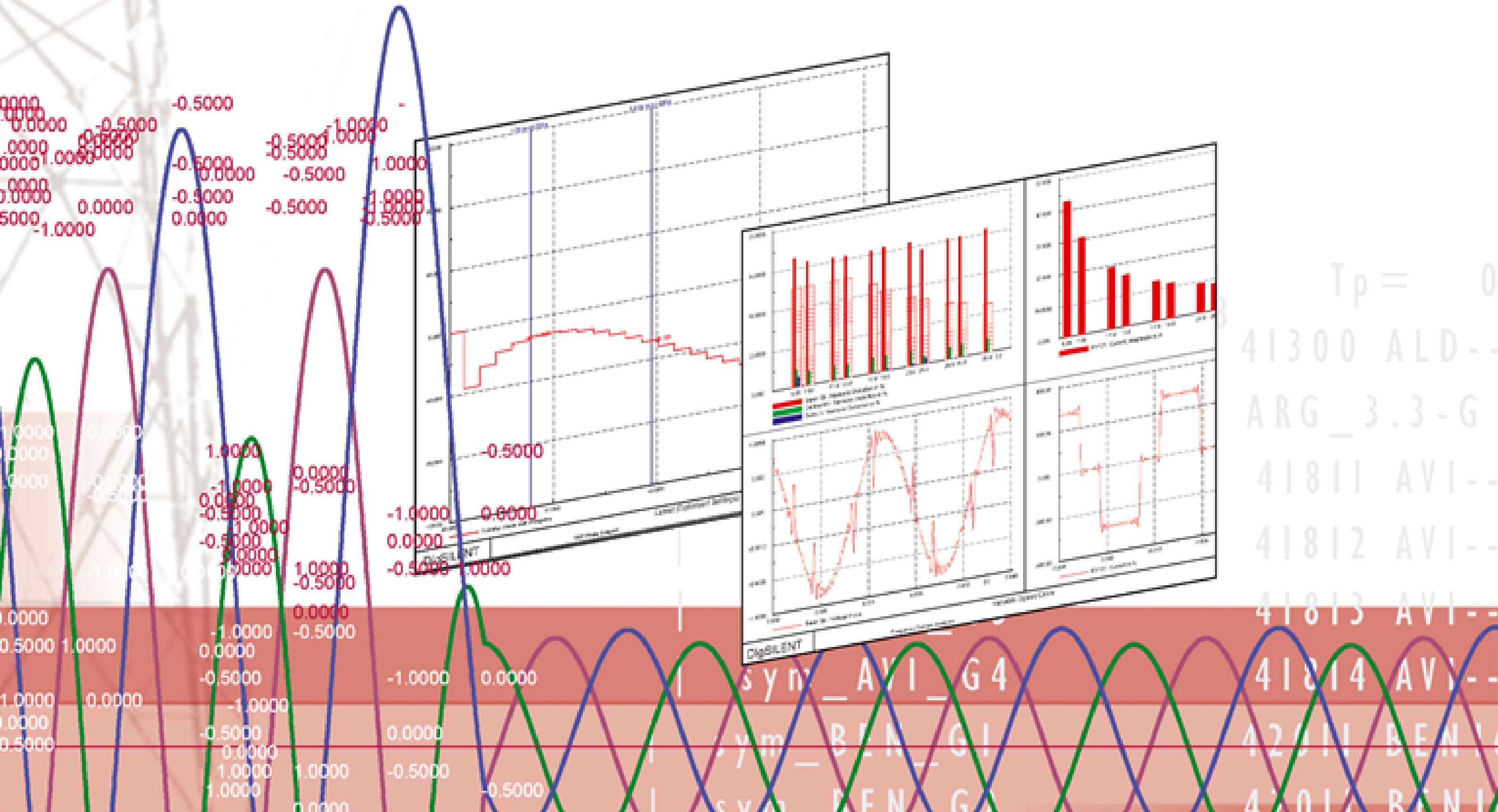
Prepared for:

Aqualectra

Curaçao - Netherland Antilles

Publisher:

DIgSILENT GmbH, December 2020



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Document Revision History

Version	Status	File	Issued	Prepared by
01	First Version	P2029_Aqualectra_Event-Analysis-20201207_REPTRIP01_R01_V01.docx	21.12.2020	J. Gómez

Table of Contents

List of Abbreviations

OEL	Over-Excitation Limiter
PFM	DIgSILENT Monitoring System
SCADA	Supervisory Control and Data Acquisition
UFLS	Under-Frequency Load-Shedding

1 Introduction

On the 7th of December 2020, between 8:00 and 8:30 AM, several events occurred in the power system of Aqualectra in Curaçao which led to a blackout in the power system. This report includes the analysis of the sequence of events and the results of the preliminary investigations.

2 Monitoring Systems

Several PFM monitoring systems are installed in the main substations of Aqualectra. However, some of them are not accessible and/or did not record the events of interest on the specific data subject to analysis. The following table shows an overview of their current status:

Table 2-1: DIgSILENT Monitoring systems – Aqualectra - Curaçao

#	Substation	Type	Status (07.12.2020)
1	Isla NDPP	PFM300	Available, with recordings available
2	Isla 66 kV	PFM300	Available, with recordings available
3	Dokweg 1	PFM300	Not accessible
4	Dokweg 2	PFM300	Not accessible
5	Dokweg 66 kV	PFM300	Available, with recordings available
6	Mundo Nobo	PFM2	Not accessible
7	Tera Cora	PFM2	Not accessible
8	Playa Canoa	PFM2	Not accessible

In addition, there is a SCADA system from Aqualectra which records measurements from multiple locations in the power system.

Annex A includes detailed information from the measurement signals available.

3 Recordings

The following recordings have been used in the analysis of the events:

Table 3-1: Recordings used in the analysis of the events

File Name	**Source**	**Resolution**	**Duration**
Generation 202011_202012_1min.xlsx	SCADA	1-minute	24/11/2020 00:00 12/11/2020 03:45
Load 202011_202012_1min.xlsx	SCADA	1-minute	24/11/2020 00:00 12/11/2020 03:45
Monitor_2020.12.07 23.59.59.dat	PFM300 – Dokweg 66 kV	1-second	07/12/2020 00:00:00.000 08/12/2020 00:00:00.000
RMS_2020.12.07 08.30.34.dat	PFM300 – Dokweg 66 kV	20-milisecond	07/12/2020 08:29:34.360 07/12/2020 08:30:34.360
Monitor_2020.12.07 23.59.59.dat	PFM300 – Isla 66 kV	1-second	07/12/2020 00:00:00.000 08/12/2020 00:00:00.000
RMS_2020.12.07 08.30.34.dat	PFM300 – Isla 66 kV	20-milisecond	07/12/2020 08:29:34.360 07/12/2020 08:30:34.360
Monitor_2020.12.07 23.59.59.dat	PFM300 – Isla NDPP	1-second	07/12/2020 00:00:00.000 08/12/2020 00:00:00.000
RMS_2020.12.07 08.30.34.dat	PFM300 – Isla NDPP	20-milisecond	07/12/2020 08:29:34.360 07/12/2020 08:30:34.360

4 Timeline of Events

Based on the available recordings from the PFM and the SCADA, as well as the information exchange with the diesel engine manufacturer Wärtsilä [1], the sequence of events is shown in the following table.

Annexes B and C include dedicated plots of the recordings used for the analysis of the events.

Table 4-1: Timeline of events

Time	**Event**
07:00:00 - 08:07:41	Power system operates stable very close to nominal frequency and with voltages slightly above nominal values (+3-5%) System demand gradually increases, which leads to a corresponding increase in the reactive power provision from the diesel units which are online in power plants Dokweg 2A and 2B. These units provide frequency and voltage control (isochronous operation mode).
08:07:41 – 08:16:24	Operators in power plants Dokweg 2A and Dokweg 2B change the operation mode of the generating units from isochronous to constant output active and reactive power operation. This causes several step-wise reductions in their reactive power provision, probably due to different setpoint than the actual value, leading to a gradual decrease in system voltage. Aqualectra informed that the operators have experienced in the past sudden disconnections of diesel units due to overloading, at times when the engines were operating close to the rated output power in isochronous mode. This was the reason why the isochronous mode was disconnected in power plants Dokweg 2A and Dokweg 2B.
08:16:24	Trip of diesel unit #13 in power plant Dokweg 2B, which leads to: • System frequency drop down to 49,02 Hz • UFLS is triggered • Frequency stabilises afterwards around 49,17 Hz
08:17:15	Trip of diesel units #15 and #16 in Dokweg 2B, which leads to a sudden frequency decrease and the activation of the UFLS. System voltage decreases from 0,95-0,96 p.u. to 0,92-0,93 p.u and is not able to stabilize (keeps decreasing)
08:18:00 – 08:20:00	Trip of wind parks Playa Canoa and Tera Cora 1, probably due to undervoltage protection set at 0,9 p.u.
08:18:32	Frequency does not recover and keeps decreasing gradually, which leads to the activation of the UFLS at approximately 48,8 Hz
08:18:33 - 08:24:29	System frequency and voltage gradually recover towards nominal values
08:24:29	Ramp-up of unit #13 in power plant Dokweg 2B, along with increase in the output power in wind park Tera Cora II, which leads to: • Frequency increase from 49,6 Hz to 51,4 Hz, and stabilisation slightly above 51,3 Hz • Voltage increase from 1,06 to 1,11 pu, and stabilisation around 1,1 p.u.
08:25:53	Generating units 15 and 16 in Dokweg 2B reconnect and start ramping up • These units provide reactive power during ramp-up despite overvoltage (above 1,1 p.u.) • System frequency and voltage start oscillating

Time	Event
08:28:00 – 08:30:00	Reconnection of wind parks Playa Canoa and Tera Cora 1
08:30:32	Disconnection of one or several diesel units in power plant Dokweg 2A, which leads to: • Frequency drops from 51,8 to 49,0 Hz and voltage drops from 1,11 p.u. to 1,07 p.u. • Afterwards, frequency and voltage increase up to 53 Hz and 1,13 p.u., respectively.
08:30:00 – 08:32:00	Trip of wind parks Playa Canoa and Tera Cora 1
08:30:40	Trip of the remaining diesel units in power plant Dokweg 2A
08:30:42	Trip of diesel units in Dokweg 2B, followed by a system blackout.

5 Conclusions and Recommendations

The analysis of the events reveals that the blackout is not a direct consequence of a single event in the power system, but to a series of events which start approximately 15 minutes before the blackout occurs.

The following are identified as considered as the most relevant contributing factors to the blackout:

- Change in the operation mode of various diesel units in power plants Dokweg 2A and Dokweg 2B from isochronous to constant output active and reactive power operation (08:07:41 – 08:16:24). Engine manufacturer Wärtsilä claims that this caused overloading in other diesel units, which eventually led to the disconnection of the power plant Dokweg 2B (08:16:24 and 08:17:15).
  - Aqualectra claims that the operators have experienced in the past sudden disconnections of diesel units due to overloading, at times when the engines were operating close to the rated output power in isochronous mode. That explains the switch on the operation mode from isochronous to constant output active and reactive power operation.
  - Ongoing discussion between Aqualectra and the engine manufacturer should provide more details regarding the exact root cause for the sudden disconnection (e.g. overloading) and the action items required towards a more reliable operation of the diesel units while providing frequency and voltage control.
  - Operation of generating units in constant power (active/reactive) mode does not necessarily lead to a stability issue in the power system, but it reduces system capability to overcome unbalances in the power system, i.e. it tends to reduce system stability margins. Therefore, voltage and frequency control should be prioritised as much as technically possible in all generating units in the power system.
- Disconnection of wind farms *Playa Canoa* and *Tera Cora 1* (08:18:00 – 08:20:00) in the post-fault phase, presumably due to undervoltage, which caused additional load shedding and increased the difficulty of the power system to recover. Similarly, their reconnection approximately 10 minutes later, when the system was still operating with significant frequency and voltage deviations, affected system stability negatively. This behaviour has been observed as well in the analysis of past events, such as the blackout on the 11th of February, 2020 [2].
  - It is recommended to discuss with the wind farm operators/owners if the protection settings in wind farms *Playa Canoa* and *Tera Cora 1* can be modified to resemble those in wind farm *Tera Cora 2* (which did not disconnect for the same events), with the objective of a more resilient operation in case of grid faults.
  - Reconnection of the wind farms should be performed manually only when system voltage and frequency are stabilised around nominal values. Moreover, the ramp-up gradients for

    both active and reactive power should be limited to values which minimise the effect on system stability.

- Diesel units in Dokweg 2B reconnected and ramped-up (08:25:53) when the system was still operating with significant frequency and voltage deviations, which affected system stability negatively. Moreover, these units were not participating in voltage and frequency control during the ramp-up, which led to an increase in system frequency and voltage which then turned into oscillations, as the other generating units in the system tried to compensate the generation increase.
    - Reconnection should be performed manually only when system voltage and frequency are stabilised around nominal values, with limited ramp-up gradients. If possible, at least voltage control should be activated during the ramp-up.

Finally, in order to support the analysis of future events, it is recommended to review all monitoring systems to make sure that they are accessible remotely and that they are configured to record all major events that may occur in the future in the power system of Aqualectra.

6 References

[1] "Telephone conference with technical representatives from Aqualectra, Wärtsilä and DIgSILENT," 18.12.2020.

[2] DIgSILENT, "P1960 - Security of Supply in Curaçao's Electricity System - Report on Trip Events in February 2020," 19.05.2020.

[3] "Dokweg 66kV - Monitor_2020.12.07 23.59.59.dat".

[4] "Isla 66kV - Monitor_2020.12.07 23.59.59.dat".

[5] "Isla NDPP- Monitor_2020.12.07 23.59.59.dat".

[6] "Dokweg 66kV - RMS_2020.12.07 08.30.34".

[7] "Isla 66kV - RMS_2020.12.07 08.30.34".

[8] "Isla NDPP - RMS_2020.12.07 08.30.34".

[9] Aqualectra, "Load 202011_202012_1min.xlsx".

[10] Aqualectra, "Generation 202011_202012_1min.xlsx".

7 Annex A: Measurement Signals

Table 7-1: Measurement signals – PFM at Dokweg 66 kV

Signal	Enabled	Feeder connection	Location
BUS-A	X		DKW66/BB1
BUS-B	X		DKW66/BB2
Spare VT		-	-
Bus coupler	X	-	DKW66/CB0
BOO	X	No cable connected yet (spare)	-
NDPP	X	No cable connected yet (spare)	-
Wartsila	X	Feeder F03	66/11 kV Transformer DW2SUT4 (Dokweg 2B - Units 15 and 16)
Isla 1	X	Feeder F04	ISLA-Dokweg2
Dokweg II-T1	X	Feeder F05	66/11 kV Transformer DW2SUT1 (Dokweg 2A - Units 09 and 10)
Parera	X	Feeder F07	Dokweg2-Parera
Weis	X	No cable connected yet (spare)	-
Nijlweg	X	No cable connected yet (spare)	-
Spare CT 1		Feeder F10	66/11 kV Transformer DW2SUT3 (Dokweg 2B - Units 13 and 14)
Isla 2	X	No cable connected yet (spare)	-
Dokweg II-T2	X	Feeder F12	66/11 kV Transformer DW2SUT2 (Dokweg 2A - Units 11 and 12)
Spare CT 2		-	-
Spare CT 3		-	-
Spare CT 4		-	-
Digital Input 1	X	-	-

Table 7-2: Measurement signals – PFM at Isla 66 kV

Signal	Enabled	Feeder connection	Location
Dwarskoppelveld sec.	X	1	ISL 66/CB.L0
spare		2	-
Weis	X	3	ISLA-Weis
BOO-I	X	4	66/30 kV Transformer BOO1
Parera-I	X	5	ISLA-Parera
NDPP-I	X	6	66/11 kV Transformer NDPP1 (Units DE1 and DE2)
Langskoppelveld sec.-I	X	7	-
Langskoppelveld sec.-II	X	8	-
Nijlweg	X	9	ISLA-Nijlweg
BOO-II	X	10	66/30 kV Transformer BOO2

Signal	Enabled	Feeder connection	Location
Parera-II	X	11	ISLA-Dokweg2
NDPP-II	X	12	66/11 kV Transformer NDPP2 (Units DE3 and DE4)
Dwarskoppelveld sec.-II	X	13	ISL 66/CB.R0

Table 7-3: Measurement signals – SCADA

Signal	Voltage	Frequency	Active Power	Reactive Power	Location
ISL F06			x	x	NDPP1 (DE1 and DE2)
ISL F12			x	x	NDPP2 (DE3 and DE4)
DK2 F06	x		x	x	-
DK2A K00	x	x			Dokweg 2A plant BB1/BB2
DK2B K00	x	x			Dokweg 2B plant BB1/BB2
TER H02			x	x	Tera Cora-Windfarm Tera Cora 1
TER H08			x	x	Tera Cora-Windfarm Tera Cora 2
BRG H04			x	x	Brievengat-Windfarm Playa Canoa
BRG H01	x				Brievengat 30kV BB1/BB2
PSA H01	x				Parasasa 30kV BB1/BB2
JPL H01	x				Julianaplein 30kV BB1/BB2
MNE H03			x	x	GT2SUT

8 Annex B: PFM Recordings

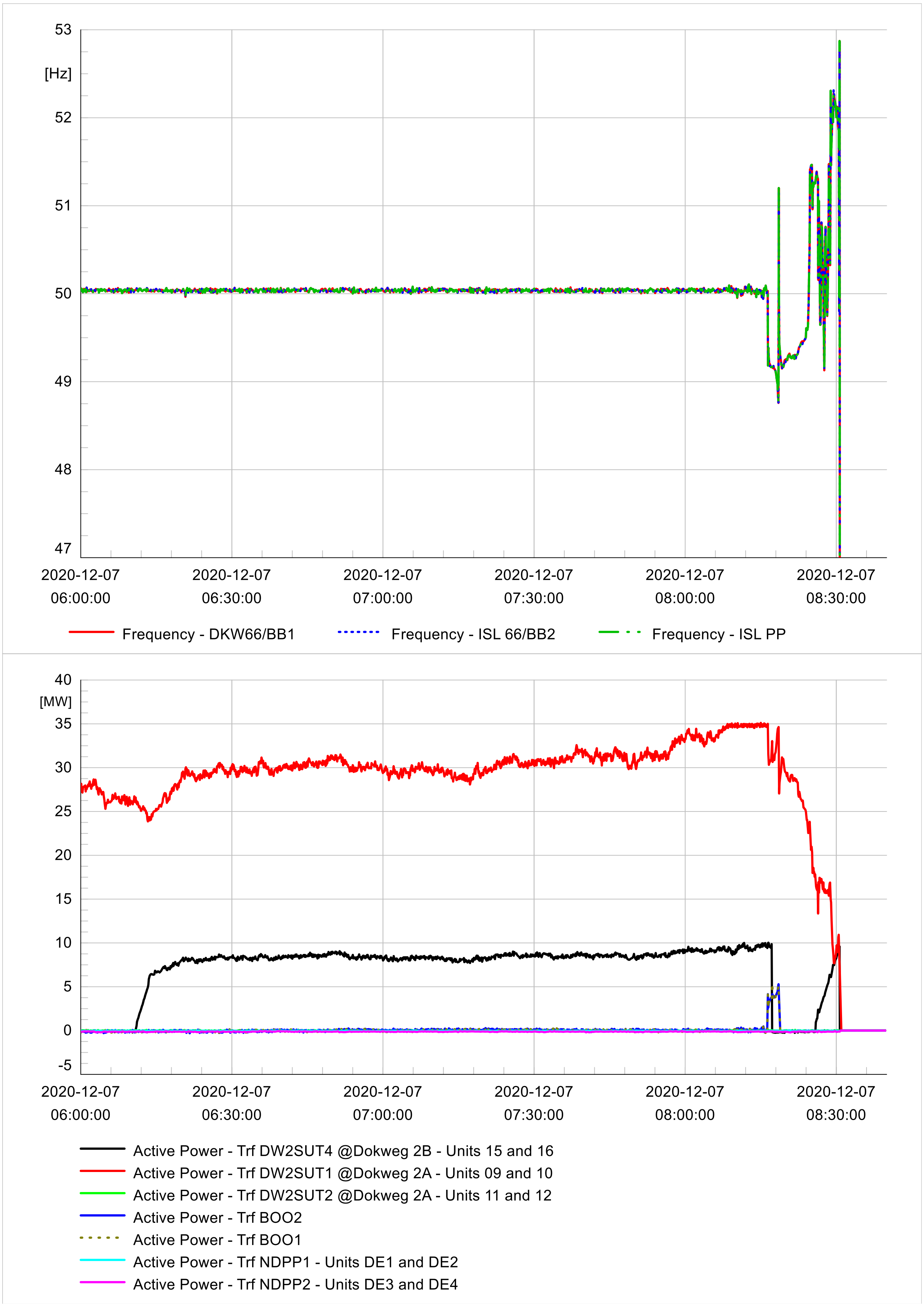


Figure 1: PFM Recordings - Frequency and Active Power – From 6:00:00 to 08:31:00 hours

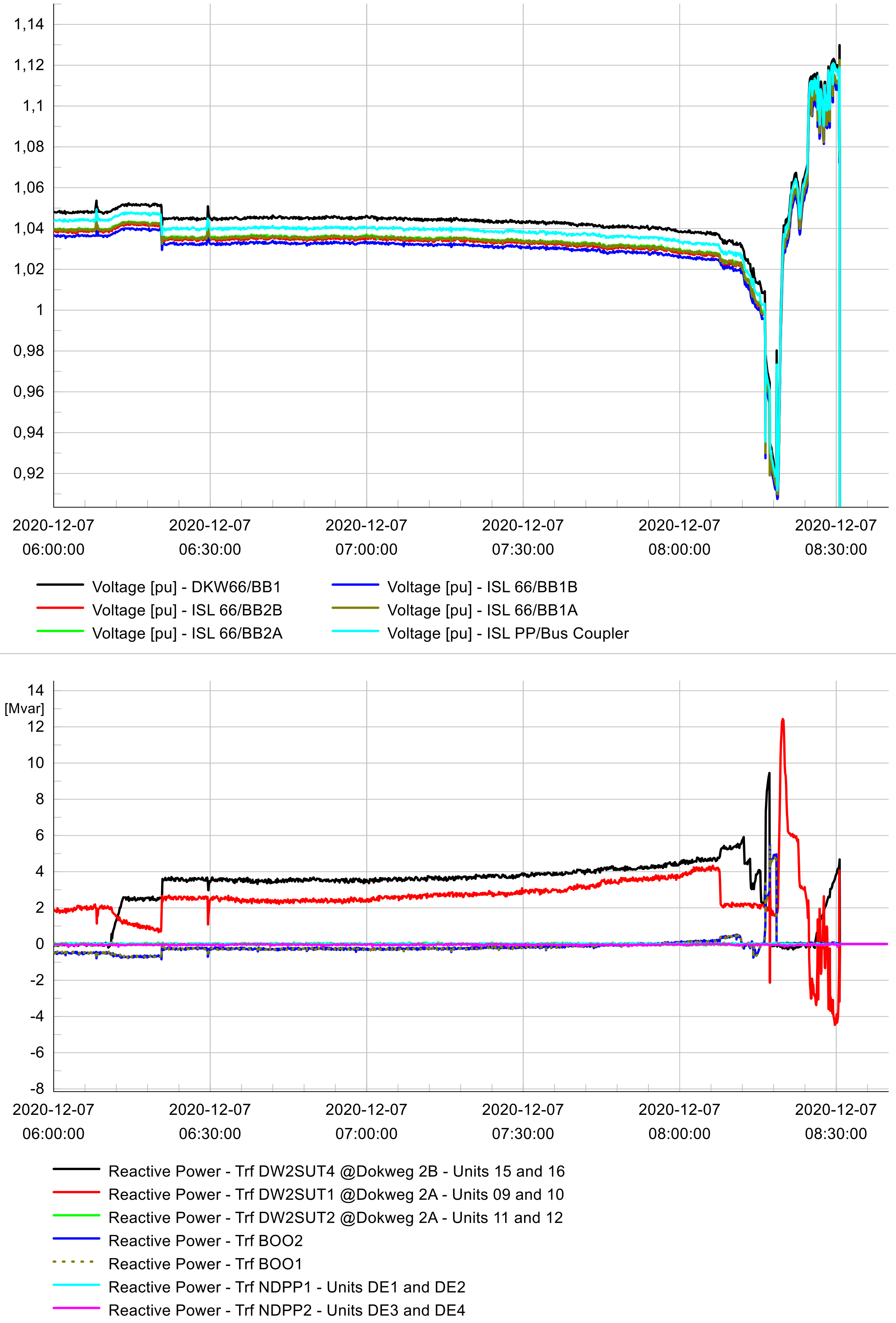


Figure 2: PFM Recordings - Voltage and Reactive Power – From 6:00:00 to 08:31:00 hours

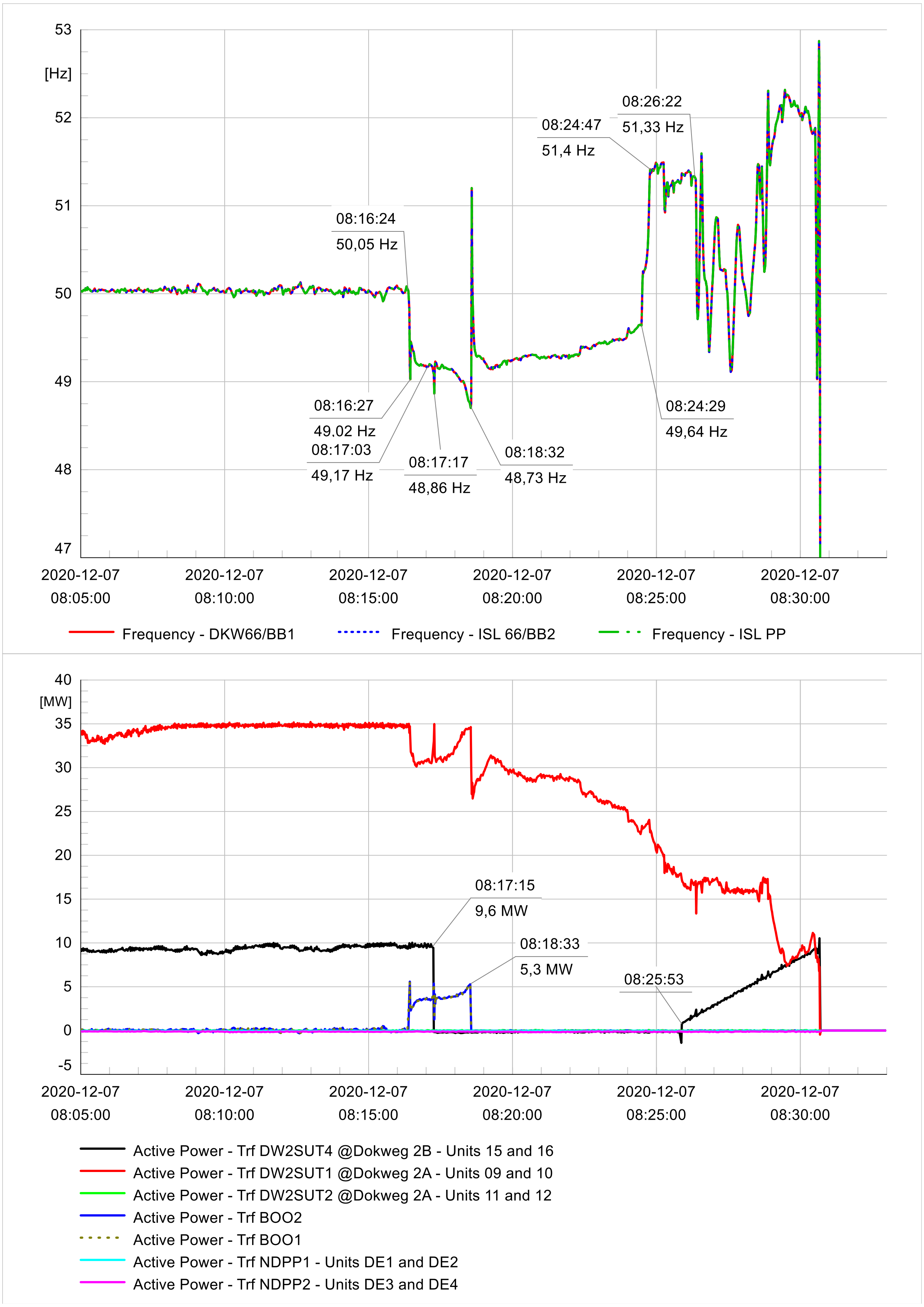


Figure 3: PFM Recordings - Frequency and Active Power – From 8:05:00 to 08:33:00 hours

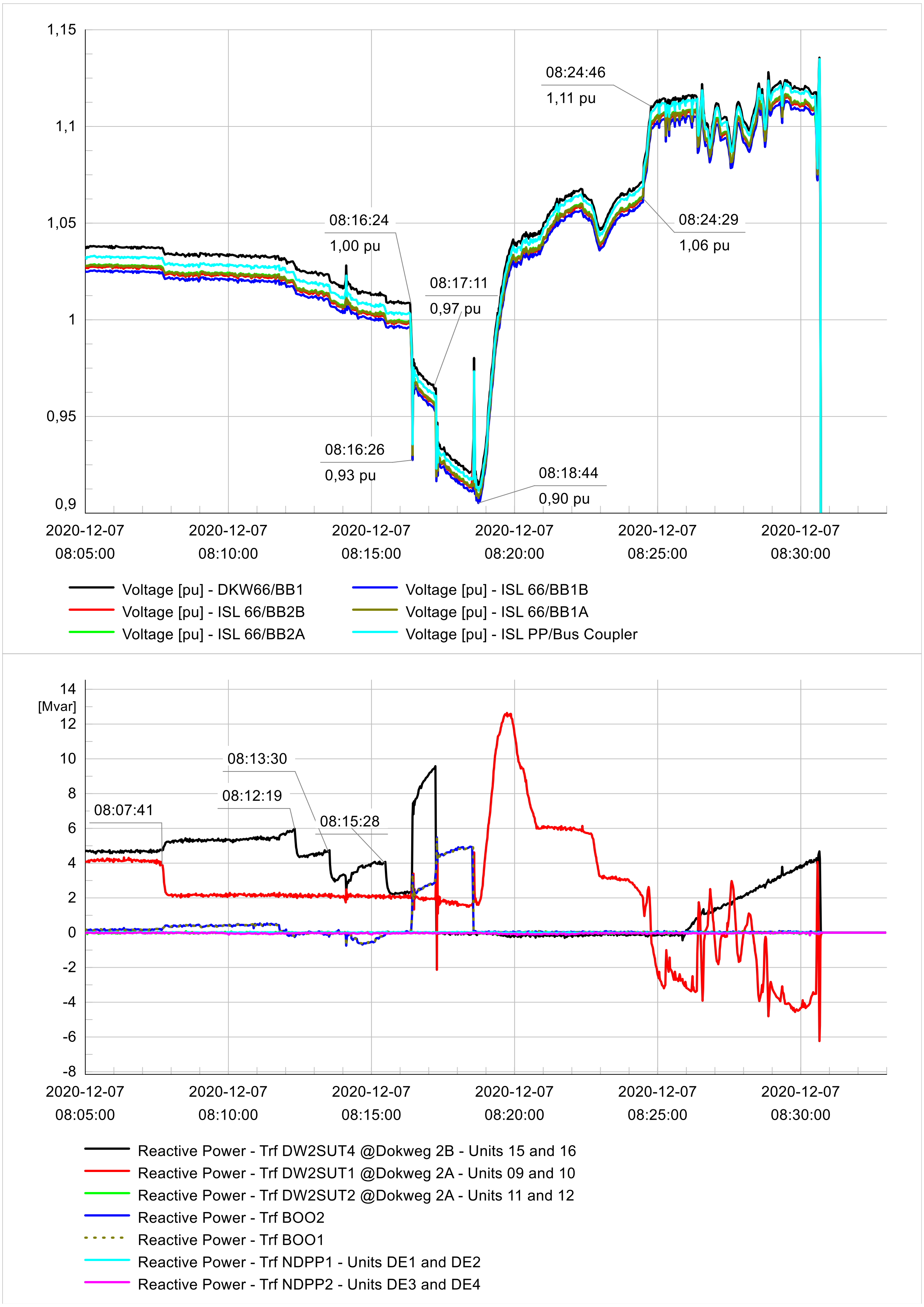


Figure 4: PFM Recordings - Voltage and Reactive Power – From 8:05:00 to 08:33:00 hours

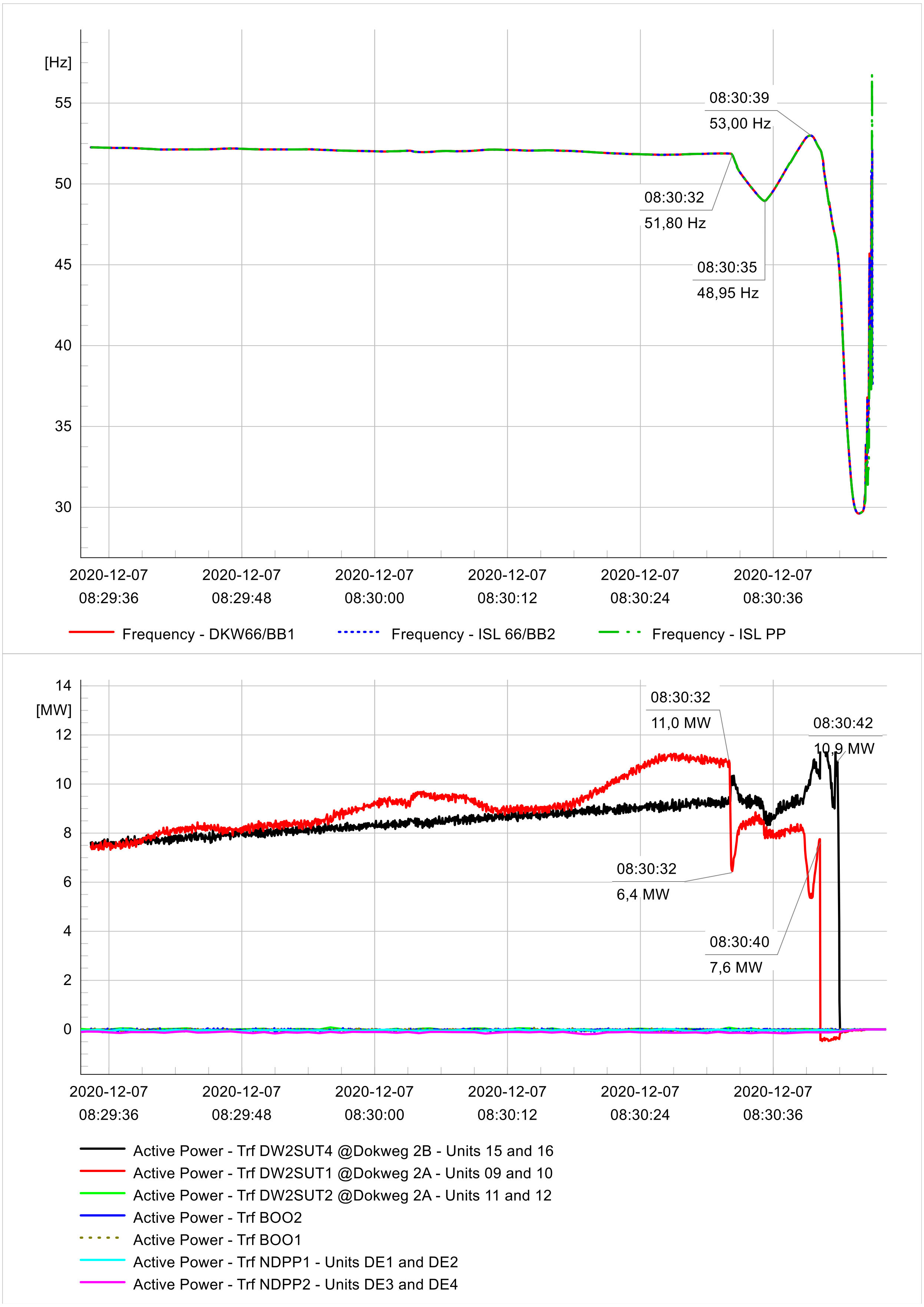


Figure 5: PFM Recordings - Frequency and Active Power – From 8:30:00 to 08:31:00 hours

9 Annex C: SCADA Recordings

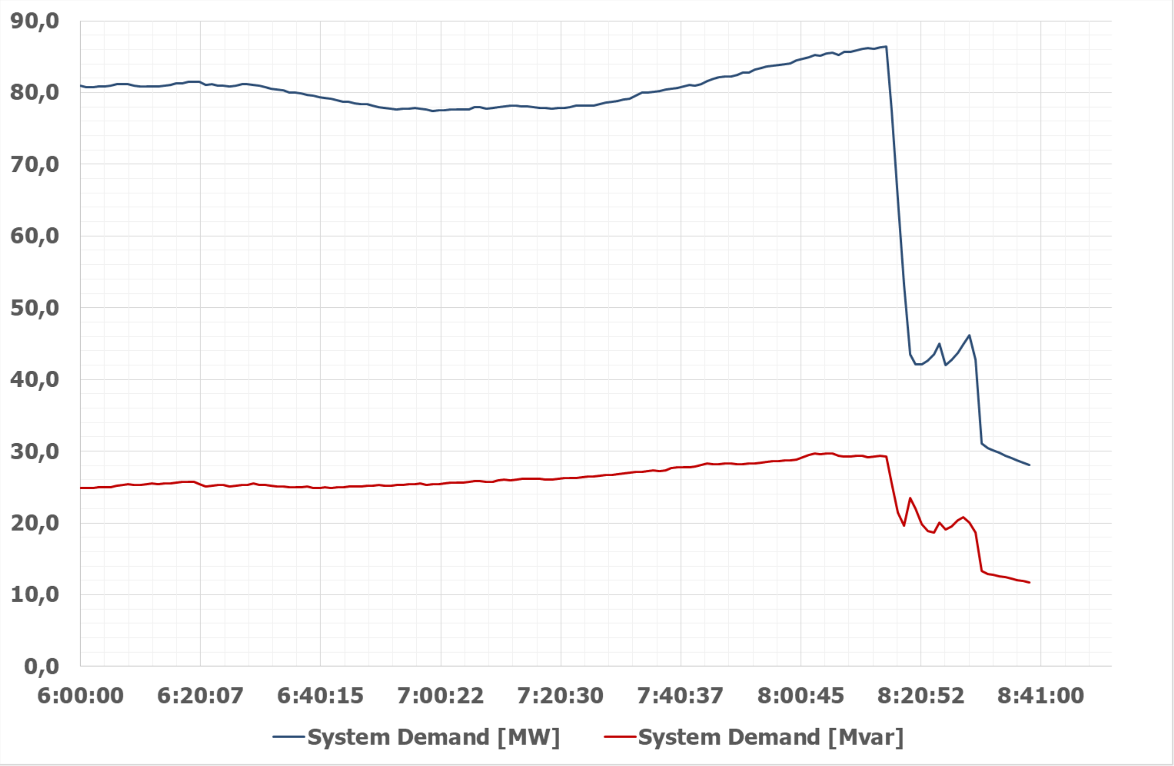


Figure 6: SCADA Recordings – System Demand– From 6:00:00 to 08:41:00 hours

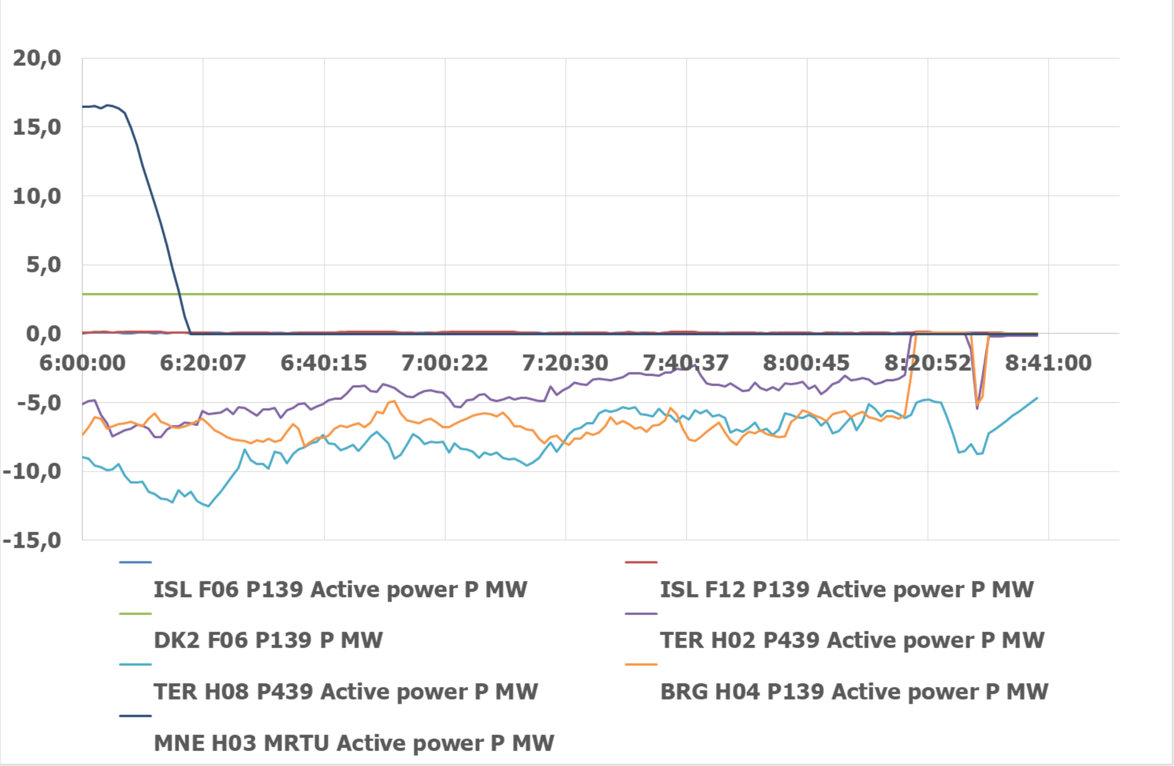


Figure 7: SCADA Recordings – Generation Output Power [MW]– From 6:00:00 to 08:41:00 hours

P2029
Security of Supply in Curaçao's Electricity System

Analysis of Grid Events - 10.12.2020

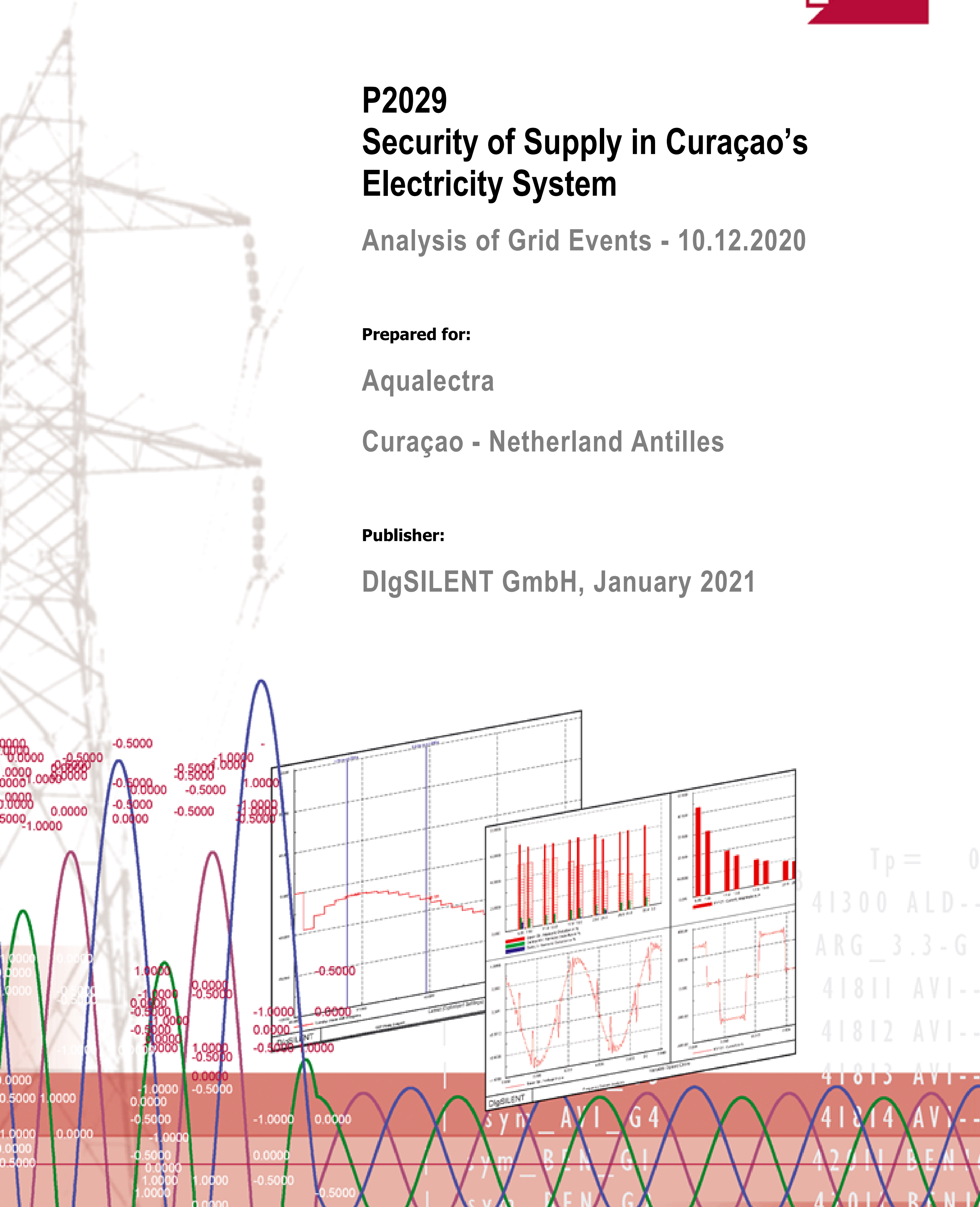
Prepared for:

Aqualectra

Curaçao - Netherland Antilles

Publisher:

DIgSILENT GmbH, January 2021



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Document Revision History

Version	Status	File	Issued	Prepared by
01	Draft Version	P2029_Aqualectra_Event-Analysis-20201210_REPTRIP02_R01_V01.docx	23.12.2020	J. Gómez
02	Final Version	P2029_Aqualectra_Event-Analysis-20201210_REPTRIP02_R01_V02.docx	19.01.2021	J. Gómez

Table of Contents

List of Abbreviations

PFM	DIgSILENT Monitoring System
SCADA	Supervisory Control and Data Acquisition
UFLS	Under-Frequency Load-Shedding

1 Introduction

On the 10th of December 2020, approximately at 15:14:35 hours, the power system of Aqualectra experienced a blackout. This report includes the analysis of the sequence of events and the results of the preliminary investigations.

2 Monitoring Systems

Several PFM monitoring systems are installed in the main substations of Aqualectra. However, some of them are not accessible and/or did not record the events of interest on the specific data subject to analysis. The following table shows an overview of their status at the time of the events:

Table 2-1: DIgSILENT Monitoring systems – Aqualectra - Curaçao

#	**Substation**	**Type**	**Status (10.12.2020)**
1	Isla NDPP	PFM300	Online, with recordings of the events available
2	Isla 66 kV	PFM300	Online, with recordings of the events available
3	Dokweg 1	PFM300	Not accessible
4	Dokweg 2	PFM300	Not accessible
5	Dokweg 66 kV	PFM300	Online, with recordings of the events available
6	Mundo Nobo	PFM2	Not accessible
7	Tera Cora	PFM2	Not accessible
8	Playa Canoa	PFM2	Not accessible

In addition, there is a SCADA system from Aqualectra which records measurements from multiple locations in the power system.

Annex A includes detailed information from the measurement signals available.

3 Recordings

The following recordings have been used in the analysis of the events:

Table 3-1: Recordings used in the analysis of the events

File Name	**Source**	**Resolution**	**Duration**
Generation 202011_202012_1min.xlsx [1]	SCADA	1-minute	24/11/2020 00:00 12/11/2020 03:45
Load 202011_202012_1min.xlsx [2]	SCADA	1-minute	24/11/2020 00:00 12/11/2020 03:45
Monitor_2020.12.10 23.59.59.dat [3]	PFM300 – Dokweg 66 kV	1-second	10/12/2020 00:00:00.000 11/12/2020 00:00:00.000
RMS_2020.12.10 15.14.35.dat [4]	PFM300 – Dokweg 66 kV	20-milisecond	10/12/2020 15:13:35.440 10/12/2020 15:14:35.440
Monitor_2020.12.10 23.59.59.dat [5]	PFM300 – Isla 66 kV	1-second	10/12/2020 00:00:00.000 11/12/2020 00:00:00.000
RMS_2020.12.10 15.14.35.dat [6]	PFM300 – Isla 66 kV	20-milisecond	10/12/2020 15:13:35.440 10/12/2020 15:14:35.440
Monitor_2020.12.10 23.59.59.dat [7]	PFM300 – Isla NDPP	1-second	10/12/2020 00:00:00.000 11/12/2020 00:00:00.000
RMS_2020.12.10 15.14.35.dat [8]	PFM300 – Isla NDPP	20-milisecond	10/12/2020 15:13:35.440 10/12/2020 15:14:35.440

4 Timeline of Events

The generation dispatch in the power system at 15:11:00 hours, prior to the blackout (15:14:35 hours), is shown in Table 4-1. The total demand at this time is 90,9 MW. Power flow across line Dokweg 66kV-Parera is zero, hence it is assumed that this line is not in operation. Power flow across line Dokweg 66kV-Isla 66 kV is 60,6 MW, which seems to be the only line connecting Dokweg 2A and 2B power plants to the rest of Aqualectra power system.

Table 4-1: Generation dispatch at 15:11:00 hours

Power Plant	**Units**	**Output Power [MW]**
Dokweg 2A	DG09	24,6
	DG10	
	DG11	
	DG12	
Dokweg 2B	DG15	18,2
	DG16	
Dokweg 2B	DG13	n/a
	DG14	n/a
NDPP	DE1	0 (offline)
	DE2	4,9
	DE3	5,0
	DE4	5,1
Dokweg1	DG1	n/a
	DG2	n/a
	DG3	n/a
	DG4	n/a
	DG5	n/a
	DG6	n/a
	DG7	n/a
Mundo Nobo	GT2	5,3
BOO	-	n/a (online)
Wind Farm Playa Canoa	-	3,6
Wind Farm Tera Cora 1	-	4,0
Wind Farm Tera Cora 2	-	8,6

Based on the available recordings from the PFM and the SCADA, the sequence of events is shown in Table 4-2. Annexes B and C include dedicated plots of the recordings used for the analysis of the events.

Table 4-2: Timeline of events

Time	Event
14:30:00 - 15:12:00	Power system operates stable at nominal frequency and with voltages close to nominal values (0,98-1,04 p.u.). Output power from diesel units in Dokweg 2A and 2B increase gradually during this time, following the slow increase in system demand. This continuous modulation suggests that these power plants are operating in isochronous mode.
15:12:00 – 15:14:35	Diesel units in Dokweg 2B start reducing gradually their output power, while diesel units in Dokweg 2A start increasing it correspondingly. It is not clear the root cause for this change in the trend observed before. It could be due to a manual changeover in the diesel units in Dokweg 2B from isochronous mode to constant power.
15:14:35	Trip of line Dokweg 66kV-Isla 66 kV when the power flow is 62 MW. The root cause is the activation of the overcurrent protection P139 in this line, adjusted at 0,88*In (~63 MW), which is consistent with the power flow measured at the line right before tripping [9]. These settings trip the line when the current exceeds 88% of the rated current, i.e. before reaching 100% loading of the line. More information about the protection settings is included in Annex D. Since this is the only line connecting Dokweg 2A and 2B power plants to the rest of Aqualectra power system, both systems separate and different frequencies are observed: fast increase in the Dokweg 2A and 2B side, and fast decay in Isla 66 kV and Isla NDPP. As a result, UFLS is triggered and substantial loss of demand is observed. Despite this, system is not capable of stabilising and frequency keeps decreasing, followed by a system blackout.

5 Conclusions and Recommendations

The analysis of the events reveals that the main cause leading to the blackout is the activation of the overcurrent protection of the line Dokweg 66kV-Isla 66 kV, currently adjusted at 0,88*In. This setting does not allow loading of the line above 88% of the rated current.

It is recommended to review these protection settings in order to verify if there is any justified limitation that prevents that, in steady-state conditions, rated current can flow continuously through the line. Moreover, this review should be extended to the rest of protection functions in the line Dokweg 66kV-Isla 66 kV, as well as the other transmission lines in Aqualectra power system.

Moreover, prior to the blackout, line Dokweg 66kV-Parera was out-of-service, hence all generation from Dokweg 2 power plant was being exported through line Dokweg 66kV-Isla 66 kV. This operation has revealed as not N-1 secure with very critical consequences for system stability. Therefore, it is recommended to review operational practices in order to define a maximum power export from Dokweg 2 power plant, especially when line Dokweg 66kV-Parera is out-of-service.

6 References

[1] Aqualectra, “Generation 202011_202012_1min.xlsx”.

[2] Aqualectra, “Load 202011_202012_1min.xlsx”.

[3] “Dokweg 66 kV - Monitor_2020.12.10 23.59.59.dat”.

[4] “Dokweg 66kV - RMS_2020.12.10 15.14.35.dat”.

[5] “Isla 66 kV - Monitor_2020.12.10 23.59.59.dat”.

[6] “Isla 66kV - RMS_2020.12.10 15.14.35.dat”.

[7] “Isla NDPP - Monitor_2020.12.10 23.59.59.dat”.

[8] “Isla NDPP - RMS_2020.12.10 15.14.35.dat”.

[9] DIgSILENT, “Email with Subject: Protection settings 66 kV Isla - 66 kV Dokweg,” 14.01.2021 12:45.

7 Annex A: Measurement Signals

Table 7-1: Measurement signals – PFM at Dokweg 66 kV

Signal	Enabled	Feeder connection	Location
BUS-A	X		DKW66/BB1
BUS-B	X		DKW66/BB2
Spare VT		-	-
Bus coupler	X	-	DKW66/CB0
BOO	X	No cable connected yet (spare)	-
NDPP	X	No cable connected yet (spare)	-
Wartsila	X	Feeder F03	66/11 kV Transformer DW2SUT4 (Dokweg 2B - Units 15 and 16)
Isla 1	X	Feeder F04	ISLA-Dokweg2
Dokweg II-T1	X	Feeder F05	66/11 kV Transformer DW2SUT1 (Dokweg 2A - Units 09 and 10)
Parera	X	Feeder F07	Dokweg2-Parera
Weis	X	No cable connected yet (spare)	-
Nijlweg	X	No cable connected yet (spare)	-
Spare CT 1		Feeder F10	66/11 kV Transformer DW2SUT3 (Dokweg 2B - Units 13 and 14)
Isla 2	X	No cable connected yet (spare)	-
Dokweg II-T2	X	Feeder F12	66/11 kV Transformer DW2SUT2 (Dokweg 2A - Units 11 and 12)
Spare CT 2		-	-
Spare CT 3		-	-
Spare CT 4		-	-
Digital Input 1	X	-	-

Table 7-2: Measurement signals – PFM at Isla 66 kV

Signal	Enabled	Feeder connection	Location
Dwarskoppelveld sec.	X	1	ISL 66/CB.L0
spare		2	-
Weis	X	3	ISLA-Weis
BOO-I	X	4	66/30 kV Transformer BOO1
Parera-I	X	5	ISLA-Parera
NDPP-I	X	6	66/11 kV Transformer NDPP1 (Units DE1 and DE2)
Langskoppelveld sec.-I	X	7	-
Langskoppelveld sec.-II	X	8	-
Nijlweg	X	9	ISLA-Nijlweg
BOO-II	X	10	66/30 kV Transformer BOO2

Signal	Enabled	Feeder connection	Location
Parera-II	X	11	ISLA-Dokweg2
NDPP-II	X	12	66/11 kV Transformer NDPP2 (Units DE3 and DE4)
Dwarskoppelveld sec.-II	X	13	ISL 66/CB.R0

Table 7-3: Measurement signals – PFM at Isla NDPP

Signal	Enabled	Feeder connection	Location
Generator 4	x	K08	DE4
Generator 3	x	K07	DE3
Generator 2	x	K04	DE2
Generator 1	x	K03	DE1

Table 7-4: Measurement signals – SCADA

Signal	Voltage	Frequency	Active Power	Reactive Power	Location
ISL F06			x	x	NDPP1 (DE1 and DE2)
ISL F12			x	x	NDPP2 (DE3 and DE4)
DK2 F06	x		x	x	-
DK2A K00	x	x			Dokweg 2A plant BB1/BB2
DK2B K00	x	x			Dokweg 2B plant BB1/BB2
TER H02			x	x	Tera Cora-Windfarm Tera Cora 1
TER H08			x	x	Tera Cora-Windfarm Tera Cora 2
BRG H04			x	x	Brievengat-Windfarm Playa Canoa
BRG H01	x				Brievengat 30kV BB1/BB2
PSA H01	x				Parasasa 30kV BB1/BB2
JPL H01	x				Julianaplein 30kV BB1/BB2
MNE H03			x	x	GT2SUT

8 Annex B: PFM Recordings

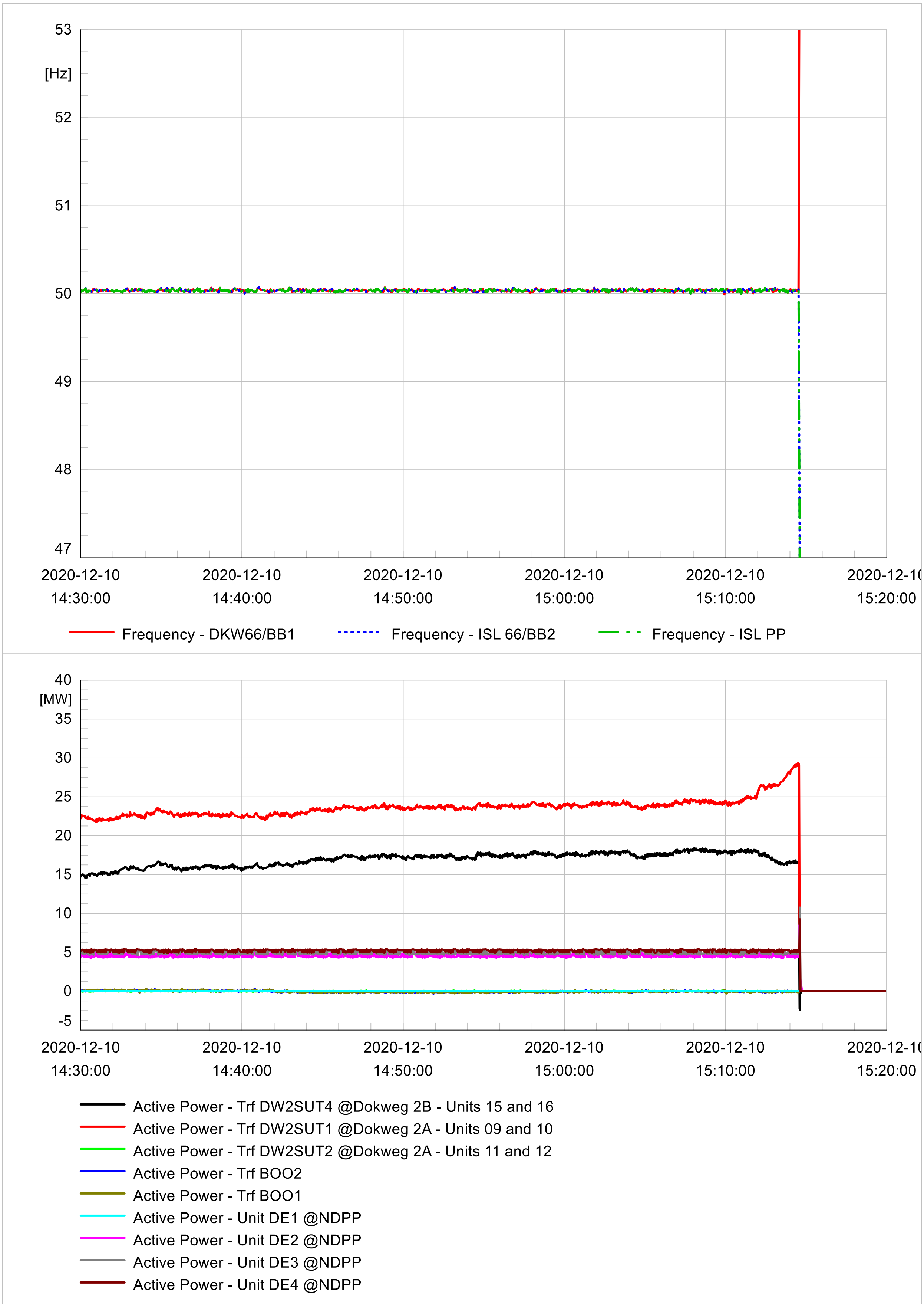


Figure 1: PFM Recordings - Frequency and Active Power – From 14:30:00 to 15:20:00 hours

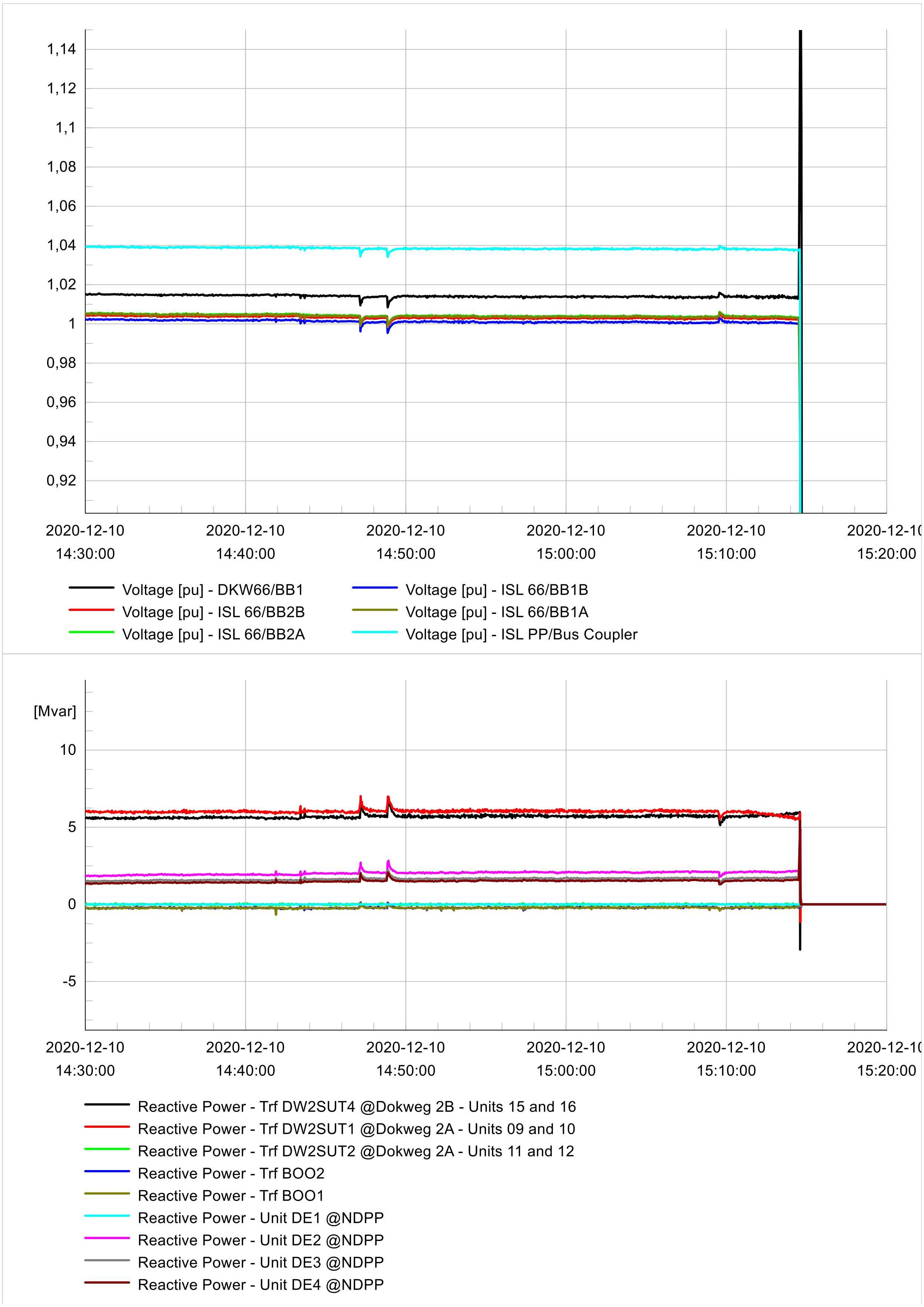


Figure 2: PFM Recordings - Voltage and Reactive Power – From 14:30:00 to 15:20:00 hours

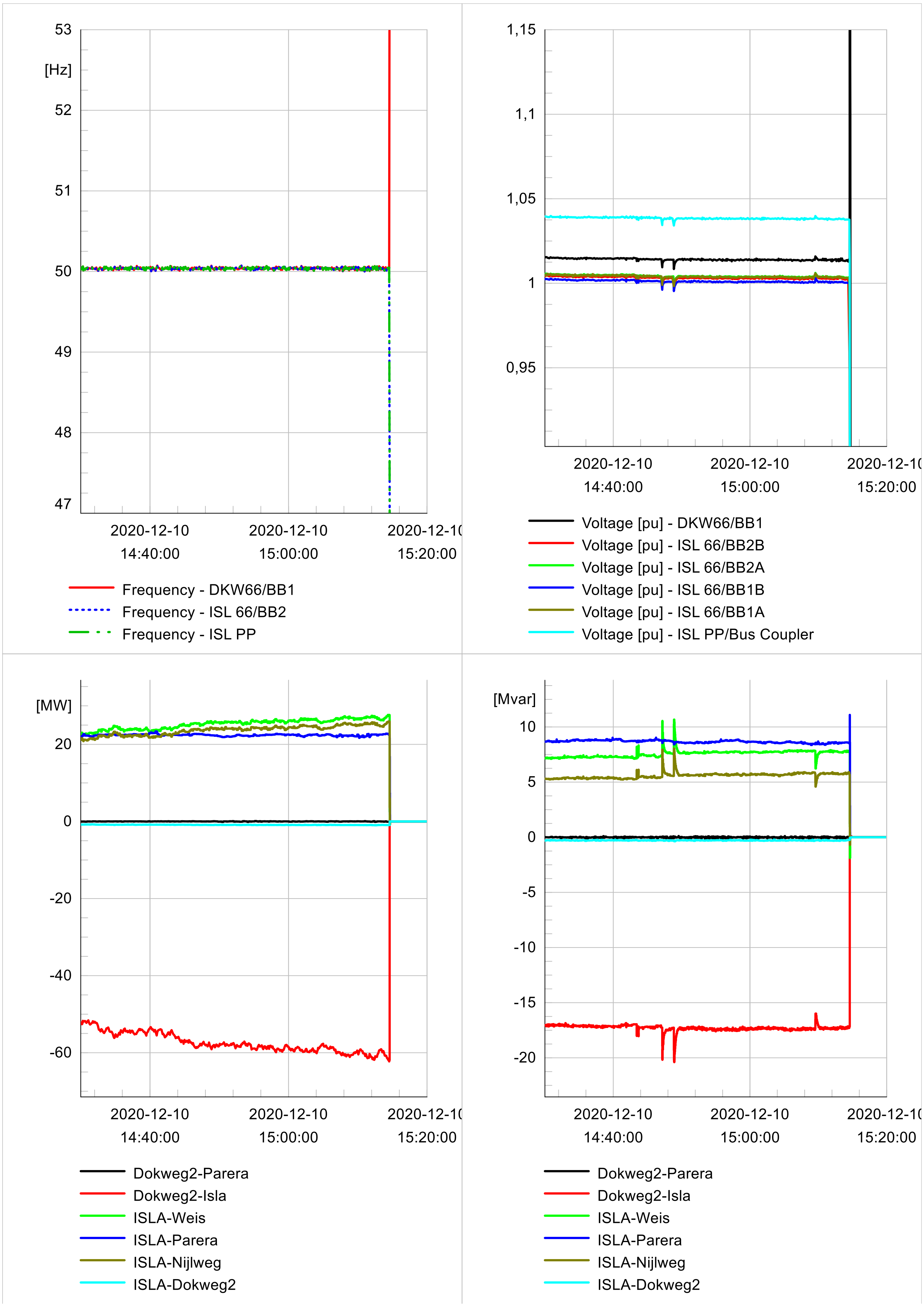


Figure 3: PFM Recordings – Frequency, Voltage and Power across Lines– From 14:30:00 to 15:20:00 hours

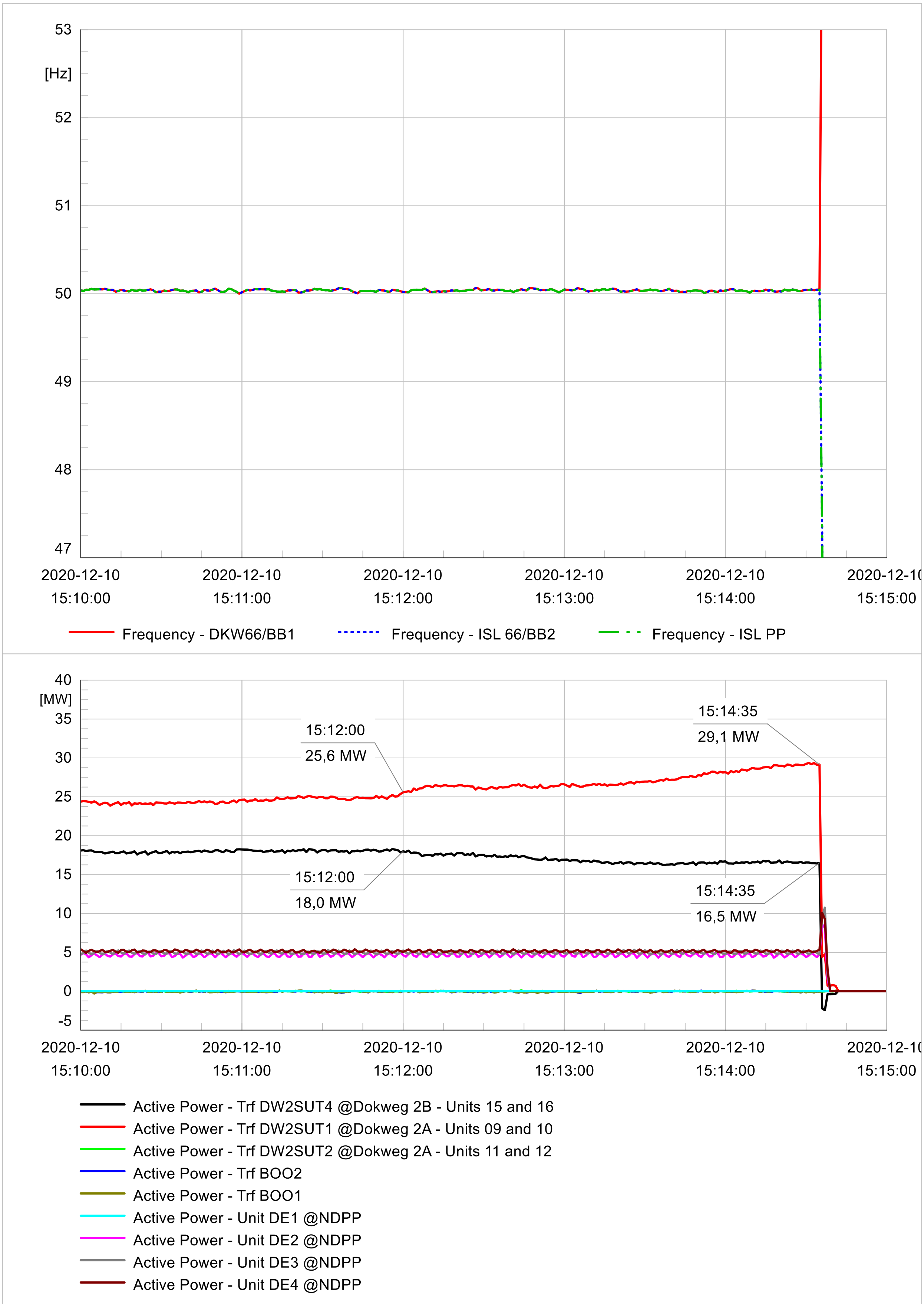


Figure 4: PFM Recordings - Frequency and Active Power – From 15:10:00 to 15:15:00 hours

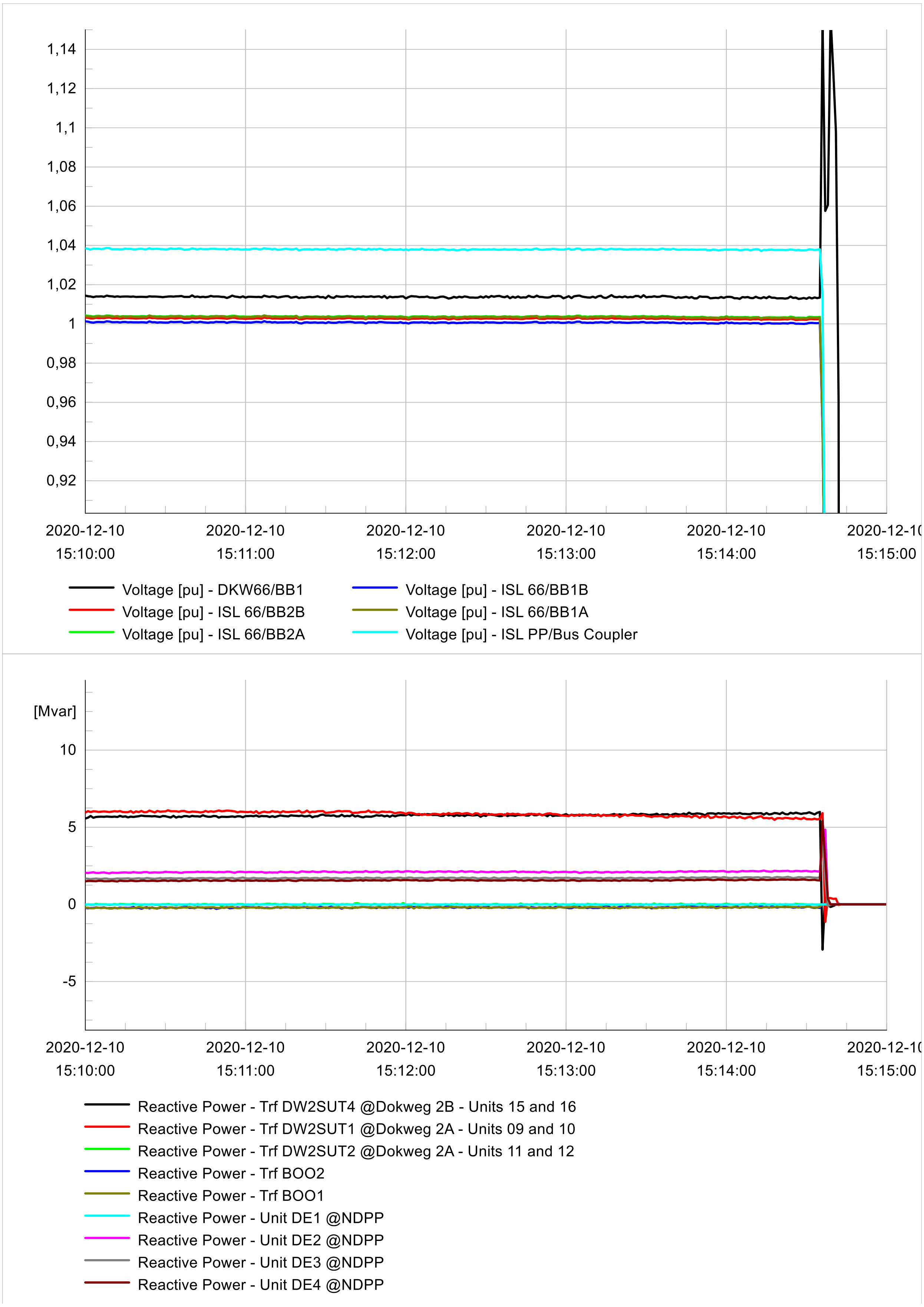


Figure 5: PFM Recordings - Voltage and Reactive Power – From 15:10:00 to 15:15:00 hours

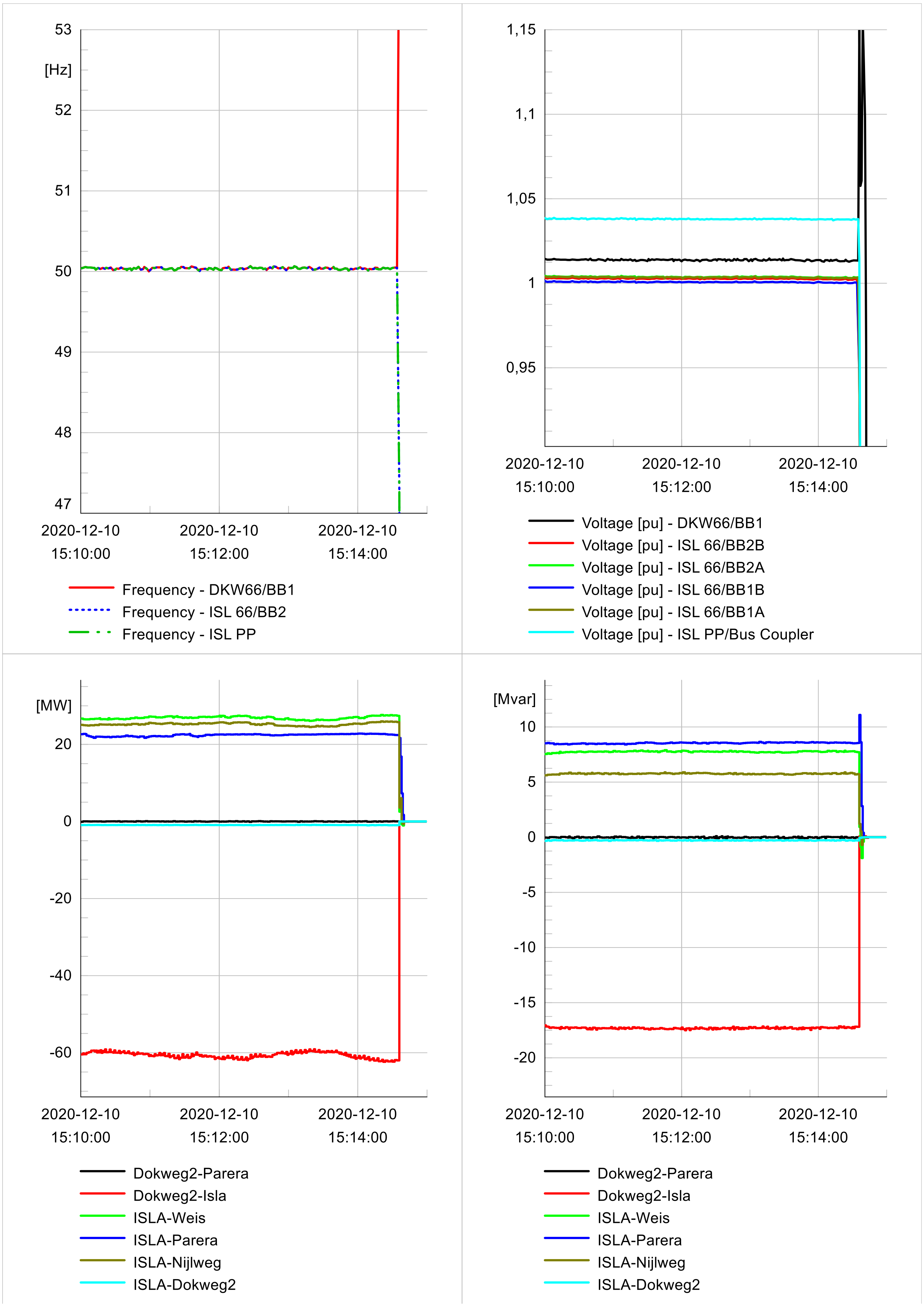


Figure 6: PFM Recordings – Frequency, Voltage and Power across Lines– From 15:10:00 to 15:15:00 hours

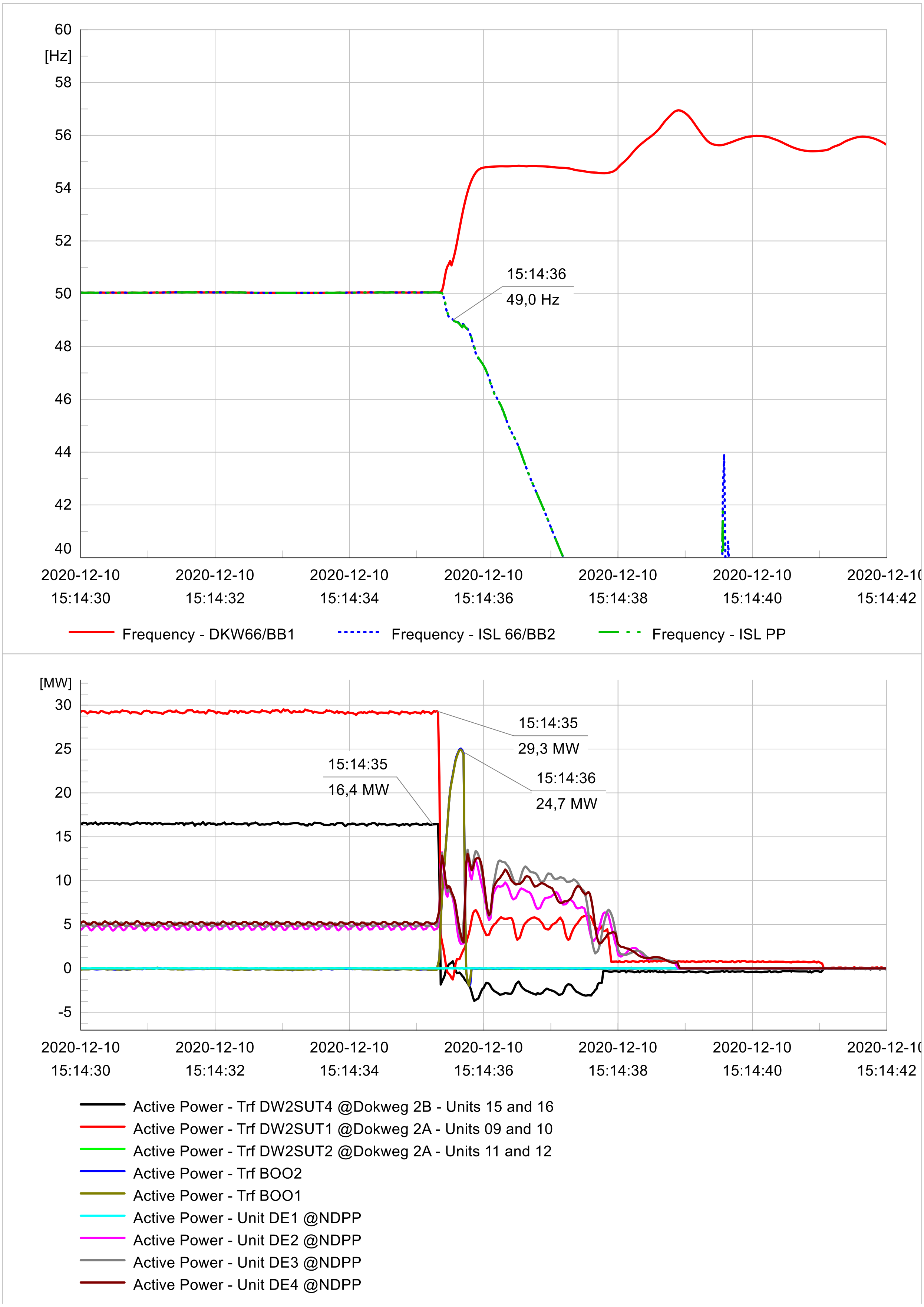


Figure 7: PFM Recordings - Frequency and Active Power – From 15:14:30 to 15:14:42 hours

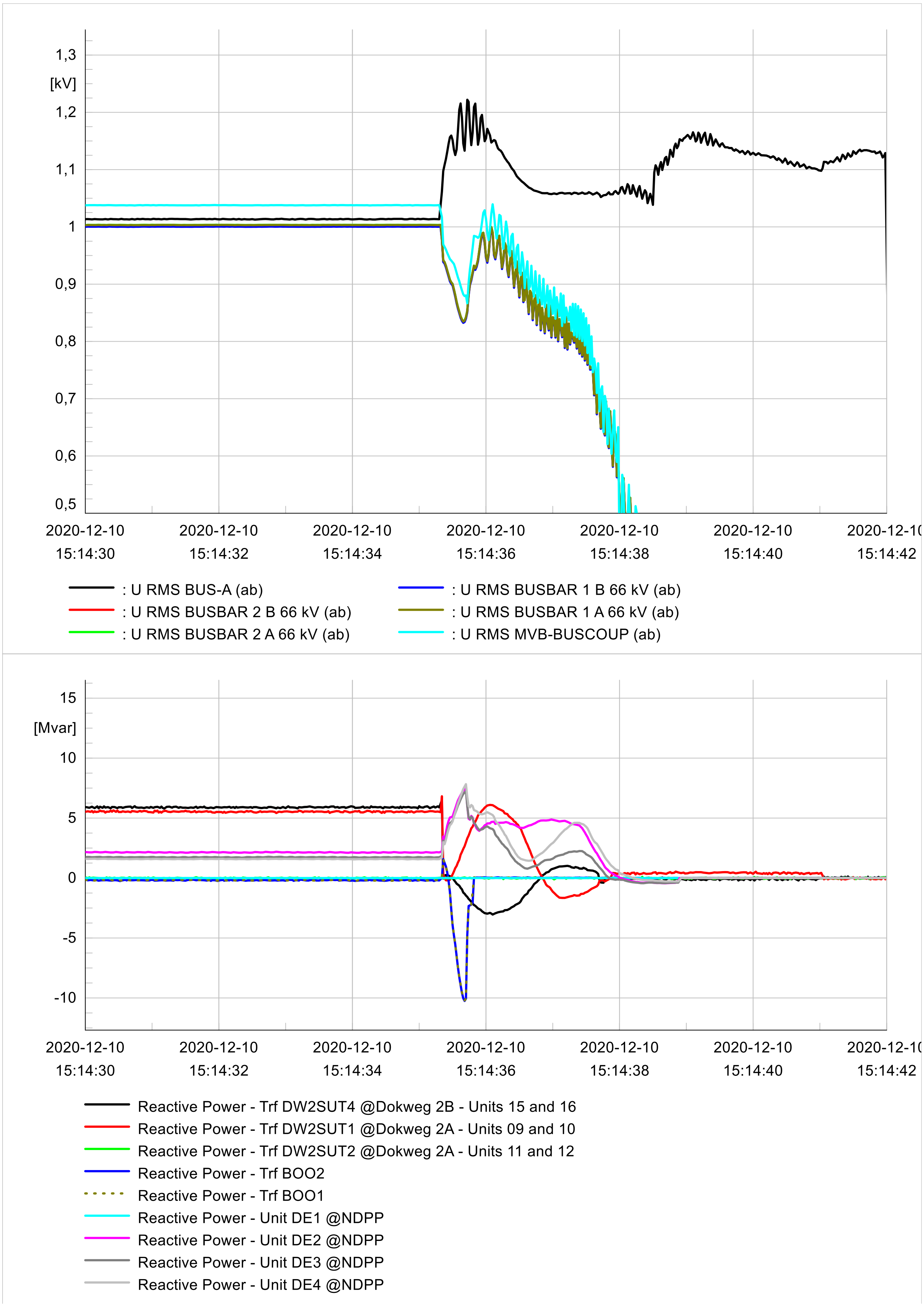


Figure 8: PFM Recordings - Voltage and Reactive Power – From 15:14:30 to 15:14:42 hours

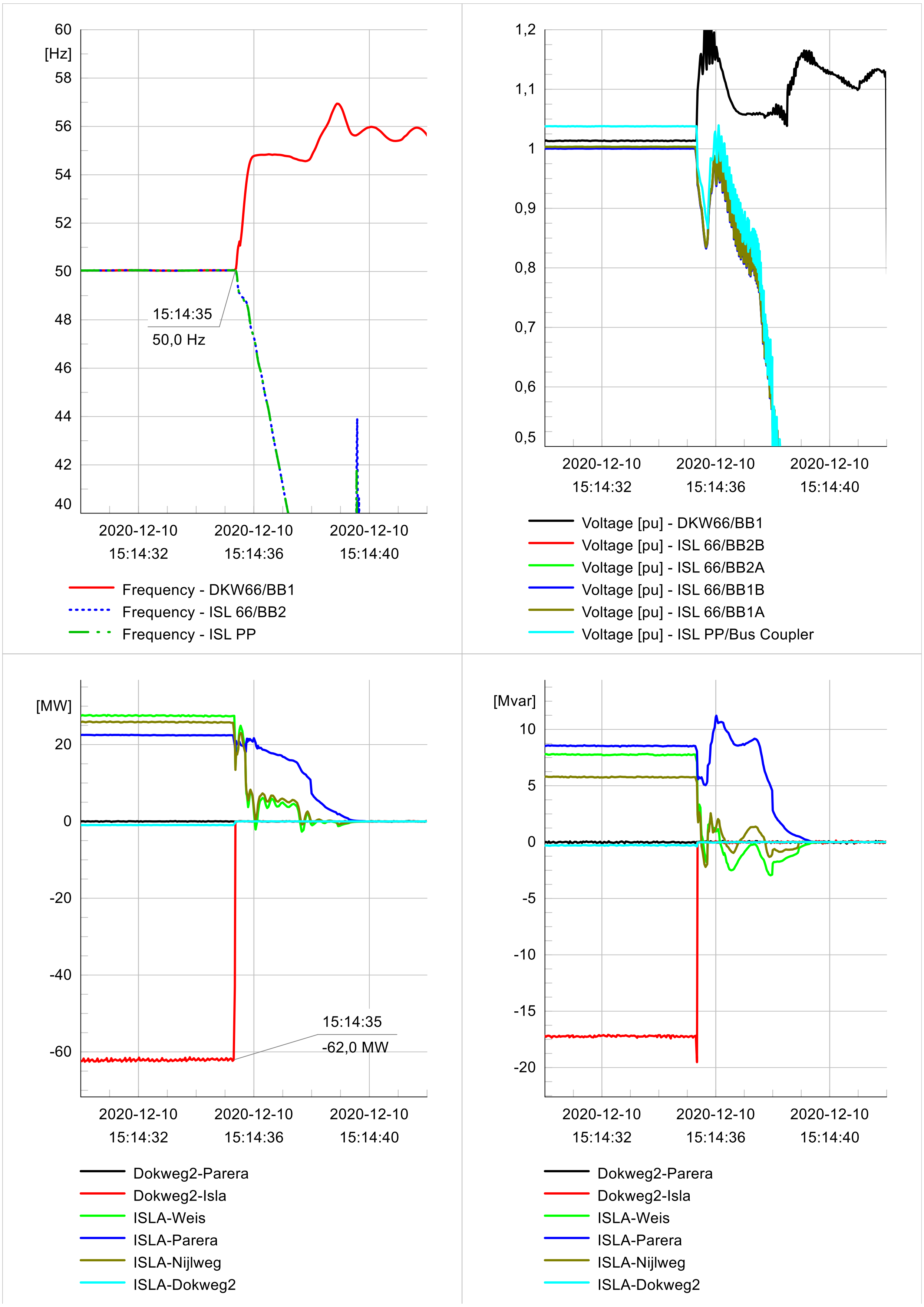


Figure 9: PFM Recordings – Frequency, Voltage and Power across Lines– From 15:14:30 to 15:14:42 hours

9 Annex C: SCADA Recordings

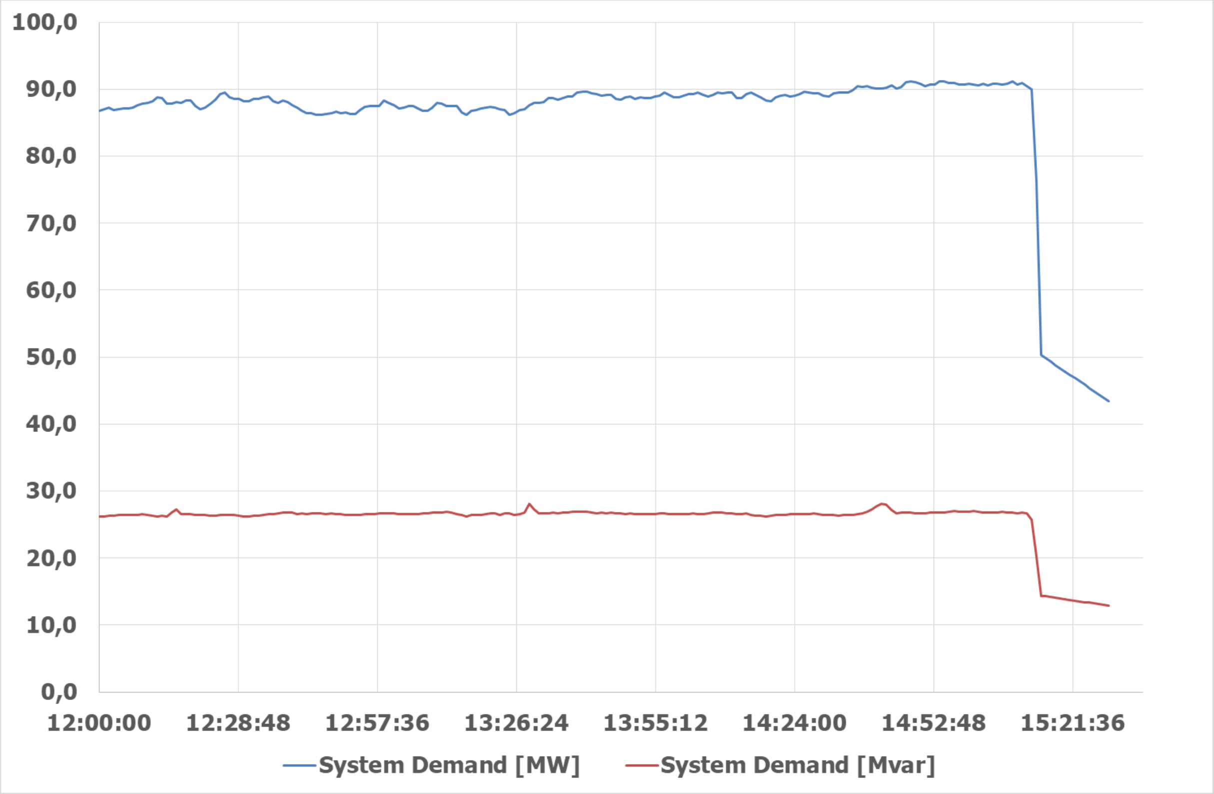


Figure 10: SCADA Recordings – System Demand– From 12:00:00 to 15:22:00 hours

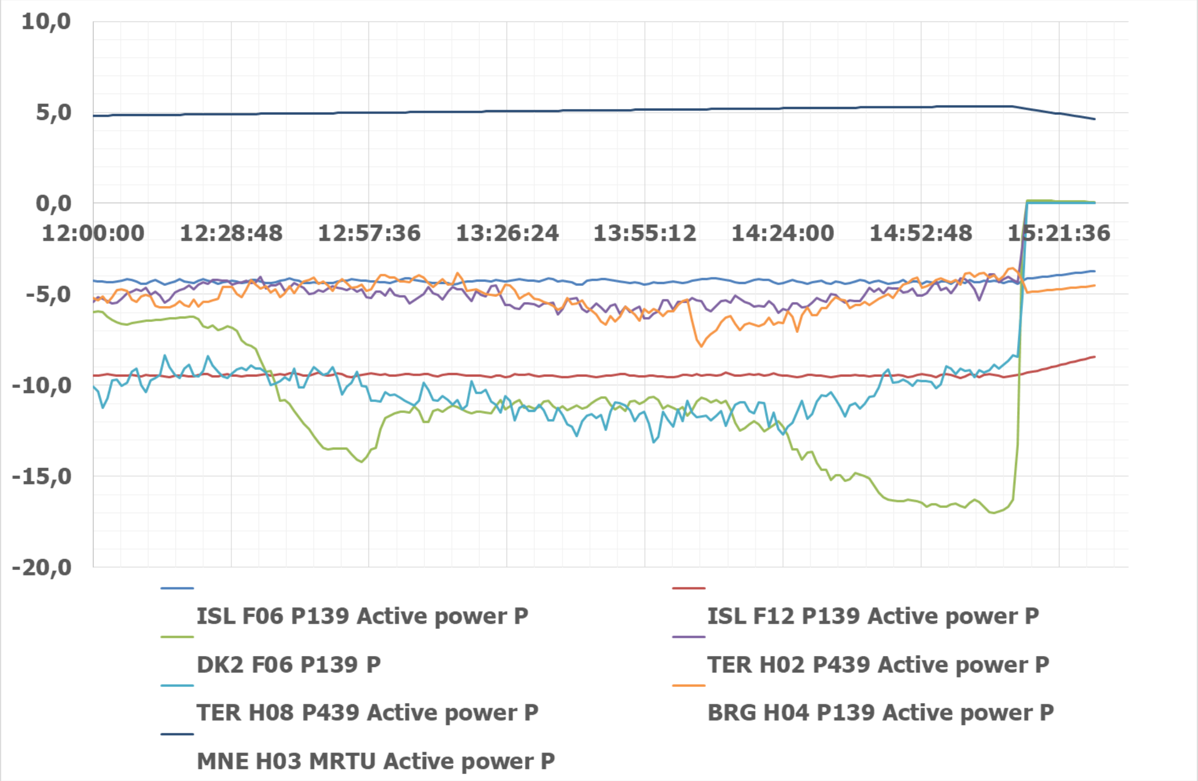


Figure 11: SCADA Recordings – Generation Output Power [MW]– From 12:00:00 to 15:22:00 hours

10 Annex D: Overcurrent Protection (P139) Settings in Line Dokweg 66kV-Isla 66 kV

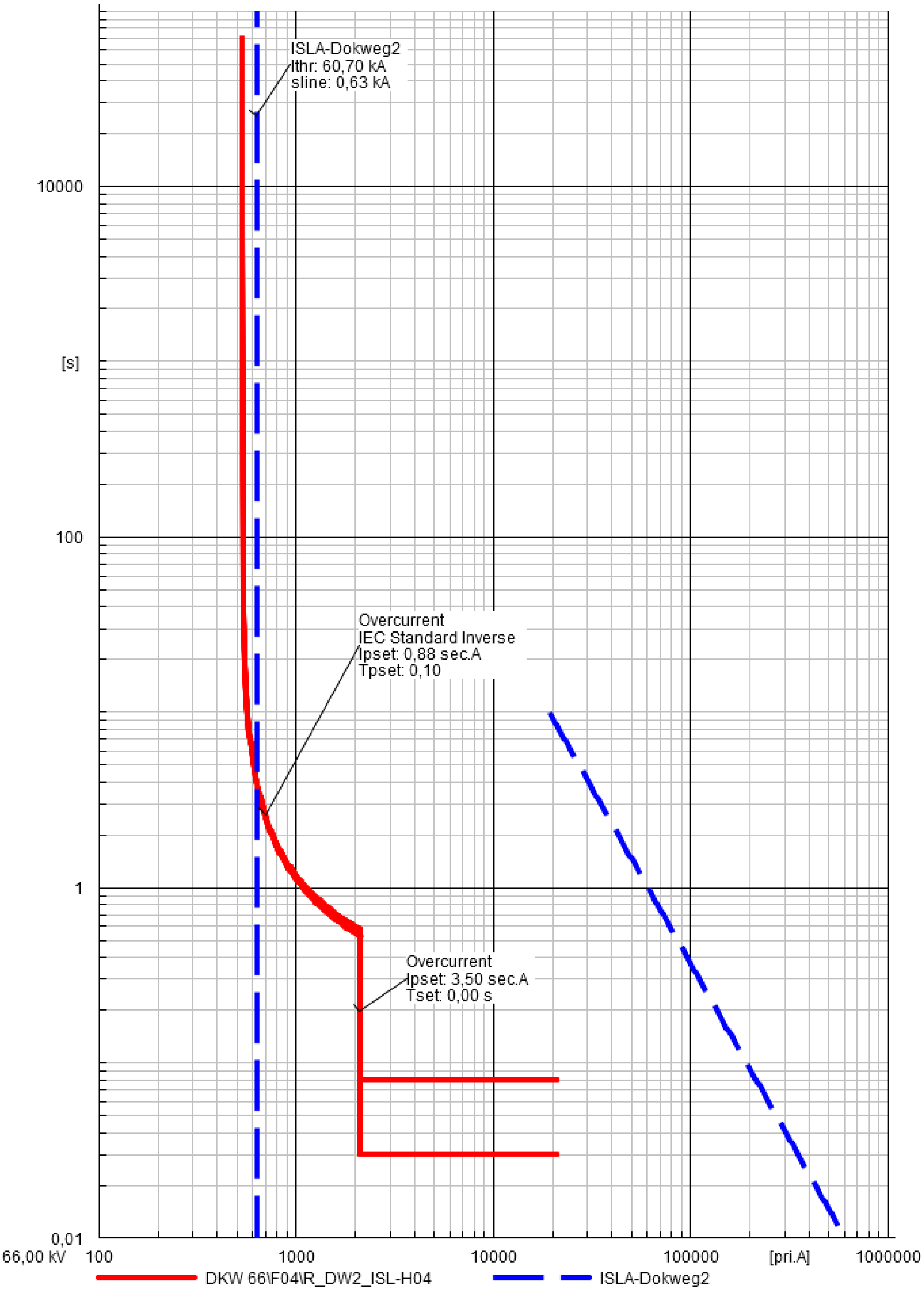


Figure 12: Overcurrent Protection (P139) Settings in Line Dokweg 66kV-Isla 66 kV [9]

P2029
Security of Supply in Curaçao's Electricity System

Analysis of Grid Events - 12.12.2020

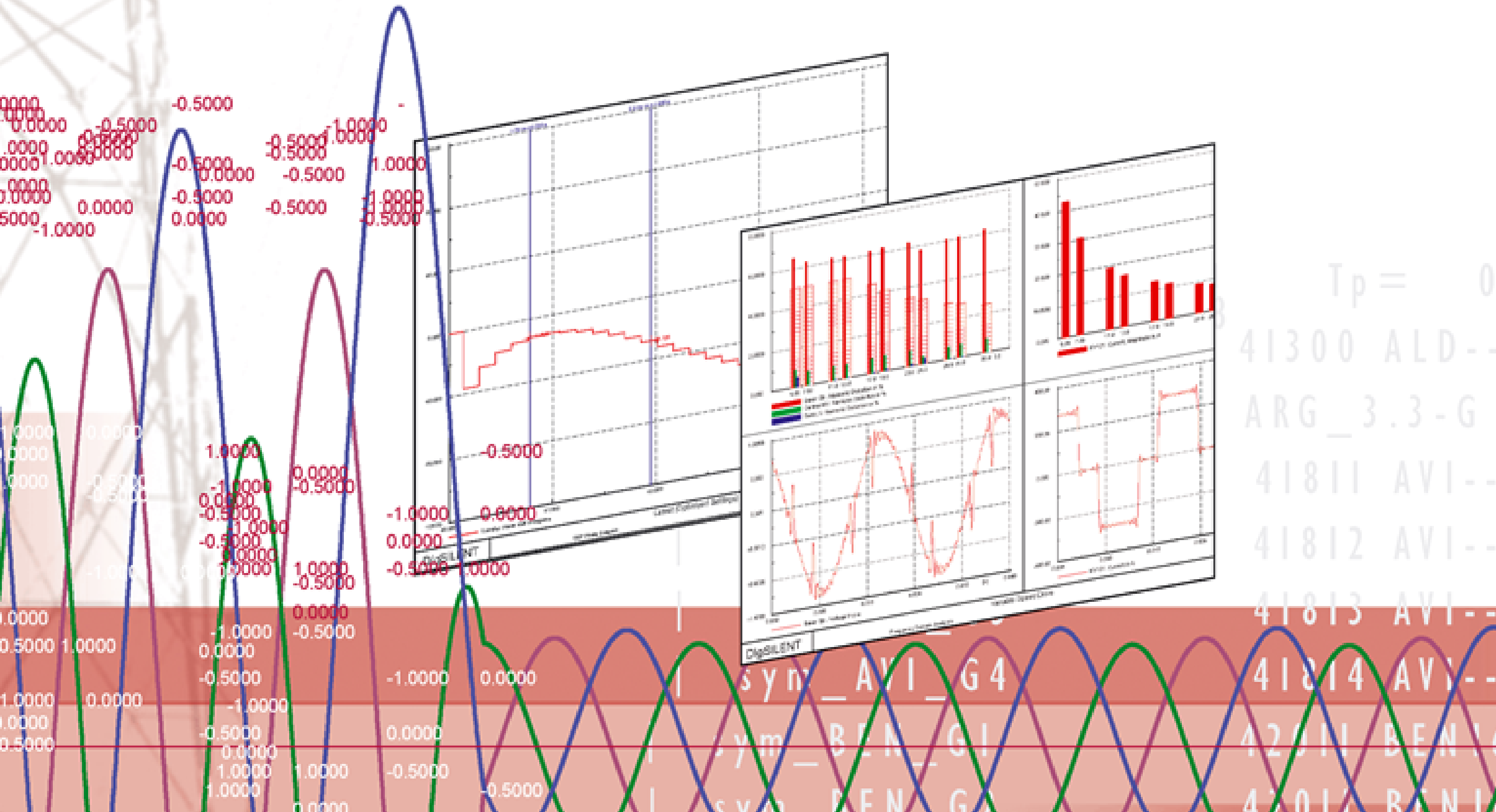
Prepared for:

Aqualectra

Curaçao - Netherland Antilles

Publisher:

DIgSILENT GmbH, January 2021



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Document Revision History

Version	Status	File	Issued	Prepared by
01	Draft Version	P2029_Aqualectra_Event-Analysis-20201212_REPTRIP03_R01_V01.docx	28.01.2021	J. Gómez

Table of Contents

List of Abbreviations

PFM	DIgSILENT Monitoring System
SCADA	Supervisory Control and Data Acquisition
UFLS	Under-Frequency Load-Shedding

1 Introduction

On the 12th of December 2020, approximately at 19:02:32 hours, the power system of Aqualectra experienced a blackout. This report includes the analysis of the sequence of events and the results of the preliminary investigations.

2 Monitoring Systems

Several PFM monitoring systems are installed in the main substations of Aqualectra. However, some of them were not accessible and/or did not record the events of interest on the specific date subject of analysis. The following table shows an overview of their status at the time of the events:

Table 2-1: DIgSILENT Monitoring systems – Aqualectra - Curaçao

#	Substation	Type	Status (12.12.2020)
1	Isla NDPP	PFM300	Online, with recordings of the events available
2	Isla 66 kV	PFM300	Online, with recordings of the events available
3	Dokweg 1	PFM300	Not accessible
4	Dokweg 2	PFM300	Not accessible
5	Dokweg 66 kV	PFM300	Online, with recordings of the events available
6	Mundo Nobo	PFM2	Not accessible
7	Tera Cora	PFM2	Not accessible
8	Playa Canoa	PFM2	Not accessible

In addition, there is a SCADA system from Aqualectra which records measurements from multiple locations in the power system.

Annex A includes detailed information of the measurement signals available.

3 Recordings

The following recordings have been used in the analysis of the events:

Table 3-1: Recordings used in the analysis of the events

File Name	**Source**	**Resolution**	**Duration**
Generation 20201124_20201222.xlsx [1]	SCADA	1-minute	24/11/2020 00:00 23/12/2020 23:59
Load 202011_202012_1min.xlsx [2]	SCADA	1-minute	24/11/2020 00:00 23/12/2020 23:59
Monitor_2020.12.12 23.59.59.dat [3]	PFM300 – Dokweg 66 kV	1-second	12/12/2020 00:00:00.000 13/12/2020 00:00:00.000
RMS_2020.12.10 15.14.35.dat [4]	PFM300 – Dokweg 66 kV	20-milisecond	12/12/2020 19:01:32.280 12/12/2020 19:02:32.280
Monitor_2020.12.12 23.59.59.dat [5]	PFM300 – Isla 66 kV	1-second	12/12/2020 00:00:00.000 13/12/2020 00:00:00.000
RMS_2020.12.10 15.14.35.dat [6]	PFM300 – Isla 66 kV	20-milisecond	12/12/2020 19:01:32.240 12/12/2020 19:02:32.240
Monitor_2020.12.12 23.59.59.dat [7]	PFM300 – Isla NDPP	1-second	12/12/2020 00:00:00.000 13/12/2020 00:00:00.000
RMS_2020.12.10 15.14.35.dat [8]	PFM300 – Isla NDPP	20-milisecond	12/12/2020 19:01:32.360 12/12/2020 19:02:32.360

4 Timeline of Events

The generation dispatch in the power system at 19:00:00 hours, prior to the blackout (19:02:32 hours), is shown in Table 4-1. The total demand at this time is 85,7 MW. Power flow across line Dokweg 66kV-Parera is zero, hence it is assumed that this line is not in operation. Power flow across line Dokweg 66kV-Isla 66 kV is 59,7 MW, which seems to be the only line connecting Dokweg 2A and 2B power plants to the rest of Aqualectra power system.

Table 4-1: Generation dispatch at 15:11:00 hours

Power Plant	**Units**	**Output Power [MW]**
Dokweg 2A	DG09	31,9
	DG10	
	DG11	
	DG12	
Dokweg 2B	DG15	8,5
	DG16	
Dokweg 2B	DG13	n/a
	DG14	n/a
NDPP	DE1	0 (offline)
	DE2	3,5
	DE3	5,1
	DE4	0 (offline)
Dokweg1	DG1	n/a
	DG2	n/a
	DG3	n/a
	DG4	n/a
	DG5	n/a
	DG6	n/a
	DG7	n/a
Mundo Nobo	GT2	16,2
BOO	-	n/a (offline)
Wind Farm Playa Canoa	-	4,9
Wind Farm Tera Cora 1	-	3,7
Wind Farm Tera Cora 2	-	6,6

Based on the available recordings from the PFM and the SCADA, the sequence of events is shown in Table 4-2. Annexes B and C include dedicated plots of the recordings used for the analysis of the events.

Table 4-2: Timeline of events

Time	**Event**
18:20:00 - 18:48:00	Power system operates stable at nominal frequency and with voltages close to nominal values (1,02-1,03 p.u.). Output power from diesel units in Dokweg 2A and 2B shows continuous modulation, which suggests that these power plants are operating in isochronous mode.
18:48:00 – 19:02:32	Power flow across line Dokweg 66kV-Isla 66 kV gradually increases from 50 MW up to above 60 MW, which is consistent with an increase in the power production in Dokweg 2A and 2B.
19:02:32	Trip of line Dokweg 66kV-Isla 66 kV when the power flow is 63,8 MW. Subsequent investigations [9] have determined that the root cause is the activation of the overcurrent protection P139 in this line, adjusted at 0,88*In (~63 MW), which is consistent with the power flow measured at the line right before tripping. These settings trip the line when the current exceeds 88% of the rated current, i.e. before reaching 100% loading of the line. More information about the protection settings is included in Annex D. Since this is the only line connecting Dokweg 2A and 2B power plants to the rest of Aqualectra power system, both systems separate and different frequencies are observed: fast increase in the Dokweg 2A and 2B side, and fast decay in Isla 66 kV and Isla NDPP. As a result, UFLS is triggered and substantial loss of demand is observed. Despite this, system is not capable of stabilising and frequency keeps decreasing, followed by a system blackout.
19:02:32 – 23:59:00	Several unsuccessful trials for power restoration are observed.

5 Conclusions and Recommendations

The blackout on the 12th of December of 2020 shares similar root causes and consequences with the blackout experienced two days earlier (10.12.2020), for which an investigation report is also available [10].

The analysis of the events reveals that the main cause leading to the blackout is the activation of the overcurrent protection of the line Dokweg 66kV-Isla 66 kV, currently adjusted at 0,88*In. This setting does not allow loading of the line above 88% of the rated current.

It is recommended to review these protection settings in order to verify if there is any justified limitation that prevents that, in steady-state conditions, rated current can flow continuously through the line. Moreover, this review should be extended to the rest of protection functions in the line Dokweg 66kV-Isla 66 kV, as well as the other transmission lines in Aqualectra power system.

Prior to the blackout, line Dokweg 66kV-Parera was out-of-service, hence all generation from Dokweg 2 power plant was being exported through line Dokweg 66kV-Isla 66 kV. This operation has revealed as not N-1 secure with very critical consequences for system stability. Therefore, it is recommended to review operational practices in order to define a maximum power export from Dokweg 2 power plant, especially when line Dokweg 66kV-Parera is out-of-service.

6 References

[1] Aqualectra, “Generation 20201124_20201222.xlsx”.

[2] Aqualectra, “Load 202011_202012_1min.xlsx”.

[3] DIgSILENT, “Monitor_2020.12.12 23.59.59.dat”.

[4] DIgSILENT, “RMS_2020.12.10 15.14.35.dat”.

[5] DIgSILENT, “Monitor_2020.12.12 23.59.59.dat”.

[6] DIgSILENT, “RMS_2020.12.10 15.14.35.dat”.

[7] DIgSILENT, “Monitor_2020.12.12 23.59.59.dat”.

[8] DIgSILENT, “RMS_2020.12.10 15.14.35.dat”.

[9] DIgSILENT, “Email with Subject: Protection settings 66 kV Isla - 66 kV Dokweg,” 14.01.2021 12:45.

[10] DIgSILENT, “P2029_Aqualectra_Event-Analysis-20201210_REPTRIP02_R01_V02.pdf”.

7 Annex A: Measurement Signals

Table 7-1: Measurement signals – PFM at Dokweg 66 kV

Signal	Enabled	Feeder connection	Location
BUS-A	X		DKW66/BB1
BUS-B	X		DKW66/BB2
Spare VT		-	-
Bus coupler	X	-	DKW66/CB0
BOO	X	No cable connected yet (spare)	-
NDPP	X	No cable connected yet (spare)	-
Wartsila	X	Feeder F03	66/11 kV Transformer DW2SUT4 (Dokweg 2B - Units 15 and 16)
Isla 1	X	Feeder F04	ISLA-Dokweg2
Dokweg II-T1	X	Feeder F05	66/11 kV Transformer DW2SUT1 (Dokweg 2A - Units 09 and 10)
Parera	X	Feeder F07	Dokweg2-Parera
Weis	X	No cable connected yet (spare)	-
Nijlweg	X	No cable connected yet (spare)	-
Spare CT 1		Feeder F10	66/11 kV Transformer DW2SUT3 (Dokweg 2B - Units 13 and 14)
Isla 2	X	No cable connected yet (spare)	-
Dokweg II-T2	X	Feeder F12	66/11 kV Transformer DW2SUT2 (Dokweg 2A - Units 11 and 12)
Spare CT 2		-	-
Spare CT 3		-	-
Spare CT 4		-	-
Digital Input 1	X	-	-

Table 7-2: Measurement signals – PFM at Isla 66 kV

Signal	Enabled	Feeder connection	Location
Dwarskoppelveld sec.	X	1	ISL 66/CB.L0
spare		2	-
Weis	X	3	ISLA-Weis
BOO-I	X	4	66/30 kV Transformer BOO1
Parera-I	X	5	ISLA-Parera
NDPP-I	X	6	66/11 kV Transformer NDPP1 (Units DE1 and DE2)
Langskoppelveld sec.-I	X	7	-
Langskoppelveld sec.-II	X	8	-
Nijlweg	X	9	ISLA-Nijlweg
BOO-II	X	10	66/30 kV Transformer BOO2

Signal	Enabled	Feeder connection	Location
Parera-II	X	11	ISLA-Dokweg2
NDPP-II	X	12	66/11 kV Transformer NDPP2 (Units DE3 and DE4)
Dwarskoppelveld sec.-II	X	13	ISL 66/CB.R0

Table 7-3: Measurement signals – PFM at Isla NDPP

Signal	Enabled	Feeder connection	Location
Generator 4	x	K08	DE4
Generator 3	x	K07	DE3
Generator 2	x	K04	DE2
Generator 1	x	K03	DE1

Table 7-4: Measurement signals – SCADA

Signal	Voltage	Frequency	Active Power	Reactive Power	Location
ISL F06			x	x	NDPP1 (DE1 and DE2)
ISL F12			x	x	NDPP2 (DE3 and DE4)
DK2 F06	x		x	x	-
DK2A K00	x	x			Dokweg 2A plant BB1/BB2
DK2B K00	x	x			Dokweg 2B plant BB1/BB2
TER H02			x	x	Tera Cora-Windfarm Tera Cora 1
TER H08			x	x	Tera Cora-Windfarm Tera Cora 2
BRG H04			x	x	Brievengat-Windfarm Playa Canoa
BRG H01	x				Brievengat 30kV BB1/BB2
PSA H01	x				Parasasa 30kV BB1/BB2
JPL H01	x				Julianaplein 30kV BB1/BB2
MNE H03			x	x	GT2SUT

8 Annex B: PFM Recordings

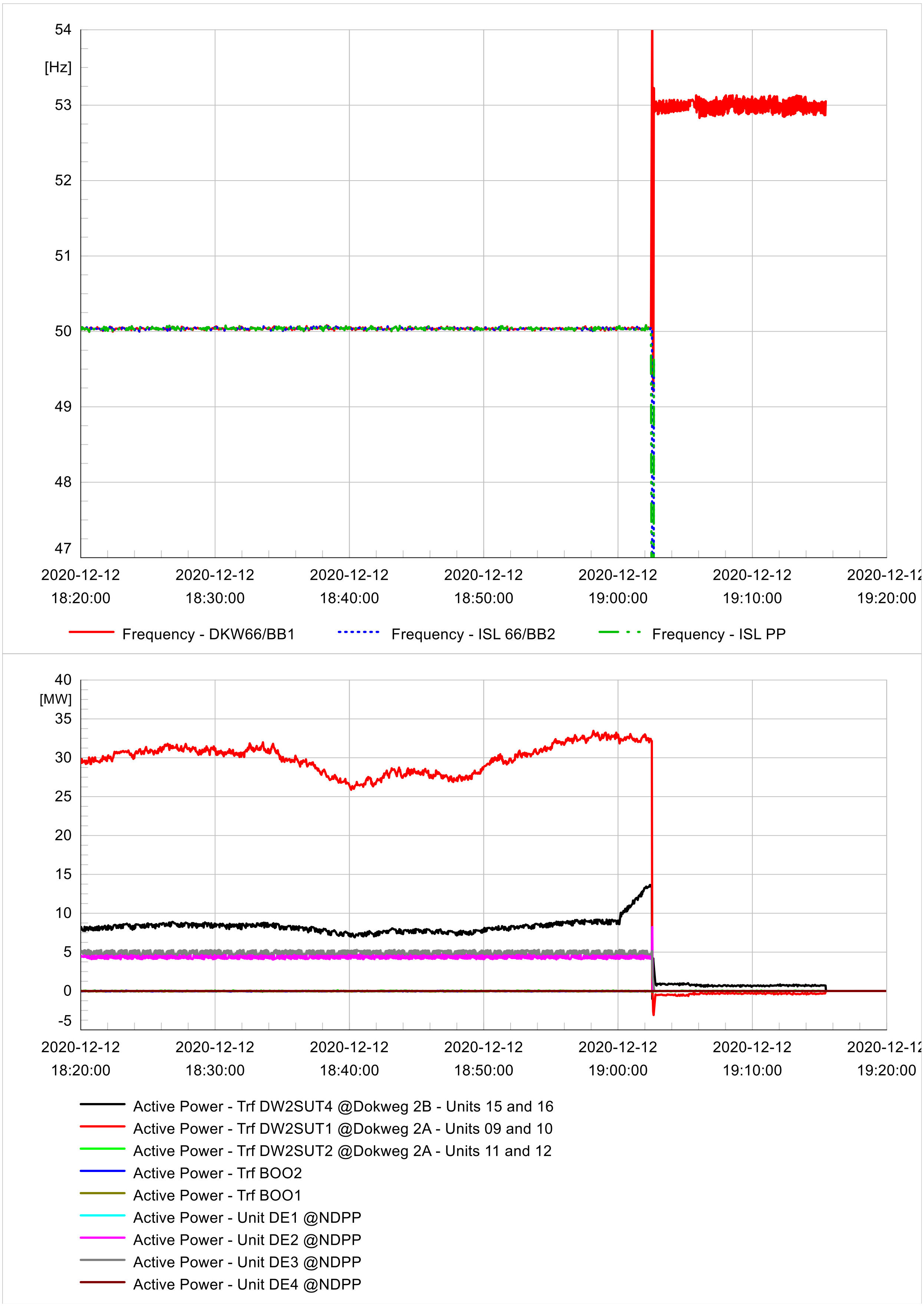


Figure 1: PFM Recordings - Frequency and Active Power – From 18:20:00 to 19:20:00 hours

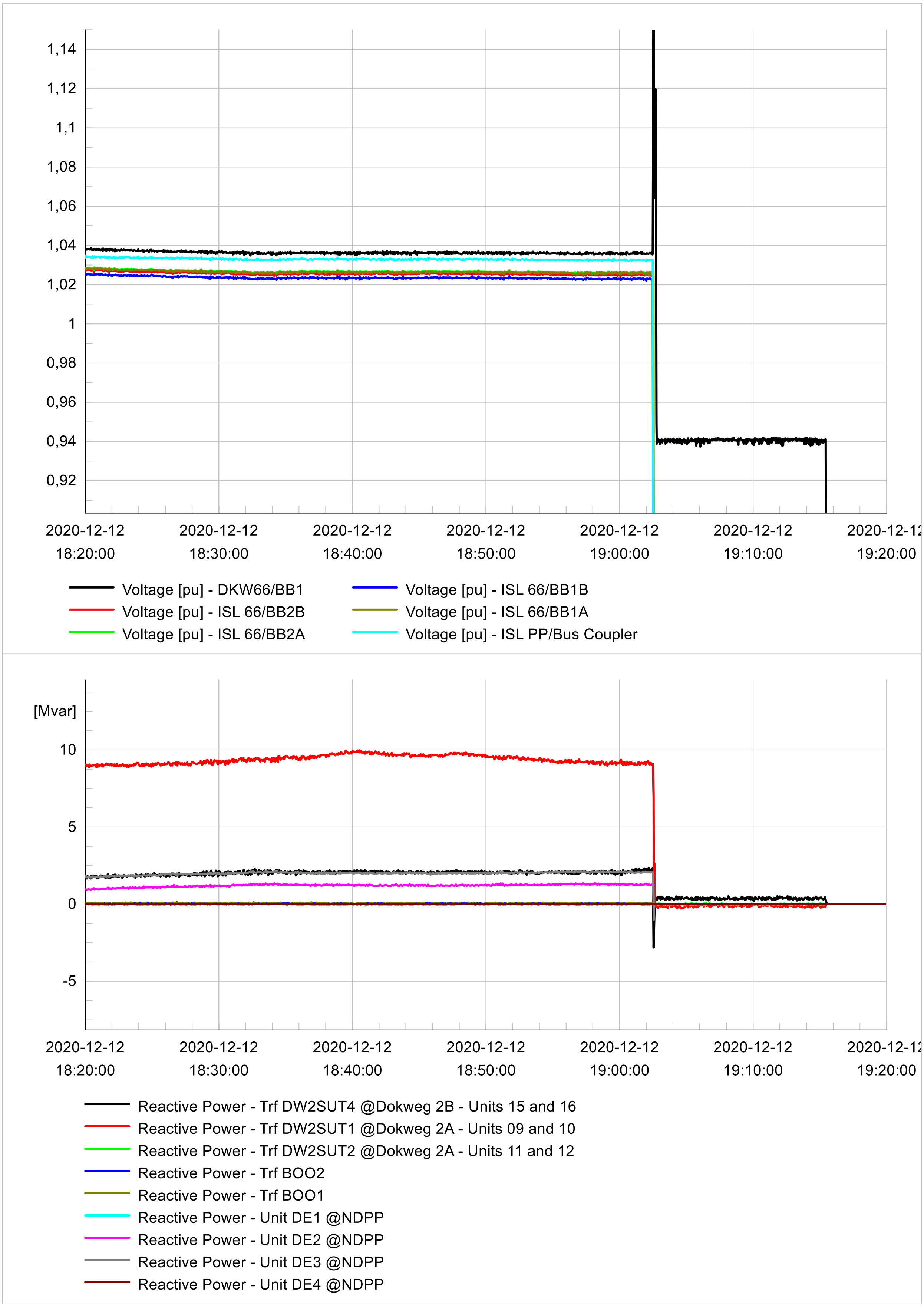


Figure 2: PFM Recordings - Voltage and Reactive Power – From 18:20:00 to 19:20:00 hours

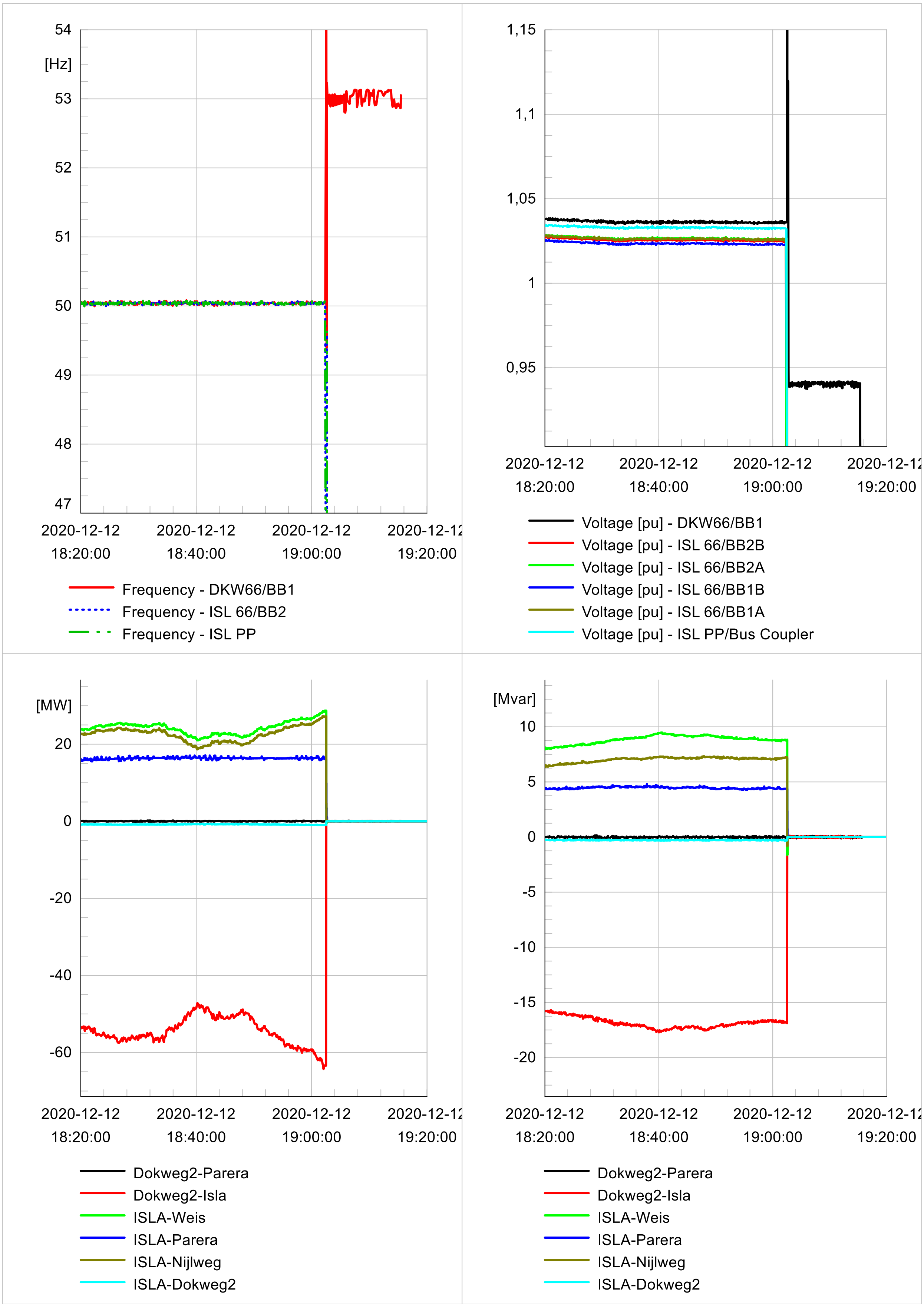


Figure 3: PFM Recordings – Frequency, Voltage and Power across Lines– From 18:20:00 to 19:20:00 hours

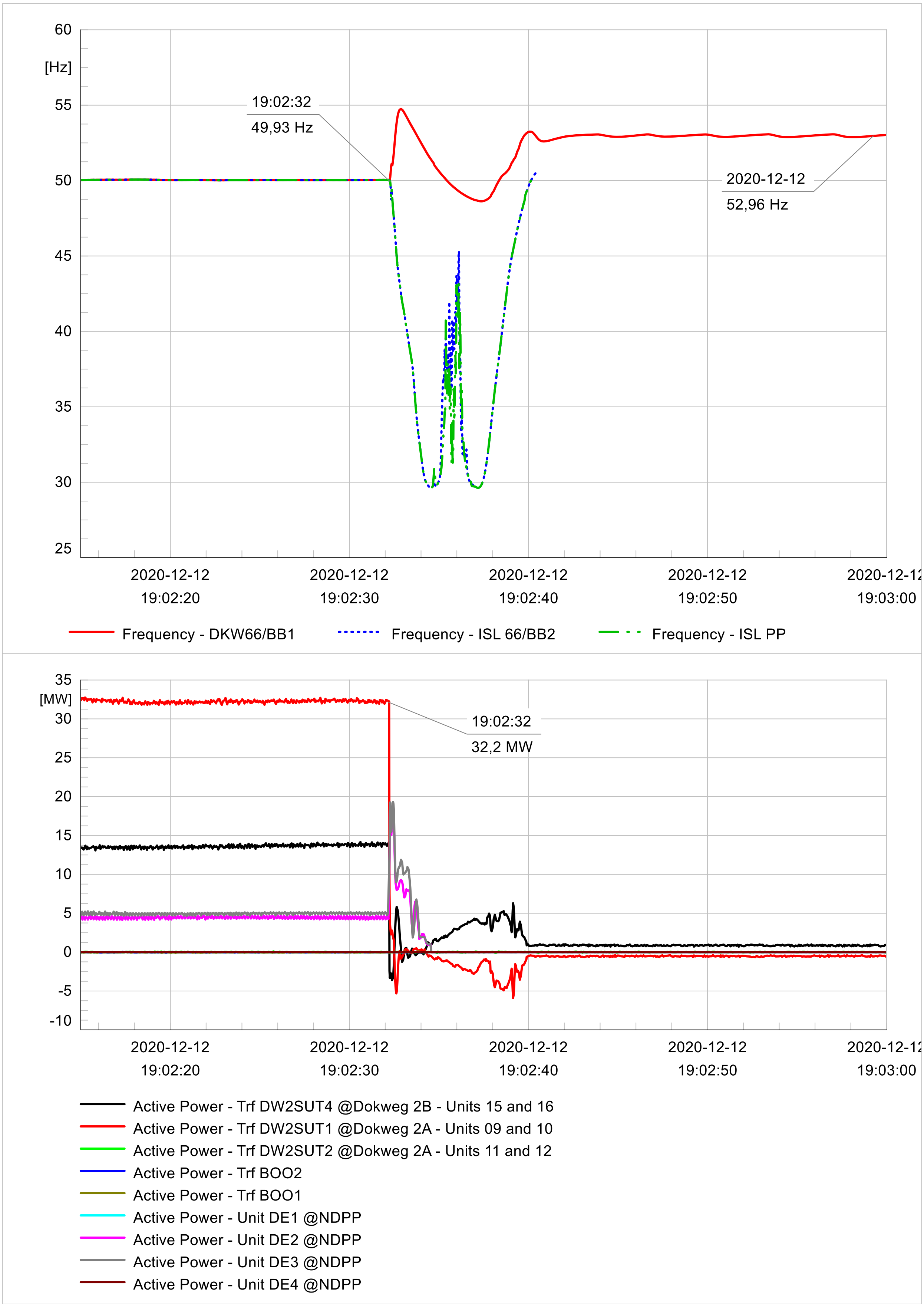


Figure 4: PFM Recordings - Frequency and Active Power – From 19:02:15 to 19:03:00 hours

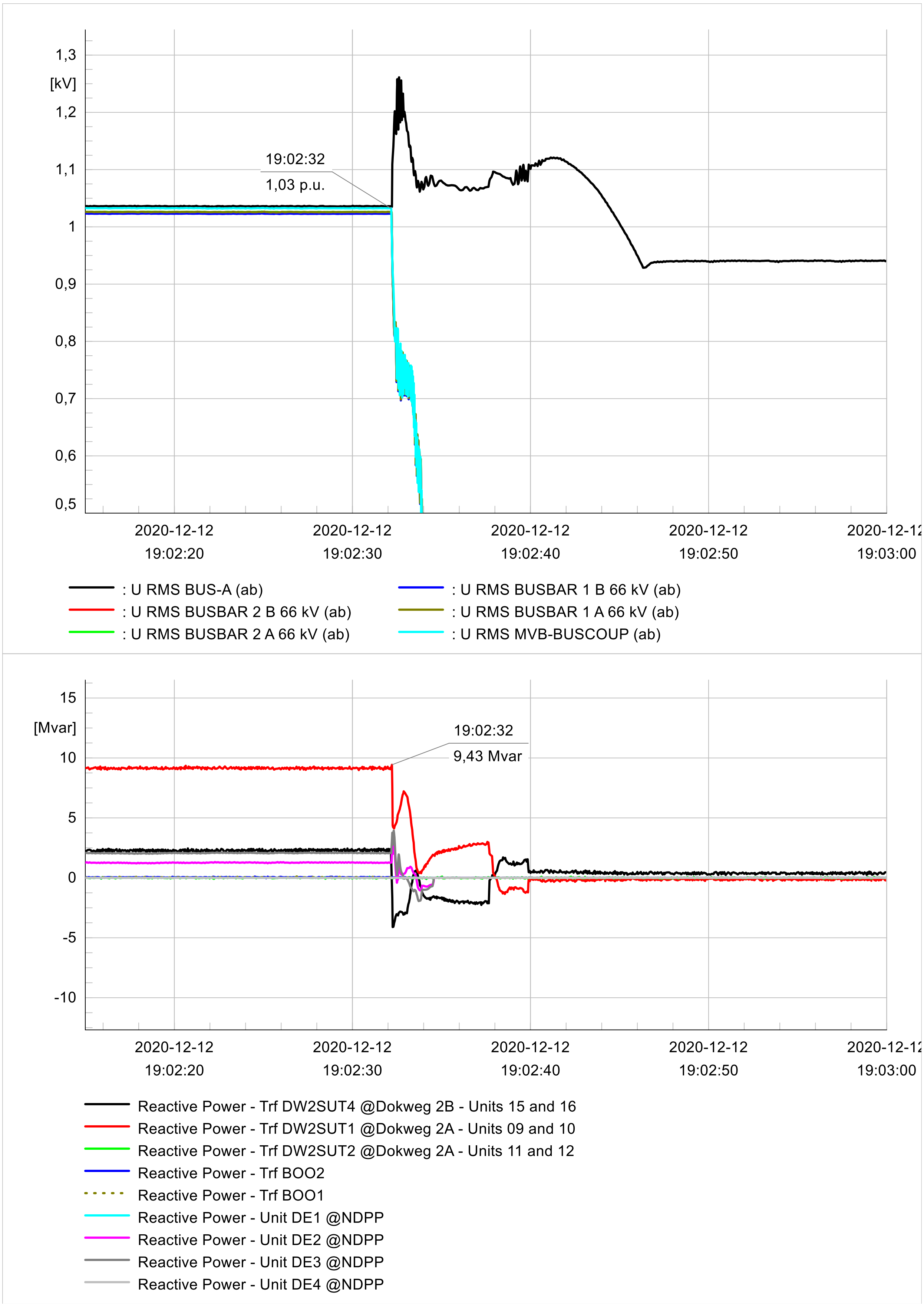


Figure 5: PFM Recordings - Voltage and Reactive Power – From 19:02:15 to 19:03:00 hours

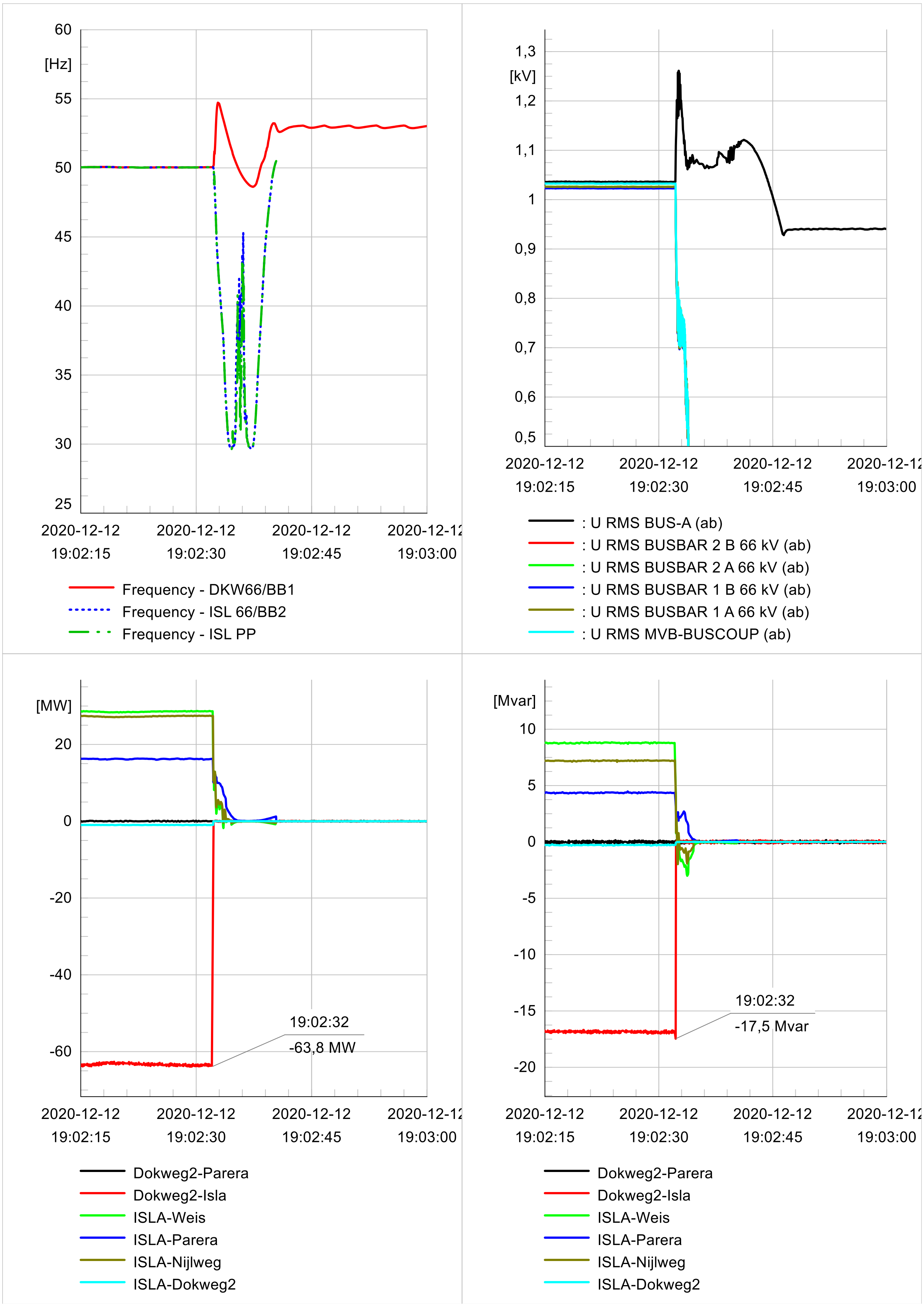


Figure 6: PFM Recordings – Frequency, Voltage and Power across Lines– From 19:02:15 to 19:03:00 hours

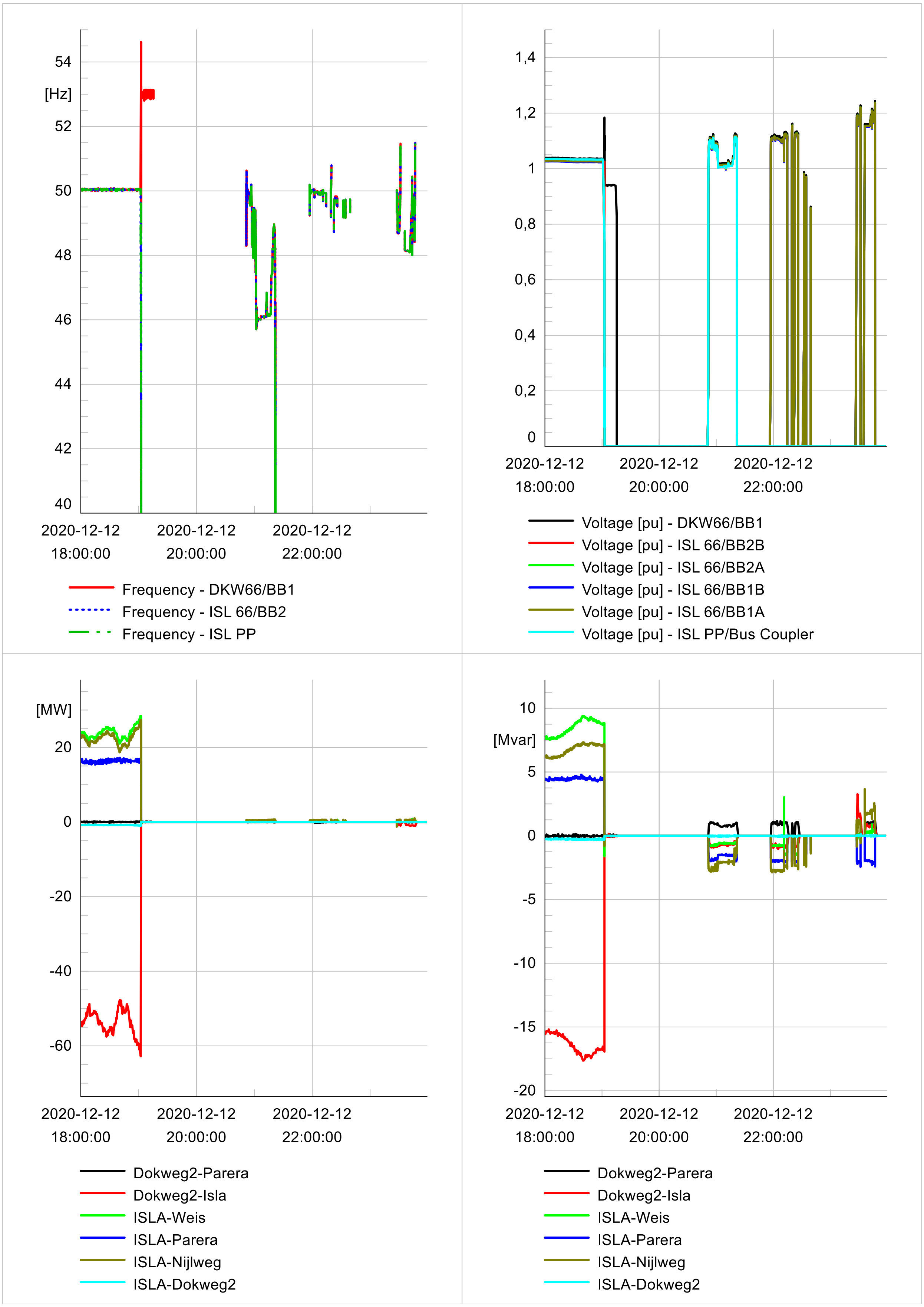


Figure 7: PFM Recordings – Frequency, Voltage and Power across Lines– From 18:00:00 to 23:59:00 hours

9 Annex C: SCADA Recordings

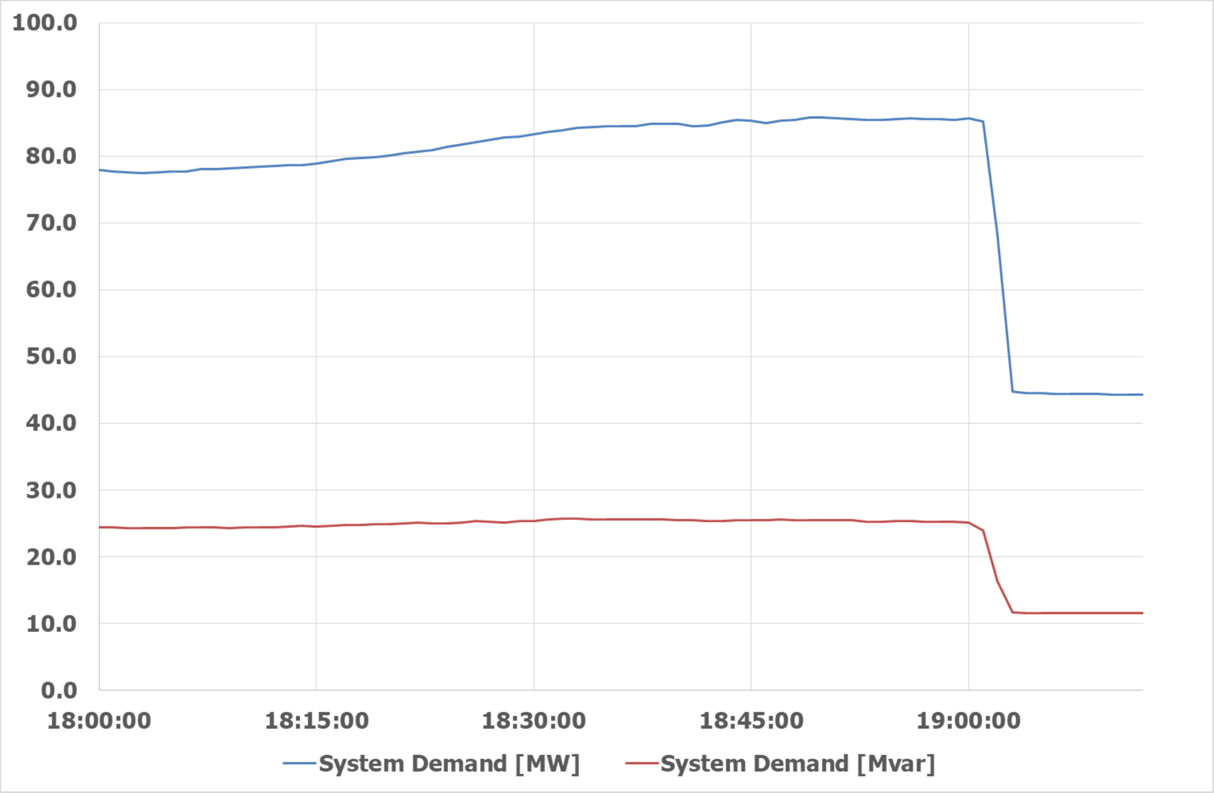


Figure 8: SCADA Recordings – System Demand– From 18:00:00 to 19:12:00 hours

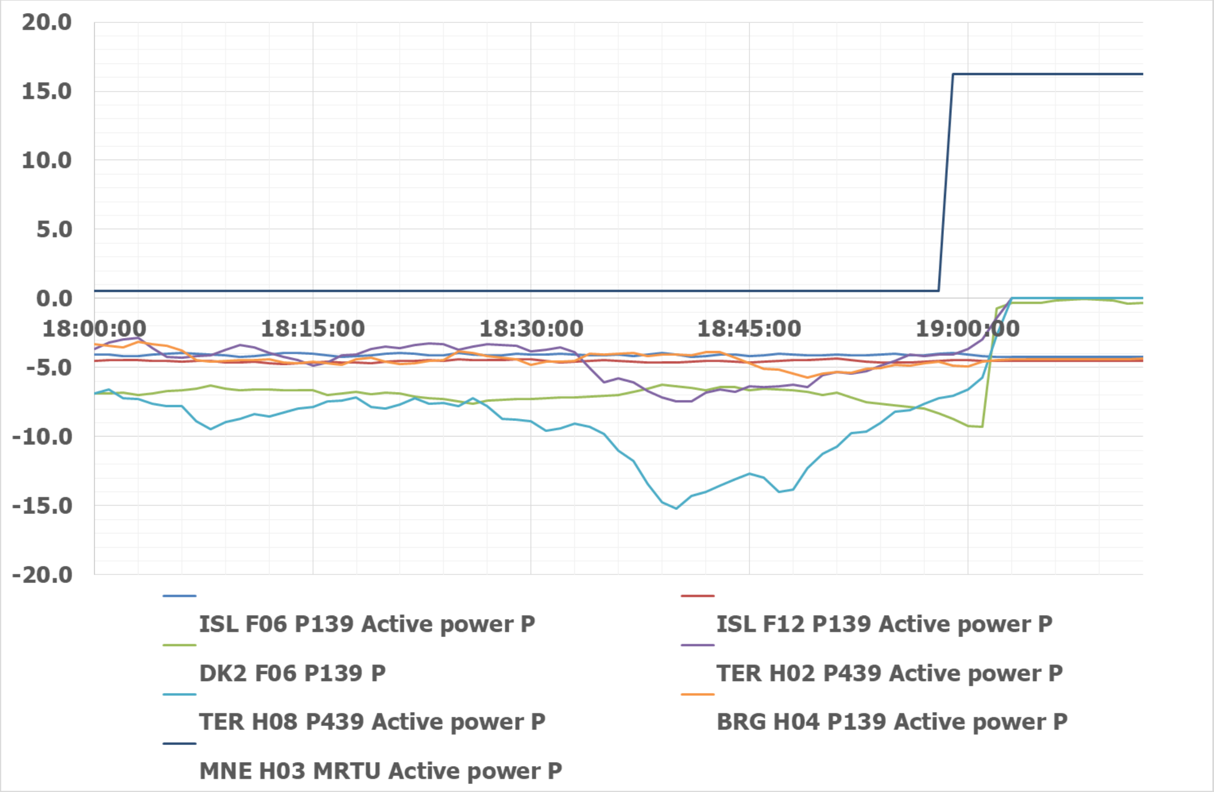


Figure 9: SCADA Recordings – Active Power Measurements [MW]– From 18:00:00 to 19:12:00 hours

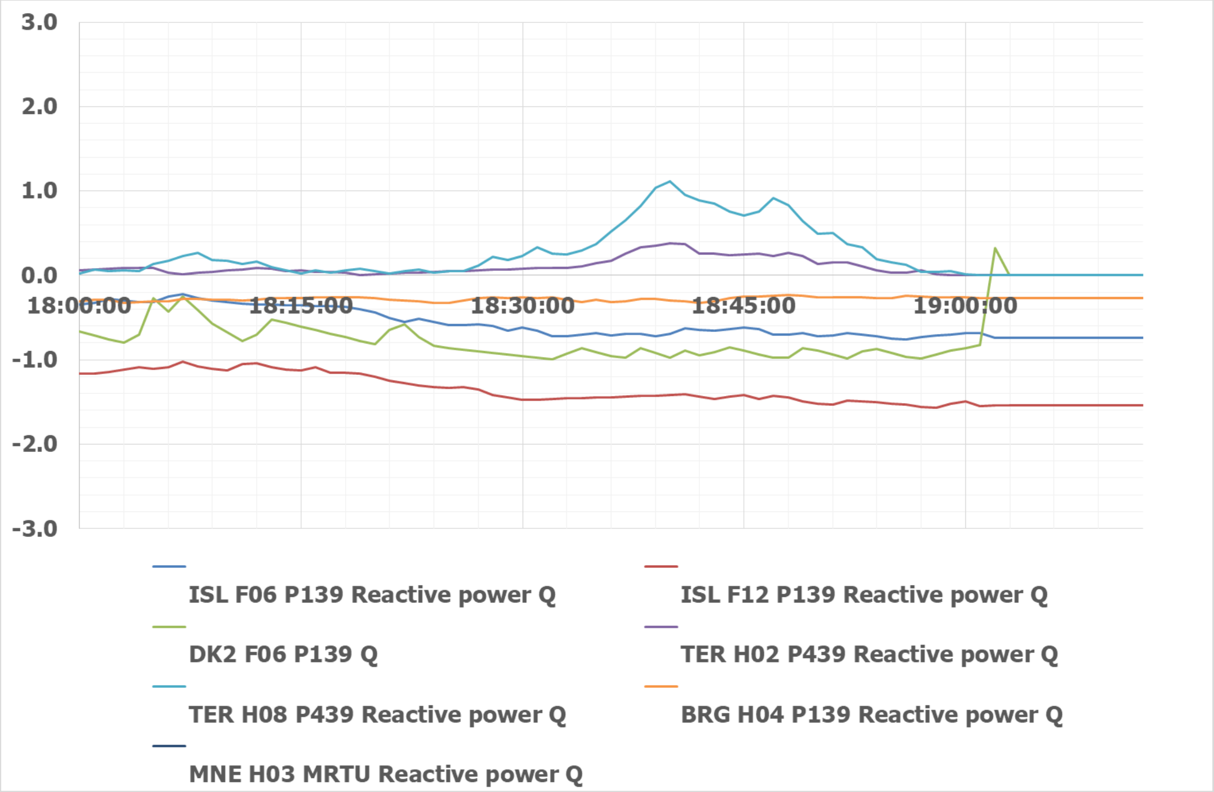


Figure 10: SCADA Recordings – Reactive Power Measurements [Mvar]– From 18:00:00 to 19:12:00 hours

10 Annex D: Overcurrent Protection (P139) Settings in Line Dokweg 66kV-Isla 66 kV

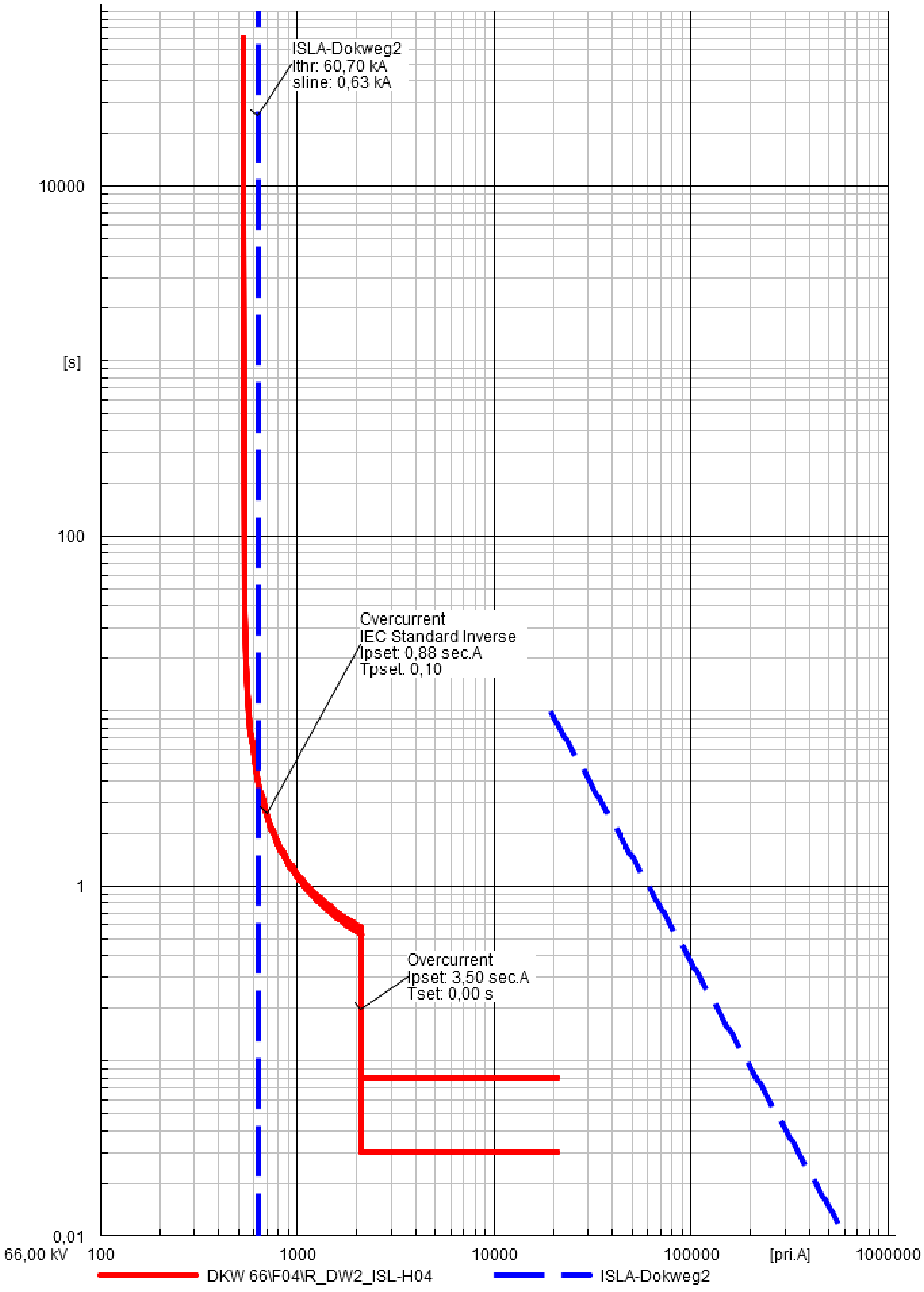


Figure 11: Overcurrent Protection (P139) Settings in Line Dokweg 66kV-Isla 66 kV [9]

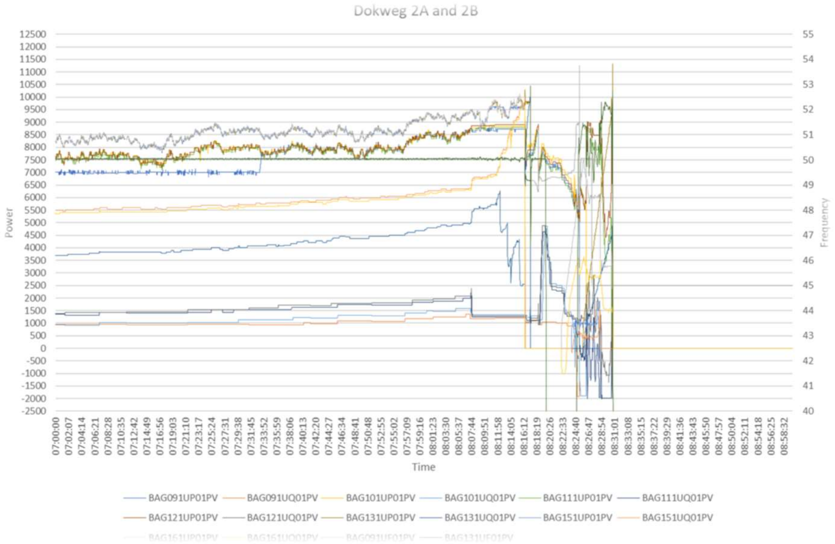
[Information Classification]

Doc. Name	Analysis of Grid Events, 7th of December 2020		
Doc. ID		**Revision**	b
Author	Jaakko Hämeenniemi – 15.1.2021	**Pages**	1 (8)
Approved by	Jaakko Hämeenniemi – 15.1.2021		

Analysis of Grid Event on 7th of December 2020

DOKWEG 2A - 2B

W32 - W34



On Behalf of Wärtsilä:

Jaakko Hämeenniemi

GM, Field and Technical Services

Technical Services

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TABLE OF CONTENTS

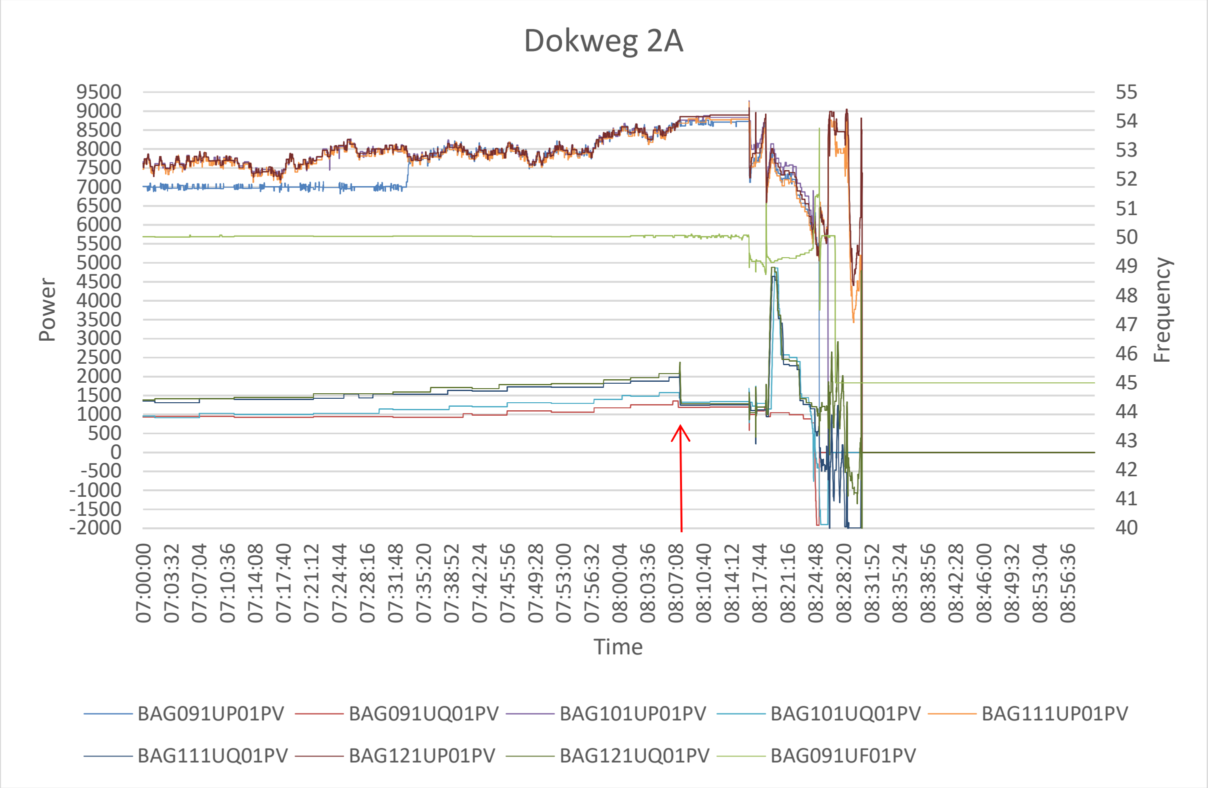
1 BACKGROUND

On the 7th of December 2020, between 08:00 – 08:30, various events took place in the power system of Aqualectra which eventually led to a blackout in the power system. This report includes analysis of the event and recommendations.

2 INSPECTIONS

Dokweg 2A and 2B WOIS (Wärtsilä Operators Interface System) data was collected, data in WOIS system is seen in 1s resolution. Data can be saved in visual format (.jpg) or in (.csv) format for that data can be exported to other systems for closer analysis. Data from Dokweg 2A and 2B was saved between 07:00-09:00 for further analysis.

3 ANALYSIS OF EVENTS



Example:

- *Info: BAGXXXUP01PV = DGXXX Active power*
- *Info: BAGXXXUQ01PV = DGXXX Active Reactive power*
- *BAGXXXUF01PV = DGXXX Frequency (note only Dg9 is shown as all other engines will show same frequency, this for clarity of the graph)*

Figure 1. Dokweg 2A, Engine active, reactive power and frequency from 07:00 to 09:00

From 07:00 to 08:07 system is operating very stable and frequency is close to nominal. One note can be mentioned that engine 9 is seen to operate in kW-mode from at least 07:00 to 07:34.

At 08:07 marked with red arrow, operators change Dokweg 2A engines operation mode from Isochronous load sharing mode to kW-mode (fixed output without load sharing). This action causes reactive power to reduce due to setpoint in WOIS was not set to correct level compared to prior operation in isochronous mode. This leads to decrease in system voltage.

"Aqualectra informed that the operators have experienced in the past sudden disconnections of diesel units due to overloading, at times when the engines were operating close to the rated output power in isochronous mode. This was the reason why the isochronous mode was disconnected in Dokweg 2A."

Wärtsilä responds to this statement that isochronous mode is tested, and engines will not overload as the mechanical limiters have been adjusted correctly. However, operators decided to switch to kW-operation anyway.

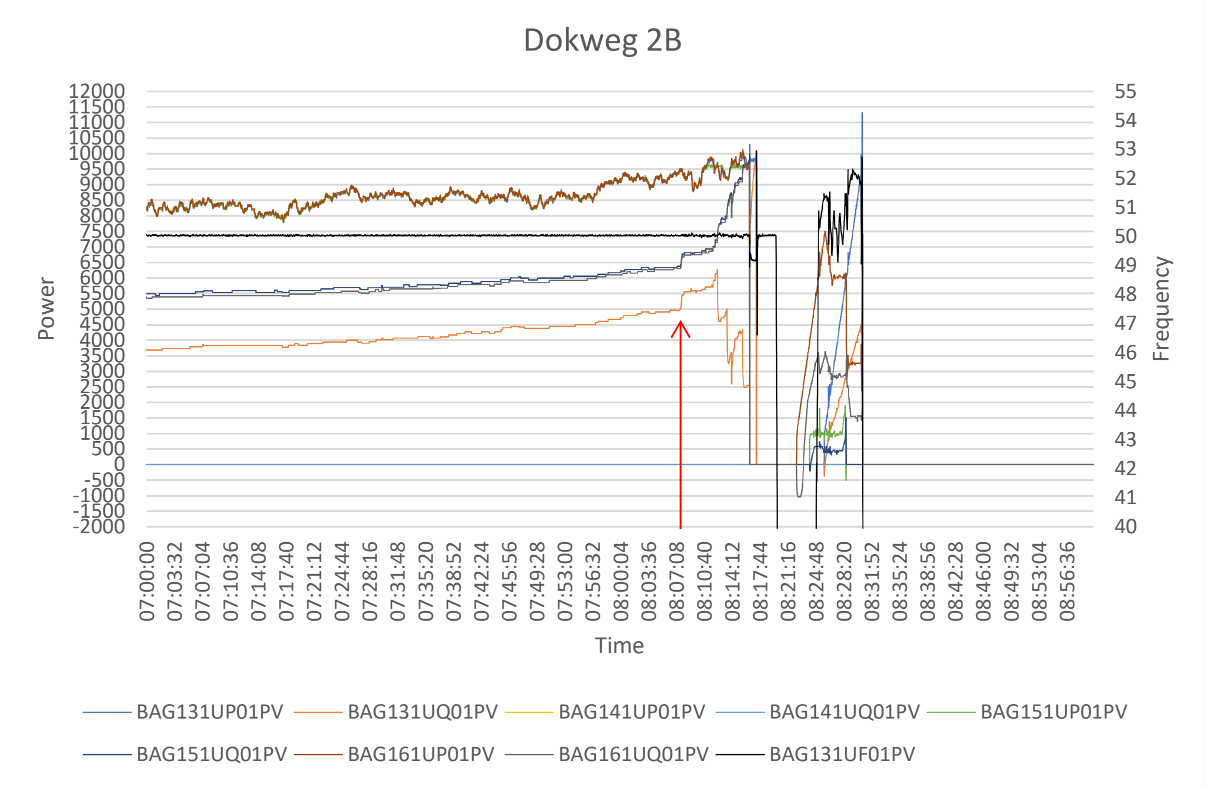


Figure 2. Dokweg 2B, Engine active, reactive power and frequency from 07:00 to 09:00

From 07:00 to 08:07 system is operating very stable and frequency is close to nominal.

At 08:07 marked with red arrow, operators change Dokweg 2A engines operation mode from Isochronous load sharing mode to kW-mode (fixed output without load sharing). This action causes reactive power to reduce due to setpoint in WOIS was not set/changed to correct level compared to prior operation in isochronous mode. This leads to decrease in system voltage. We can see that Dokweg 2B tried to support system voltage by increasing the reactive power drastically. At 08:16-08:17 Engine 13 trips due to overcurrent of reactive power and the system frequency has been dropping to 49.17-49.21Hz.

At 08:17-08:18 Engines 15 and 16 trips due to overcurrent what leads to sudden frequency decrease and system voltage decrease. Eventually these events lead to system blackout in Dokweg 2A and 2B even the fast re-start of engines 13,15 and 16 which was not able to support the system sufficiently.

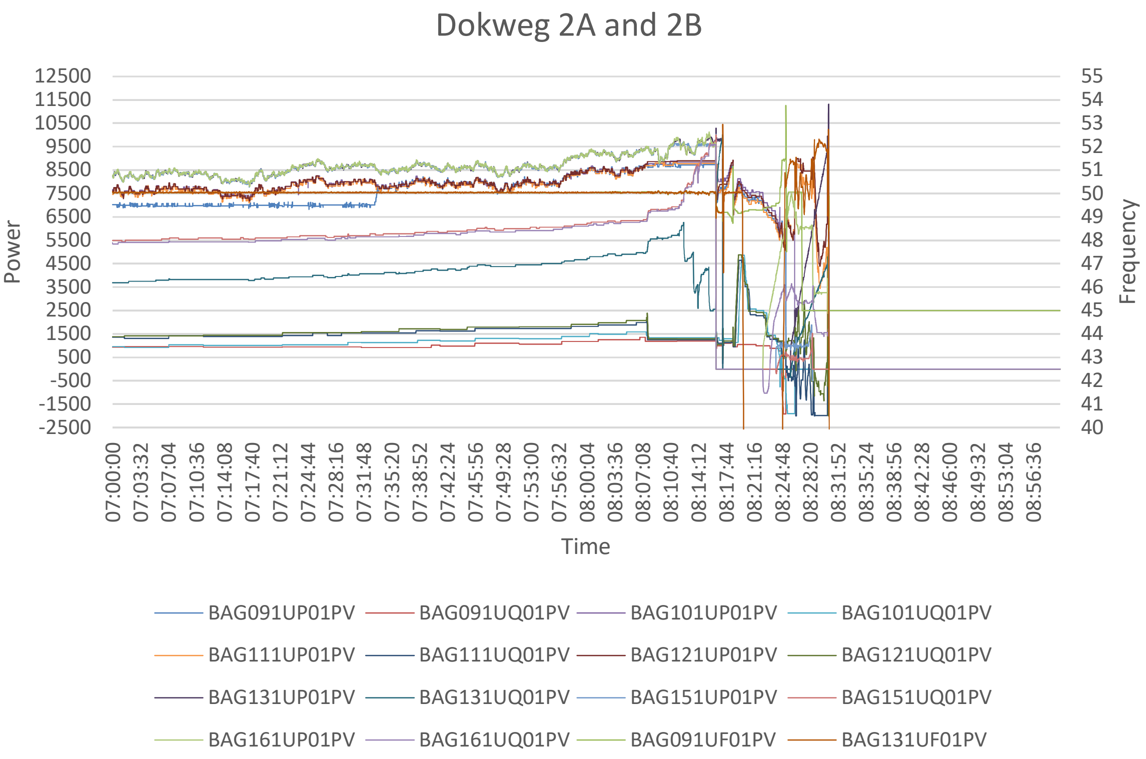


Figure 3. Dokweg 2A and 2B, Engine active, reactive power and frequency from 07:00 to 09:00

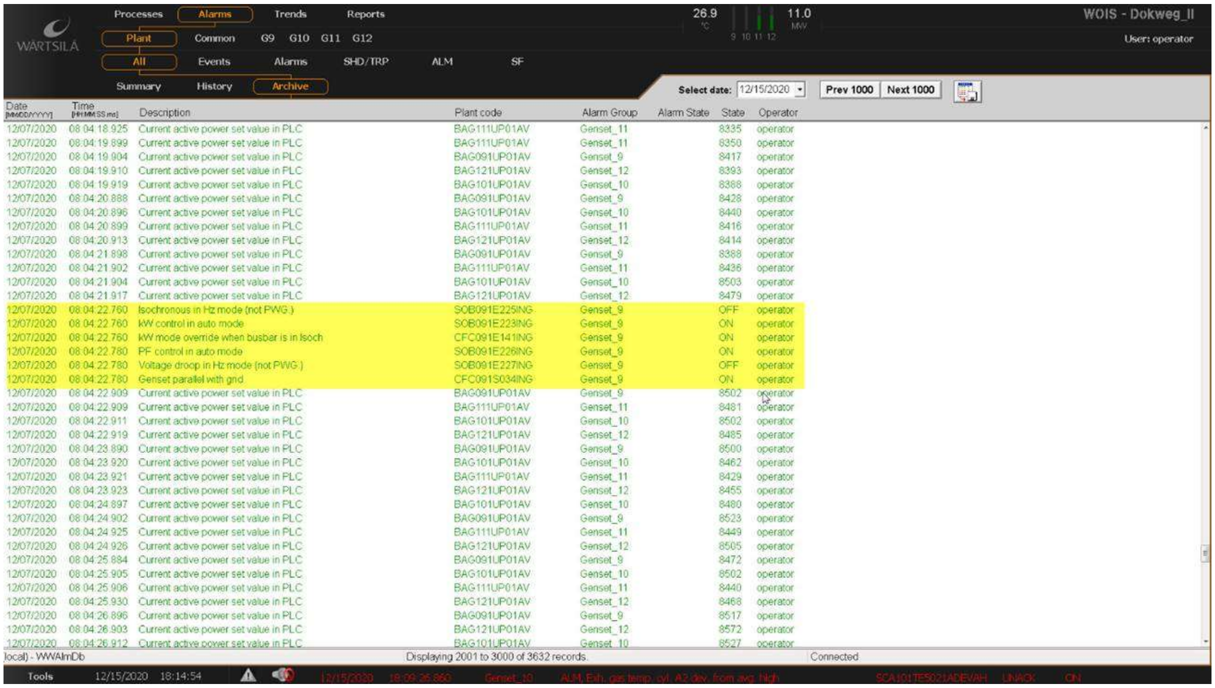
4 CONCLUSION AND RECOMMENDATIONS

Change in operation mode at Dokweg 2A from isochronous load sharing to kW-mode caused overloading the units in Dokweg 2B due to sudden decrease in reactive power.

Wärtsilä recommends arranging a training for operators to gain the trust back to different operation modes and prevent any failures of choosing correct operation mode for any different situation.

Additional test to be executed to proof functionality of the Isochronous load sharing system and showing that engines will not go into overload. This for the operators to gain trust in the in the integrity of the system.

Operating mode changes, starting 8:04 am:

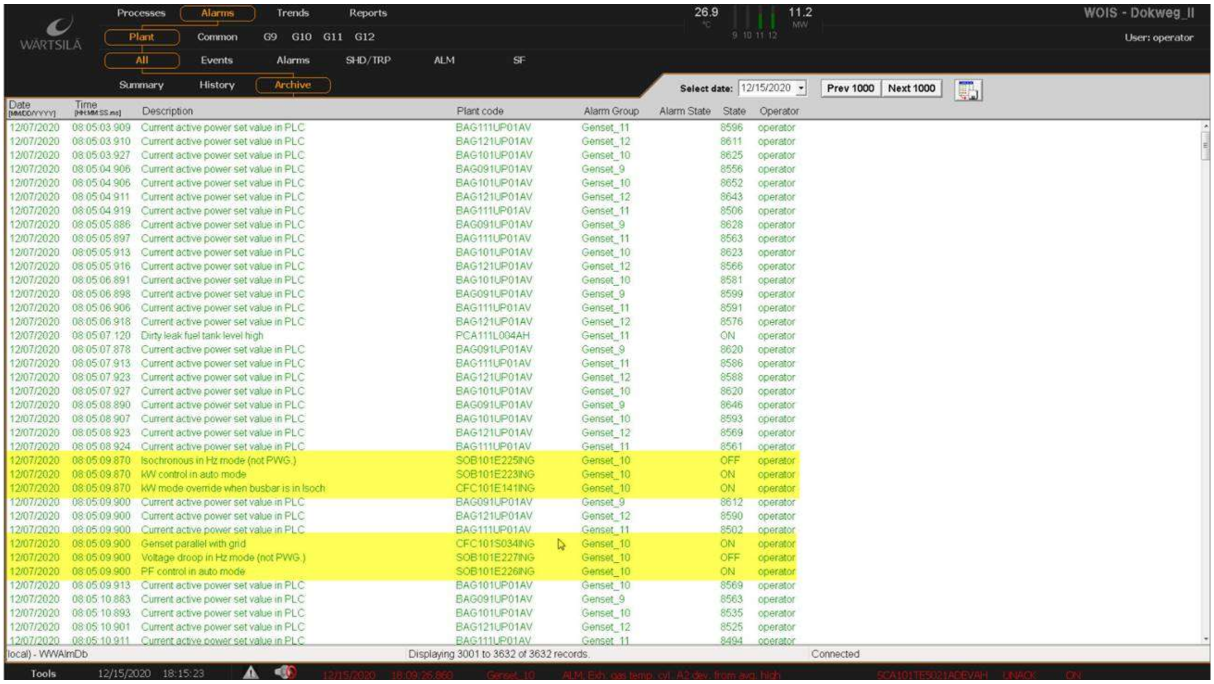


Date [MM/DD/YYYY]	Time [HH:MM:SS.ms]	Description	Plant code	Alarm Group	Alarm State	State	Operator
12/07/2020	08:04:18.925	Current active power set value in PLC	BAG111UP01AV	Genset_11		8335	operator
12/07/2020	08:04:19.899	Current active power set value in PLC	BAG111UP01AV	Genset_11		8350	operator
12/07/2020	08:04:19.904	Current active power set value in PLC	BAG091UP01AV	Genset_9		8417	operator
12/07/2020	08:04:19.910	Current active power set value in PLC	BAG121UP01AV	Genset_12		8393	operator
12/07/2020	08:04:19.919	Current active power set value in PLC	BAG101UP01AV	Genset_10		8388	operator
12/07/2020	08:04:20.888	Current active power set value in PLC	BAG091UP01AV	Genset_9		8428	operator
12/07/2020	08:04:20.896	Current active power set value in PLC	BAG101UP01AV	Genset_10		8440	operator
12/07/2020	08:04:20.899	Current active power set value in PLC	BAG111UP01AV	Genset_11		8416	operator
12/07/2020	08:04:20.913	Current active power set value in PLC	BAG121UP01AV	Genset_12		8414	operator
12/07/2020	08:04:21.898	Current active power set value in PLC	BAG091UP01AV	Genset_9		8388	operator
12/07/2020	08:04:21.902	Current active power set value in PLC	BAG111UP01AV	Genset_11		8436	operator
12/07/2020	08:04:21.904	Current active power set value in PLC	BAG101UP01AV	Genset_10		8503	operator
12/07/2020	08:04:21.917	Current active power set value in PLC	BAG121UP01AV	Genset_12		8479	operator
12/07/2020	08:04:22.760	Isochronous in Hz mode (not PWG.)	SOB091E225ING	Genset_9		OFF	operator
12/07/2020	08:04:22.760	kW control in auto mode	SOB091E223ING	Genset_9		ON	operator
12/07/2020	08:04:22.760	kW mode override when busbar is in Isoch	CFC091E141ING	Genset_9		ON	operator
12/07/2020	08:04:22.780	PF control in auto mode	SOB091E226ING	Genset_9		ON	operator
12/07/2020	08:04:22.780	Voltage droop in Hz mode (not PWG.)	SOB091E227ING	Genset_9		OFF	operator
12/07/2020	08:04:22.780	Genset parallel with grid	CFC091S034ING	Genset_9		ON	operator
12/07/2020	08:04:22.909	Current active power set value in PLC	BAG091UP01AV	Genset_9		8502	operator
12/07/2020	08:04:22.909	Current active power set value in PLC	BAG111UP01AV	Genset_11		8481	operator
12/07/2020	08:04:22.911	Current active power set value in PLC	BAG101UP01AV	Genset_10		8502	operator
12/07/2020	08:04:22.919	Current active power set value in PLC	BAG121UP01AV	Genset_12		8485	operator
12/07/2020	08:04:23.890	Current active power set value in PLC	BAG091UP01AV	Genset_9		8500	operator
12/07/2020	08:04:23.920	Current active power set value in PLC	BAG101UP01AV	Genset_10		8462	operator
12/07/2020	08:04:23.921	Current active power set value in PLC	BAG111UP01AV	Genset_11		8429	operator
12/07/2020	08:04:23.923	Current active power set value in PLC	BAG121UP01AV	Genset_12		8455	operator
12/07/2020	08:04:24.897	Current active power set value in PLC	BAG101UP01AV	Genset_10		8480	operator
12/07/2020	08:04:24.902	Current active power set value in PLC	BAG091UP01AV	Genset_9		8523	operator
12/07/2020	08:04:24.925	Current active power set value in PLC	BAG111UP01AV	Genset_11		8449	operator
12/07/2020	08:04:24.926	Current active power set value in PLC	BAG121UP01AV	Genset_12		8505	operator
12/07/2020	08:04:25.884	Current active power set value in PLC	BAG091UP01AV	Genset_9		8472	operator
12/07/2020	08:04:25.905	Current active power set value in PLC	BAG101UP01AV	Genset_10		8502	operator
12/07/2020	08:04:25.906	Current active power set value in PLC	BAG111UP01AV	Genset_11		8440	operator
12/07/2020	08:04:25.930	Current active power set value in PLC	BAG121UP01AV	Genset_12		8468	operator
12/07/2020	08:04:26.896	Current active power set value in PLC	BAG091UP01AV	Genset_9		8517	operator
12/07/2020	08:04:26.903	Current active power set value in PLC	BAG121UP01AV	Genset_12		8572	operator
12/07/2020	08:04:26.912	Current active power set value in PLC	BAG101UP01AV	Genset_10		8527	operator

(local) - WWAlmDb Displaying 2001 to 3000 of 3632 records. Connected

Tools 12/15/2020 18:14:54 12/15/2020 18:09:26.860 Genset_10 ALM: Exh. gas temp. cyl. A2 dev. from avg. high SCA101TE5021ADEVAH UNACK ON

Figure 4 Engine 9.

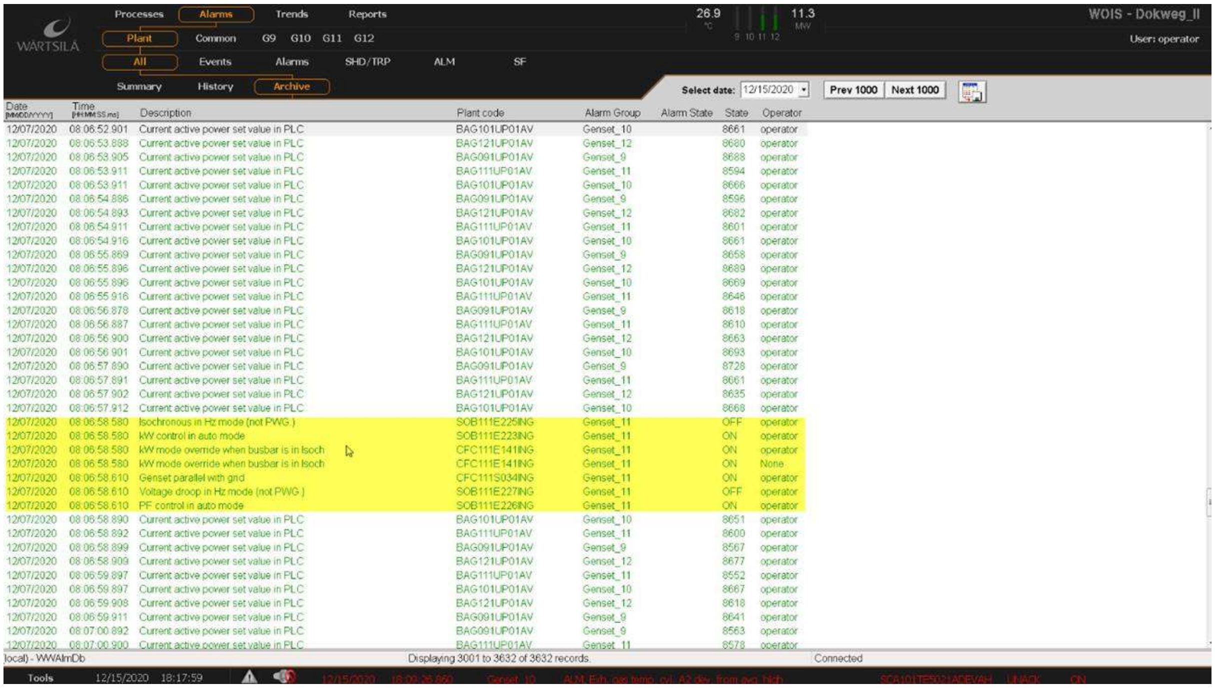


Date [MM/DD/YYYY]	Time [HH:MM:SS.ms]	Description	Plant code	Alarm Group	Alarm State	State	Operator
12/07/2020	08:05:03.909	Current active power set value in PLC	BAG111UP01AV	Genset_11		8596	operator
12/07/2020	08:05:03.910	Current active power set value in PLC	BAG121UP01AV	Genset_12		8611	operator
12/07/2020	08:05:03.927	Current active power set value in PLC	BAG101UP01AV	Genset_10		8625	operator
12/07/2020	08:05:04.906	Current active power set value in PLC	BAG091UP01AV	Genset_9		8556	operator
12/07/2020	08:05:04.906	Current active power set value in PLC	BAG101UP01AV	Genset_10		8652	operator
12/07/2020	08:05:04.911	Current active power set value in PLC	BAG121UP01AV	Genset_12		8643	operator
12/07/2020	08:05:04.919	Current active power set value in PLC	BAG111UP01AV	Genset_11		8506	operator
12/07/2020	08:05:05.886	Current active power set value in PLC	BAG091UP01AV	Genset_9		8628	operator
12/07/2020	08:05:05.897	Current active power set value in PLC	BAG111UP01AV	Genset_11		8563	operator
12/07/2020	08:05:05.913	Current active power set value in PLC	BAG101UP01AV	Genset_10		8623	operator
12/07/2020	08:05:05.916	Current active power set value in PLC	BAG121UP01AV	Genset_12		8566	operator
12/07/2020	08:05:06.891	Current active power set value in PLC	BAG101UP01AV	Genset_10		8581	operator
12/07/2020	08:05:06.898	Current active power set value in PLC	BAG091UP01AV	Genset_9		8599	operator
12/07/2020	08:05:06.906	Current active power set value in PLC	BAG111UP01AV	Genset_11		8591	operator
12/07/2020	08:05:06.918	Current active power set value in PLC	BAG121UP01AV	Genset_12		8576	operator
12/07/2020	08:05:07.120	Dirty leak fuel tank level high	PCA111L004AH	Genset_11		ON	operator
12/07/2020	08:05:07.878	Current active power set value in PLC	BAG091UP01AV	Genset_9		8620	operator
12/07/2020	08:05:07.913	Current active power set value in PLC	BAG111UP01AV	Genset_11		8586	operator
12/07/2020	08:05:07.923	Current active power set value in PLC	BAG121UP01AV	Genset_12		8588	operator
12/07/2020	08:05:07.927	Current active power set value in PLC	BAG101UP01AV	Genset_10		8620	operator
12/07/2020	08:05:08.890	Current active power set value in PLC	BAG091UP01AV	Genset_9		8646	operator
12/07/2020	08:05:08.907	Current active power set value in PLC	BAG101UP01AV	Genset_10		8593	operator
12/07/2020	08:05:08.923	Current active power set value in PLC	BAG121UP01AV	Genset_12		8569	operator
12/07/2020	08:05:08.924	Current active power set value in PLC	BAG111UP01AV	Genset_11		8561	operator
12/07/2020	08:05:09.870	Isochronous in Hz mode (not PWG.)	SOB101E225ING	Genset_10		OFF	operator
12/07/2020	08:05:09.870	kW control in auto mode	SOB101E223ING	Genset_10		ON	operator
12/07/2020	08:05:09.870	kW mode override when busbar is in Isoch	CFC101E141ING	Genset_10		ON	operator
12/07/2020	08:05:09.900	Current active power set value in PLC	BAG091UP01AV	Genset_9		8612	operator
12/07/2020	08:05:09.900	Current active power set value in PLC	BAG121UP01AV	Genset_12		8590	operator
12/07/2020	08:05:09.900	Current active power set value in PLC	BAG111UP01AV	Genset_11		8502	operator
12/07/2020	08:05:09.900	Genset parallel with grid	CFC101S034ING	Genset_10		ON	operator
12/07/2020	08:05:09.900	Voltage droop in Hz mode (not PWG.)	SOB101E227ING	Genset_10		OFF	operator
12/07/2020	08:05:09.900	PF control in auto mode	SOB101E226ING	Genset_10		ON	operator
12/07/2020	08:05:09.913	Current active power set value in PLC	BAG101UP01AV	Genset_10		8569	operator
12/07/2020	08:05:10.883	Current active power set value in PLC	BAG091UP01AV	Genset_9		8563	operator
12/07/2020	08:05:10.893	Current active power set value in PLC	BAG101UP01AV	Genset_10		8535	operator
12/07/2020	08:05:10.901	Current active power set value in PLC	BAG121UP01AV	Genset_12		8525	operator
12/07/2020	08:05:10.911	Current active power set value in PLC	BAG111UP01AV	Genset_11		8494	operator

(local) - WWAlmDb Displaying 3001 to 3632 of 3632 records. Connected

Tools 12/15/2020 18:15:23 12/15/2020 18:09:26.860 Genset_10 ALM: Exh. gas temp. cyl. A2 dev. from avg. high SCA101TE5021ADEVAH UNACK ON

Figure 5 Engine 10.



Date [MM/DD/YYYY]	Time [HH:MM:SS.ms]	Description	Plant code	Alarm Group	Alarm State	State	Operator
12/07/2020	08:06:52.901	Current active power set value in PLC	BAG101UP01AV	Genset_10		8661	operator
12/07/2020	08:06:53.888	Current active power set value in PLC	BAG121UP01AV	Genset_12		8680	operator
12/07/2020	08:06:53.905	Current active power set value in PLC	BAG091UP01AV	Genset_9		8688	operator
12/07/2020	08:06:53.911	Current active power set value in PLC	BAG111UP01AV	Genset_11		8594	operator
12/07/2020	08:06:53.911	Current active power set value in PLC	BAG101UP01AV	Genset_10		8666	operator
12/07/2020	08:06:54.886	Current active power set value in PLC	BAG091UP01AV	Genset_9		8596	operator
12/07/2020	08:06:54.893	Current active power set value in PLC	BAG121UP01AV	Genset_12		8682	operator
12/07/2020	08:06:54.911	Current active power set value in PLC	BAG111UP01AV	Genset_11		8601	operator
12/07/2020	08:06:54.916	Current active power set value in PLC	BAG101UP01AV	Genset_10		8661	operator
12/07/2020	08:06:55.869	Current active power set value in PLC	BAG091UP01AV	Genset_9		8658	operator
12/07/2020	08:06:55.896	Current active power set value in PLC	BAG121UP01AV	Genset_12		8689	operator
12/07/2020	08:06:55.896	Current active power set value in PLC	BAG101UP01AV	Genset_10		8669	operator
12/07/2020	08:06:55.916	Current active power set value in PLC	BAG111UP01AV	Genset_11		8646	operator
12/07/2020	08:06:56.878	Current active power set value in PLC	BAG091UP01AV	Genset_9		8618	operator
12/07/2020	08:06:56.887	Current active power set value in PLC	BAG111UP01AV	Genset_11		8610	operator
12/07/2020	08:06:56.900	Current active power set value in PLC	BAG121UP01AV	Genset_12		8663	operator
12/07/2020	08:06:56.901	Current active power set value in PLC	BAG101UP01AV	Genset_10		8693	operator
12/07/2020	08:06:57.890	Current active power set value in PLC	BAG091UP01AV	Genset_9		8728	operator
12/07/2020	08:06:57.891	Current active power set value in PLC	BAG111UP01AV	Genset_11		8661	operator
12/07/2020	08:06:57.902	Current active power set value in PLC	BAG121UP01AV	Genset_12		8635	operator
12/07/2020	08:06:57.912	Current active power set value in PLC	BAG101UP01AV	Genset_10		8668	operator
12/07/2020	08:06:58.580	Isochronous in Hz mode (not PWG.)	SOB111E225ING	Genset_11		OFF	operator
12/07/2020	08:06:58.580	kW control in auto mode	SOB111E223ING	Genset_11		ON	operator
12/07/2020	08:06:58.580	kW mode override when busbar is in Isoch	CFC111E141ING	Genset_11		ON	operator
12/07/2020	08:06:58.580	kW mode override when busbar is in Isoch	CFC111E141ING	Genset_11		ON	None
12/07/2020	08:06:58.610	Genset parallel with grid	CFC111S034ING	Genset_11		ON	operator
12/07/2020	08:06:58.610	Voltage droop in Hz mode (not PWG.)	SOB111E227ING	Genset_11		OFF	operator
12/07/2020	08:06:58.610	PF control in auto mode	SOB111E226ING	Genset_11		ON	operator
12/07/2020	08:06:58.890	Current active power set value in PLC	BAG101UP01AV	Genset_10		8651	operator
12/07/2020	08:06:58.892	Current active power set value in PLC	BAG111UP01AV	Genset_11		8600	operator
12/07/2020	08:06:58.899	Current active power set value in PLC	BAG091UP01AV	Genset_9		8567	operator
12/07/2020	08:06:58.909	Current active power set value in PLC	BAG121UP01AV	Genset_12		8677	operator
12/07/2020	08:06:59.897	Current active power set value in PLC	BAG111UP01AV	Genset_11		8552	operator
12/07/2020	08:06:59.897	Current active power set value in PLC	BAG101UP01AV	Genset_10		8667	operator
12/07/2020	08:06:59.908	Current active power set value in PLC	BAG121UP01AV	Genset_12		8618	operator
12/07/2020	08:06:59.911	Current active power set value in PLC	BAG091UP01AV	Genset_9		8641	operator
12/07/2020	08:07:00.892	Current active power set value in PLC	BAG091UP01AV	Genset_9		8563	operator
12/07/2020	08:07:00.900	Current active power set value in PLC	BAG111UP01AV	Genset_11		8578	operator

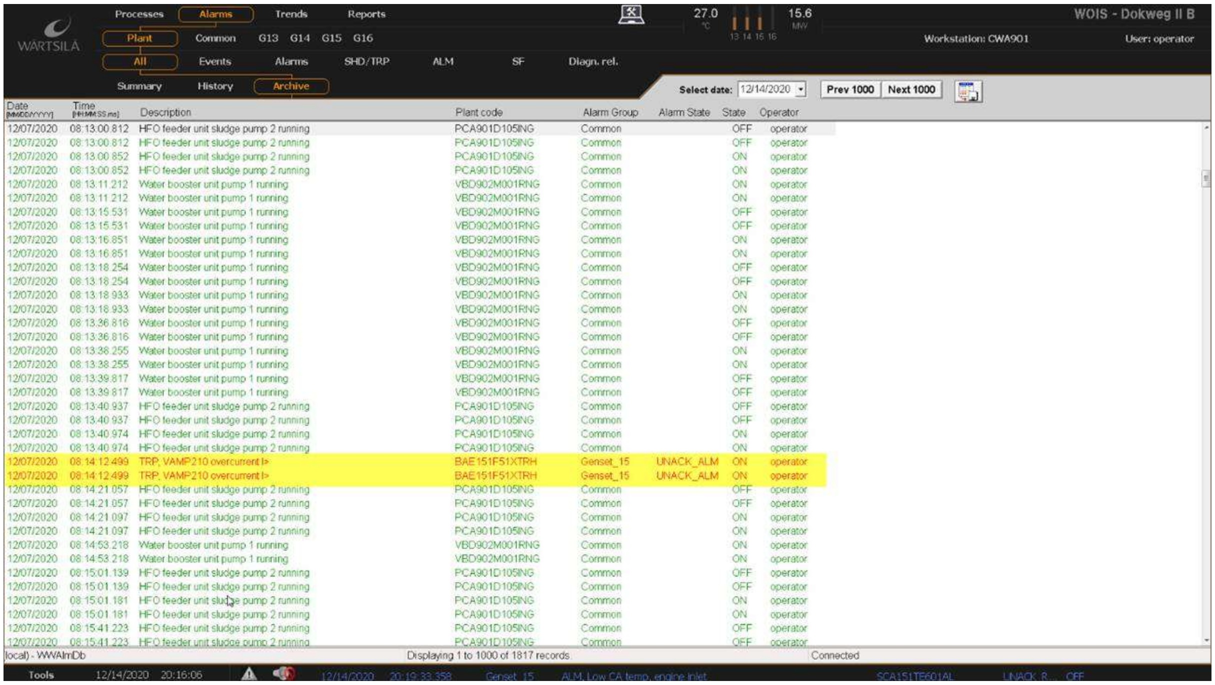
(local) - WWAlmDb Displaying 3001 to 3632 of 3632 records. Connected

12/15/2020 18:09:26.860 Genset_10 ALM, Exh. gas temp. cyl. A2 dev. from avg. high SCA101TE5021ADEVAH UNACK ON

Figure 6 Engine 11.

Engine 15 first unit what trip from overcurrent.

This is Dokweg 2B engine what try to support network. Compensating low voltage with high reactive power.



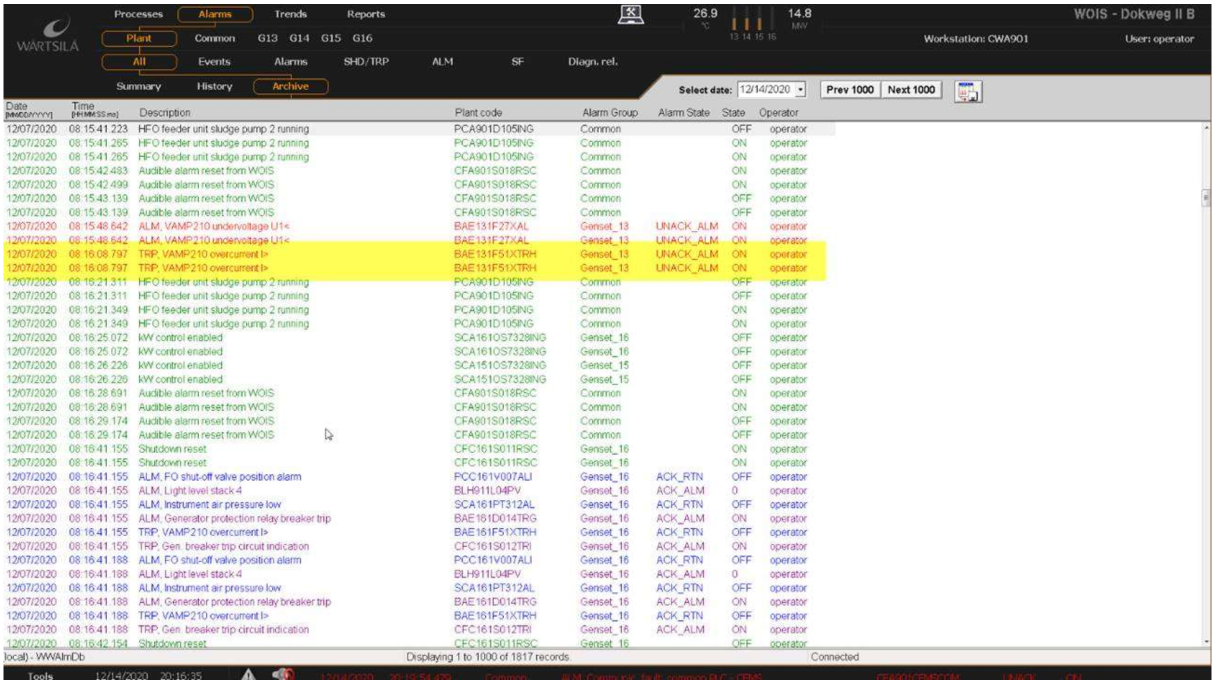
Date [MM/DD/YYYY]	Time [HH:MM:SS.ms]	Description	Plant code	Alarm Group	Alarm State	State	Operator
12/07/2020	08:13:00.812	HFO feeder unit sludge pump 2 running	PCA901D105ING	Common		OFF	operator
12/07/2020	08:13:00.812	HFO feeder unit sludge pump 2 running	PCA901D105ING	Common		OFF	operator
12/07/2020	08:13:00.852	HFO feeder unit sludge pump 2 running	PCA901D105ING	Common		ON	operator
12/07/2020	08:13:00.852	HFO feeder unit sludge pump 2 running	PCA901D105ING	Common		ON	operator
12/07/2020	08:13:11.212	Water booster unit pump 1 running	VBD902M001RNG	Common		ON	operator
12/07/2020	08:13:11.212	Water booster unit pump 1 running	VBD902M001RNG	Common		ON	operator
12/07/2020	08:13:15.531	Water booster unit pump 1 running	VBD902M001RNG	Common		OFF	operator
12/07/2020	08:13:15.531	Water booster unit pump 1 running	VBD902M001RNG	Common		OFF	operator
12/07/2020	08:13:16.851	Water booster unit pump 1 running	VBD902M001RNG	Common		ON	operator
12/07/2020	08:13:16.851	Water booster unit pump 1 running	VBD902M001RNG	Common		ON	operator
12/07/2020	08:13:18.254	Water booster unit pump 1 running	VBD902M001RNG	Common		OFF	operator
12/07/2020	08:13:18.254	Water booster unit pump 1 running	VBD902M001RNG	Common		OFF	operator
12/07/2020	08:13:18.933	Water booster unit pump 1 running	VBD902M001RNG	Common		ON	operator
12/07/2020	08:13:18.933	Water booster unit pump 1 running	VBD902M001RNG	Common		ON	operator
12/07/2020	08:13:36.816	Water booster unit pump 1 running	VBD902M001RNG	Common		OFF	operator
12/07/2020	08:13:36.816	Water booster unit pump 1 running	VBD902M001RNG	Common		OFF	operator
12/07/2020	08:13:38.255	Water booster unit pump 1 running	VBD902M001RNG	Common		ON	operator
12/07/2020	08:13:38.255	Water booster unit pump 1 running	VBD902M001RNG	Common		ON	operator
12/07/2020	08:13:39.817	Water booster unit pump 1 running	VBD902M001RNG	Common		OFF	operator
12/07/2020	08:13:39.817	Water booster unit pump 1 running	VBD902M001RNG	Common		OFF	operator
12/07/2020	08:13:40.937	HFO feeder unit sludge pump 2 running	PCA901D105ING	Common		OFF	operator
12/07/2020	08:13:40.937	HFO feeder unit sludge pump 2 running	PCA901D105ING	Common		OFF	operator
12/07/2020	08:13:40.974	HFO feeder unit sludge pump 2 running	PCA901D105ING	Common		ON	operator
12/07/2020	08:13:40.974	HFO feeder unit sludge pump 2 running	PCA901D105ING	Common		ON	operator
12/07/2020	08:14:12.499	TRP, VAMP210 overcurrent I>	BAE151F51XTRH	Genset_15	UNACK_ALM	ON	operator
12/07/2020	08:14:12.499	TRP, VAMP210 overcurrent I>	BAE151F51XTRH	Genset_15	UNACK_ALM	ON	operator
12/07/2020	08:14:21.057	HFO feeder unit sludge pump 2 running	PCA901D105ING	Common		OFF	operator
12/07/2020	08:14:21.057	HFO feeder unit sludge pump 2 running	PCA901D105ING	Common		OFF	operator
12/07/2020	08:14:21.097	HFO feeder unit sludge pump 2 running	PCA901D105ING	Common		ON	operator
12/07/2020	08:14:21.097	HFO feeder unit sludge pump 2 running	PCA901D105ING	Common		ON	operator
12/07/2020	08:14:53.218	Water booster unit pump 1 running	VBD902M001RNG	Common		ON	operator
12/07/2020	08:14:53.218	Water booster unit pump 1 running	VBD902M001RNG	Common		ON	operator
12/07/2020	08:15:01.139	HFO feeder unit sludge pump 2 running	PCA901D105ING	Common		OFF	operator
12/07/2020	08:15:01.139	HFO feeder unit sludge pump 2 running	PCA901D105ING	Common		OFF	operator
12/07/2020	08:15:01.181	HFO feeder unit sludge pump 2 running	PCA901D105ING	Common		ON	operator
12/07/2020	08:15:01.181	HFO feeder unit sludge pump 2 running	PCA901D105ING	Common		ON	operator
12/07/2020	08:15:41.223	HFO feeder unit sludge pump 2 running	PCA901D105ING	Common		OFF	operator
12/07/2020	08:15:41.223	HFO feeder unit sludge pump 2 running	PCA901D105ING	Common		OFF	operator

(local) - WWAlmDb Displaying 1 to 1000 of 1817 records. Connected

12/14/2020 20:19:33.358 Genset_15 ALM, Low CA temp. engine inlet SCA151TE601AL UNACK_R... OFF

Figure 7 Engine 15 overcurrent trip.

2 min later engine 13 trip from over current.

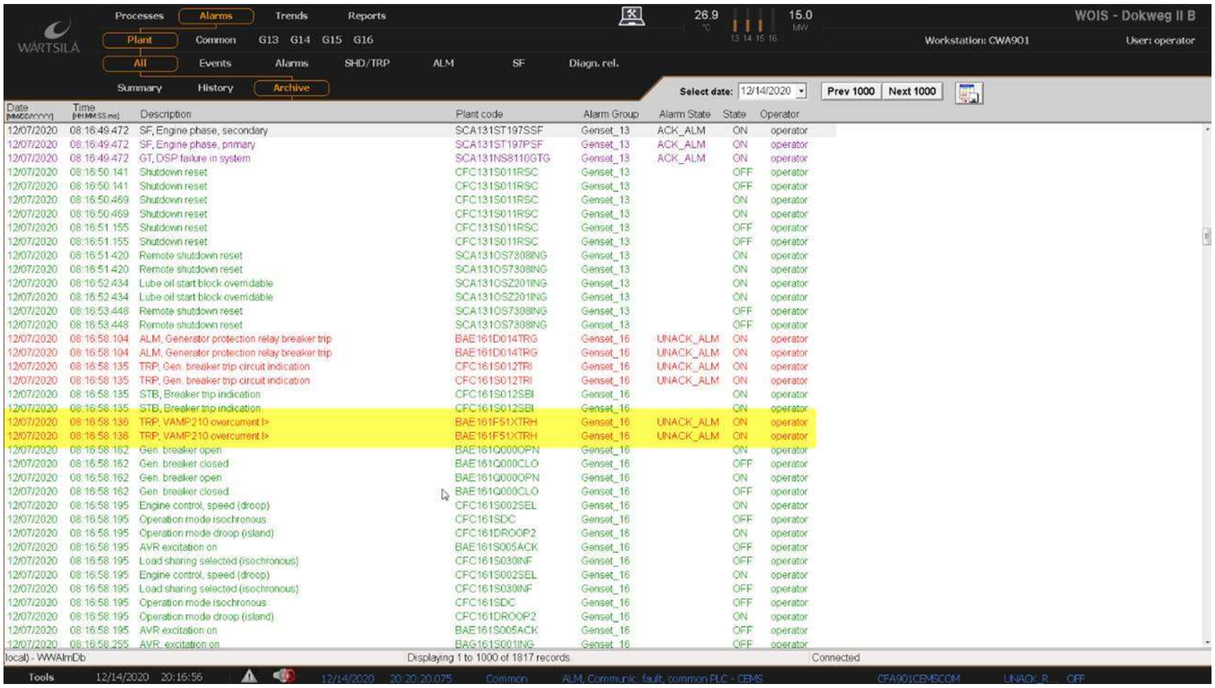


Date [MM/DD/YYYY]	Time [HH:MM:SS.ms]	Description	Plant code	Alarm Group	Alarm State	State	Operator
12/07/2020	08:15:41.223	HFO feeder unit sludge pump 2 running	PCA901D105ING	Common		OFF	operator
12/07/2020	08:15:41.265	HFO feeder unit sludge pump 2 running	PCA901D105ING	Common		ON	operator
12/07/2020	08:15:41.265	HFO feeder unit sludge pump 2 running	PCA901D105ING	Common		ON	operator
12/07/2020	08:15:42.483	Audible alarm reset from WOIS	CFA901S018RSC	Common		ON	operator
12/07/2020	08:15:42.499	Audible alarm reset from WOIS	CFA901S018RSC	Common		ON	operator
12/07/2020	08:15:43.139	Audible alarm reset from WOIS	CFA901S018RSC	Common		OFF	operator
12/07/2020	08:15:43.139	Audible alarm reset from WOIS	CFA901S018RSC	Common		OFF	operator
12/07/2020	08:15:48.642	ALM, VAMP210 undervoltage U1<	BAE131F27XAL	Genset_13	UNACK_ALM	ON	operator
12/07/2020	08:15:48.642	ALM, VAMP210 undervoltage U1<	BAE131F27XAL	Genset_13	UNACK_ALM	ON	operator
12/07/2020	08:16:08.797	TRP, VAMP210 overcurrent I>	BAE131F51XTRH	Genset_13	UNACK_ALM	ON	operator
12/07/2020	08:16:08.797	TRP, VAMP210 overcurrent I>	BAE131F51XTRH	Genset_13	UNACK_ALM	ON	operator
12/07/2020	08:16:21.311	HFO feeder unit sludge pump 2 running	PCA901D105ING	Common		OFF	operator
12/07/2020	08:16:21.311	HFO feeder unit sludge pump 2 running	PCA901D105ING	Common		OFF	operator
12/07/2020	08:16:21.349	HFO feeder unit sludge pump 2 running	PCA901D105ING	Common		ON	operator
12/07/2020	08:16:21.349	HFO feeder unit sludge pump 2 running	PCA901D105ING	Common		ON	operator
12/07/2020	08:16:25.072	kW control enabled	SCA161OS7328ING	Genset_16		OFF	operator
12/07/2020	08:16:25.072	kW control enabled	SCA161OS7328ING	Genset_16		OFF	operator
12/07/2020	08:16:26.226	kW control enabled	SCA151OS7328ING	Genset_15		OFF	operator
12/07/2020	08:16:26.226	kW control enabled	SCA151OS7328ING	Genset_15		OFF	operator
12/07/2020	08:16:28.691	Audible alarm reset from WOIS	CFA901S018RSC	Common		ON	operator
12/07/2020	08:16:28.691	Audible alarm reset from WOIS	CFA901S018RSC	Common		ON	operator
12/07/2020	08:16:29.174	Audible alarm reset from WOIS	CFA901S018RSC	Common		OFF	operator
12/07/2020	08:16:29.174	Audible alarm reset from WOIS	CFA901S018RSC	Common		OFF	operator
12/07/2020	08:16:41.155	Shutdown reset	CFC161S011RSC	Genset_16		ON	operator
12/07/2020	08:16:41.155	Shutdown reset	CFC161S011RSC	Genset_16		ON	operator
12/07/2020	08:16:41.155	ALM, FO shut-off valve position alarm	PCC161V007ALI	Genset_16	ACK_RTN	OFF	operator
12/07/2020	08:16:41.155	ALM, Light level stack 4	BLH911L04PV	Genset_16	ACK_ALM	0	operator
12/07/2020	08:16:41.155	ALM, Instrument air pressure low	SCA161PT312AL	Genset_16	ACK_RTN	OFF	operator
12/07/2020	08:16:41.155	ALM, Generator protection relay breaker trip	BAE161D014TRG	Genset_16	ACK_ALM	ON	operator
12/07/2020	08:16:41.155	TRP, VAMP210 overcurrent I>	BAE161F51XTRH	Genset_16	ACK_RTN	OFF	operator
12/07/2020	08:16:41.155	TRP, Gen. breaker trip circuit indication	CFC161S012TRI	Genset_16	ACK_ALM	ON	operator
12/07/2020	08:16:41.188	ALM, FO shut-off valve position alarm	PCC161V007ALI	Genset_16	ACK_RTN	OFF	operator
12/07/2020	08:16:41.188	ALM, Light level stack 4	BLH911L04PV	Genset_16	ACK_ALM	0	operator
12/07/2020	08:16:41.188	ALM, Instrument air pressure low	SCA161PT312AL	Genset_16	ACK_RTN	OFF	operator
12/07/2020	08:16:41.188	ALM, Generator protection relay breaker trip	BAE161D014TRG	Genset_16	ACK_ALM	ON	operator
12/07/2020	08:16:41.188	TRP, VAMP210 overcurrent I>	BAE161F51XTRH	Genset_16	ACK_RTN	OFF	operator
12/07/2020	08:16:41.188	TRP, Gen. breaker trip circuit indication	CFC161S012TRI	Genset_16	ACK_ALM	ON	operator
12/07/2020	08:16:42.154	Shutdown reset	CFC161S011RSC	Genset_16		OFF	operator

local) - WWAlmDb Displaying 1 to 1000 of 1817 records. Connected

Tools 12/14/2020 20:16:35 12/14/2020 20:19:54.479 Common ALM, Communic. fault, common PLC - CEMS CFA901CEMSCOM UNACK ON

Figure 8 Engine 13 trip.



Date [MM/DD/YYYY]	Time [HH:MM:SS.ms]	Description	Plant code	Alarm Group	Alarm State	State	Operator
12/07/2020	08:16:49.472	SF, Engine phase, secondary	SCA131ST197SSF	Genset_13	ACK_ALM	ON	operator
12/07/2020	08:16:49.472	SF, Engine phase, primary	SCA131ST197PSF	Genset_13	ACK_ALM	ON	operator
12/07/2020	08:16:49.472	GT, DSP failure in system	SCA131NS8110GTG	Genset_13	ACK_ALM	ON	operator
12/07/2020	08:16:50.141	Shutdown reset	CFC131S011RSC	Genset_13		OFF	operator
12/07/2020	08:16:50.141	Shutdown reset	CFC131S011RSC	Genset_13		OFF	operator
12/07/2020	08:16:50.469	Shutdown reset	CFC131S011RSC	Genset_13		ON	operator
12/07/2020	08:16:50.469	Shutdown reset	CFC131S011RSC	Genset_13		ON	operator
12/07/2020	08:16:51.155	Shutdown reset	CFC131S011RSC	Genset_13		OFF	operator
12/07/2020	08:16:51.155	Shutdown reset	CFC131S011RSC	Genset_13		OFF	operator
12/07/2020	08:16:51.420	Remote shutdown reset	SCA131OS7308ING	Genset_13		ON	operator
12/07/2020	08:16:51.420	Remote shutdown reset	SCA131OS7308ING	Genset_13		ON	operator
12/07/2020	08:16:52.434	Lube oil start block overridable	SCA131OSZ201ING	Genset_13		ON	operator
12/07/2020	08:16:52.434	Lube oil start block overridable	SCA131OSZ201ING	Genset_13		ON	operator
12/07/2020	08:16:53.448	Remote shutdown reset	SCA131OS7308ING	Genset_13		OFF	operator
12/07/2020	08:16:53.448	Remote shutdown reset	SCA131OS7308ING	Genset_13		OFF	operator
12/07/2020	08:16:58.104	ALM, Generator protection relay breaker trip	BAE161D014TRG	Genset_16	UNACK_ALM	ON	operator
12/07/2020	08:16:58.104	ALM, Generator protection relay breaker trip	BAE161D014TRG	Genset_16	UNACK_ALM	ON	operator
12/07/2020	08:16:58.135	TRP, Gen. breaker trip circuit indication	CFC161S012TRI	Genset_16	UNACK_ALM	ON	operator
12/07/2020	08:16:58.135	TRP, Gen. breaker trip circuit indication	CFC161S012TRI	Genset_16	UNACK_ALM	ON	operator
12/07/2020	08:16:58.135	STB, Breaker trip indication	CFC161S012SBI	Genset_16		ON	operator
12/07/2020	08:16:58.135	STB, Breaker trip indication	CFC161S012SBI	Genset_16		ON	operator
12/07/2020	08:16:58.136	TRP, VAMP210 overcurrent I>	BAE161F51XTRH	Genset_16	UNACK_ALM	ON	operator
12/07/2020	08:16:58.136	TRP, VAMP210 overcurrent I>	BAE161F51XTRH	Genset_16	UNACK_ALM	ON	operator
12/07/2020	08:16:58.162	Gen. breaker open	BAE161Q000OPN	Genset_16		ON	operator
12/07/2020	08:16:58.162	Gen. breaker closed	BAE161Q000CLO	Genset_16		OFF	operator
12/07/2020	08:16:58.162	Gen. breaker open	BAE161Q000OPN	Genset_16		ON	operator
12/07/2020	08:16:58.162	Gen. breaker closed	BAE161Q000CLO	Genset_16		OFF	operator
12/07/2020	08:16:58.195	Engine control, speed (droop)	CFC161S002SEL	Genset_16		ON	operator
12/07/2020	08:16:58.195	Operation mode isochronous	CFC161SDC	Genset_16		OFF	operator
12/07/2020	08:16:58.195	Operation mode droop (island)	CFC161DROOP2	Genset_16		ON	operator
12/07/2020	08:16:58.195	AVR excitation on	BAE161S005ACK	Genset_16		OFF	operator
12/07/2020	08:16:58.195	Load sharing selected (isochronous)	CFC161S030INF	Genset_16		OFF	operator
12/07/2020	08:16:58.195	Engine control, speed (droop)	CFC161S002SEL	Genset_16		ON	operator
12/07/2020	08:16:58.195	Load sharing selected (isochronous)	CFC161S030INF	Genset_16		OFF	operator
12/07/2020	08:16:58.195	Operation mode isochronous	CFC161SDC	Genset_16		OFF	operator
12/07/2020	08:16:58.195	Operation mode droop (island)	CFC161DROOP2	Genset_16		ON	operator
12/07/2020	08:16:58.195	AVR excitation on	BAE161S005ACK	Genset_16		OFF	operator
12/07/2020	08:16:58.255	AVR, excitation on	BAG161S001ING	Genset_16		OFF	operator

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Tools 12/14/2020 20:16:56 12/14/2020 20:20:20.075 Common ALM, Communic. fault, common PLC - CEMS CFA901CEMSCOM UNACK_R... OFF

Figure 9 Engine 16 overcurrent trip.

[Information Classification]

Doc. Name	Analysis of Grid Events, 10th of December 2020		
Doc. ID		**Revision**	a
Author	Jaakko Hämeenniemi – 15.01.2021	**Pages**	1 (8)
Approved by	Jaakko Hämeenniemi – 15.01.2021		

Analysis of Grid Event on 10th of December 2020

DOKWEG 2A - 2B

W32 - W34

On Behalf of Wärtsilä:

Jaakko Hämeenniemi

GM, Field and Technical Services

Technical Services

TABLE OF CONTENTS

1 BACKGROUND

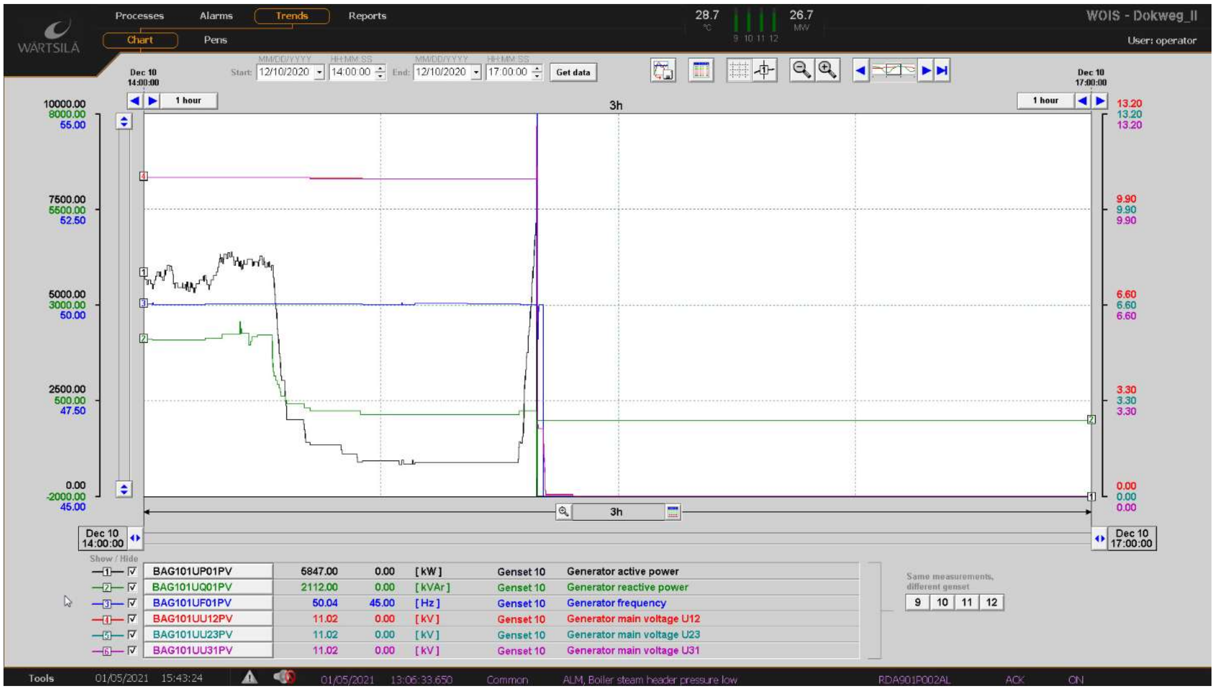
On the 10th of December 2020, between 14:45 – 15:45, various events took place in the power system of Aqualectra which eventually led to a blackout in the power system. This report includes analysis of the event and recommendations.

2 INSPECTIONS

Dokweg 2A and 2B WOIS (Wärtsilä Operators Interface System) data was collected, data in WOIS system is seen in 1s resolution. Data can be saved in visual format (.jpg) or in (.csv) format for that data can be exported to other systems for closer analysis. Data from Dokweg 2A and 2B was saved between 14:00-17:00 for further analysis.

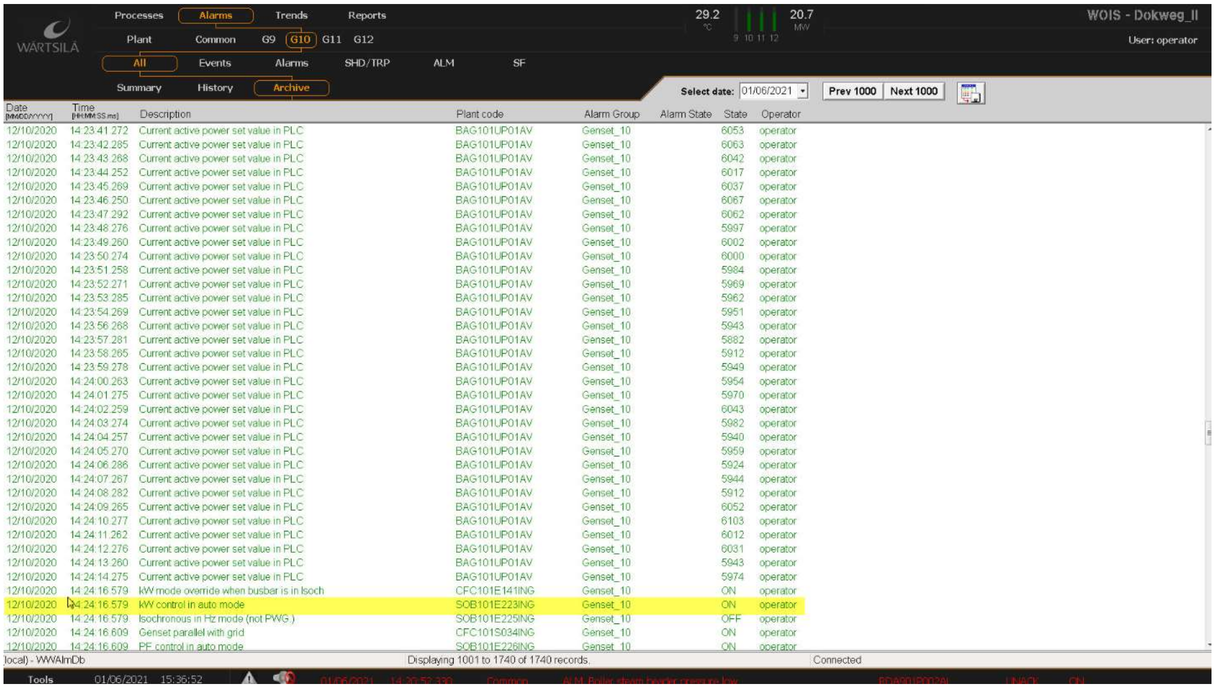
3 ANALYSIS OF EVENTS

- Engine 10 turbo washing December 10th, 2020, 14:24:14 engine mode to kW and P.F
- 14:31:20 turbine wash active. Load 1300 kW.
- 15:11:06 turbine was completed.
- 15:11:55 engine set Isochronous operation from WOIS. Load ramping from 1300 to 7250 kW.
- 15:14:38 trip from reverse power. Auto stop active in several cylinder temps. Probably caused high ramp rate after turbo washing. B3 cylinder temp deviation alarm active longest time.



1 ☑	BAG101UP01PV	5847.00	0.00	[kW]	Genset 10	Generator active power
2 ☑	BAG101UQ01PV	2112.00	0.00	[kVAr]	Genset 10	Generator reactive power
3 ☑	BAG101UF01PV	50.04	45.00	[Hz]	Genset 10	Generator frequency
4 ☑	BAG101UU12PV	11.02	0.00	[kV]	Genset 10	Generator main voltage U12
5 ☑	BAG101UU23PV	11.02	0.00	[kV]	Genset 10	Generator main voltage U23
6 ☑	BAG101UU31PV	11.02	0.00	[kV]	Genset 10	Generator main voltage U31

Figure 1 Engine 10 turbo washing.

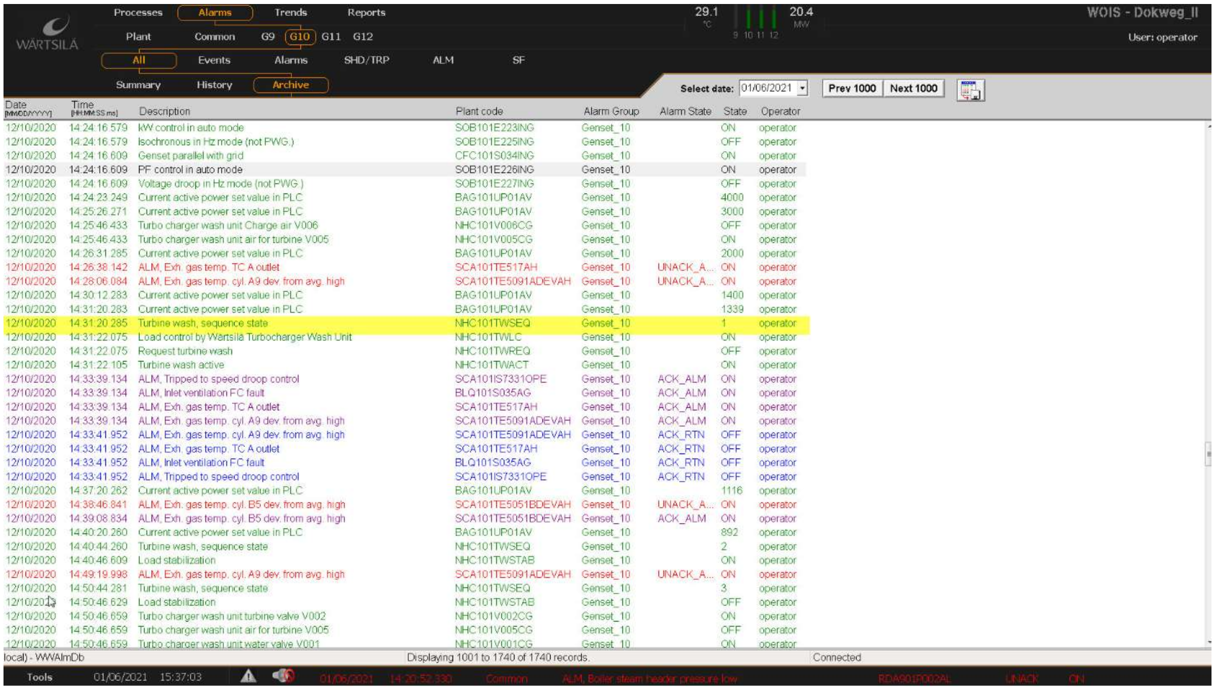


Select date: 01/06/2021

Date [MM/DD/YYYY]	Time [HH:MM:SS.ms]	Description	Plant code	Alarm Group	Alarm State	State	Operator
12/10/2020	14:23:41.272	Current active power set value in PLC	BAG101UP01AV	Genset_10		6053	operator
12/10/2020	14:23:42.285	Current active power set value in PLC	BAG101UP01AV	Genset_10		6063	operator
12/10/2020	14:23:43.268	Current active power set value in PLC	BAG101UP01AV	Genset_10		6042	operator
12/10/2020	14:23:44.252	Current active power set value in PLC	BAG101UP01AV	Genset_10		6017	operator
12/10/2020	14:23:45.269	Current active power set value in PLC	BAG101UP01AV	Genset_10		6037	operator
12/10/2020	14:23:46.250	Current active power set value in PLC	BAG101UP01AV	Genset_10		6067	operator
12/10/2020	14:23:47.292	Current active power set value in PLC	BAG101UP01AV	Genset_10		6062	operator
12/10/2020	14:23:48.276	Current active power set value in PLC	BAG101UP01AV	Genset_10		5997	operator
12/10/2020	14:23:49.260	Current active power set value in PLC	BAG101UP01AV	Genset_10		6002	operator
12/10/2020	14:23:50.274	Current active power set value in PLC	BAG101UP01AV	Genset_10		6000	operator
12/10/2020	14:23:51.258	Current active power set value in PLC	BAG101UP01AV	Genset_10		5984	operator
12/10/2020	14:23:52.271	Current active power set value in PLC	BAG101UP01AV	Genset_10		5969	operator
12/10/2020	14:23:53.285	Current active power set value in PLC	BAG101UP01AV	Genset_10		5962	operator
12/10/2020	14:23:54.269	Current active power set value in PLC	BAG101UP01AV	Genset_10		5951	operator
12/10/2020	14:23:56.268	Current active power set value in PLC	BAG101UP01AV	Genset_10		5943	operator
12/10/2020	14:23:57.281	Current active power set value in PLC	BAG101UP01AV	Genset_10		5882	operator
12/10/2020	14:23:58.265	Current active power set value in PLC	BAG101UP01AV	Genset_10		5912	operator
12/10/2020	14:23:59.278	Current active power set value in PLC	BAG101UP01AV	Genset_10		5949	operator
12/10/2020	14:24:00.263	Current active power set value in PLC	BAG101UP01AV	Genset_10		5954	operator
12/10/2020	14:24:01.275	Current active power set value in PLC	BAG101UP01AV	Genset_10		5970	operator
12/10/2020	14:24:02.259	Current active power set value in PLC	BAG101UP01AV	Genset_10		6043	operator
12/10/2020	14:24:03.274	Current active power set value in PLC	BAG101UP01AV	Genset_10		5982	operator
12/10/2020	14:24:04.257	Current active power set value in PLC	BAG101UP01AV	Genset_10		5940	operator
12/10/2020	14:24:05.270	Current active power set value in PLC	BAG101UP01AV	Genset_10		5959	operator
12/10/2020	14:24:06.286	Current active power set value in PLC	BAG101UP01AV	Genset_10		5924	operator
12/10/2020	14:24:07.267	Current active power set value in PLC	BAG101UP01AV	Genset_10		5944	operator
12/10/2020	14:24:08.282	Current active power set value in PLC	BAG101UP01AV	Genset_10		5912	operator
12/10/2020	14:24:09.265	Current active power set value in PLC	BAG101UP01AV	Genset_10		6052	operator
12/10/2020	14:24:10.277	Current active power set value in PLC	BAG101UP01AV	Genset_10		6103	operator
12/10/2020	14:24:11.262	Current active power set value in PLC	BAG101UP01AV	Genset_10		6012	operator
12/10/2020	14:24:12.276	Current active power set value in PLC	BAG101UP01AV	Genset_10		6031	operator
12/10/2020	14:24:13.260	Current active power set value in PLC	BAG101UP01AV	Genset_10		5943	operator
12/10/2020	14:24:14.275	Current active power set value in PLC	BAG101UP01AV	Genset_10		5974	operator
12/10/2020	14:24:16.579	kW mode override when busbar is in Isoch	CFC101E141ING	Genset_10		ON	operator
12/10/2020	14:24:16.579	kW control in auto mode	SOB101E223ING	Genset_10		ON	operator
12/10/2020	14:24:16.579	Isochronous in Hz mode (not PWG.)	SOB101E225ING	Genset_10		OFF	operator
12/10/2020	14:24:16.609	Genset parallel with grid	CFC101S034ING	Genset_10		ON	operator
12/10/2020	14:24:16.609	PF control in auto mode	SOB101E226ING	Genset_10		ON	operator

(local) - WWAlmDb Displaying 1001 to 1740 of 1740 records. Connected

Figure 2 Operating mode.



Date [MM/DD/YYYY]	Time [HH:MM:SS.ms]	Description	Plant code	Alarm Group	Alarm State	State	Operator
12/10/2020	14:24:16.579	kW control in auto mode	SOB101E223ING	Genset_10		ON	operator
12/10/2020	14:24:16.579	Isochronous in Hz mode (not PWG.)	SOB101E225ING	Genset_10		OFF	operator
12/10/2020	14:24:16.609	Genset parallel with grid	CFC101S034ING	Genset_10		ON	operator
12/10/2020	14:24:16.609	PF control in auto mode	SOB101E226ING	Genset_10		ON	operator
12/10/2020	14:24:16.609	Voltage droop in Hz mode (not PWG.)	SOB101E227ING	Genset_10		OFF	operator
12/10/2020	14:24:23.249	Current active power set value in PLC	BAG101UP01AV	Genset_10		4000	operator
12/10/2020	14:25:26.271	Current active power set value in PLC	BAG101UP01AV	Genset_10		3000	operator
12/10/2020	14:25:46.433	Turbo charger wash unit Charge air V006	NHC101V006CG	Genset_10		OFF	operator
12/10/2020	14:25:46.433	Turbo charger wash unit air for turbine V005	NHC101V005CG	Genset_10		ON	operator
12/10/2020	14:26:31.285	Current active power set value in PLC	BAG101UP01AV	Genset_10		2000	operator
12/10/2020	14:26:38.142	ALM, Exh. gas temp. TC A outlet	SCA101TE517AH	Genset_10	UNACK_A...	ON	operator
12/10/2020	14:28:06.084	ALM, Exh. gas temp. cyl. A9 dev. from avg. high	SCA101TE5091ADEVAH	Genset_10	UNACK_A...	ON	operator
12/10/2020	14:30:12.283	Current active power set value in PLC	BAG101UP01AV	Genset_10		1400	operator
12/10/2020	14:31:20.283	Current active power set value in PLC	BAG101UP01AV	Genset_10		1339	operator
12/10/2020	14:31:20.285	Turbine wash, sequence state	NHC101TWSEQ	Genset_10		1	operator
12/10/2020	14:31:22.075	Load control by Wartsila Turbocharger Wash Unit	NHC101TWLC	Genset_10		ON	operator
12/10/2020	14:31:22.075	Request turbine wash	NHC101TWREQ	Genset_10		OFF	operator
12/10/2020	14:31:22.105	Turbine wash active	NHC101TWACT	Genset_10		ON	operator
12/10/2020	14:33:39.134	ALM, Tripped to speed droop control	SCA101IS7331OPE	Genset_10	ACK_ALM	ON	operator
12/10/2020	14:33:39.134	ALM, Inlet ventilation FC fault	BLQ101S035AG	Genset_10	ACK_ALM	ON	operator
12/10/2020	14:33:39.134	ALM, Exh. gas temp. TC A outlet	SCA101TE517AH	Genset_10	ACK_ALM	ON	operator
12/10/2020	14:33:39.134	ALM, Exh. gas temp. cyl. A9 dev. from avg. high	SCA101TE5091ADEVAH	Genset_10	ACK_ALM	ON	operator
12/10/2020	14:33:41.952	ALM, Exh. gas temp. cyl. A9 dev. from avg. high	SCA101TE5091ADEVAH	Genset_10	ACK_RTN	OFF	operator
12/10/2020	14:33:41.952	ALM, Exh. gas temp. TC A outlet	SCA101TE517AH	Genset_10	ACK_RTN	OFF	operator
12/10/2020	14:33:41.952	ALM, Inlet ventilation FC fault	BLQ101S035AG	Genset_10	ACK_RTN	OFF	operator
12/10/2020	14:33:41.952	ALM, Tripped to speed droop control	SCA101IS7331OPE	Genset_10	ACK_RTN	OFF	operator
12/10/2020	14:37:20.262	Current active power set value in PLC	BAG101UP01AV	Genset_10		1116	operator
12/10/2020	14:38:46.841	ALM, Exh. gas temp. cyl. B5 dev. from avg. high	SCA101TE5051BDEVAH	Genset_10	UNACK_A...	ON	operator
12/10/2020	14:39:08.834	ALM, Exh. gas temp. cyl. B5 dev. from avg. high	SCA101TE5051BDEVAH	Genset_10	ACK_ALM	ON	operator
12/10/2020	14:40:20.260	Current active power set value in PLC	BAG101UP01AV	Genset_10		892	operator
12/10/2020	14:40:44.260	Turbine wash, sequence state	NHC101TWSEQ	Genset_10		2	operator
12/10/2020	14:40:46.609	Load stabilization	NHC101TWSTAB	Genset_10		ON	operator
12/10/2020	14:49:19.998	ALM, Exh. gas temp. cyl. A9 dev. from avg. high	SCA101TE5091ADEVAH	Genset_10	UNACK_A...	ON	operator
12/10/2020	14:50:44.281	Turbine wash, sequence state	NHC101TWSEQ	Genset_10		3	operator
12/10/2020	14:50:46.629	Load stabilization	NHC101TWSTAB	Genset_10		OFF	operator
12/10/2020	14:50:46.659	Turbo charger wash unit turbine valve V002	NHC101V002CG	Genset_10		ON	operator
12/10/2020	14:50:46.659	Turbo charger wash unit air for turbine V005	NHC101V005CG	Genset_10		OFF	operator
12/10/2020	14:50:46.659	Turbo charger wash unit water valve V001	NHC101V001CG	Genset_10		ON	operator

local) - WWAlmDb
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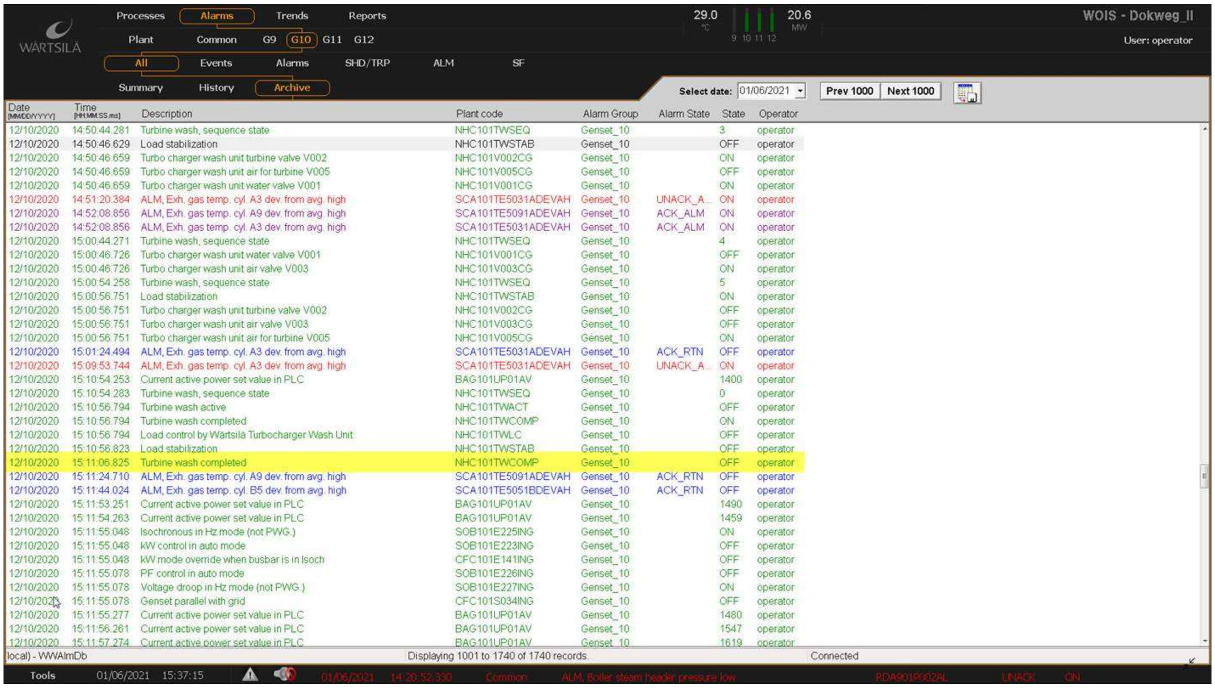
Tools 01/06/2021 15:37:03 01/06/2021 14:20:52.330 Common ALM, Boiler steam header pressure low RDA901P002AL UNACK ON

Figure 3 Turbine washing.



Date [MM/DD/YYYY]	Time [HH:MM:SS.ms]	Description	Plant code	Alarm Group	Alarm State	State	Operator
12/10/2020	14:50:44.281	Turbine wash, sequence state	NHC101TWSEQ	Genset_10		3	operator
12/10/2020	14:50:46.629	Load stabilization	NHC101TWSTAB	Genset_10		OFF	operator
12/10/2020	14:50:46.659	Turbo charger wash unit turbine valve V002	NHC101V002CG	Genset_10		ON	operator
12/10/2020	14:50:46.659	Turbo charger wash unit air for turbine V005	NHC101V005CG	Genset_10		OFF	operator
12/10/2020	14:50:46.659	Turbo charger wash unit water valve V001	NHC101V001CG	Genset_10		ON	operator
12/10/2020	14:51:20.384	ALM, Exh. gas temp. cyl. A3 dev. from avg. high	SCA101TE5031ADEVAH	Genset_10	UNACK_A...	ON	operator
12/10/2020	14:52:08.856	ALM, Exh. gas temp. cyl. A9 dev. from avg. high	SCA101TE5091ADEVAH	Genset_10	ACK_ALM	ON	operator
12/10/2020	14:52:08.856	ALM, Exh. gas temp. cyl. A3 dev. from avg. high	SCA101TE5031ADEVAH	Genset_10	ACK_ALM	ON	operator
12/10/2020	15:00:44.271	Turbine wash, sequence state	NHC101TWSEQ	Genset_10		4	operator
12/10/2020	15:00:46.726	Turbo charger wash unit water valve V001	NHC101V001CG	Genset_10		OFF	operator
12/10/2020	15:00:46.726	Turbo charger wash unit air valve V003	NHC101V003CG	Genset_10		ON	operator
12/10/2020	15:00:54.258	Turbine wash, sequence state	NHC101TWSEQ	Genset_10		5	operator
12/10/2020	15:00:56.751	Load stabilization	NHC101TWSTAB	Genset_10		ON	operator
12/10/2020	15:00:56.751	Turbo charger wash unit turbine valve V002	NHC101V002CG	Genset_10		OFF	operator
12/10/2020	15:00:56.751	Turbo charger wash unit air valve V003	NHC101V003CG	Genset_10		OFF	operator
12/10/2020	15:00:56.751	Turbo charger wash unit air for turbine V005	NHC101V005CG	Genset_10		ON	operator
12/10/2020	15:01:24.494	ALM, Exh. gas temp. cyl. A3 dev. from avg. high	SCA101TE5031ADEVAH	Genset_10	ACK_RTN	OFF	operator
12/10/2020	15:09:53.744	ALM, Exh. gas temp. cyl. A3 dev. from avg. high	SCA101TE5031ADEVAH	Genset_10	UNACK_A...	ON	operator
12/10/2020	15:10:54.253	Current active power set value in PLC	BAG101UP01AV	Genset_10		1400	operator
12/10/2020	15:10:54.283	Turbine wash, sequence state	NHC101TWSEQ	Genset_10		0	operator
12/10/2020	15:10:56.794	Turbine wash active	NHC101TWACT	Genset_10		OFF	operator
12/10/2020	15:10:56.794	Turbine wash completed	NHC101TWCOMP	Genset_10		ON	operator
12/10/2020	15:10:56.794	Load control by Wärtsilä Turbocharger Wash Unit	NHC101TWLC	Genset_10		OFF	operator
12/10/2020	15:10:56.823	Load stabilization	NHC101TWSTAB	Genset_10		OFF	operator
12/10/2020	15:11:06.825	Turbine wash completed	NHC101TWCOMP	Genset_10		OFF	operator
12/10/2020	15:11:24.710	ALM, Exh. gas temp. cyl. A9 dev. from avg. high	SCA101TE5091ADEVAH	Genset_10	ACK_RTN	OFF	operator
12/10/2020	15:11:44.024	ALM, Exh. gas temp. cyl. B5 dev. from avg. high	SCA101TE5051BDEVAH	Genset_10	ACK_RTN	OFF	operator
12/10/2020	15:11:53.251	Current active power set value in PLC	BAG101UP01AV	Genset_10		1490	operator
12/10/2020	15:11:54.263	Current active power set value in PLC	BAG101UP01AV	Genset_10		1459	operator
12/10/2020	15:11:55.048	Isochronous in Hz mode (not PWG.)	SOB101E225ING	Genset_10		ON	operator
12/10/2020	15:11:55.048	kW control in auto mode	SOB101E223ING	Genset_10		OFF	operator
12/10/2020	15:11:55.048	kW mode override when busbar is in Isoch	CFC101E141ING	Genset_10		OFF	operator
12/10/2020	15:11:55.078	PF control in auto mode	SOB101E226ING	Genset_10		OFF	operator
12/10/2020	15:11:55.078	Voltage droop in Hz mode (not PWG.)	SOB101E227ING	Genset_10		ON	operator
12/10/2020	15:11:55.078	Genset parallel with grid	CFC101S034ING	Genset_10		OFF	operator
12/10/2020	15:11:55.277	Current active power set value in PLC	BAG101UP01AV	Genset_10		1480	operator
12/10/2020	15:11:56.261	Current active power set value in PLC	BAG101UP01AV	Genset_10		1547	operator
12/10/2020	15:11:57.274	Current active power set value in PLC	BAG101UP01AV	Genset_10		1619	operator

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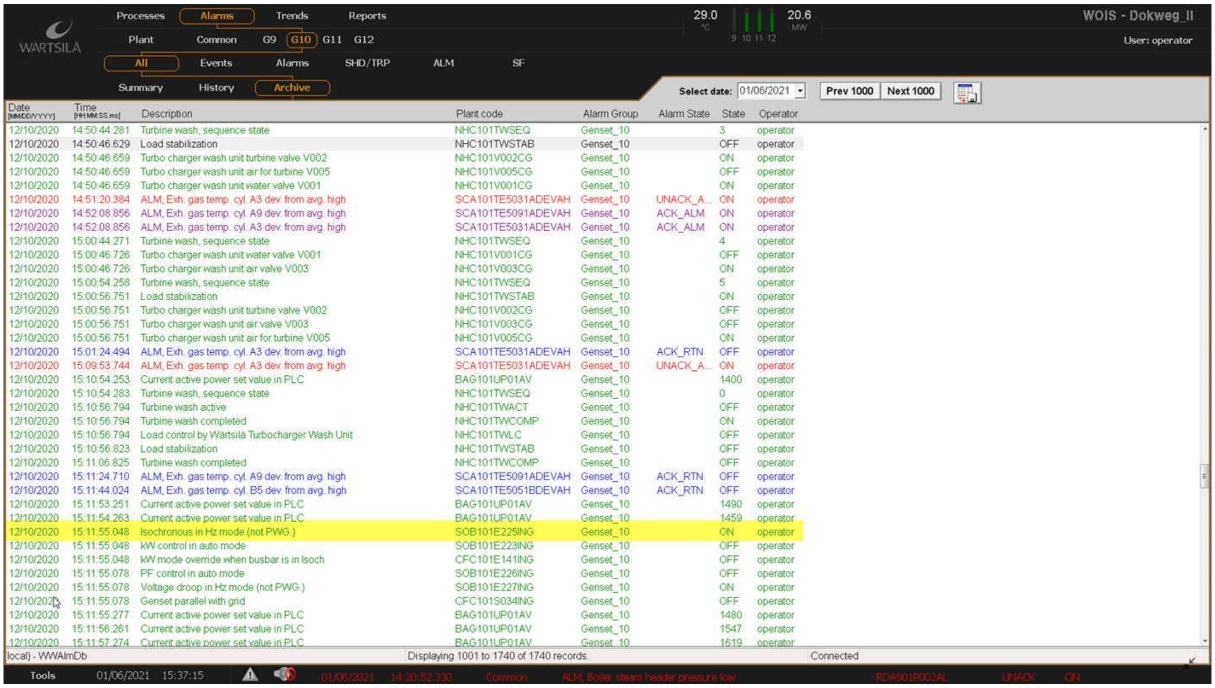
Figure 4 Turbine washing completed.

Engine 10 set to auto / Isochronous, Ramping automatically load -> load sharing level.



Date [MM/DD/YYYY]	Time [HH:MM:SS.ms]	Description	Plant code	Alarm Group	Alarm State	State	Operator
12/10/2020	14:50:44.281	Turbine wash, sequence state	NHC101TWSEQ	Genset_10		3	operator
12/10/2020	14:50:46.629	Load stabilization	NHC101TWSTAB	Genset_10		OFF	operator
12/10/2020	14:50:46.659	Turbo charger wash unit turbine valve V002	NHC101V002CG	Genset_10		ON	operator
12/10/2020	14:50:46.659	Turbo charger wash unit air for turbine V005	NHC101V005CG	Genset_10		OFF	operator
12/10/2020	14:50:46.659	Turbo charger wash unit water valve V001	NHC101V001CG	Genset_10		ON	operator
12/10/2020	14:51:20.384	ALM, Exh. gas temp. cyl. A3 dev. from avg. high	SCA101TE5031ADEVAH	Genset_10	UNACK_A...	ON	operator
12/10/2020	14:52:08.856	ALM, Exh. gas temp. cyl. A9 dev. from avg. high	SCA101TE5091ADEVAH	Genset_10	ACK_ALM	ON	operator
12/10/2020	14:52:08.856	ALM, Exh. gas temp. cyl. A3 dev. from avg. high	SCA101TE5031ADEVAH	Genset_10	ACK_ALM	ON	operator
12/10/2020	15:00:44.271	Turbine wash, sequence state	NHC101TWSEQ	Genset_10		4	operator
12/10/2020	15:00:46.726	Turbo charger wash unit water valve V001	NHC101V001CG	Genset_10		OFF	operator
12/10/2020	15:00:46.726	Turbo charger wash unit air valve V003	NHC101V003CG	Genset_10		ON	operator
12/10/2020	15:00:54.258	Turbine wash, sequence state	NHC101TWSEQ	Genset_10		5	operator
12/10/2020	15:00:56.751	Load stabilization	NHC101TWSTAB	Genset_10		ON	operator
12/10/2020	15:00:56.751	Turbo charger wash unit turbine valve V002	NHC101V002CG	Genset_10		OFF	operator
12/10/2020	15:00:56.751	Turbo charger wash unit air valve V003	NHC101V003CG	Genset_10		OFF	operator
12/10/2020	15:00:56.751	Turbo charger wash unit air for turbine V005	NHC101V005CG	Genset_10		ON	operator
12/10/2020	15:01:24.494	ALM, Exh. gas temp. cyl. A3 dev. from avg. high	SCA101TE5031ADEVAH	Genset_10	ACK_RTN	OFF	operator
12/10/2020	15:09:53.744	ALM, Exh. gas temp. cyl. A3 dev. from avg. high	SCA101TE5031ADEVAH	Genset_10	UNACK_A...	ON	operator
12/10/2020	15:10:54.253	Current active power set value in PLC	BAG101UP01AV	Genset_10		1400	operator
12/10/2020	15:10:54.283	Turbine wash, sequence state	NHC101TWSEQ	Genset_10		0	operator
12/10/2020	15:10:56.794	Turbine wash active	NHC101TWACT	Genset_10		OFF	operator
12/10/2020	15:10:56.794	Turbine wash completed	NHC101TWCOMP	Genset_10		ON	operator
12/10/2020	15:10:56.794	Load control by Wärtsilä Turbocharger Wash Unit	NHC101TWLC	Genset_10		OFF	operator
12/10/2020	15:10:56.823	Load stabilization	NHC101TWSTAB	Genset_10		OFF	operator
12/10/2020	15:11:06.825	Turbine wash completed	NHC101TWCOMP	Genset_10		OFF	operator
12/10/2020	15:11:24.710	ALM, Exh. gas temp. cyl. A9 dev. from avg. high	SCA101TE5091ADEVAH	Genset_10	ACK_RTN	OFF	operator
12/10/2020	15:11:44.024	ALM, Exh. gas temp. cyl. B5 dev. from avg. high	SCA101TE5051BDEVAH	Genset_10	ACK_RTN	OFF	operator
12/10/2020	15:11:53.251	Current active power set value in PLC	BAG101UP01AV	Genset_10		1490	operator
12/10/2020	15:11:54.263	Current active power set value in PLC	BAG101UP01AV	Genset_10		1459	operator
12/10/2020	15:11:55.048	Isochronous in Hz mode (not PWG.)	SOB101E225ING	Genset_10		ON	operator
12/10/2020	15:11:55.048	kW control in auto mode	SOB101E223ING	Genset_10		OFF	operator
12/10/2020	15:11:55.048	kW mode override when busbar is in Isoch	CFC101E141ING	Genset_10		OFF	operator
12/10/2020	15:11:55.078	PF control in auto mode	SOB101E226ING	Genset_10		OFF	operator
12/10/2020	15:11:55.078	Voltage droop in Hz mode (not PWG.)	SOB101E227ING	Genset_10		ON	operator
12/10/2020	15:11:55.078	Genset parallel with grid	CFC101S034ING	Genset_10		OFF	operator
12/10/2020	15:11:55.277	Current active power set value in PLC	BAG101UP01AV	Genset_10		1480	operator
12/10/2020	15:11:56.261	Current active power set value in PLC	BAG101UP01AV	Genset_10		1547	operator
12/10/2020	15:11:57.274	Current active power set value in PLC	BAG101UP01AV	Genset_10		1619	operator

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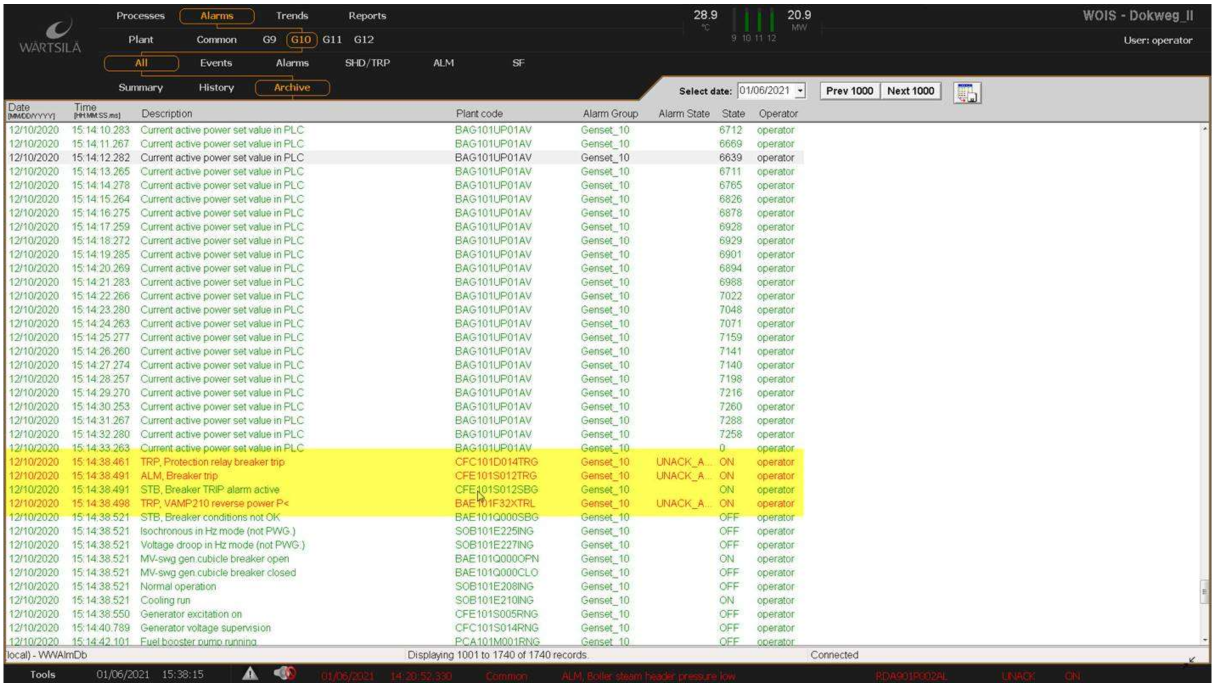
Figure 5 Isochronous mode.



Date [MM/DD/YYYY]	Time [HH:MM:SS.ms]	Description	Plant code	Alarm Group	Alarm State	State	Operator
12/10/2020	15:14:10.283	Current active power set value in PLC	BAG101UP01AV	Genset_10		6712	operator
12/10/2020	15:14:11.267	Current active power set value in PLC	BAG101UP01AV	Genset_10		6669	operator
12/10/2020	15:14:12.282	Current active power set value in PLC	BAG101UP01AV	Genset_10		6639	operator
12/10/2020	15:14:13.265	Current active power set value in PLC	BAG101UP01AV	Genset_10		6711	operator
12/10/2020	15:14:14.278	Current active power set value in PLC	BAG101UP01AV	Genset_10		6765	operator
12/10/2020	15:14:15.264	Current active power set value in PLC	BAG101UP01AV	Genset_10		6826	operator
12/10/2020	15:14:16.275	Current active power set value in PLC	BAG101UP01AV	Genset_10		6878	operator
12/10/2020	15:14:17.259	Current active power set value in PLC	BAG101UP01AV	Genset_10		6928	operator
12/10/2020	15:14:18.272	Current active power set value in PLC	BAG101UP01AV	Genset_10		6929	operator
12/10/2020	15:14:19.285	Current active power set value in PLC	BAG101UP01AV	Genset_10		6901	operator
12/10/2020	15:14:20.269	Current active power set value in PLC	BAG101UP01AV	Genset_10		6894	operator
12/10/2020	15:14:21.283	Current active power set value in PLC	BAG101UP01AV	Genset_10		6988	operator
12/10/2020	15:14:22.266	Current active power set value in PLC	BAG101UP01AV	Genset_10		7022	operator
12/10/2020	15:14:23.280	Current active power set value in PLC	BAG101UP01AV	Genset_10		7048	operator
12/10/2020	15:14:24.263	Current active power set value in PLC	BAG101UP01AV	Genset_10		7071	operator
12/10/2020	15:14:25.277	Current active power set value in PLC	BAG101UP01AV	Genset_10		7159	operator
12/10/2020	15:14:26.260	Current active power set value in PLC	BAG101UP01AV	Genset_10		7141	operator
12/10/2020	15:14:27.274	Current active power set value in PLC	BAG101UP01AV	Genset_10		7140	operator
12/10/2020	15:14:28.257	Current active power set value in PLC	BAG101UP01AV	Genset_10		7198	operator
12/10/2020	15:14:29.270	Current active power set value in PLC	BAG101UP01AV	Genset_10		7216	operator
12/10/2020	15:14:30.253	Current active power set value in PLC	BAG101UP01AV	Genset_10		7260	operator
12/10/2020	15:14:31.267	Current active power set value in PLC	BAG101UP01AV	Genset_10		7288	operator
12/10/2020	15:14:32.280	Current active power set value in PLC	BAG101UP01AV	Genset_10		7258	operator
12/10/2020	15:14:33.263	Current active power set value in PLC	BAG101UP01AV	Genset_10		0	operator
12/10/2020	15:14:38.461	TRP, Protection relay breaker trip	CFC101D014TRG	Genset_10	UNACK_A...	ON	operator
12/10/2020	15:14:38.491	ALM, Breaker trip	CFE101S012TRG	Genset_10	UNACK_A...	ON	operator
12/10/2020	15:14:38.491	STB, Breaker TRIP alarm active	CFE101S012SBG	Genset_10		ON	operator
12/10/2020	15:14:38.498	TRP, VAMP210 reverse power P<	BAE101F32XTRL	Genset_10	UNACK_A...	ON	operator
12/10/2020	15:14:38.521	STB, Breaker conditions not OK	BAE101Q000SBG	Genset_10		OFF	operator
12/10/2020	15:14:38.521	Isochronous in Hz mode (not PWG.)	SOB101E225ING	Genset_10		OFF	operator
12/10/2020	15:14:38.521	Voltage droop in Hz mode (not PWG.)	SOB101E227ING	Genset_10		OFF	operator
12/10/2020	15:14:38.521	MV-swg gen.cubicle breaker open	BAE101Q000OPN	Genset_10		ON	operator
12/10/2020	15:14:38.521	MV-swg gen.cubicle breaker closed	BAE101Q000CLO	Genset_10		OFF	operator
12/10/2020	15:14:38.521	Normal operation	SOB101E208ING	Genset_10		OFF	operator
12/10/2020	15:14:38.521	Cooling run	SOB101E210ING	Genset_10		ON	operator
12/10/2020	15:14:38.550	Generator excitation on	CFE101S005RNG	Genset_10		OFF	operator
12/10/2020	15:14:40.789	Generator voltage supervision	CFC101S014RNG	Genset_10		OFF	operator
12/10/2020	15:14:42.101	Fuel booster pump running	PCA101M001RNG	Genset_10		OFF	operator

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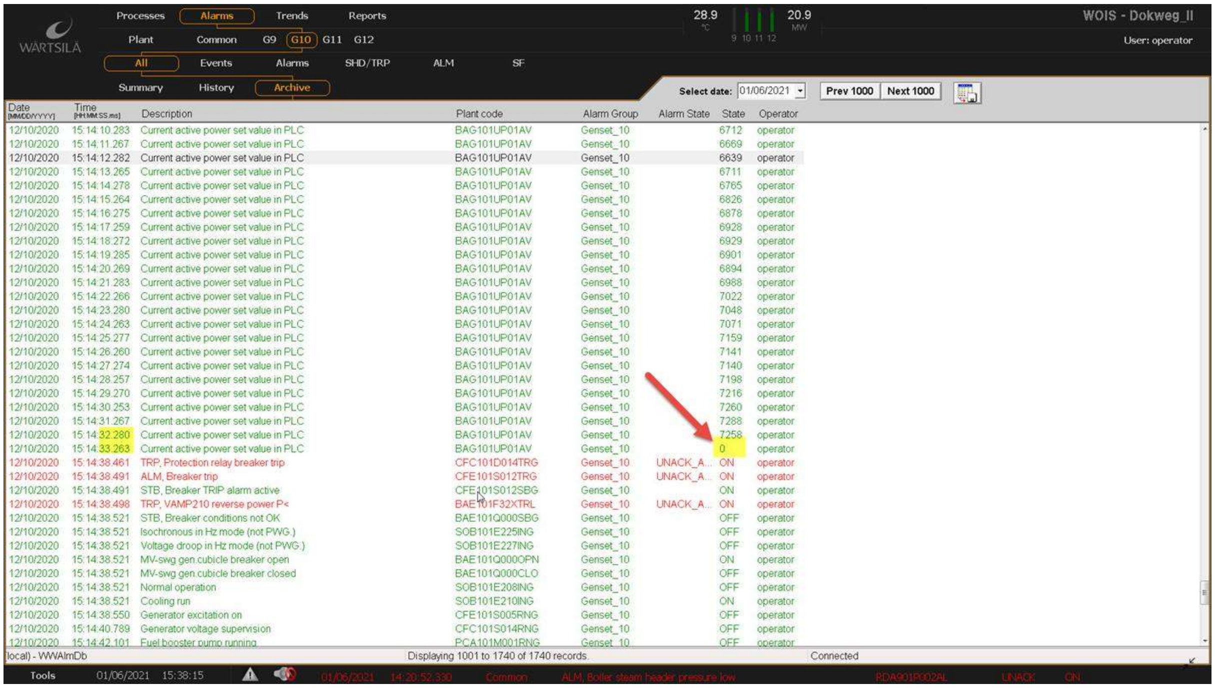
Engine ramping down. This has been UNIC setpoint in Isochronous. After this generator breaker trip from reverse.

From UNIC



Date [MM/DD/YYYY]	Time [HH:MM:SS.ms]	Description	Plant code	Alarm Group	Alarm State	State	Operator
12/10/2020	15:14:10.283	Current active power set value in PLC	BAG101UP01AV	Genset_10		6712	operator
12/10/2020	15:14:11.267	Current active power set value in PLC	BAG101UP01AV	Genset_10		6669	operator
12/10/2020	15:14:12.282	Current active power set value in PLC	BAG101UP01AV	Genset_10		6639	operator
12/10/2020	15:14:13.265	Current active power set value in PLC	BAG101UP01AV	Genset_10		6711	operator
12/10/2020	15:14:14.278	Current active power set value in PLC	BAG101UP01AV	Genset_10		6765	operator
12/10/2020	15:14:15.264	Current active power set value in PLC	BAG101UP01AV	Genset_10		6826	operator
12/10/2020	15:14:16.275	Current active power set value in PLC	BAG101UP01AV	Genset_10		6878	operator
12/10/2020	15:14:17.259	Current active power set value in PLC	BAG101UP01AV	Genset_10		6928	operator
12/10/2020	15:14:18.272	Current active power set value in PLC	BAG101UP01AV	Genset_10		6929	operator
12/10/2020	15:14:19.285	Current active power set value in PLC	BAG101UP01AV	Genset_10		6901	operator
12/10/2020	15:14:20.269	Current active power set value in PLC	BAG101UP01AV	Genset_10		6894	operator
12/10/2020	15:14:21.283	Current active power set value in PLC	BAG101UP01AV	Genset_10		6988	operator
12/10/2020	15:14:22.266	Current active power set value in PLC	BAG101UP01AV	Genset_10		7022	operator
12/10/2020	15:14:23.280	Current active power set value in PLC	BAG101UP01AV	Genset_10		7048	operator
12/10/2020	15:14:24.263	Current active power set value in PLC	BAG101UP01AV	Genset_10		7071	operator
12/10/2020	15:14:25.277	Current active power set value in PLC	BAG101UP01AV	Genset_10		7159	operator
12/10/2020	15:14:26.260	Current active power set value in PLC	BAG101UP01AV	Genset_10		7141	operator
12/10/2020	15:14:27.274	Current active power set value in PLC	BAG101UP01AV	Genset_10		7140	operator
12/10/2020	15:14:28.257	Current active power set value in PLC	BAG101UP01AV	Genset_10		7198	operator
12/10/2020	15:14:29.270	Current active power set value in PLC	BAG101UP01AV	Genset_10		7216	operator
12/10/2020	15:14:30.253	Current active power set value in PLC	BAG101UP01AV	Genset_10		7260	operator
12/10/2020	15:14:31.267	Current active power set value in PLC	BAG101UP01AV	Genset_10		7288	operator
12/10/2020	15:14:32.280	Current active power set value in PLC	BAG101UP01AV	Genset_10		7258	operator
12/10/2020	15:14:33.263	Current active power set value in PLC	BAG101UP01AV	Genset_10		0	operator
12/10/2020	15:14:38.461	TRP, Protection relay breaker trip	CFC101D014TRG	Genset_10	UNACK_A...	ON	operator
12/10/2020	15:14:38.491	ALM, Breaker trip	CFE101S012TRG	Genset_10	UNACK_A...	ON	operator
12/10/2020	15:14:38.491	STB, Breaker TRIP alarm active	CFE101S012SBG	Genset_10		ON	operator
12/10/2020	15:14:38.498	TRP, VAMP210 reverse power P<	BAE101F32XTRL	Genset_10	UNACK_A...	ON	operator
12/10/2020	15:14:38.521	STB, Breaker conditions not OK	BAE101Q000SBG	Genset_10		OFF	operator
12/10/2020	15:14:38.521	Isochronous in Hz mode (not PWG.)	SOB101E225ING	Genset_10		OFF	operator
12/10/2020	15:14:38.521	Voltage droop in Hz mode (not PWG.)	SOB101E227ING	Genset_10		OFF	operator
12/10/2020	15:14:38.521	MV-swg gen.cubicle breaker open	BAE101Q000OPN	Genset_10		ON	operator
12/10/2020	15:14:38.521	MV-swg gen.cubicle breaker closed	BAE101Q000CLO	Genset_10		OFF	operator
12/10/2020	15:14:38.521	Normal operation	SOB101E208ING	Genset_10		OFF	operator
12/10/2020	15:14:38.521	Cooling run	SOB101E210ING	Genset_10		ON	operator
12/10/2020	15:14:38.550	Generator excitation on	CFE101S005RNG	Genset_10		OFF	operator
12/10/2020	15:14:40.789	Generator voltage supervision	CFC101S014RNG	Genset_10		OFF	operator
12/10/2020	15:14:42.101	Fuel booster pump running	PCA101M001RNG	Genset_10		OFF	operator

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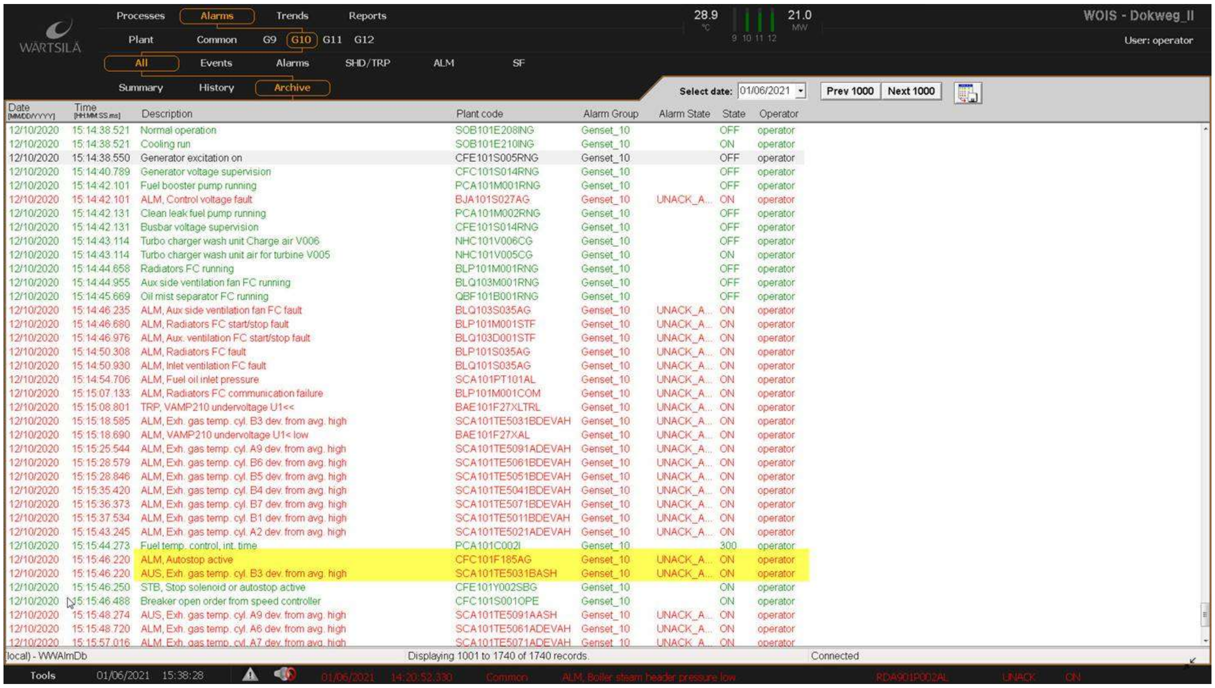
Figure 6 setpoint went to zero before breaker trip.



Date [MM/DD/YYYY]	Time [HH:MM:SS.ms]	Description	Plant code	Alarm Group	Alarm State	State	Operator
12/10/2020	15:14:38.521	Normal operation	SOB101E208ING	Genset_10		OFF	operator
12/10/2020	15:14:38.521	Cooling run	SOB101E210ING	Genset_10		ON	operator
12/10/2020	15:14:38.550	Generator excitation on	CFE101S005RNG	Genset_10		OFF	operator
12/10/2020	15:14:40.789	Generator voltage supervision	CFC101S014RNG	Genset_10		OFF	operator
12/10/2020	15:14:42.101	Fuel booster pump running	PCA101M001RNG	Genset_10		OFF	operator
12/10/2020	15:14:42.101	ALM, Control voltage fault	BJA101S027AG	Genset_10	UNACK_A...	ON	operator
12/10/2020	15:14:42.131	Clean leak fuel pump running	PCA101M002RNG	Genset_10		OFF	operator
12/10/2020	15:14:42.131	Busbar voltage supervision	CFE101S014RNG	Genset_10		OFF	operator
12/10/2020	15:14:43.114	Turbo charger wash unit Charge air V006	NHC101V006CG	Genset_10		OFF	operator
12/10/2020	15:14:43.114	Turbo charger wash unit air for turbine V005	NHC101V005CG	Genset_10		ON	operator
12/10/2020	15:14:44.658	Radiators FC running	BLP101M001RNG	Genset_10		OFF	operator
12/10/2020	15:14:44.955	Aux side ventilation fan FC running	BLQ103M001RNG	Genset_10		OFF	operator
12/10/2020	15:14:45.669	Oil mist separator FC running	QBF101B001RNG	Genset_10		OFF	operator
12/10/2020	15:14:46.235	ALM, Aux side ventilation fan FC fault	BLQ103S035AG	Genset_10	UNACK_A...	ON	operator
12/10/2020	15:14:46.680	ALM, Radiators FC start/stop fault	BLP101M001STF	Genset_10	UNACK_A...	ON	operator
12/10/2020	15:14:46.976	ALM, Aux. ventilation FC start/stop fault	BLQ103D001STF	Genset_10	UNACK_A...	ON	operator
12/10/2020	15:14:50.308	ALM, Radiators FC fault	BLP101S035AG	Genset_10	UNACK_A...	ON	operator
12/10/2020	15:14:50.930	ALM, Inlet ventilation FC fault	BLQ101S035AG	Genset_10	UNACK_A...	ON	operator
12/10/2020	15:14:54.706	ALM, Fuel oil inlet pressure	SCA101PT101AL	Genset_10	UNACK_A...	ON	operator
12/10/2020	15:15:07.133	ALM, Radiators FC communication failure	BLP101M001COM	Genset_10	UNACK_A...	ON	operator
12/10/2020	15:15:08.801	TRP, VAMP210 undervoltage U1<<	BAE101F27XLTRL	Genset_10	UNACK_A...	ON	operator
12/10/2020	15:15:18.585	ALM, Exh. gas temp. cyl. B3 dev. from avg. high	SCA101TE5031BDEVAH	Genset_10	UNACK_A...	ON	operator
12/10/2020	15:15:18.690	ALM, VAMP210 undervoltage U1< low	BAE101F27XAL	Genset_10	UNACK_A...	ON	operator
12/10/2020	15:15:25.544	ALM, Exh. gas temp. cyl. A9 dev. from avg. high	SCA101TE5091ADEVAH	Genset_10	UNACK_A...	ON	operator
12/10/2020	15:15:28.579	ALM, Exh. gas temp. cyl. B6 dev. from avg. high	SCA101TE5061BDEVAH	Genset_10	UNACK_A...	ON	operator
12/10/2020	15:15:28.846	ALM, Exh. gas temp. cyl. B5 dev. from avg. high	SCA101TE5051BDEVAH	Genset_10	UNACK_A...	ON	operator
12/10/2020	15:15:35.420	ALM, Exh. gas temp. cyl. B4 dev. from avg. high	SCA101TE5041BDEVAH	Genset_10	UNACK_A...	ON	operator
12/10/2020	15:15:36.373	ALM, Exh. gas temp. cyl. B7 dev. from avg. high	SCA101TE5071BDEVAH	Genset_10	UNACK_A...	ON	operator
12/10/2020	15:15:37.534	ALM, Exh. gas temp. cyl. B1 dev. from avg. high	SCA101TE5011BDEVAH	Genset_10	UNACK_A...	ON	operator
12/10/2020	15:15:43.245	ALM, Exh. gas temp. cyl. A2 dev. from avg. high	SCA101TE5021ADEVAH	Genset_10	UNACK_A...	ON	operator
12/10/2020	15:15:44.273	Fuel temp. control, int. time	PCA101C002I	Genset_10		300	operator
12/10/2020	15:15:46.220	ALM, Autostop active	CFC101F185AG	Genset_10	UNACK_A...	ON	operator
12/10/2020	15:15:46.220	AUS, Exh. gas temp. cyl. B3 dev. from avg. high	SCA101TE5031BASH	Genset_10	UNACK_A...	ON	operator
12/10/2020	15:15:46.250	STB, Stop solenoid or autostop active	CFE101Y002SBG	Genset_10		ON	operator
12/10/2020	15:15:46.488	Breaker open order from speed controller	CFC101S001OPE	Genset_10		ON	operator
12/10/2020	15:15:48.274	AUS, Exh. gas temp. cyl. A9 dev. from avg. high	SCA101TE5091AASH	Genset_10	UNACK_A...	ON	operator
12/10/2020	15:15:48.720	ALM, Exh. gas temp. cyl. A6 dev. from avg. high	SCA101TE5061ADEVAH	Genset_10	UNACK_A...	ON	operator
12/10/2020	15:15:57.016	ALM, Exh. gas temp. cyl. A7 dev. from avg. high	SCA101TE5071ADEVAH	Genset_10	UNACK_A...	ON	operator

(local) - WWAlmDb Displaying 1001 to 1740 of 1740 records. Connected

Tools 01/06/2021 15:38:28 01/06/2021 14:20:52.330 Common ALM, Boiler steam header pressure low RDA901P002AL UNACK ON

Figure 7 Auto stop active in several cylinders. Too high deviation in exhaust gas temp. B3!

4 CONCLUSION AND RECOMMENDATIONS

15:11:55 engine set Isochronous operation from WOIS. Load ramping from 1300 to 7250 kW. It would have been more advisable to operate unit in kW-mode and ramp load in steps to normal operating load to avoid high exhaust gas temperatures. After this enable Isochronous operation.

Doc. Name	Analysis of Grid Events, 12th of December 2020		
Doc. ID		**Revision**	a
Author	Jaakko Hämeenniemi – 15.01.2021	**Pages**	1 (6)
Approved by	Jaakko Hämeenniemi – 15.01.2021		

Analysis of Grid Event on 12th of December 2020

DOKWEG 2A - 2B

W32 - W34

On Behalf of Wärtsilä:

Jaakko Hämeenniemi

GM, Field and Technical Services

Technical Services

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TABLE OF CONTENTS

1 BACKGROUND

On the 12th of December 2020, between 18:30 – 19:30, various events took place in the power system of Aqualectra which eventually led to a blackout in the power system. This report includes analysis of the event and recommendations.

2 INSPECTIONS

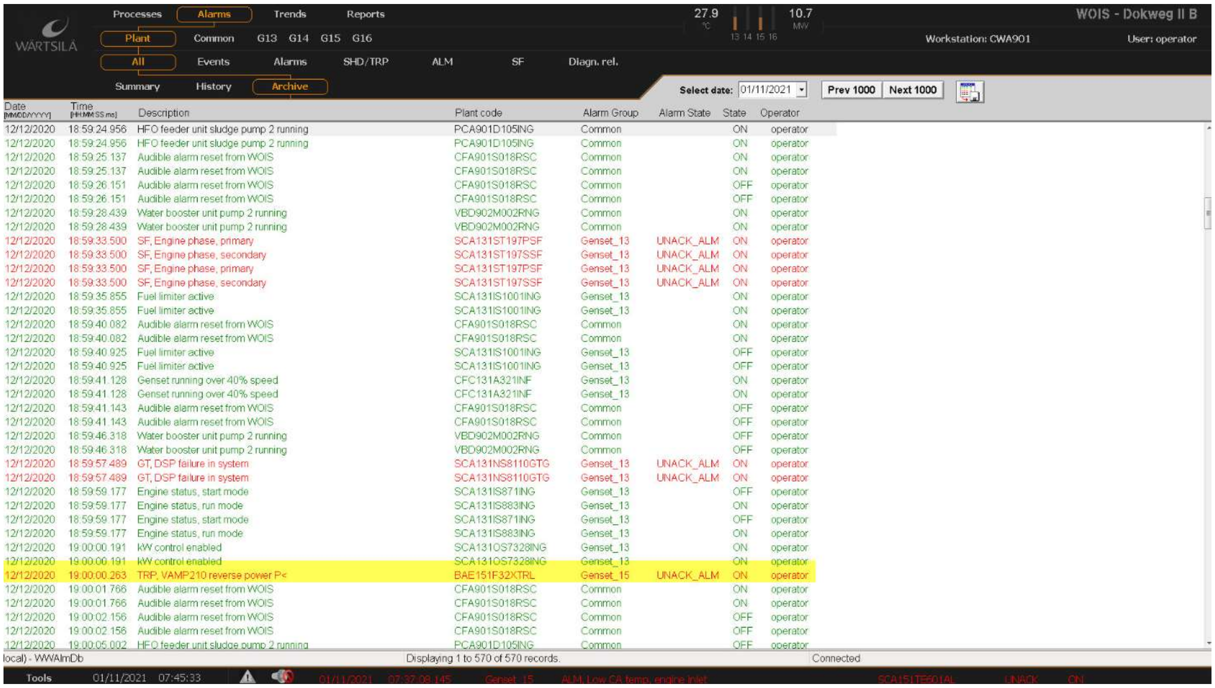
Dokweg 2A and 2B WOIS (Wärtsilä Operators Interface System) data was collected, data in WOIS system is seen in 1s resolution. Data can be saved in visual format (.jpg) or in (.csv) format for that data can be exported to other systems for closer analysis. Data from Dokweg 2A and 2B was saved between 18:00-21:00 for further analysis.

3 ANALYSIS OF EVENTS

- Unit 15 trip 19:00:00 from reverse power. This would indicate that something bigger event in network side. Probably some feeder opens etc. Engine has tried to reduce load and finally trip due reverse power protection.

- Unit 14 trip 19:03:07 from reverse power. Engine has probably tried to maintain frequency and when it has been too high unit ramp load down until it trips from reverse power protection.

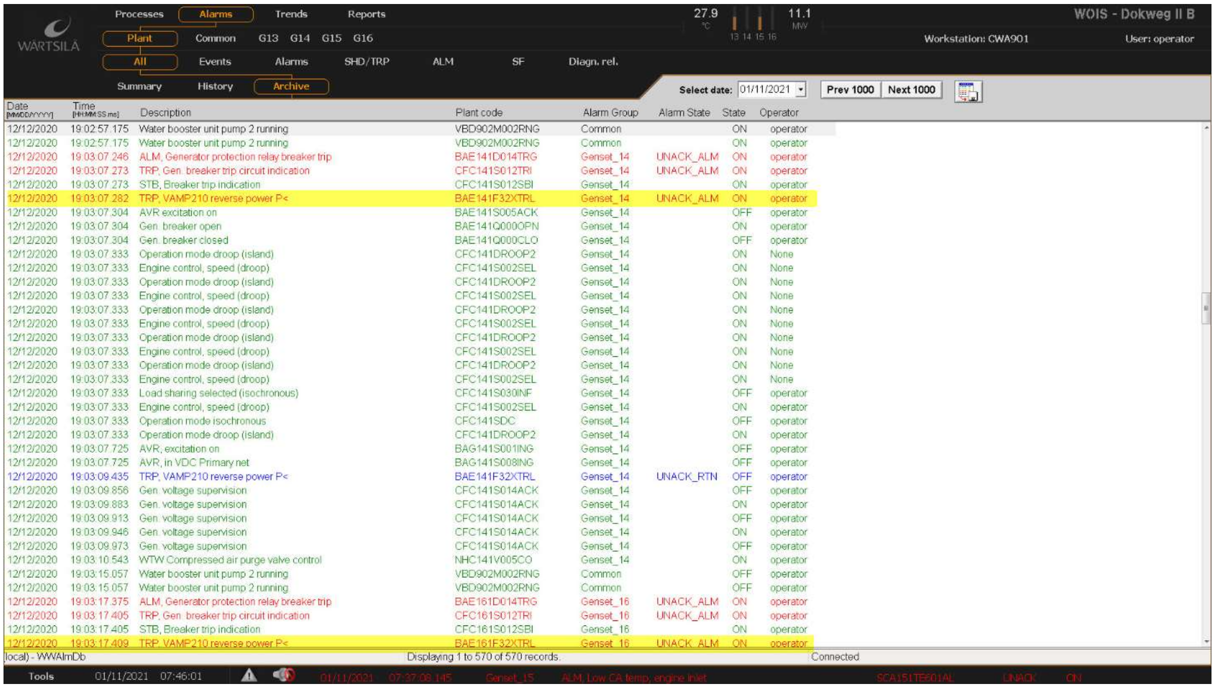
- Unit 16 trip 19:03:17 from reverse power. Engine has probably tried to maintain frequency and when it has been too high unit ramp load down until it trips from reverse power protection.



Date [MM/DD/YYYY]	Time [HH:MM:SS.ms]	Description	Plant code	Alarm Group	Alarm State	State	Operator
12/12/2020	18:59:24.956	HFO feeder unit sludge pump 2 running	PCA901D105ING	Common		ON	operator
12/12/2020	18:59:24.956	HFO feeder unit sludge pump 2 running	PCA901D105ING	Common		ON	operator
12/12/2020	18:59:25.137	Audible alarm reset from WOIS	CFA901S018RSC	Common		ON	operator
12/12/2020	18:59:25.137	Audible alarm reset from WOIS	CFA901S018RSC	Common		ON	operator
12/12/2020	18:59:26.151	Audible alarm reset from WOIS	CFA901S018RSC	Common		OFF	operator
12/12/2020	18:59:26.151	Audible alarm reset from WOIS	CFA901S018RSC	Common		OFF	operator
12/12/2020	18:59:28.439	Water booster unit pump 2 running	VBD902M002RNG	Common		ON	operator
12/12/2020	18:59:28.439	Water booster unit pump 2 running	VBD902M002RNG	Common		ON	operator
12/12/2020	18:59:33.500	SF, Engine phase, primary	SCA131ST197PSF	Genset_13	UNACK_ALM	ON	operator
12/12/2020	18:59:33.500	SF, Engine phase, secondary	SCA131ST197SSF	Genset_13	UNACK_ALM	ON	operator
12/12/2020	18:59:33.500	SF, Engine phase, primary	SCA131ST197PSF	Genset_13	UNACK_ALM	ON	operator
12/12/2020	18:59:33.500	SF, Engine phase, secondary	SCA131ST197SSF	Genset_13	UNACK_ALM	ON	operator
12/12/2020	18:59:35.855	Fuel limiter active	SCA131IS1001ING	Genset_13		ON	operator
12/12/2020	18:59:35.855	Fuel limiter active	SCA131IS1001ING	Genset_13		ON	operator
12/12/2020	18:59:40.082	Audible alarm reset from WOIS	CFA901S018RSC	Common		ON	operator
12/12/2020	18:59:40.082	Audible alarm reset from WOIS	CFA901S018RSC	Common		ON	operator
12/12/2020	18:59:40.925	Fuel limiter active	SCA131IS1001ING	Genset_13		OFF	operator
12/12/2020	18:59:40.925	Fuel limiter active	SCA131IS1001ING	Genset_13		OFF	operator
12/12/2020	18:59:41.128	Genset running over 40% speed	CFC131A321INF	Genset_13		ON	operator
12/12/2020	18:59:41.128	Genset running over 40% speed	CFC131A321INF	Genset_13		ON	operator
12/12/2020	18:59:41.143	Audible alarm reset from WOIS	CFA901S018RSC	Common		OFF	operator
12/12/2020	18:59:41.143	Audible alarm reset from WOIS	CFA901S018RSC	Common		OFF	operator
12/12/2020	18:59:46.318	Water booster unit pump 2 running	VBD902M002RNG	Common		OFF	operator
12/12/2020	18:59:46.318	Water booster unit pump 2 running	VBD902M002RNG	Common		OFF	operator
12/12/2020	18:59:57.489	GT, DSP failure in system	SCA131NS8110GTG	Genset_13	UNACK_ALM	ON	operator
12/12/2020	18:59:57.489	GT, DSP failure in system	SCA131NS8110GTG	Genset_13	UNACK_ALM	ON	operator
12/12/2020	18:59:59.177	Engine status, start mode	SCA131IS871ING	Genset_13		OFF	operator
12/12/2020	18:59:59.177	Engine status, run mode	SCA131IS883ING	Genset_13		ON	operator
12/12/2020	18:59:59.177	Engine status, start mode	SCA131IS871ING	Genset_13		OFF	operator
12/12/2020	18:59:59.177	Engine status, run mode	SCA131IS883ING	Genset_13		ON	operator
12/12/2020	19:00:00.191	kW control enabled	SCA131OS7328ING	Genset_13		ON	operator
12/12/2020	19:00:00.191	kW control enabled	SCA131OS7328ING	Genset_13		ON	operator
12/12/2020	19:00:00.263	TRP, VAMP210 reverse power P<	BAE151F32XTRL	Genset_15	UNACK_ALM	ON	operator
12/12/2020	19:00:01.766	Audible alarm reset from WOIS	CFA901S018RSC	Common		ON	operator
12/12/2020	19:00:01.766	Audible alarm reset from WOIS	CFA901S018RSC	Common		ON	operator
12/12/2020	19:00:02.156	Audible alarm reset from WOIS	CFA901S018RSC	Common		OFF	operator
12/12/2020	19:00:02.156	Audible alarm reset from WOIS	CFA901S018RSC	Common		OFF	operator
12/12/2020	19:00:05.002	HFO feeder unit sludge pump 2 running	PCA901D105ING	Common		OFF	operator

local) - WWAlmDb Displaying 1 to 570 of 570 records. Connected

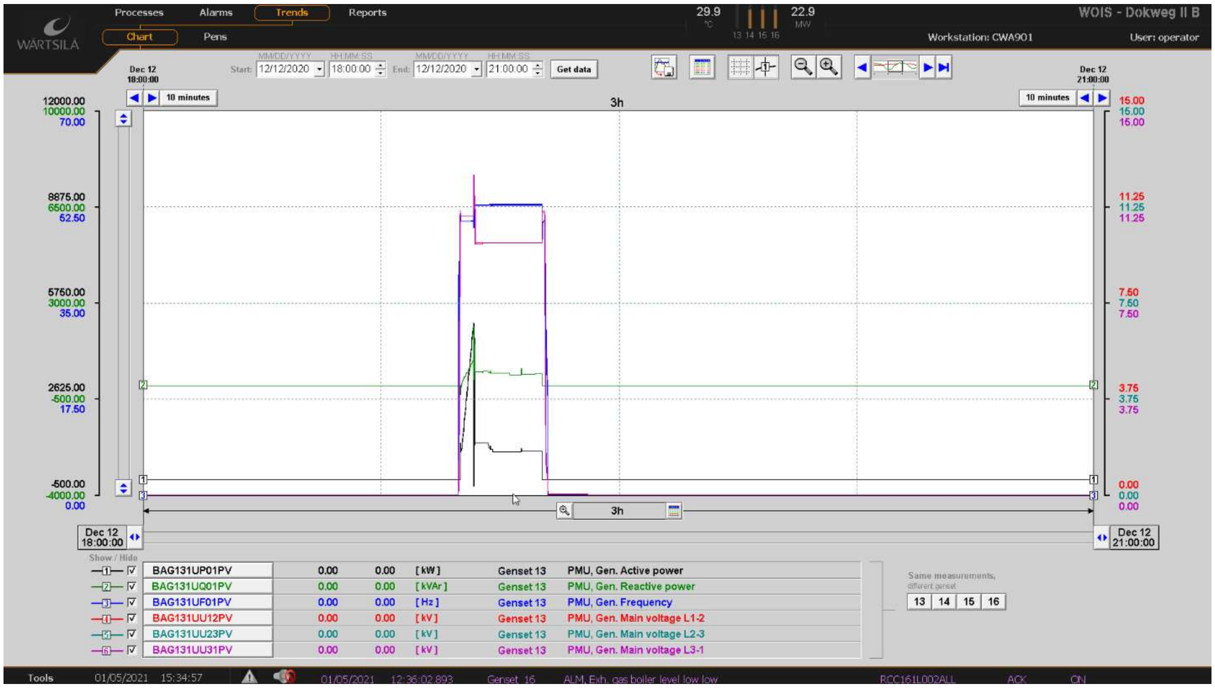
Tools 01/11/2021 07:45:33 01/11/2021 07:37:08.145 Genset_15 ALM, Low CA temp. engine inlet SCA151TE601AL UNACK ON



Date [MM/DD/YYYY]	Time [HH:MM:SS.ms]	Description	Plant code	Alarm Group	Alarm State	State	Operator
12/12/2020	19:02:57.175	Water booster unit pump 2 running	VBD902M002RNG	Common		ON	operator
12/12/2020	19:02:57.175	Water booster unit pump 2 running	VBD902M002RNG	Common		ON	operator
12/12/2020	19:03:07.246	ALM, Generator protection relay breaker trip	BAE141D014TRG	Genset_14	UNACK_ALM	ON	operator
12/12/2020	19:03:07.273	TRP, Gen. breaker trip circuit indication	CFC141S012TRI	Genset_14	UNACK_ALM	ON	operator
12/12/2020	19:03:07.273	STB, Breaker trip indication	CFC141S012SBI	Genset_14		ON	operator
12/12/2020	19:03:07.282	TRP, VAMP210 reverse power P<	BAE141F32XTRL	Genset_14	UNACK_ALM	ON	operator
12/12/2020	19:03:07.304	AVR excitation on	BAE141S005ACK	Genset_14		OFF	operator
12/12/2020	19:03:07.304	Gen. breaker open	BAE141Q000OPN	Genset_14		ON	operator
12/12/2020	19:03:07.304	Gen. breaker closed	BAE141Q000CLO	Genset_14		OFF	operator
12/12/2020	19:03:07.333	Operation mode droop (island)	CFC141DROOP2	Genset_14		ON	None
12/12/2020	19:03:07.333	Engine control, speed (droop)	CFC141S002SEL	Genset_14		ON	None
12/12/2020	19:03:07.333	Operation mode droop (island)	CFC141DROOP2	Genset_14		ON	None
12/12/2020	19:03:07.333	Engine control, speed (droop)	CFC141S002SEL	Genset_14		ON	None
12/12/2020	19:03:07.333	Operation mode droop (island)	CFC141DROOP2	Genset_14		ON	None
12/12/2020	19:03:07.333	Engine control, speed (droop)	CFC141S002SEL	Genset_14		ON	None
12/12/2020	19:03:07.333	Operation mode droop (island)	CFC141DROOP2	Genset_14		ON	None
12/12/2020	19:03:07.333	Engine control, speed (droop)	CFC141S002SEL	Genset_14		ON	None
12/12/2020	19:03:07.333	Operation mode droop (island)	CFC141DROOP2	Genset_14		ON	None
12/12/2020	19:03:07.333	Engine control, speed (droop)	CFC141S002SEL	Genset_14		ON	None
12/12/2020	19:03:07.333	Load sharing selected (isochronous)	CFC141S030INF	Genset_14		OFF	operator
12/12/2020	19:03:07.333	Engine control, speed (droop)	CFC141S002SEL	Genset_14		ON	operator
12/12/2020	19:03:07.333	Operation mode isochronous	CFC141SDC	Genset_14		OFF	operator
12/12/2020	19:03:07.333	Operation mode droop (island)	CFC141DROOP2	Genset_14		ON	operator
12/12/2020	19:03:07.725	AVR, excitation on	BAG141S001ING	Genset_14		OFF	operator
12/12/2020	19:03:07.725	AVR, in VDC Primary net	BAG141S008ING	Genset_14		OFF	operator
12/12/2020	19:03:09.435	TRP, VAMP210 reverse power P<	BAE141F32XTRL	Genset_14	UNACK_RTN	OFF	operator
12/12/2020	19:03:09.856	Gen. voltage supervision	CFC141S014ACK	Genset_14		OFF	operator
12/12/2020	19:03:09.883	Gen. voltage supervision	CFC141S014ACK	Genset_14		ON	operator
12/12/2020	19:03:09.913	Gen. voltage supervision	CFC141S014ACK	Genset_14		OFF	operator
12/12/2020	19:03:09.946	Gen. voltage supervision	CFC141S014ACK	Genset_14		ON	operator
12/12/2020	19:03:09.973	Gen. voltage supervision	CFC141S014ACK	Genset_14		OFF	operator
12/12/2020	19:03:10.543	WTW Compressed air purge valve control	NHC141V005CO	Genset_14		ON	operator
12/12/2020	19:03:15.057	Water booster unit pump 2 running	VBD902M002RNG	Common		OFF	operator
12/12/2020	19:03:15.057	Water booster unit pump 2 running	VBD902M002RNG	Common		OFF	operator
12/12/2020	19:03:17.375	ALM, Generator protection relay breaker trip	BAE161D014TRG	Genset_16	UNACK_ALM	ON	operator
12/12/2020	19:03:17.405	TRP, Gen. breaker trip circuit indication	CFC161S012TRI	Genset_16	UNACK_ALM	ON	operator
12/12/2020	19:03:17.405	STB, Breaker trip indication	CFC161S012SBI	Genset_16		ON	operator
12/12/2020	19:03:17.409	TRP, VAMP210 reverse power P<	BAE161F32XTRL	Genset_16	UNACK_ALM	ON	operator

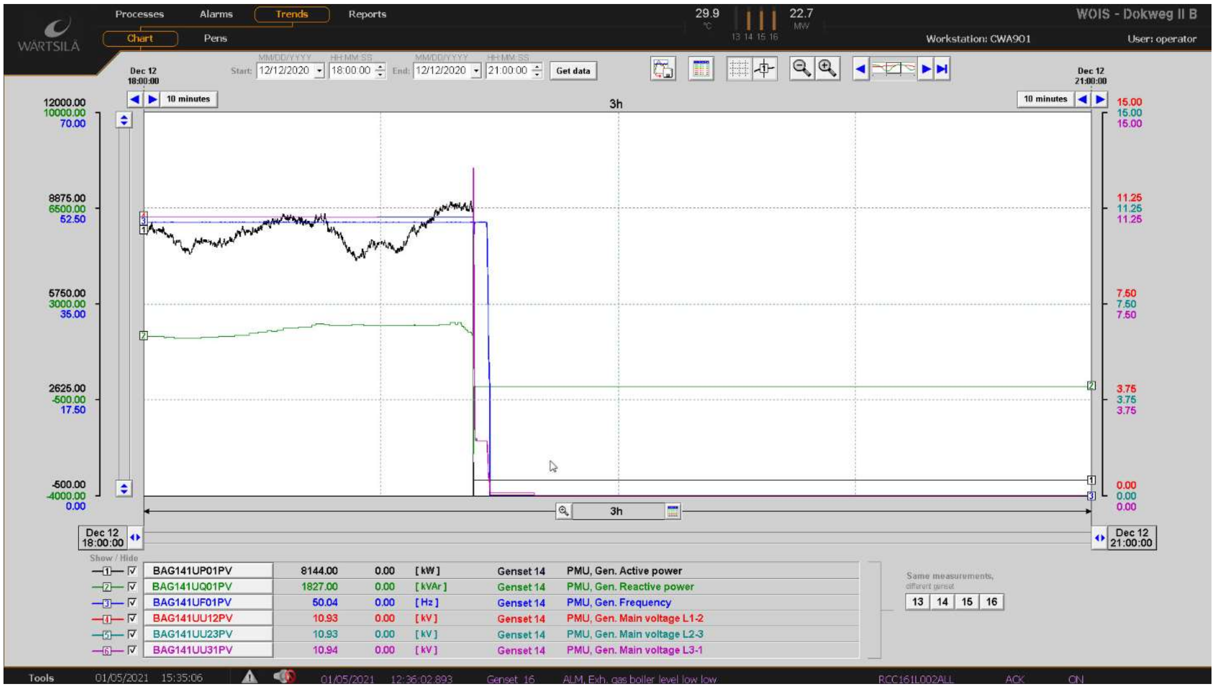
(local) - WWAlmDb Displaying 1 to 570 of 570 records. Connected

Tools 01/11/2021 07:46:01 01/11/2021 07:37:08.145 Genset_15 ALM, Low CA temp. engine inlet SCA151TE601AL UNACK ON



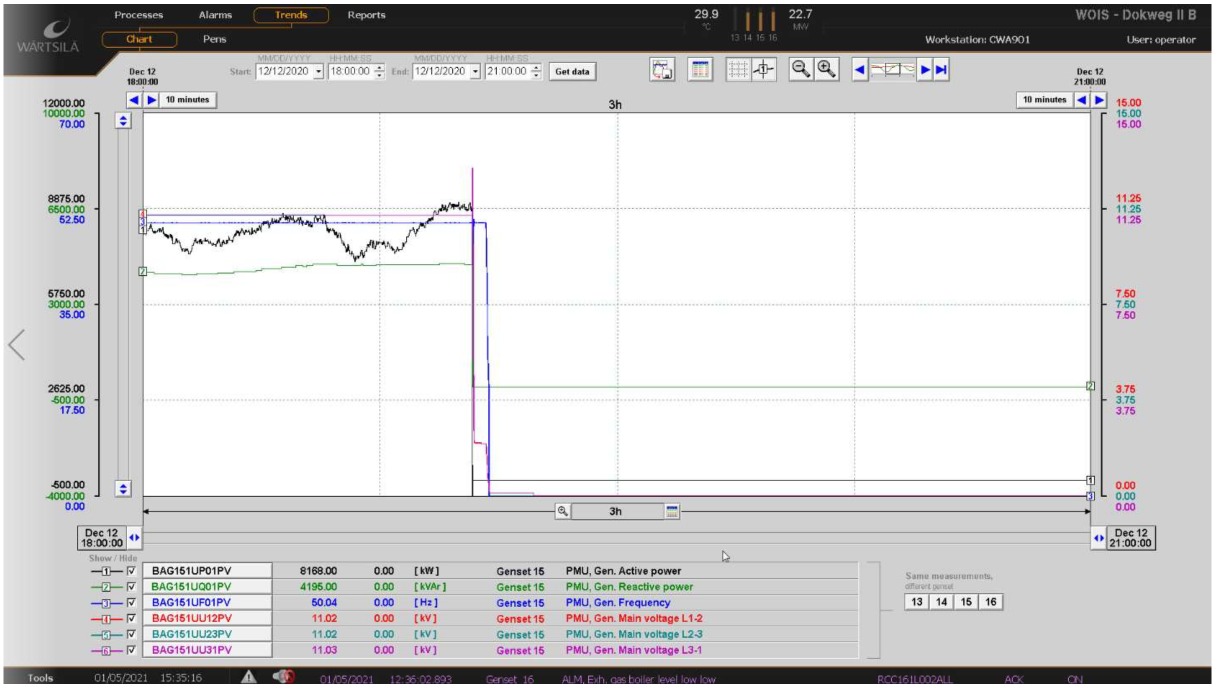
1 ☑	BAG131UP01PV	0.00	0.00	[kW]	Genset 13	PMU, Gen. Active power
2 ☑	BAG131UQ01PV	0.00	0.00	[kVAr]	Genset 13	PMU, Gen. Reactive power
3 ☑	BAG131UF01PV	0.00	0.00	[Hz]	Genset 13	PMU, Gen. Frequency
4 ☑	BAG131UU12PV	0.00	0.00	[kV]	Genset 13	PMU, Gen. Main voltage L1-2
5 ☑	BAG131UU23PV	0.00	0.00	[kV]	Genset 13	PMU, Gen. Main voltage L2-3
6 ☑	BAG131UU31PV	0.00	0.00	[kV]	Genset 13	PMU, Gen. Main voltage L3-1

01/05/2021 15:34:57 01/05/2021 12:36:02.893 Genset 16 ALM, Exh. gas boiler level low low RCC161L002ALL ACK ON

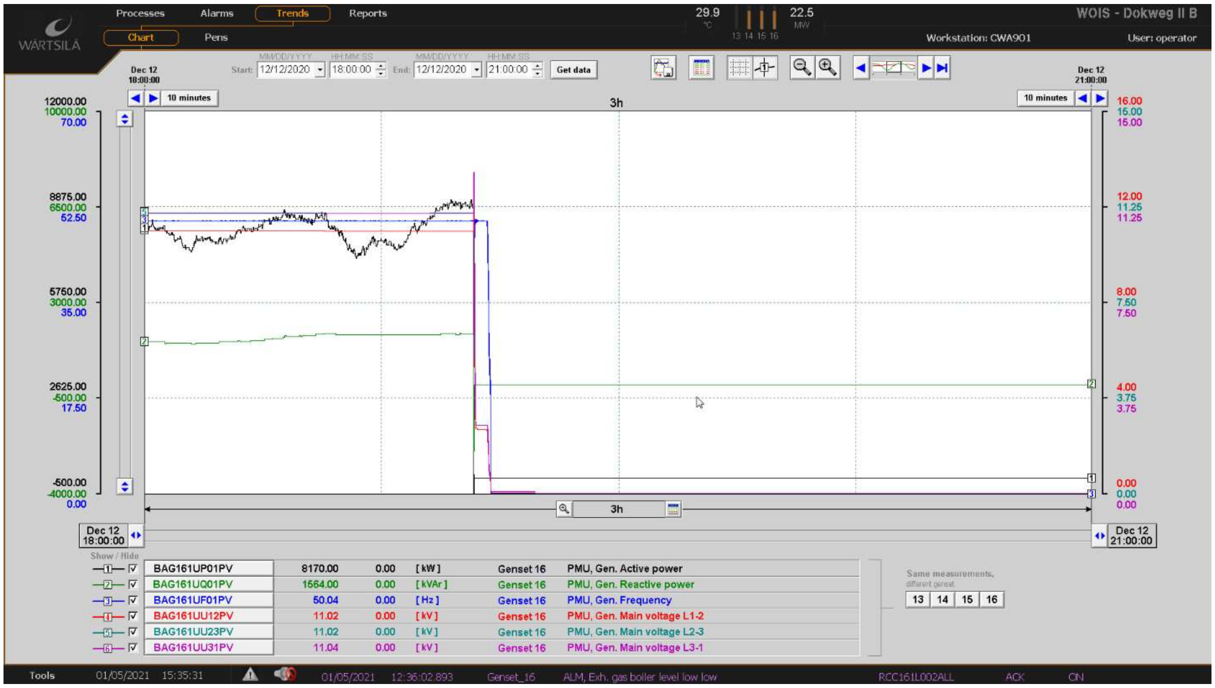


1 ☑	BAG141UP01PV	8144.00	0.00	[kW]	Genset 14	PMU, Gen. Active power
2 ☑	BAG141UQ01PV	1827.00	0.00	[kVAr]	Genset 14	PMU, Gen. Reactive power
3 ☑	BAG141UF01PV	50.04	0.00	[Hz]	Genset 14	PMU, Gen. Frequency
4 ☑	BAG141UU12PV	10.93	0.00	[kV]	Genset 14	PMU, Gen. Main voltage L1-2
5 ☑	BAG141UU23PV	10.93	0.00	[kV]	Genset 14	PMU, Gen. Main voltage L2-3
6 ☑	BAG141UU31PV	10.94	0.00	[kV]	Genset 14	PMU, Gen. Main voltage L3-1

01/05/2021 15:35:06 01/05/2021 12:36:02.893 Genset 16 ALM, Exh. gas boiler level low low RCC161L002ALL ACK ON



1 ☑	BAG151UP01PV	8168.00	0.00	[kW]	Genset 15	PMU, Gen. Active power
2 ☑	BAG151UQ01PV	4195.00	0.00	[kVAr]	Genset 15	PMU, Gen. Reactive power
3 ☑	BAG151UF01PV	50.04	0.00	[Hz]	Genset 15	PMU, Gen. Frequency
4 ☑	BAG151UU12PV	11.02	0.00	[kV]	Genset 15	PMU, Gen. Main voltage L1-2
5 ☑	BAG151UU23PV	11.02	0.00	[kV]	Genset 15	PMU, Gen. Main voltage L2-3
6 ☑	BAG151UU31PV	11.03	0.00	[kV]	Genset 15	PMU, Gen. Main voltage L3-1



1 ☑	BAG161UP01PV	8170.00	0.00	[kW]	Genset 16	PMU, Gen. Active power
2 ☑	BAG161UQ01PV	1564.00	0.00	[kVAr]	Genset 16	PMU, Gen. Reactive power
3 ☑	BAG161UF01PV	50.04	0.00	[Hz]	Genset 16	PMU, Gen. Frequency
4 ☑	BAG161UU12PV	11.02	0.00	[kV]	Genset 16	PMU, Gen. Main voltage L1-2
5 ☑	BAG161UU23PV	11.02	0.00	[kV]	Genset 16	PMU, Gen. Main voltage L2-3
6 ☑	BAG161UU31PV	11.04	0.00	[kV]	Genset 16	PMU, Gen. Main voltage L3-1

4 CONCLUSION

According received information it seems that December 12, 2020 problems start from grid event. After grid event units try to balance frequency and were ramping down until reverse protection trip generator breakers.

[Information Classification]

Doc. Name	Analysis of Grid Events, 4th of January 2021		
Doc. ID		**Revision**	a
Author	Jaakko Hämeenniemi – 15.01.2021	**Pages**	1 (6)
Approved by	Jaakko Hämeenniemi – 15.01.2021		

Analysis of Grid Event on 4th of January 2021

DOKWEG 2A - 2B

W32 - W34

On Behalf of Wärtsilä:

Jaakko Hämeenniemi

GM, Field and Technical Services

Technical Services

TABLE OF CONTENTS

1 BACKGROUND

On the 4th of January 2021, 14:17:07, various events took place in the power system of Aqualectra which eventually led to a blackout in the power system. This report includes analysis of the event.

2 INSPECTIONS

Dokweg 2A and 2B WOIS (Wärtsilä Operators Interface System) data was collected, data in WOIS system is seen in 1s resolution. Data can be saved in visual format (.jpg) or in (.csv) format for that data can be exported to other systems for closer analysis. Data from Dokweg 2A and 2B was saved between 13:00-15:00 for further analysis.

3 ANALYSIS OF EVENTS

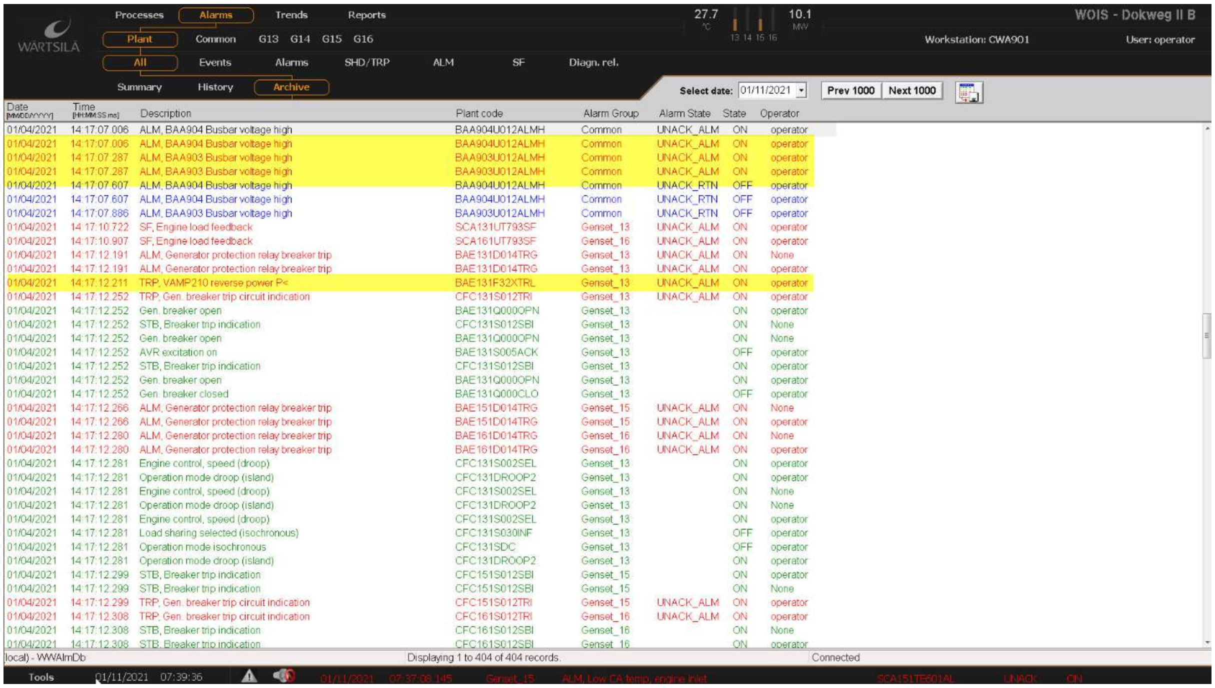
- Grid side events what cause high voltage alarm 14:17:07.

- Unit 13 trip 14:17:12:221 from reverse power. This has been caused due engine has tried to reduce frequency to nominal by ramping load down until reverse power protection trips generator breaker.

- Unit 16 trip 14:17:12:316 from reverse power. This has been caused due engine has tried to reduce frequency to nominal by ramping load down until reverse power protection trips generator breaker.

- Unit 15 trip 14:17:12:323 from reverse power. This has been caused due engine has tried to reduce frequency to nominal by ramping load down until reverse power protection trips generator breaker.

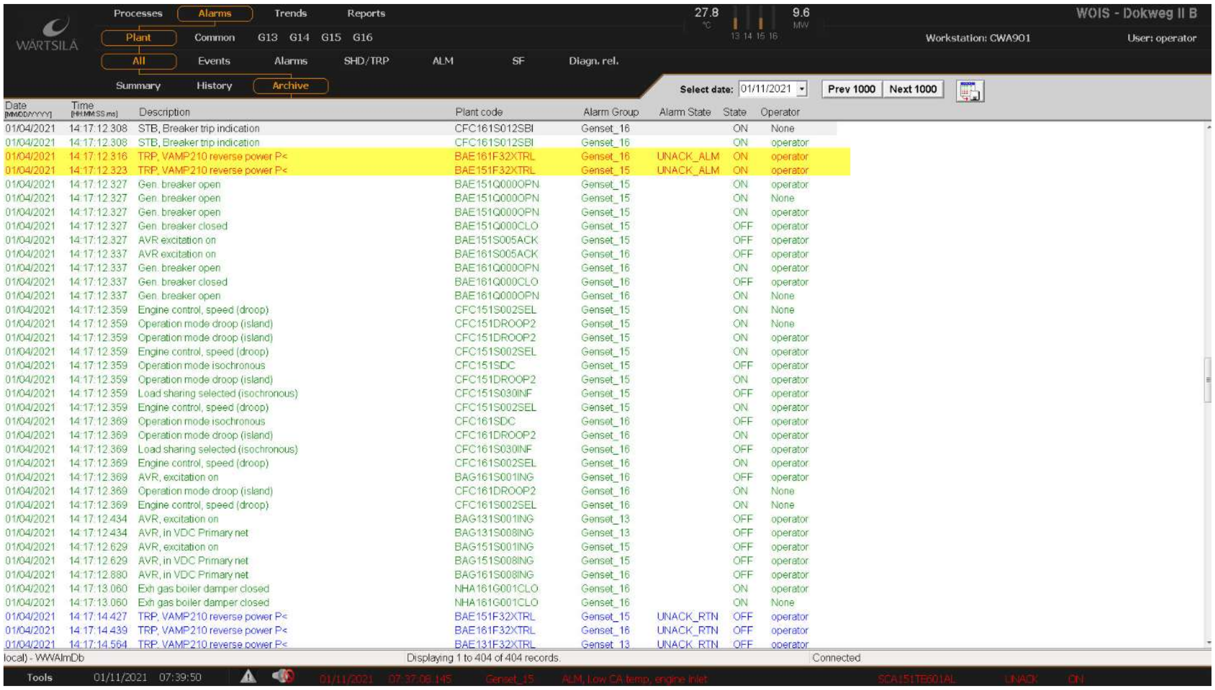
- Unit 14 unload to 800 kW and stay running.



Date [MM/DD/YYYY]	Time [HH:MM:SS.ms]	Description	Plant code	Alarm Group	Alarm State	State	Operator
01/04/2021	14:17:07.006	ALM, BAA904 Busbar voltage high	BAA904U012ALMH	Common	UNACK_ALM	ON	operator
01/04/2021	14:17:07.006	ALM, BAA904 Busbar voltage high	BAA904U012ALMH	Common	UNACK_ALM	ON	operator
01/04/2021	14:17:07.287	ALM, BAA903 Busbar voltage high	BAA903U012ALMH	Common	UNACK_ALM	ON	operator
01/04/2021	14:17:07.287	ALM, BAA903 Busbar voltage high	BAA903U012ALMH	Common	UNACK_ALM	ON	operator
01/04/2021	14:17:07.607	ALM, BAA904 Busbar voltage high	BAA904U012ALMH	Common	UNACK_RTN	OFF	operator
01/04/2021	14:17:07.607	ALM, BAA904 Busbar voltage high	BAA904U012ALMH	Common	UNACK_RTN	OFF	operator
01/04/2021	14:17:07.886	ALM, BAA903 Busbar voltage high	BAA903U012ALMH	Common	UNACK_RTN	OFF	operator
01/04/2021	14:17:10.722	SF, Engine load feedback	SCA131UT793SF	Genset_13	UNACK_ALM	ON	operator
01/04/2021	14:17:10.907	SF, Engine load feedback	SCA161UT793SF	Genset_16	UNACK_ALM	ON	operator
01/04/2021	14:17:12.191	ALM, Generator protection relay breaker trip	BAE131D014TRG	Genset_13	UNACK_ALM	ON	None
01/04/2021	14:17:12.191	ALM, Generator protection relay breaker trip	BAE131D014TRG	Genset_13	UNACK_ALM	ON	operator
01/04/2021	14:17:12.211	TRP, VAMP210 reverse power P<	BAE131F32XTRL	Genset_13	UNACK_ALM	ON	operator
01/04/2021	14:17:12.252	TRP, Gen. breaker trip circuit indication	CFC131S012TRI	Genset_13	UNACK_ALM	ON	operator
01/04/2021	14:17:12.252	Gen. breaker open	BAE131Q000OPN	Genset_13		ON	operator
01/04/2021	14:17:12.252	STB, Breaker trip indication	CFC131S012SBI	Genset_13		ON	None
01/04/2021	14:17:12.252	Gen. breaker open	BAE131Q000OPN	Genset_13		ON	None
01/04/2021	14:17:12.252	AVR excitation on	BAE131S005ACK	Genset_13		OFF	operator
01/04/2021	14:17:12.252	STB, Breaker trip indication	CFC131S012SBI	Genset_13		ON	operator
01/04/2021	14:17:12.252	Gen. breaker open	BAE131Q000OPN	Genset_13		ON	operator
01/04/2021	14:17:12.252	Gen. breaker closed	BAE131Q000CLO	Genset_13		OFF	operator
01/04/2021	14:17:12.266	ALM, Generator protection relay breaker trip	BAE151D014TRG	Genset_15	UNACK_ALM	ON	None
01/04/2021	14:17:12.266	ALM, Generator protection relay breaker trip	BAE151D014TRG	Genset_15	UNACK_ALM	ON	operator
01/04/2021	14:17:12.280	ALM, Generator protection relay breaker trip	BAE161D014TRG	Genset_16	UNACK_ALM	ON	None
01/04/2021	14:17:12.280	ALM, Generator protection relay breaker trip	BAE161D014TRG	Genset_16	UNACK_ALM	ON	operator
01/04/2021	14:17:12.281	Engine control, speed (droop)	CFC131S002SEL	Genset_13		ON	operator
01/04/2021	14:17:12.281	Operation mode droop (island)	CFC131DROOP2	Genset_13		ON	operator
01/04/2021	14:17:12.281	Engine control, speed (droop)	CFC131S002SEL	Genset_13		ON	None
01/04/2021	14:17:12.281	Operation mode droop (island)	CFC131DROOP2	Genset_13		ON	None
01/04/2021	14:17:12.281	Engine control, speed (droop)	CFC131S002SEL	Genset_13		ON	operator
01/04/2021	14:17:12.281	Load sharing selected (isochronous)	CFC131S030INF	Genset_13		OFF	operator
01/04/2021	14:17:12.281	Operation mode isochronous	CFC131SDC	Genset_13		OFF	operator
01/04/2021	14:17:12.281	Operation mode droop (island)	CFC131DROOP2	Genset_13		ON	operator
01/04/2021	14:17:12.299	STB, Breaker trip indication	CFC151S012SBI	Genset_15		ON	operator
01/04/2021	14:17:12.299	STB, Breaker trip indication	CFC151S012SBI	Genset_15		ON	None
01/04/2021	14:17:12.299	TRP, Gen. breaker trip circuit indication	CFC151S012TRI	Genset_15	UNACK_ALM	ON	operator
01/04/2021	14:17:12.308	TRP, Gen. breaker trip circuit indication	CFC161S012TRI	Genset_16	UNACK_ALM	ON	operator
01/04/2021	14:17:12.308	STB, Breaker trip indication	CFC161S012SBI	Genset_16		ON	None
01/04/2021	14:17:12.308	STB, Breaker trip indication	CFC161S012SBI	Genset_16		ON	operator

(local) - WWAlmDb Displaying 1 to 404 of 404 records. Connected

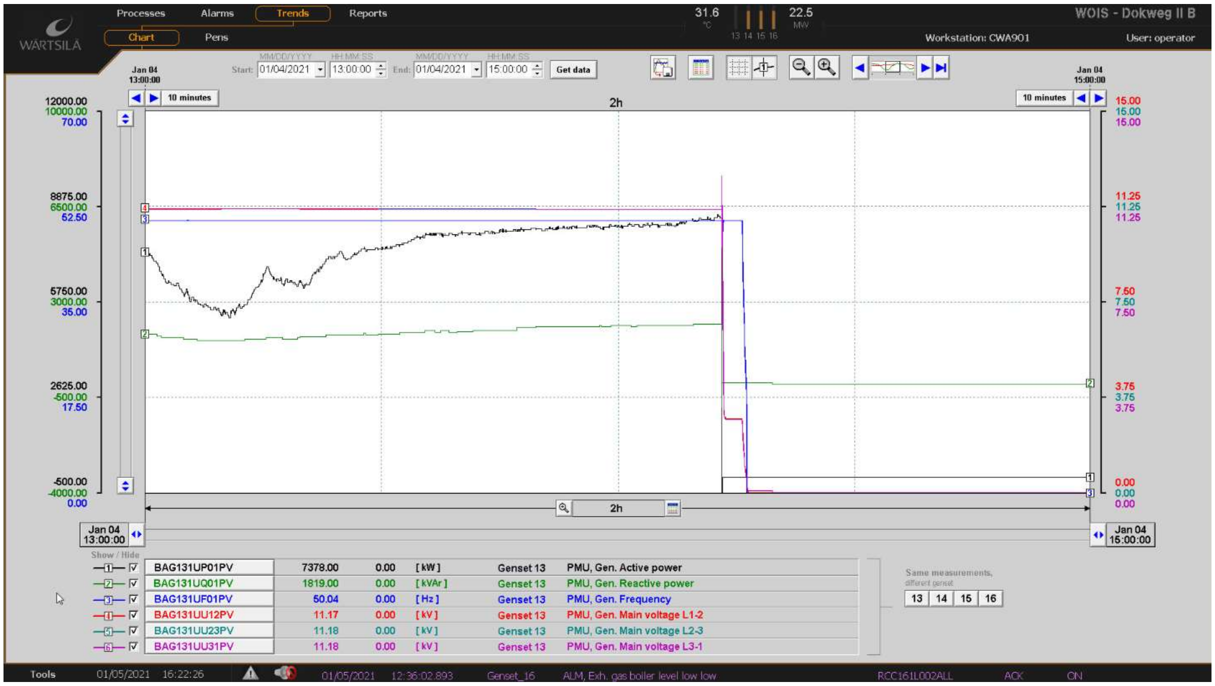
01/11/2021 07:39:36 01/11/2021 07:37:08.145 Genset_15 ALM, Low CA temp, engine inlet SCA151TE601AL UNACK ON



Date [MM/DD/YYYY]	Time [HH:MM:SS.ms]	Description	Plant code	Alarm Group	Alarm State	State	Operator
01/04/2021	14:17:12.308	STB, Breaker trip indication	CFC161S012SBI	Genset_16		ON	None
01/04/2021	14:17:12.308	STB, Breaker trip indication	CFC161S012SBI	Genset_16		ON	operator
01/04/2021	14:17:12.316	TRP, VAMP210 reverse power P<	BAE161F32XTRL	Genset_16	UNACK_ALM	ON	operator
01/04/2021	14:17:12.323	TRP, VAMP210 reverse power P<	BAE151F32XTRL	Genset_15	UNACK_ALM	ON	operator
01/04/2021	14:17:12.327	Gen. breaker open	BAE151Q000OPN	Genset_15		ON	operator
01/04/2021	14:17:12.327	Gen. breaker open	BAE151Q000OPN	Genset_15		ON	None
01/04/2021	14:17:12.327	Gen. breaker open	BAE151Q000OPN	Genset_15		ON	operator
01/04/2021	14:17:12.327	Gen. breaker closed	BAE151Q000CLO	Genset_15		OFF	operator
01/04/2021	14:17:12.327	AVR excitation on	BAE151S005ACK	Genset_15		OFF	operator
01/04/2021	14:17:12.337	AVR excitation on	BAE161S005ACK	Genset_16		OFF	operator
01/04/2021	14:17:12.337	Gen. breaker open	BAE161Q000OPN	Genset_16		ON	operator
01/04/2021	14:17:12.337	Gen. breaker closed	BAE161Q000CLO	Genset_16		OFF	operator
01/04/2021	14:17:12.337	Gen. breaker open	BAE161Q000OPN	Genset_16		ON	None
01/04/2021	14:17:12.359	Engine control, speed (droop)	CFC151S002SEL	Genset_15		ON	None
01/04/2021	14:17:12.359	Operation mode droop (island)	CFC151DROOP2	Genset_15		ON	None
01/04/2021	14:17:12.359	Operation mode droop (island)	CFC151DROOP2	Genset_15		ON	operator
01/04/2021	14:17:12.359	Engine control, speed (droop)	CFC151S002SEL	Genset_15		ON	operator
01/04/2021	14:17:12.359	Operation mode isochronous	CFC151SDC	Genset_15		OFF	operator
01/04/2021	14:17:12.359	Operation mode droop (island)	CFC151DROOP2	Genset_15		ON	operator
01/04/2021	14:17:12.359	Load sharing selected (isochronous)	CFC151S030INF	Genset_15		OFF	operator
01/04/2021	14:17:12.359	Engine control, speed (droop)	CFC151S002SEL	Genset_15		ON	operator
01/04/2021	14:17:12.369	Operation mode isochronous	CFC161SDC	Genset_16		OFF	operator
01/04/2021	14:17:12.369	Operation mode droop (island)	CFC161DROOP2	Genset_16		ON	operator
01/04/2021	14:17:12.369	Load sharing selected (isochronous)	CFC161S030INF	Genset_16		OFF	operator
01/04/2021	14:17:12.369	Engine control, speed (droop)	CFC161S002SEL	Genset_16		ON	operator
01/04/2021	14:17:12.369	AVR, excitation on	BAG161S001ING	Genset_16		OFF	operator
01/04/2021	14:17:12.369	Operation mode droop (island)	CFC161DROOP2	Genset_16		ON	None
01/04/2021	14:17:12.369	Engine control, speed (droop)	CFC161S002SEL	Genset_16		ON	None
01/04/2021	14:17:12.434	AVR, excitation on	BAG131S001ING	Genset_13		OFF	operator
01/04/2021	14:17:12.434	AVR, in VDC Primary net	BAG131S008ING	Genset_13		OFF	operator
01/04/2021	14:17:12.629	AVR, excitation on	BAG151S001ING	Genset_15		OFF	operator
01/04/2021	14:17:12.629	AVR, in VDC Primary net	BAG151S008ING	Genset_15		OFF	operator
01/04/2021	14:17:12.880	AVR, in VDC Primary net	BAG161S008ING	Genset_16		OFF	operator
01/04/2021	14:17:13.060	Exh gas boiler damper closed	NHA161G001CLO	Genset_16		ON	operator
01/04/2021	14:17:13.060	Exh gas boiler damper closed	NHA161G001CLO	Genset_16		ON	None
01/04/2021	14:17:14.427	TRP, VAMP210 reverse power P<	BAE151F32XTRL	Genset_15	UNACK_RTN	OFF	operator
01/04/2021	14:17:14.439	TRP, VAMP210 reverse power P<	BAE161F32XTRL	Genset_16	UNACK_RTN	OFF	operator
01/04/2021	14:17:14.564	TRP, VAMP210 reverse power P<	BAE131F32XTRL	Genset_13	UNACK_RTN	OFF	operator

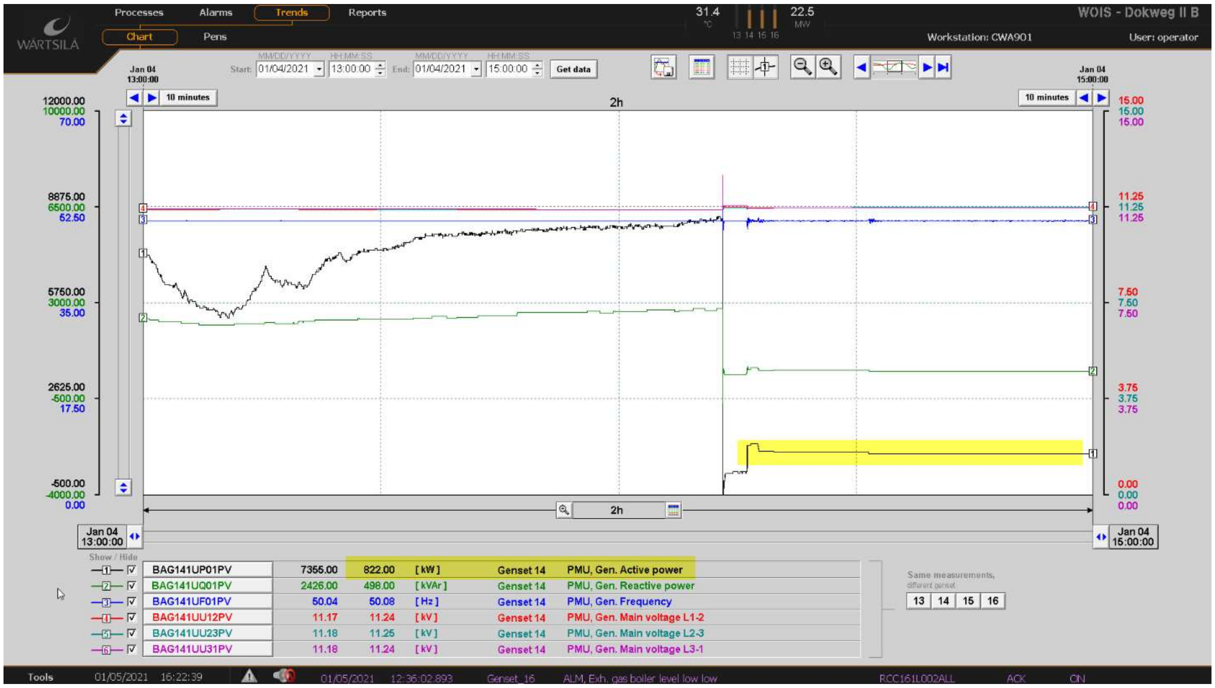
(local) - WWAlmDb Displaying 1 to 404 of 404 records. Connected

01/11/2021 07:39:50 01/11/2021 07:37:08.145 Genset_15 ALM, Low CA temp, engine inlet SCA151TE601AL UNACK ON



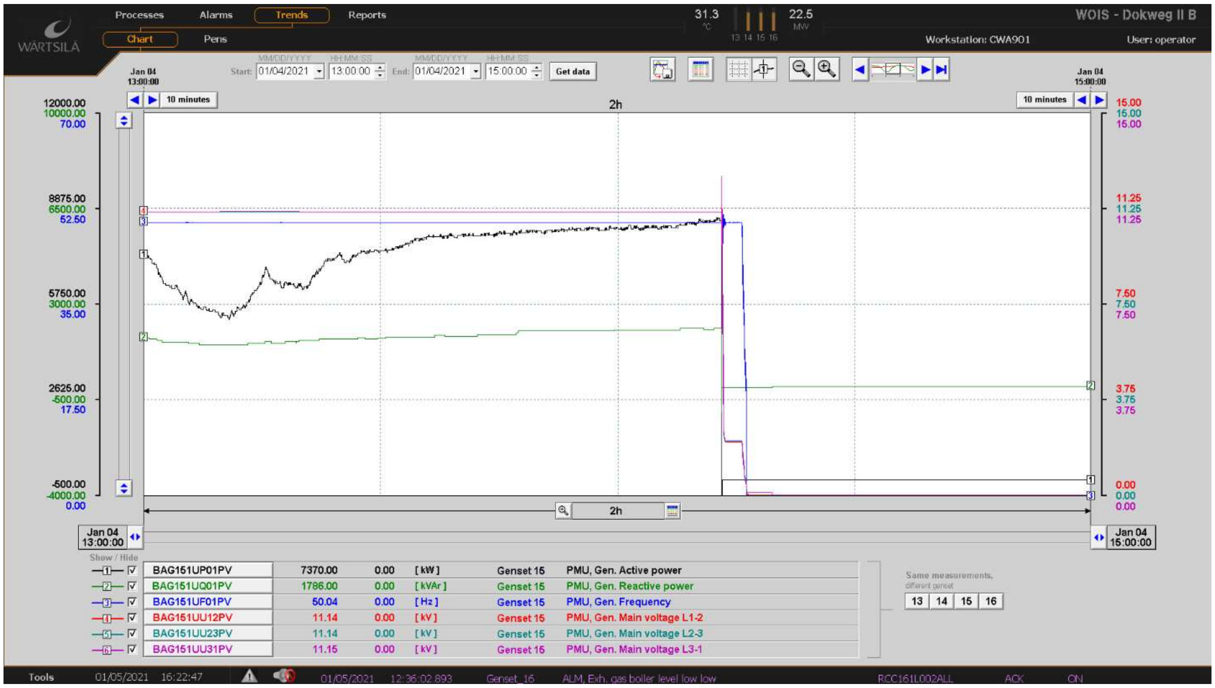
1 ☑ BAG131UP01PV	7378.00	0.00	[kW]	Genset 13	PMU, Gen. Active power
2 ☑ BAG131UQ01PV	1819.00	0.00	[kVAr]	Genset 13	PMU, Gen. Reactive power
3 ☑ BAG131UF01PV	50.04	0.00	[Hz]	Genset 13	PMU, Gen. Frequency
4 ☑ BAG131UU12PV	11.17	0.00	[kV]	Genset 13	PMU, Gen. Main voltage L1-2
5 ☑ BAG131UU23PV	11.18	0.00	[kV]	Genset 13	PMU, Gen. Main voltage L2-3
6 ☑ BAG131UU31PV	11.18	0.00	[kV]	Genset 13	PMU, Gen. Main voltage L3-1

```
01/05/2021 16:22:26   01/05/2021 12:36:02.893 Genset_16 ALM, Exh. gas boiler level low low RCC161L002ALL ACK ON
```



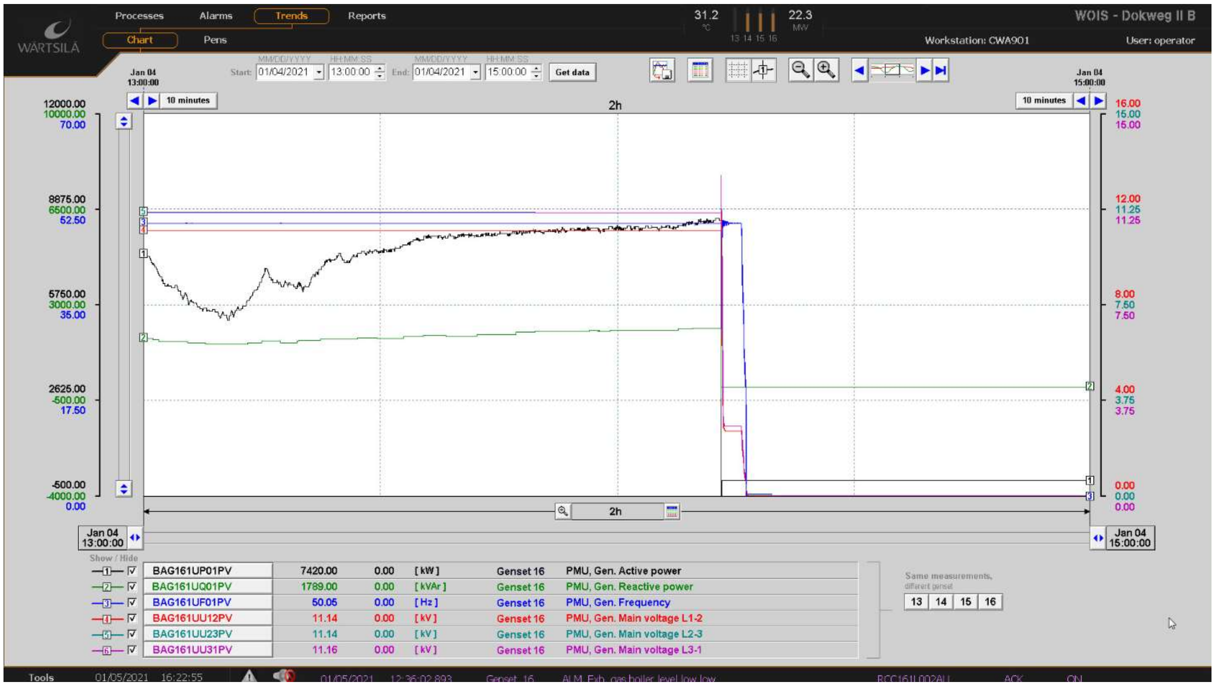
1 ☑ BAG141UP01PV	7355.00	822.00	[kW]	Genset 14	PMU, Gen. Active power
2 ☑ BAG141UQ01PV	2426.00	498.00	[kVAr]	Genset 14	PMU, Gen. Reactive power
3 ☑ BAG141UF01PV	50.04	50.08	[Hz]	Genset 14	PMU, Gen. Frequency
4 ☑ BAG141UU12PV	11.17	11.24	[kV]	Genset 14	PMU, Gen. Main voltage L1-2
5 ☑ BAG141UU23PV	11.18	11.25	[kV]	Genset 14	PMU, Gen. Main voltage L2-3
6 ☑ BAG141UU31PV	11.18	11.24	[kV]	Genset 14	PMU, Gen. Main voltage L3-1

```
01/05/2021 16:22:39   01/05/2021 12:36:02.893 Genset_16 ALM, Exh. gas boiler level low low RCC161L002ALL ACK ON
```



BAG151UP01PV	7370.00	0.00	[kW]	Genset 15	PMU, Gen. Active power
BAG151UQ01PV	1786.00	0.00	[kVAr]	Genset 15	PMU, Gen. Reactive power
BAG151UF01PV	50.04	0.00	[Hz]	Genset 15	PMU, Gen. Frequency
BAG151UU12PV	11.14	0.00	[kV]	Genset 15	PMU, Gen. Main voltage L1-2
BAG151UU23PV	11.14	0.00	[kV]	Genset 15	PMU, Gen. Main voltage L2-3
BAG151UU31PV	11.15	0.00	[kV]	Genset 15	PMU, Gen. Main voltage L3-1

```
01/05/2021 16:22:47   01/05/2021 12:36:02.893 Genset_16 ALM, Exh. gas boiler level low low RCC161L002ALL ACK ON
```



BAG161UP01PV	7420.00	0.00	[kW]	Genset 16	PMU, Gen. Active power
BAG161UQ01PV	1789.00	0.00	[kVAr]	Genset 16	PMU, Gen. Reactive power
BAG161UF01PV	50.05	0.00	[Hz]	Genset 16	PMU, Gen. Frequency
BAG161UU12PV	11.14	0.00	[kV]	Genset 16	PMU, Gen. Main voltage L1-2
BAG161UU23PV	11.14	0.00	[kV]	Genset 16	PMU, Gen. Main voltage L2-3
BAG161UU31PV	11.16	0.00	[kV]	Genset 16	PMU, Gen. Main voltage L3-1

```
01/05/2021 16:22:55   01/05/2021 12:36:02.893 Genset_16 ALM, Exh. gas boiler level low low RCC161L002ALL ACK ON
```

4 CONCLUSION

There has been big event in distribution side. Some feeder or bigger breaker has been opened and units have been unloading due high frequency / engine speed.

Dokweg 66kV Substation – Testing Report

The following activities were carried out during the site visit Jan 10 – Jan 13, 2021:

Sunday Jan 10, 2021

1- The first task undertaken was to retrieve the setting files and the event records of relays P521 and P139 of Feeder F04 (Isla).
The relevant setting values for relay tripping are:

F04-P521: I>= 0.88 In. Set → NO (it was in YES and apparently it was changed to NO by Lenin on Dec 12, 2020)
F04-P139: I>=0.88 In. IDMT IEC Standard Inverse.

There was no trip event recorded by the P521 relay. However, a current value higher than 0.88 In was registered by the P139 relay.
This high current value agrees with the new situation (Isla Feeder) caused by the outage of the Parera (F07) feeder.

2- The same task was performed at the Refinery. It was verified that neither of the two relays - P521 and P139- recorded a fault condition.

Monday Jan 11, 2021

3- Setting files and event files of the relays installed in the below circuits were retrieved:

BAO901 to F05	TRAFO 1	DOKWEG IIA
BAO902 to F12	TRAFO 2	DOKWEG IIA (CB out of service)
BAO903 to F03	TRAFO 1	DOKWEG IIB
BAO904 to F10	TRAFO 2	DOKWEG IIB

No tripping event was found in any of the relays.

4- It was verified that the Feeder F04 tripping events of 10 and 12 of December 2020 and 4 January 2021, were started by a high current detected by overcurrent relay P139. As a result of this situation, Aqualectra have decided to inhibit the delayed overcurrent setting of the P139 relay until a new relay study is prepared taking into consideration the changes caused by the commissioning of the new generating plant DOKWEG IIB.

Tuesday Jan 12, 2021

14-1-21

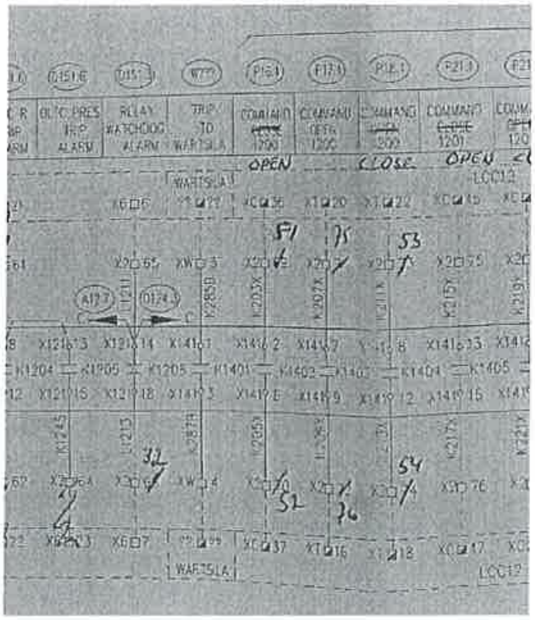
14-1-21

The tripping of the Feeder F03 C. Breaker was investigated. This circuit is connected to the Transformer #3 of DOKWEG II B.
It was noticed that this Feeder F03 and the Feeder F10 were modified to allow the generation expansion carried out in 2018. The wiring was changed to leave the circuits identical to feeders F05 and F12. The setting of the P139 relays also had to be changed accordingly.

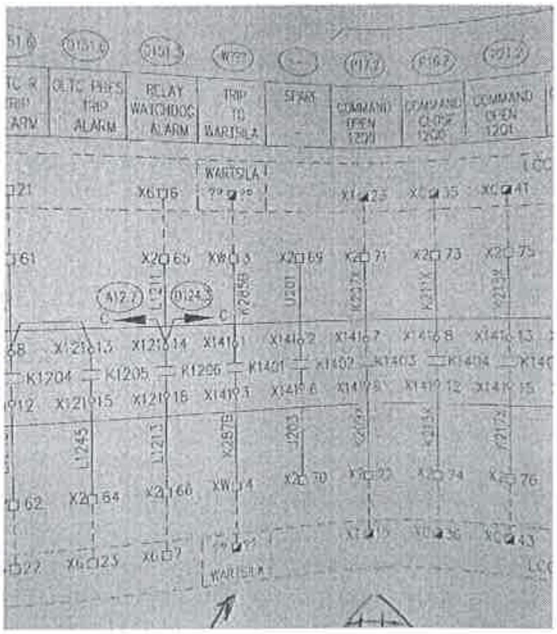
5- When the circuits were compared, a difference was found in the wiring. Please refer to the below photos. At feeder F03 the relay contact K1402 was wired to a trip contact. The second photo shows the As Built version of feeder F05 / F12 which shows contact K1402 as "Spare".

6- When an alarm is received from the GIS local control panels (LCC), if the control is set in the "Remote" position, the relay contact K1402 will cause the trip of the 66kV circuit breaker. This event was repeated by us with the feeder that is out of service.
No other comparation were carried out between original project (F05/F12) and modification in 2018.

As built drawing by Aqualectra modification 2018



As built drawing original by K-Line 2014



Wednesday Jan 13, 2021

7- The three relays P746, Bus Differential Protection were checked. No trip events were recorded.

14-1-21

14-1-21

8- Schneider have suggested that the relay P746, phase B, be sent out to their factory for repairs as an alarm is "On" continuously. This issue cannot be fixed at site.

CONCLUSIONS

The reason for the trips that occurred on the 10 and 12 of December 2020 and 4 of January 2021 was the high current detected by the P139 relay of the feeder F04 (Isla). The 66kV feeder current was higher than the relay setting value (Iref =0.88 In) of the P139 relay.

With regards to the tripping of the 66kV circuit breaker of the feeder F03 (Transformer #3) it should be pointed out that due to a wiring error, a regular alarm originated in the GIS control panel (LCC) sent a trip signal to the c. breaker.

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Report prepared by: Angel Tamburelli – Jan 14, 2021

14-1-21

Angel Tamburelli
K-LIUC
14-1-21

DNV·GL

Memo aan:		**Memo nummer:**	NA
D. Jonis	Aqualectra	**Van:**	H.E. Dijk
		Datum:	9-1-2021
Kopie:		**Opgesteld door:**	H.E. Dijk W. Kuijpers

Samenvatting stand van zaken met betrekking tot het onderzoek naar de black-outs

In december 2020 is Curaçao getroffen door aantal black-outs. Deze vonden plaats op 7, 10 en 12 december. Naar aanleiding hiervan heeft Aqualectra DNV GL gevraagd om een onafhankelijk onderzoek uit te voeren naar de hoofdoorzaak van deze black-outs en op basis van de uitkomst aanbevelingen ter voorkoming van de black-outs voor de korte en lange termijn te doen.

Ten tijde van het onderzoek heeft op 4-1-2021 een black-out plaatsgevonden. Analyse hiervan wordt ook in het onderzoek betrokken.

Deze memo is bedoeld om de stand van zaken vanuit DNV GL perspectief door te geven, om onze huidige inzichten met Aqualectra te delen en om na te gaan of er in dit stadium van het onderzoek – het onderzoek is geenszins afgerond – kortetermijnoplossingen zijn voor het voorkomen van dit soort black-outs. De bijlage vermeldt de referenties van de belangrijkste documenten/bronnen op basis waarvan we tot de inzichten zijn gekomen.

Met de grootste nadruk vermelden wij dat ons huidige inzicht gebaseerd is op onvolledige informatie en dat dit later kan wijzigen, wanneer ons additionele informatie ter beschikking wordt gesteld.

Oorzaak black-out – onder voorbehoud

Uit de geraadpleegde documenten betreffende december black-outs leiden wij af dat Aqualectra moeite heeft met het beheersen van haar spanning-blindvermogenshuishouden, met name het effectief inzetten van de spanning-blindvermogensregeling van de generatoreenheden. Referentie 1, 4, 5 en 6 maken hier melding van in relatie tot het zoeken naar de hoofdoorzaak van de black-outs van 7, 10 en 12 december 2020. Alleen referentie 6 (Wärtsilä) geeft een aanbeveling op basis van hun onderzoek en kennelijk op meer informatie (“het ontbreken van vertrouwen bij de operator”) die niet in het betreffende onderzoeksrapport is opgenomen: trainen van de operators.

Relevant voor het zoeken naar een oplossing op korte termijn is de voorlopige constatering dat het vertrouwen bij de operators bij het zelfstandig en automatisch functioneren van de regelingen van de generatoreenheden ontbreekt of dat er onvoldoende instructies en trainingen zijn gegeven aan de operators. Tegen deze constatering kan echter worden ingebracht dat operators over een lange periode de eenheden hebben ingezet en zeer waarschijnlijk op een op succesvolle manier dus ook de generatorregelingen. Kennelijk zijn de operators in december 2020 geconfronteerd met voor hen uitzonderlijke netsituaties waardoor het in voorkomende gevallen (bijvoorbeeld als de eenheden tegen hun grens aan moeten worden bedreven) de generatorregelingen niet optimaal functioneerden. In het uiterste geval leidt zo’n uitzonderlijke situatie tot een black-out. Een belangrijke voorwaarde voor het automatisch laten functioneren van zowel de spannings-blindvermogensregeling als ook de frequentie-werkzaam vermogensregeling is het beschikhaar houden van voldoende draaiende reserve (spinning reserve) en stand-by reserve (tijdig opstarten stand-by generatoren) om variaties in windparkvermogen en belastingsvraag en uitval van generatoren en CRU adequaat op te vangen.

De black-out van 10 december en mogelijk ook van 12 december lijkt veroorzaakt te zijn door een te laag ingestelde back-up overstroombeveiliging in de 66 kV verbinding Dokweg 2 – Isla. Voor deze cruciale verbinding (feitelijk de koppeling van de cruciale centrales Dokweg 2 met het 66 kV net en de overige opwekking en netbelasting) lijkt bovendien geen N-1 redundantie aanwezig, die automatisch en zonder onderbreking het getransporteerde vermogen overneemt

Oplossing korte termijn – onder voorbehoud

Voor de korte termijn zien wij een *no-regret*-oplossing: wat (na grondiger onderzoek) uiteindelijk de hoofdoorzaak van de black-outs is geweest, de voorgestelde maatregel voor de korte termijn zal deel uitmaken van de langetermijnoplossing. Ons voorstel houdt rekening met beide genoemde aspecten:

- De inzet van de generatoreenheden afstemmen op de kennis en ervaring van de operators met de netsituatie(s).
- On-the-job training van Aqualectra-operators door Wärtsilä.
- Korte instructie/beschrijving met de volgende onderwerpen:
    - concept spannings- en frequentieregeling: welke generatoren staan op spannings- en frequentieregeling (isochroon en/of droop) en welke op instelbaar vast (blind)vermogen
    - benodigde draaiende reserve
    - wanneer stand-by eenheden op te starten of uit bedrijf te nemen.
    - Wanneer handmatig belasting afschakelen om black-out te voorkomen
- Controle beveiligingsinstellingen Dokweg 2 – Isla kabel (is al in uitvoering, zie e-mail Jason)
- Voeden Parera rechtstreeks vanaf Dokweg 2. Dit ontlast de verbinding Dokweg 2 – Isla
- Via modelsimulatie nagaan of de verbinding Dokweg 2 – Parera welke redundantie kan bieden voor de verbinding Dokweg 2 – Isla, eventueel in combinatie met verschuiving dispatch van Dokweg 2 naar NDPP-Dokweg 1 – GT.

Oplossing lange termijn

Voor het zoek en vinden van de langetermijnoplossingen van de het spanning-blindvermogensvraagstuk bij Aqualectra zal het storingsonderzoek moeten worden afgerond op basis van additionele informatie, wellicht ondersteund door netberekeningen. Onderdeel hiervan zal onder andere een uitvalanalyse zijn, een aspect die gezien de storing van 4 januari 2021 zeer relevant is geworden.

Daarnaast bevelen we een review van de beveiligingscoördinatie van het 66 kV net en generatorbeveiligingen aan.

BIJLAGE

Referentie	Datum	Beschikbaar gestelde informatie en voorlopig respons
1	15-12-2020	DIgSILENT raport, P1960; Security of Supply in Curaçao’s Electricity System; Report on Trip Events in February 2020
2	15-12-2020	E-mail van Darick Jonis; Meest relevante informatie: • De trapstanden van de NDPP-transformatoren stonden verkeerd bij de storing van 12 december. • Recentelijk is de regeling van (sommige) generatoren gezet op isochroon (*isochronous mode*) • Aqualectra vermoedt dat na de black-out van 7 december de instelling van de isochroon regeling veranderd was waardoor Aqualectra moeite had met het stabiliseren van de frequentie bij het herstel van de elektriciteitsvoorziening (12 december). • Inmiddels heeft Aqualectra in overleg met Wärtsilä de instelling van de isochrone regeling weer aangepast. • Aqualectra constateert (geruime tijd) spanningsschommelingen in het net die gepaard gaan met schommelingen in de blindvermogenslevering van de MAN-dieselgeneratoren van CRU: de cosinus phi van de generatoren schommelt tussen positief en negatief
3	16-12-2020	E-mail van Darick Jonis; Informatie betreffende de black-out van 7 december 2020: • Registratie verloop van frequentie, en actief en reactief vermogen van de eenheden (Dokweg 2A en 2B, en BOO1 en BOO2) • Registratie verloop van de 66 kV spanning (Dokweg en Isla)
4	24-12-2020	E-mail van Harold Dijk; Analyse van Wim Kuijper van black-out 7december 2020. Belangrijkste conclusies (voornamelijk) gebaseerd op de ontvangen registraties: • Het systeemgedrag is niet of zeer moeilijk te verklaren: de registraties zijn zeer beperkt, er ontbreken een aantal opwekeenheden en windparken. • Vermoedelijk is de black-out ingeleid is door een blindvermogenstekort, waardoor de spanning langzaam zakte, maar nog altijd binnen normale grenzen was. • Onder zeer groot voorbehoud is gesteld: de spanningsregeling en/of bediening door operators was/is niet op orde.
5	4-1-2021	E-mail van Darick Jonis

Referentie	Datum	Beschikbaar gestelde informatie en voorlopig respons
		• DIgSILENT rapport, P2029; Security of Supply in Curaçao's Electricity System; Analysis of Grid Events - 07.12.2020 Conclusie: de verandering van de regeling van de Dokweg 2A en Dokweg 2B dieselgeneratoren van isochroon modus naar constant kW en kvar modus is de belangrijkste oorzaak van de black-out • DIgSILENT rapport, P2029; Security of Supply in Curaçao's Electricity System; Analysis of Grid Events - 10.12.2020 Nog geen conclusies • 4x hourly dispatch van de in bedrijf zijnde eenheden (7-12,2020 /8hrs, 10-12-2020/14hrs, 12-12-20/17hrs en 1-4-2021/9hrs)
6	4-1-2021	E-mail van Kees de Grijs • Wartsila document, Analysis of Grid Event on 7th of December 2020; DOKWEG 2A - 2B; W32 - W34 • Voornaamste conclusie: Verandering van de regeling van de eenheden in Dokweg 2A van isochroon modus naar de kW-modus veroorzaakte overbelasting van de eenheden in Dokweg 2B door een plotselinge afname van blindvermogen. • Aanbeveling: Een training voor operators om het vertrouwen terug te winnen in verschillende bedrijfsvoeringsmodi van de eenheden en om te bewerkstelligen dat voor voorkomende situaties de juiste bedieningsmodus wordt gekozen.
6	6-1-2021	E-mail van Wim Kuijpers • De trip van de Dokweg 66 kV kabel Dokweg 2 – Isla, (hoogstwaarschijnlijk) door de back-up overstroom beveiliging in de kabeldifferentiaal beveiliging (e-mail Jason Smit aan Digsilent)– de vraag is of de beveiliging correct is ingesteld. • De operators hebben geen ingrepen verricht aan de regelinstellingen (modus) van de generatoren

Memo aan:		**Memo nummer:**	NA
D. Jonis	Aqualectra	**Van:**	H.E. Dijk
		Datum:	12-1-2021
Kopie:		**Opgesteld door:**	H.E. Dijk W. Kuijpers

Planning van de inzet van de productie-eenheden en bepaling van bijbehorende MW- en Mvar regelstrategie

In de memo van d.d. 9-1-2021 die een samenvatting van de stand van zaken met betrekking tot het onderzoek naar de december black-outs behandelt, is een aantal aanbevelingen opgenomen. Eén van de aanbevelingen betreft de planning van de inzet van de productie-eenheden en bepaling van bijbehorende kW- en kvar regelstrategie. Deze follow-up memo richt zich hierop. Meer specifiek houdt deze memo zich bezig met beantwoording van de volgende vraag:

- Welke de productie-eenheden van Aqualectra moeten worden ingezet als:
  - de voorspelling (in uurwaarden) voor de volgende dag van de opwekking (in kW bij cos phi=x[1]) van de windparken bekend c.q. bepaald is
  - de voorspelling (in uurwaarden) voor de volgende dag van de belasting (in kW en kvar) bekend c.q. bepaald is
- rekening houdend met de
  - beschikbaarheidseis van vermogensreserve (primaire reserve en secundaire/draaiende reserve): hoeveel, hoe snel beschikbaar?
  - Bedrijfsvoeringsfilosofie/regelconcept van Aqualectra ten aanzien van:
    - Frequentievermogensregeling
    - Spanningsblindvermogensregeling
    - Isochrone regeling (isochronous control), regeling met statiek (droop control, constante (blind)vermogen
    - Belastingafschakeling (load shedding)
    - Automatisch/Handbediening

Bij de beantwoording van deze vraag wordt aan de hand van het opvragen van documenten en/of het doorvragen aan Aqualectra operators de huidige situatie betreffende voorbereiding en uitvoering van de bedrijfsvoering en zo helder mogelijk geformuleerd. Vervolgens wordt, indien nodig, in nauw samenwerking met Aqualectra experts de aangepaste voorbereiding en uitvoering van de bedrijfsvoering. Om de veranderingen overzichtelijk in beeld te brengen wordt de huidige wijze van bedrijfsvoering naast de aangepaste gezet in een onderstaande tabel. De nodige veranderingen moeten op korte termijn haalbaar zijn, kunnen worden ingevoerd en uitgevoerd (door de operators).

---

[1] De windparken leveren aan het net met nu met een cosinu phi = x, met x = 1; het is mogelijk dat in de toekomst x=0.9 wordt gevraagd.

Een meer uitgebreide beschrijving is in de bijlage opgenomen.

Tabel 1 Huidige en aangepaste wijze van bedrijfsvoering

	Huidige wijze van bedrijfsvoering	Aangepaste wijze van bedrijfsvoering
	Inzetprincipes	
Bedrijfsvoeringsfilosofie	Regelprincipes:	
Voorbereiding bedrijfsvoering (Dag – 1)	Voorspelling van levering van de windparken op basis van Hoe?	Voorspelling van levering van de windparken op basis van de windvoorspelling. Hoe
	Voorspelling van de belasting op basis van belastingspatronen (kW$_i$,ti), i = 1,..24 Hoe?	Voorspelling van de belasting op basis van belastingspatronen waarden (kW$_i$,ti) en kvar$_i$, i = 1,..24 Hoe
	Planning inzet van de productie-eenheden	
Bedrijfsvoering (Dag=0)		

Vragen Aqualectra ter beschrijving van de huidige en aangepaste wijze van bedrijfsvoering

1. Meetdata opwekking ter indicatie van de vermogensvraag en de dispatch van de opwekeenheden:
   a. MW en Mvar output van de individuele generatoren (dieselgeneratoren, gasturbine), indparken, BOO koppeling, (en PV indien al grootschalig aanwezig)
   b. MW en Mvar flow in 66 kV verbindingen en 66/30 kV en 66/11 kV transformatoren

   c. Spanningen op 66 kV stations en op 30 kV en 11 kV hoofdstations waar 66/30 kV en 66/11 kV transformatoren zijn aangesloten
   d. Stand regelschakelaars 66/30 kV en 66/11 kV transformatoren
   e. Meetdata op uurbasis over twee representatieve weken. Bij voorkeur een week met veel wind en een week met weinig wind

2. Overzicht met nominale vermogens (MW, cos phi) van de individuele opwekeenheden
3. Operatorsinstructies met betrekking dispatch en/of spannings- en frequentieregeling van eenheden
4. Normale bedrijfvoering: welke opwekeenheden staan in isochroon regeling, statiekregeling resp. op vast vermogen. Dit voor zowel werkzaam vermogen (frequentie-vermogensregeling) als blindvermogen (spannings-blindvermogens-arbeidsfactorregeling)
5. Selke 66/30 en 66/11 kV transformatoren staan op automatische spanningsregeling en welke spanning wordt automatisch geregeld (66 kV of 30kV of 11 kV)?

BIJLAGE

Aqualectra – Blackout investigation report

Prepared by: Pablo Ariza on January 14th 2021

Schneider representative signature:____________________________

Customer signature: ____

Date:____

Schneider Electric
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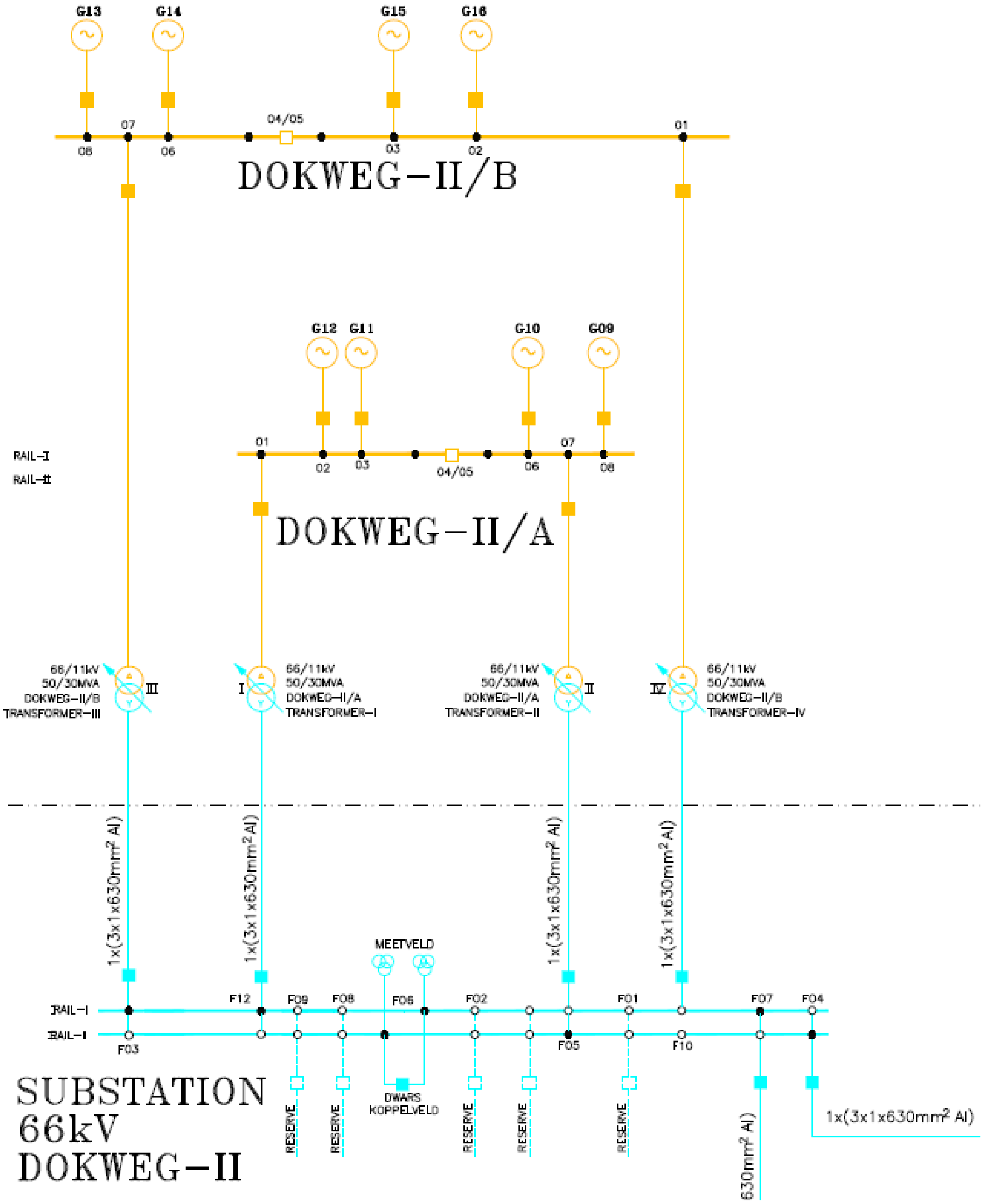
schneider-electric.com

1 Background

In December 2020, Schneider Canada was contacted by K-Line International in regards to an issue that their customer Aqualectra was having with Schneider MiCOM relays. Aqualectra is the main utility company in Curaçao. The issue in question was described as a possible misoperation of the P746 busbar protection relays in the 66kV GIS SWG that K-Line provided and commissioned in Curaçao within a project they executed in 2015 which caused an island wide blackout on December 10th and 12th. Schneider Canada got in contact with an Aqualectra representative in order for them to extract the necessary files from the P746 relays (settings, logic, events, disturbance records) so that they were sent to us for analysis. After some email correspondence, we were able to receive from Aqualectra some of the requested information and after a preliminary analysis, it was not believed that the P746 had issued a trip to the entire busbar and caused the blackout. Aqualectra still decided to turn off the P746 relays in order to avoid another blackout and on January 4th, another trip on one of the feeder breakers of the 66kV GIS SWG occurred, therefore Aqualectra requested that a representative from K-Line International and a representative from Scheider Canada travelled to Curaçao in order to investigate what was the cause of these trips.

2 Investigation plan

During the email exchanges that were had with Aqualectra, we were told that the circuit breakers that operated were Bay 03, Bay 04 and Bay 10. The breaker that caused the blackout was Bay 04, and upon starting up the system after the blackout, on some instances Bays 03 and 10 operated (see below SLD):

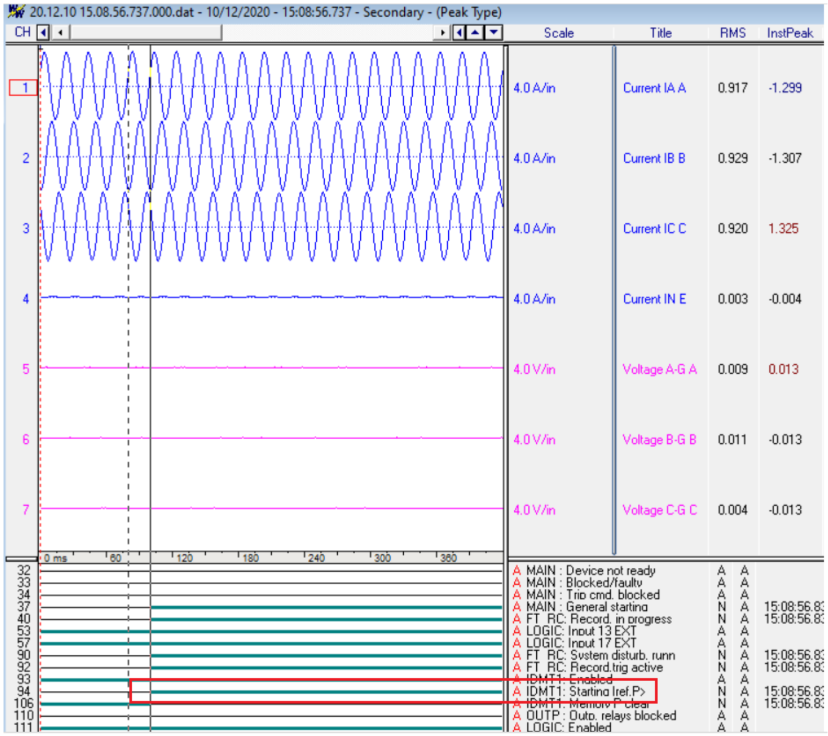


Bay 03 and Bay 10 are incoming from the 11kV Dokweg-II/B substation and Bay 04 is a feeder that goes to the 66kV Isla sybstation. It is important to note that when this project was delivered on 2015, there was only the Dokweg-IIA substation. On 2019, Aqualectra added the Dokweg-IIB substation and converted two of the bays of the 66kV GIS SWG from feeder bay to transformer bays. These two bays that were transformed are bays 03 and 10, which are the ones that tripped during the start-up of the system after the blackout caused by the operation of Bay 04. Since the P746 busbar protection relays were off during the January 4th blackout, the plan was to connect to the protection relays in the affected bays (03, 04 and 10) in order to extract the settings, logic, events and disturbance records in order to analyze what the relays did during these blackouts and try to find the cause of the trip.

3 Investigation on Bay 04

Bay 04 of the 66kV GIS SWG is protected by two MiCOM relays: P521 (for cable differential protection) and P139 (for overcurrent protection). We connected to both relays and extracted all the necessary files for the analysis. Since this is a feeder to the 66kV Isla substation, we connected to the P139 and P521 from the Isla substation to analyze what those relays saw as well.

The two relays on the 66kV Isla substation did not register any relevant events for the dates in question (December 10th, December 12th and January 4th), therefore we concentrated our efforts in the relays of Bay 04 of the 66kV SWG. Upon analysis, we can see that on the dates of December 10th, 12th and January 4th, the P139 triggered a disturbance record that shows that the IDMT overcurrent function picked up:

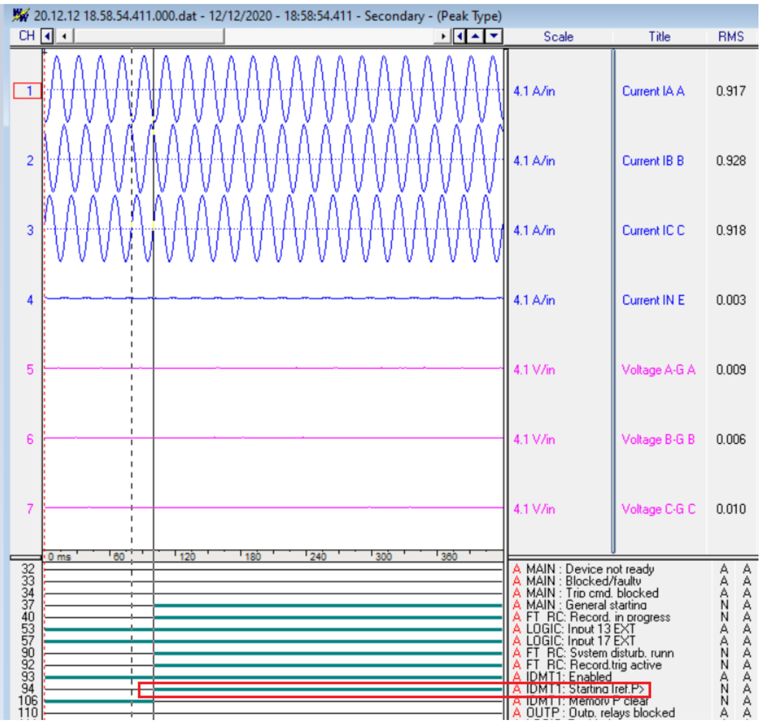


20.12.10 15.08.56.737.000.dat - 10/12/2020 - 15:08:56.737 - Secondary - (Peak Type)

CH	Scale	Title	RMS	InstPeak
1	4.0 A/in	Current IA A	0.917	-1.299
2	4.0 A/in	Current IB B	0.929	-1.307
3	4.0 A/in	Current IC C	0.920	1.325
4	4.0 A/in	Current IN E	0.003	-0.004
5	4.0 V/in	Voltage A-G A	0.009	0.013
6	4.0 V/in	Voltage B-G B	0.011	-0.013
7	4.0 V/in	Voltage C-G C	0.004	-0.013

32	A MAIN : Device not ready	A	A	
33	A MAIN : Blocked/faulty	A	A	
34	A MAIN : Trip cmd. blocked	A	A	
37	A MAIN : General starting	N	A	15:08:56.8
40	A FT_RC: Record. in progress	N	A	15:08:56.8
53	A LOGIC: Input 13 EXT	A	A	
57	A LOGIC: Input 17 EXT	A	A	
90	A FT_RC: System disturb. runn	N	A	15:08:56.8
92	A FT_RC: Record.trig active	N	A	15:08:56.8
93	A IDMT1: Enabled	A	A	
94	A IDMT1: Starting Iref,P>	N	A	15:08:56.8
106	A IDMT1: Memory P clear	N	A	15:08:56.8
110	A OUTP : Outp. relays blocked	A	A	
111	A LOGIC: Enabled	A	A	

Figure 1 - P139 Disturbance record of Dec 10th 2020



20.12.12 18.58.54.411.000.dat - 12/12/2020 - 18:58:54.411 - Secondary - (Peak Type)

CH	Scale	Title	RMS
1	4.1 A/in	Current IA A	0.917
2	4.1 A/in	Current IB B	0.928
3	4.1 A/in	Current IC C	0.918
4	4.1 A/in	Current IN E	0.003
5	4.1 V/in	Voltage A-G A	0.009
6	4.1 V/in	Voltage B-G B	0.006
7	4.1 V/in	Voltage C-G C	0.010

32	A MAIN : Device not ready	A	A
33	A MAIN : Blocked/faulty	A	A
34	A MAIN : Trip cmd. blocked	A	A
37	A MAIN : General starting	N	A
40	A FT_RC: Record. in progress	N	A
53	A LOGIC: Input 13 EXT	A	A
57	A LOGIC: Input 17 EXT	A	A
90	A FT_RC: System disturb. runn	N	A
92	A FT_RC: Record.trig active	N	A
93	A IDMT1: Enabled	A	A
94	A IDMT1: Starting Iref,P>	N	A
106	A IDMT1: Memory P clear	N	A
110	A OUTP : Outp. relays blocked	A	A

Figure 2 - P139 Disturbance record of Dec 12th 2020

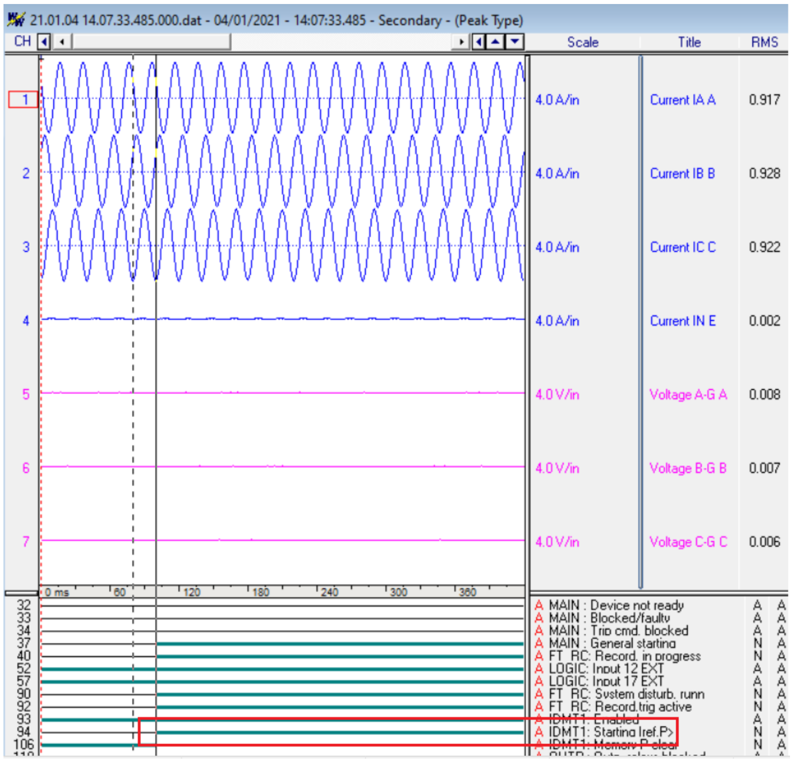
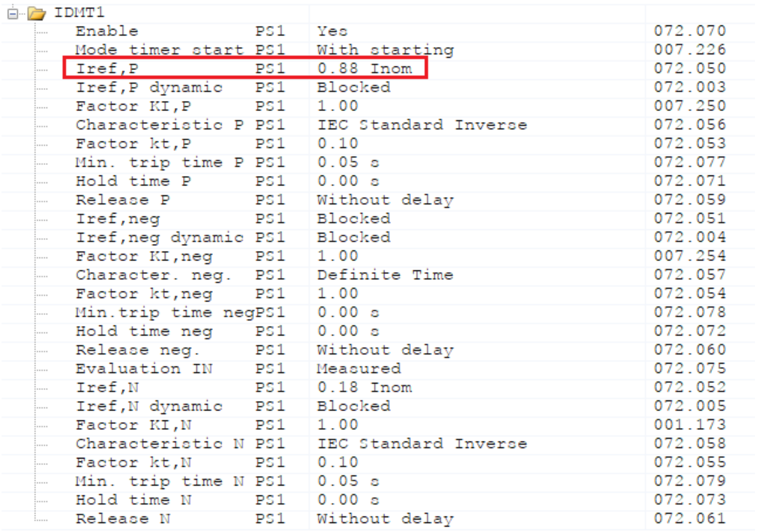


Figure 3 - P139 Disturbance record of Jan 4th 2021

The current value on all three occasions when the IDMT function picked up was around 0.928 A secondary, which is 556.8A primary given that the CT is 600:1. When we see the settings of the IDMT function, we can see that the Iref P> value is 0.88*Inom (Inom = 600A) which is 528A:



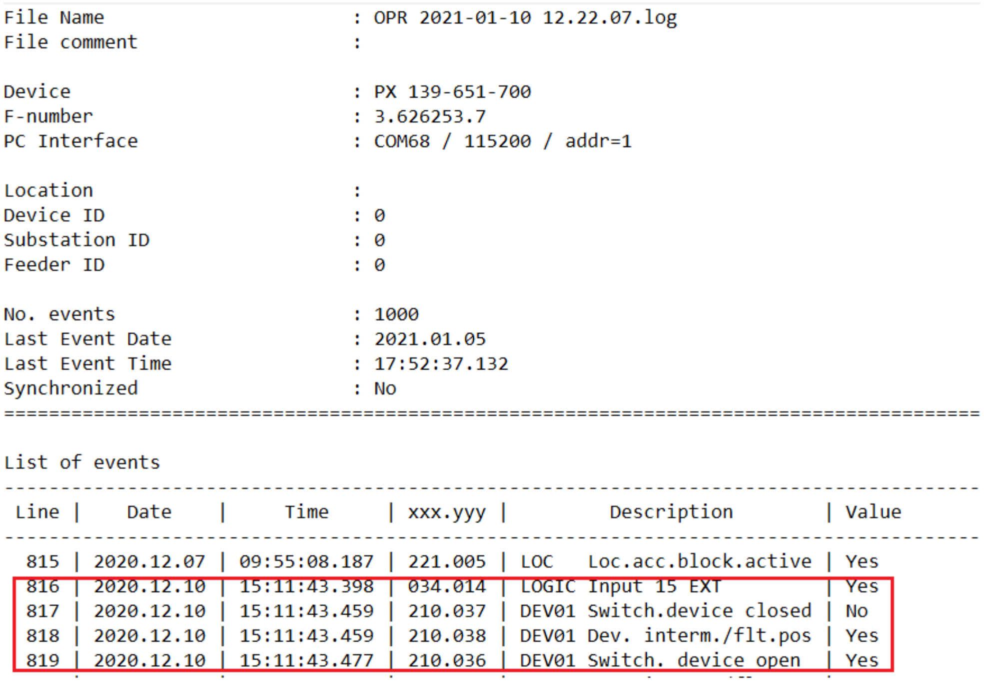
IDMT1			
Enable	PS1	Yes	072.070
Mode timer start	PS1	With starting	007.226
Iref,P	PS1	0.88 Inom	072.050
Iref,P dynamic	PS1	Blocked	072.003
Factor KI,P	PS1	1.00	007.250
Characteristic P	PS1	IEC Standard Inverse	072.056
Factor kt,P	PS1	0.10	072.053
Min. trip time P	PS1	0.05 s	072.077
Hold time P	PS1	0.00 s	072.071
Release P	PS1	Without delay	072.059
Iref,neg	PS1	Blocked	072.051
Iref,neg dynamic	PS1	Blocked	072.004
Factor KI,neg	PS1	1.00	007.254
Character. neg.	PS1	Definite Time	072.057
Factor kt,neg	PS1	1.00	072.054
Min.trip time neg	PS1	0.00 s	072.078
Hold time neg	PS1	0.00 s	072.072
Release neg.	PS1	Without delay	072.060
Evaluation IN	PS1	Measured	072.075
Iref,N	PS1	0.18 Inom	072.052
Iref,N dynamic	PS1	Blocked	072.005
Factor KI,N	PS1	1.00	001.173
Characteristic N	PS1	IEC Standard Inverse	072.058
Factor kt,N	PS1	0.10	072.055
Min. trip time N	PS1	0.05 s	072.079
Hold time N	PS1	0.00 s	072.073
Release N	PS1	Without delay	072.061

Figure 4 - IDMT settings on P139 of Bay 04

We can then conclude that because the current seen by the P139 is higher than the IDMT threshold (556.8A > 528A), this has caused the P139 to issue a trip to the Bay 04 circuit breaker on December 10th, December 12th 2020 and January 4th 2021.

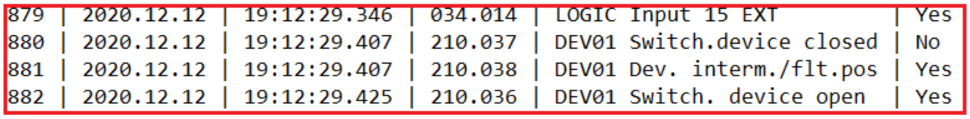
4 Investigation on Bay 03

Bay 03 of the 66kV GIS SWG is protected by three MiCOM relays: two P631 (for transformer differential protection) and P139 (for overcurrent protection). We connected to all three relays and extracted all the necessary files for the analysis. The P631 relays did not register any relevant information for the dates in question. When we analyze the P139 relay, we can see that there are no Disturbance records for 2020 or 2021, which points out to the fact that the circuit breaker did not operate upon a protection element activating but rather it tripped because of something else. We then analyzed the Operating Data recording and we noticed that there was a common pattern on all three dates in question:



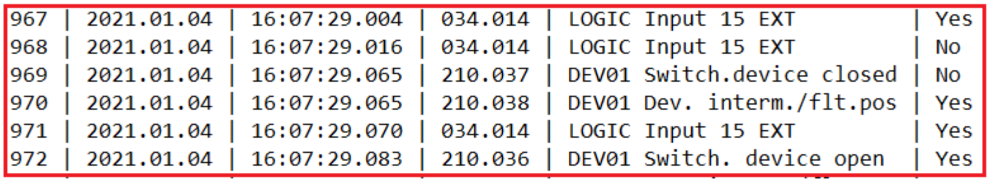
```
File Name                     : OPR 2021-01-10 12.22.07.log
File comment                  :

Device                        : PX 139-651-700
F-number                      : 3.626253.7
PC Interface                  : COM68 / 115200 / addr=1

Location                      :
Device ID                     : 0
Substation ID                 : 0
Feeder ID                     : 0

No. events                    : 1000
Last Event Date               : 2021.01.05
Last Event Time               : 17:52:37.132
Synchronized                  : No
=======================================================================================

List of events
---------------------------------------------------------------------------------------
 Line |    Date    |     Time     | xxx.yyy |        Description          | Value
---------------------------------------------------------------------------------------
  815 | 2020.12.07 | 09:55:08.187 | 221.005 | LOC   Loc.acc.block.active | Yes
  816 | 2020.12.10 | 15:11:43.398 | 034.014 | LOGIC Input 15 EXT         | Yes
  817 | 2020.12.10 | 15:11:43.459 | 210.037 | DEV01 Switch.device closed | No
  818 | 2020.12.10 | 15:11:43.459 | 210.038 | DEV01 Dev. interm./flt.pos | Yes
  819 | 2020.12.10 | 15:11:43.477 | 210.036 | DEV01 Switch. device open  | Yes
```

Figure 5 - Operating data on Dec 10th 2020



```
879 | 2020.12.12 | 19:12:29.346 | 034.014 | LOGIC Input 15 EXT           | Yes
880 | 2020.12.12 | 19:12:29.407 | 210.037 | DEV01 Switch.device closed | No
881 | 2020.12.12 | 19:12:29.407 | 210.038 | DEV01 Dev. interm./flt.pos | Yes
882 | 2020.12.12 | 19:12:29.425 | 210.036 | DEV01 Switch. device open  | Yes
```

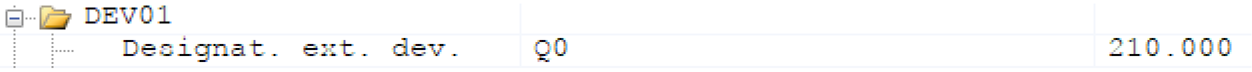
Figure 6 - Operating data on Dec 12th 2020



```
967 | 2021.01.04 | 16:07:29.004 | 034.014 | LOGIC Input 15 EXT           | Yes
968 | 2021.01.04 | 16:07:29.016 | 034.014 | LOGIC Input 15 EXT           | No
969 | 2021.01.04 | 16:07:29.065 | 210.037 | DEV01 Switch.device closed | No
970 | 2021.01.04 | 16:07:29.065 | 210.038 | DEV01 Dev. interm./flt.pos | Yes
971 | 2021.01.04 | 16:07:29.070 | 034.014 | LOGIC Input 15 EXT           | Yes
972 | 2021.01.04 | 16:07:29.083 | 210.036 | DEV01 Switch. device open  | Yes
```

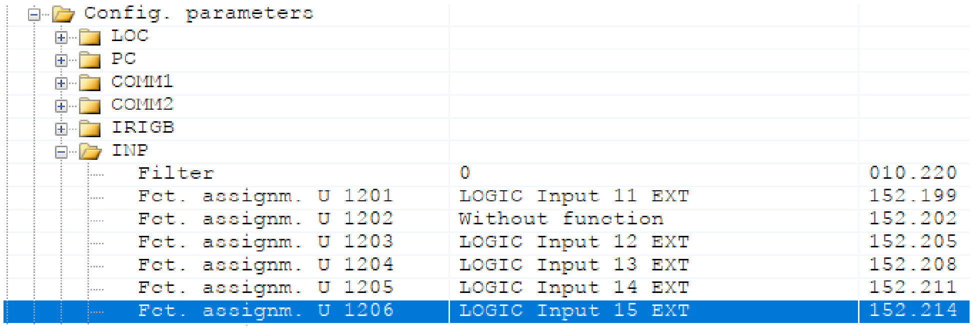
Figure 7 - Operating data on Jan 4th 2021

As we can see above, it appears that the signal **LOGIC Input 15 EXT** is always present just before the circuit breaker opens (which we can see by the signal DEV01 which is assigned to Q0):



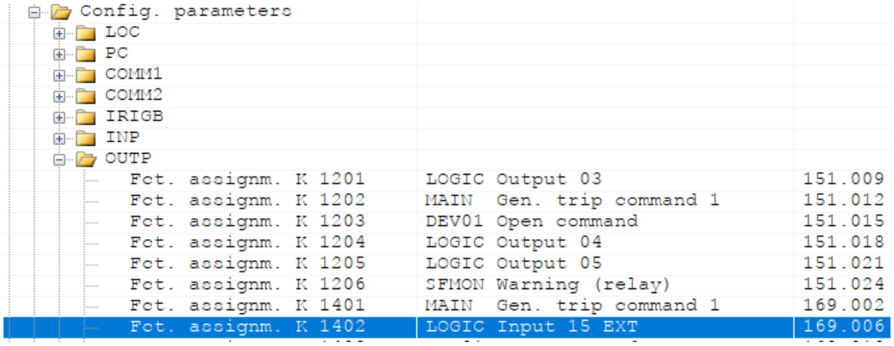
```
DEV01
    Designat. ext. dev.    Q0                                210.000
```

Additionally, when we measure the time between the **LOGIC Input 15 EXT** signal appears and the **DEV01 Switch.device closed** signal disappears, it is always 61ms, which is about the normal time for the operation of a circuit breaker. This led us to believe that it was possible that **LOGIC Input 15 EXT** was the cause of the trip. This signal is an internal signal to the relay that can be used for various purposes, therefore we proceeded to analyze the settings file to find out how this signal was used:



```
Config. parameters
    LOC
    PC
    COMM1
    COMM2
    IRIGB
    INP
        Filter                  0                       010.220
        Fct. assignm. U 1201    LOGIC Input 11 EXT      152.199
        Fct. assignm. U 1202    Without function        152.202
        Fct. assignm. U 1203    LOGIC Input 12 EXT      152.205
        Fct. assignm. U 1204    LOGIC Input 13 EXT      152.208
        Fct. assignm. U 1205    LOGIC Input 14 EXT      152.211
        Fct. assignm. U 1206    LOGIC Input 15 EXT      152.214
```

Figure 8 - Input assignment to LOGIC Input 15 EXT



```
Config. parameters
  LOC
  PC
  COMM1
  COMM2
  IRIGB
  INP
  OUTP
    Fct. assignm. K 1201    LOGIC Output 03               151.009
    Fct. assignm. K 1202    MAIN  Gen. trip command 1     151.012
    Fct. assignm. K 1203    DEV01 Open command            151.015
    Fct. assignm. K 1204    LOGIC Output 04               151.018
    Fct. assignm. K 1205    LOGIC Output 05               151.021
    Fct. assignm. K 1206    SFMON Warning (relay)         151.024
    Fct. assignm. K 1401    MAIN  Gen. trip command 1     169.002
    Fct. assignm. K 1402    LOGIC Input 15 EXT            169.006
```

Figure 9 - Output assingment to LOGIC Input 15 EXT

As we can see above, Digital input **U1206** will activate the internal signal **LOGIC Input 15 EXT** which will in turn activate Output relay **K1402**. When we look at the DC schematics, we can see that Digital input U1206 is activated by an alarm coming from the LCC GIS:

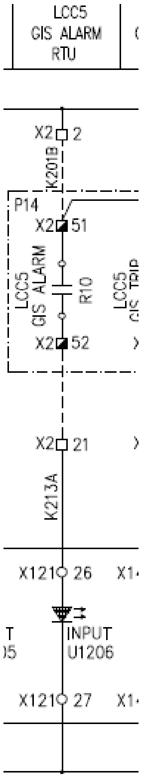


Figure 10 - Digital input U1206

We then checked the DC schematics to see what was the purpose of Output relay K1402 and to our surprise, we saw that it was a spare:

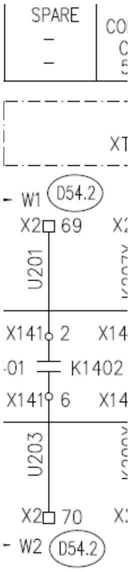


Figure 11 - Output relay K1402 as spare

When we discussed with Aqualectra about the transformation of Bays 03 and 10 during the addition of the Dokweg-IIB substation and we were told that those two bays were rewired exactly as Bays 05 and 12 (which were two original Transformer bays from when the project was first delivered). We then asked to see the drawings that were used for this rewiring and we discovered that there was an wiring error and that in fact Output relay K1402 was wired to an open command to the circuit breaker:

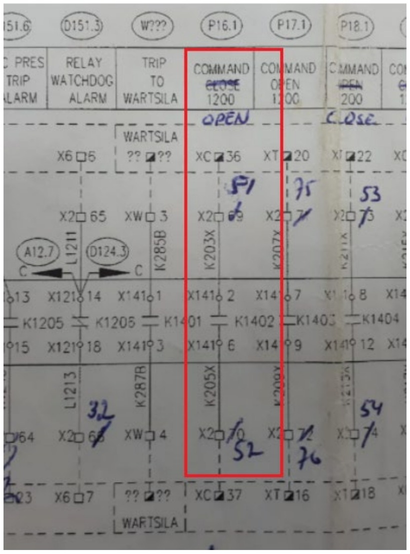


Figure 12 - Output relay K1402 going to Open command

Since during our visit the transformer of Bay 03 was out of service, we got the approval from Aqualectra to isolate that transformer and perform some testing to confirm our suspicion of the cause of the trip. We proceeded to isolate the transformer and closed the circuit breaker and then we activated Digital input U1206 which caused it to open, which confirmed our suspicion and the cause of the trip. It is important to note that this open command to the circuit breaker will only operate if the Local/Remote switch on the LCC is on the Remote mode. If the Local/Remote switch is in Local, the circuit breaker will not operate if Digital input U1206 is activated.

5 Investigation on Bay 10

Just as Bay 03, the same applies to Bay 10.

6 Conclusion

As per the above analysis, we can conclude that the cause of the blackouts are as follows:

1. The current that is flowing through circuit breaker of Bay 04 is above the threshold of the IDMT overcurrent protection of the P139 which directed the relay to trip the breaker.

2. There is a wiring error on transformer bays 03 and 10 which causes the P139 relays to issue a trip if Digital Input U1206 is activated.

7 Actions taken and recommendations

After the addition of Dokweg-IIB substation, there was not a protection study that was performed in order to update the settings. It is recommended that a protection study is conducted in order to analyze all the new scenarios that are possible given that the 66kV substation now has 4 incoming transformers instead of 2 as it was when the project was delivered so that the protection settings on the MiCOM relays can be adjusted. Aqualectra asked the Scheider representative to turn off the IDMT function on the P139 of Bay 04 and at the Parera substation in order to avoid a nuisance trip until the new study is conducted. Additionally, the incorrect wiring of output K1402 at Bay 03 was temporarily removed to avoid nuisance tripping. It was planned to do the same thing to Bay 10, however since Bay 10 is in service it has not yet been done and will be done in the future by Aqualectra. No other wiring checks were performed on Bays 03 and 10 since the as built drawings were not readily available. It is recommended to perform a full commissioning of these two Bays whenever they can be out of service and generate clear as built drawings in order to avoid future problems as we cannot guarantee as of now that all problems have been fixed in those two bays.

Once the investigation was done, we turned back on the P746 relays and it was discovered that one of the relays (the one for Phase B) has an alarm that cannot be cleared, so Schneider recommends to take that P746 out of service and send it for repairs.

From: Garmes, Rudolf
To: Smit, Jason; Granger, Jahnastasio; Ferrero, Richen; Kwidama, Rensley; Carolie, Morris
Cc: Jonis, Darick; Muzo, Vianney
Subject: FW: Setting new AVR DECS 250 NDPP (Isla site)
Date: Sunday, January 10, 2021 4:20:39 PM
Attachments: image001.png
image002.png
image003.png
image004.png
image005.png
image006.png
aqualectra_30d5eb97-4c7a-43b0-80a7-2d3bb825b0fa.png
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footer_youtube_526d8355-4e0d-4f64-bf14-0b09cfe436fc.png
footer_linkedin_aa84db98-c550-46b2-b9bd-595529bf6a01.png

Heren,

Zie onderstaand email van BWSC en de beschreven bevindingen mbt het omklappen van de powerfactor van de generatoren te MAN van positief naar negatief en visaversa. Tevens zijn er acties die ze van ons verwachten om verder te gaan met hun onderzoek. Ik heb de verwachte acties geel ge-highlight.

Laten we deze acties voor einde van de werkdag op maandag 11 januari 2021 klaar hebben en opgestuurd hebben naar de personen van BWSC (en AQ) hieronder vermeld in vorige email.

Mvg,

AQUALECTRA
CURAÇAO WATER AND POWER

Rudolf Garmes
Manager Power Supply Chain
T +(5999) 463-2396
E rugarmes@aqualectra.com
W www.aqualectra.com

From: Henrik Strøberg <hjs@bwsc.dk>
Date: Saturday, January 9, 2021 at 4:44 PM
To: "Rudolf Garmes (Lito)" <rugarmes@aqualectra.com>
Cc: "Kwidama, Rensley" <rkwidama@aqualectra.com>, Stig Nielsen <sin@bwsc.dk>, Robert Erkens <rte@bwsc.dk>, Nikolaj Østergaard Sørensen <nzs@bwsc.dk>, Peter Schiøth <pesc@bwsc.dk>
Subject: RE: Setting new AVR DECS 250 NDPP (Isla site)

Dear Rudolf,
Please find below the situation during the blackout January 4th.
DE1, DE2 & DE3 were not in operation. Only DE4 were in operation.
There were no fluctuations neither no under excitation on DE4.
It seems that DE4 were stable until the shutdown.

Regarding the concerns about fast changes from over- to under excitation. The below graphs shows that big and fast changes from PF 1 to PF **-**1.
I think a natural and logic confusion occurs because of the scaling of the PF on the graph representation. Be aware that PF 1 is equal to PF -1, as well as PF 0,99 is very close to PF -0,99. There is only 0,02 in difference.
The fast jump and fluctuations from 1 to -1 looks wrong but it is not the case.
A jump from e.g. 0,8 to -0,1 would be the case if we should judge the AVR to fluctuate the excitation from over- to under excited. Additionally an under excitation -0,1 or -0,2 would most likely cause loss of synchronism if the generator is under load.
However I can see at the DIGSILENT curves from the trips in February a measurement of negative reactive power. A deeper investigation is needed to judge if the AVR's on the NDPP (Isla site) station is causing such.
Unfortunately some of the measurements from February are not trustworthy due to failures on several PFM's.

- Therefore it is important to receive the latest DIGSILENT report which contain measurements from well working PFM's. Thank you. (ACTION @Jason Smit)

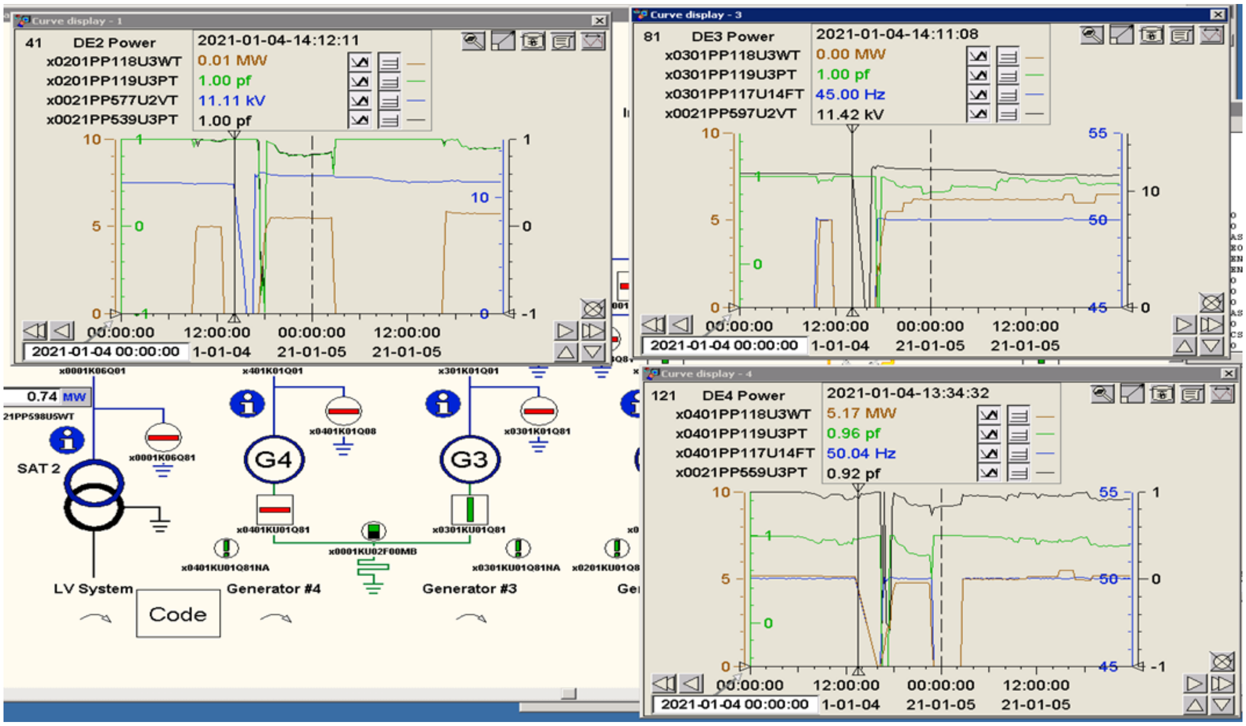
As we agreed Friday evening on WhatsApp I need following AVR information's:

1. Reading from the AVR's display: Please inform about the AVR's operation mode (PF or ?) (ACTION @Granger Jahnastasio)
2. Event and failure logs from AVR's. You need to download Bestcom SW from Basler homepage. (ACTION @Ferrero, Richen, @Carolie, Morris, @Kwidama, Rensley)
3. Downloading of all 4 AVR settings. You need to download Bestcom SW from Basler homepage. . (ACTION @Ferrero, Richen, @Carolie, Morris, @Kwidama, Rensley)
4.

We will Monday continue the investigation and agree next step.
We will inform accordingly.

Thank you
Henrik

Blackout 2021-01-04 14:12…



Curve display - 1
41 DE2 Power 2021-01-04-14:12:11
x0201PP118U3WT 0.01 MW
x0201PP119U3PT 1.00 pf
x0021PP577U2VT 11.11 kV
x0021PP539U3PT 1.00 pf

Curve display - 3
81 DE3 Power 2021-01-04-14:11:08
x0301PP118U3WT 0.00 MW
x0301PP119U3PT 1.00 pf
x0301PP117U14FT 45.00 Hz
x0021PP597U2VT 11.42 kV

Curve display - 4
121 DE4 Power 2021-01-04-13:34:32
x0401PP118U3WT 5.17 MW
x0401PP119U3PT 0.96 pf
x0401PP117U14FT 50.04 Hz
x0021PP559U3PT 0.92 pf

From: Garmes, Rudolf <rugarmes@aqualectra.com>
Sent: 9. januar 2021 16:23
To: Robert Erkens <rte@bwsc.dk>
Cc: Kwidama, Rensley <rkwidama@aqualectra.com>; Stig Nielsen <sin@bwsc.dk>; Henrik Strøberg <hjs@bwsc.dk>
Subject: Re: Setting new AVR DECS 250 NDPP (Isla site)

Robert,

Thank you for your prompt reply.
On February 11th, 2020 we had a blackout in Curaçao. In the last month again we had 3 blackouts and last Monday again 1.
What we've seen just shortly prior to the blackout in February 2020 was that the engines at the MAN power plant go from over to under excitation and back within a few seconds. This happend a few times. It is for this reason we requested via Nikolaj and Henrik that this part would be investigated. To us it seams very strange and almost impossible that this type of change in powerfactor of the generators is normal.

We hope BWSC can help Aqualectra fast in this matter. The stakes are high and we need your assistance very urgently.

Thank you in advance.

Rudolf Garmes
Power Supply Chain Manager
Aqualectra

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Mob: +5999 526 8885
E-mail: rugarmes@aqualectra.com

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On Jan 9, 2021, at 9:17 AM, Robert Erkens <rte@bwsc.dk> wrote:

Dear Rensley

I just had a phone conversation with Stig Nielsen our Technical Manager and also with Tor Hasselgren.

The parameter from the AVR will not and cannot change just by them self.
Attachments are the reports of DG-01 – 02 – 03 - 04.

Would you be so kind and inform me what is the problem you are have right now on the station?
I am asking this because Tor Hasselgren asked me what is the problem so he can give his input of what can be wrong.

Just let me know if you need more from my side.

Med venlig hilsen / Best regards
Robert Erkens

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Direct phone: +45 48 12 52 77
Mobile: +45 61 60 45 90
Burmeister & Wain Scandinavian Contractor A/S
Gydevang 35 | P.O. Box 235 | DK-3450 Allerød | Denmark
Phone: +45 4814 0022 | Fax: +45 4814 0150 | www.bwsc.com

From: Kwidama, Rensley <rkwidama@aqualectra.com>
Sent: 8. januar 2021 19:06
To: Robert Erkens <rte@bwsc.dk>
Cc: Garmes, Rudolf <rugarmes@aqualectra.com>
Subject: FW: Setting new AVR DECS 250 NDPP (Isla site)

Hello Robert,

On February 18 Morten sent the settings done by Tor but I have only from DG-1.

Is it possible that you can verify for me in your older mails that the other three was also sent and if not how can we communicate with Tor to get them ? We need those settings a.s.a.p. for Stroberg Henrik to do
some investigations for us so please your help.

Med venlig hilsen,

<image001.png>

Rensley Kwidama
Coordinator Instr. Maint. Power Plant

T	+(5999) 463-2624
E	rkwidama@aqualectra.com
W	www.aqualectra.com

<image002.png> <image003.png> <image004.png> <image005.png>

From: Carolie, Morris <mcarolie@aqualectra.com>
Sent: Monday, February 18, 2019 2:56 PM
To: Kwidama, Rensley <rkwidama@aqualectra.com>; Schotborgh, Henri <hschotborgh@aqualectra.com>
Subject: FW: Setting new AVR DECS 250 NDPP (Isla site)

F.Y.I

From: Morten Kühlmann Hansen [mailto:mokh@bwsc.dk]
Sent: Monday, February 18, 2019 2:39 AM
To: Carolie, Morris
Cc: Robert Erkens; Peter Schiøth
Subject: RE: Setting new AVR DECS 250 NDPP (Isla site)

Dear Mr. Carolie

As request you will find the settings done by Tor Hasselgren back in 2016.
About the as build drawings I will have to search the archive and will get back to you later.

Med venlig hilsen / Best regards
Morten Kühlmann Hansen
Direkte tlf: +45 48125729

From: Carolie, Morris <mcarolie@aqualectra.com>
Sent: 15. februar 2019 21:10
To: Morten Kühlmann Hansen <mokh@bwsc.dk>
Cc: Robert Erkens <rte@bwsc.dk>
Subject: Setting new AVR DECS 250 NDPP (Isla site)

Hi Morten,

Morten as you know in July 2016 the AVR specialist Tor Hasselgren has install 4 new AVR Decs 250 on the 4 generators at NDPP.
My question is can you make contact with Tor Hasselgren so we can receive the settings(parameters) install on the Decs 250.
We also need the as build drawings of the installed AVR's Decs 250.

Hope to get your feedback very soon.

Best regards.

Morris.B.Carolie
Supervisor : Electrical & Instrument Maintenance
Aqualectra Production
Cell Phone : (00599-9) 5117949
Phone : (00599-9) 4632592
e-mail at work : mcarolie@aqualectra.com
e-mail at home : morrismosh@hotmail.com

<170207 Aquaelectra Isla DG01 DECS 250 settings after commissioning.pdf>
<170210 Aquaelectra Isla DG02 DECS 250 settings after commissioning.pdf>
<170210 Aquaelectra Isla DG04 DECS 250 settings after commissioning.pdf>
<170916 DG03 AVR parameters commissionied.pdf>

Blackout events recovery actions

	Action Type	Conclusion for action	Action describtion	Status	Statius describtion	Due-date for action	Responsable	Accountable	Informed	Consulted
1	February 7th Recommendations	Generation units in power plant NDPP occasionally and unexpectedly changed their operation from over-excited to under-excited, causing transient voltage drops down to approximately 0.9 p.u. in all network locations	Detailed investigation in power plant NDPP to determine the root cause for the observed behavior. Definition of mitigation measures to assure a stable operation.	In Progress	Analysis being performed by BWSC. first indication is that an operator error has occurred	03/26/21	J. Granger	R. Garmers	D. Jonis Investigative Committee	BWSC
2	⊟ February 7th Recommendations	Windfarms "Playa Canoa" and Tera Cora I diconnected during the events, most probably due to the undervoltage protection settings, which are currently adjusted at 0.9 p.u.and 3 seconds. However, windfarm Tera Cora 2 did not disconnect during the same events.	Assessment to determine if the protection settings in windfarms Playa Canoa and Tera Cora I can be modified to resemble those in Windfarm Tera Cora II, with the objective of a more robust and uninterrupted operation in case of grid faults.	Finished	Letter has been send to Nu Capital. Further more various meetings with Vestas and Nu Capital are taking place		J. Smit	R. Garmers	D. Jonis	Nu Capital
3	February 7th Recommendations	Reconnection of Windfarms Playa Canoa and Tera Cora I and subsequent output power ramp-up leads to transient over frequency in the network	Reduction of the ramp-up gradient in windfarm Playa Canoa and Tera Cora I + II to minimize the impact on network frequency	Finished	Letter has been send to Nu Capital. Further more various meetings with Vestas and Nu Capital are taking place		J. Smit	R. Garmers	D. Jonis	Nu Capital
4	⊟ February 7th Recommendations	Generators in Dokweg IIA disconnected unexpectedly on the February 11th, right after one of the voltage drop events occurred. However, for the same event the day before, those generators remained connected.	Further investigations to determine the root cause of the disconnection	In Progress	Various actions taking place		J. Granger	R. Garmers	D. Jonis Investigative Committee	DigiSilent K-Line Schneider Wärtsilä
5	February 7th Recommendations	Generators in Dokweg IIA disconnected unexpectedly on the February 11th, right after one of the voltage drop events occurred. However, for the same event the day before, those generators remained connected.	Investigate the Protection system of the 66 / 30 kV	Finished	K-Line and Schneider are investigating the performance of the protection system		A. Guillermo	J. Smit	D. Jonis R. Garmes	K-Line Schneider
6	February 7th Recommendations	Generators in Dokweg IIA disconnected unexpectedly on the February 11th, right after one of the voltage drop events occurred. However, for the same event the day before, those generators remained connected.	Investigate the function of SCADA	In Progress			A. Guillermo	J. Smit	D. Jonis R. Garmes	ABB-Scada
7	February 7th Recommendations	Generators in Dokweg IIA disconnected unexpectedly on the February 11th, right after one of the voltage drop events occurred. However, for the same event the day before, those generators remained connected.	Investigate why the voltage drop occurred in the grid	Finished	The voltage drop was caused by changing the operation mode of the power plants		R. Garmes	D. Jonis	None	DNV-GL
8	February 7th Recommendations	Generators in Dokweg IIA disconnected unexpectedly on the February 11th, right after one of the voltage drop events occurred. However, for the same event the day before, those generators remained connected.	Perform an 66/30 kV protection system study	In Progress	DigiSilent has already engaged in this study. due to internal delays this study has not yet been completed		J. Smit	R. Garmers	D. Jonis	DigiSilent
9	February 7th Recommendations	Generators in Dokweg IIA seem to be critical for system stability: their disconnection on the February 11th led to significant voltage and frequency variations which eventually caused the blackout	Further investigation to review the overall system concept for frequency and voltage regulation	In Progress	DNV-GL is performing an voltage stability study		R. Garmes	D. Jonis	None	DNV-GL
10	February 7th Recommendations	Generators in Dokweg IIA and Dokweg IIB show differences in their dynamic behavior for frequency and voltage control. Units in Dokweg IIB seem to have a superseded controller (e.g. power plant controller) which leads to a delayed response in case of fast frequency and'or voltage variations due to e.g. grid faults.	Detailed investigation to determine frequency and voltage control characteristics in all power plants. assessment of unit performance with respect to overall system control strategy, i.e. if performance criteria are fulfilled.	In Progress	DNV-GL is performing an voltage stability study		R. Garmes	D. Jonis	None	DNV-GL DigiSilent
11	February 7th Recommendations	PFM configuration is not completely consistent with current network topology (e.g. signal IDs, spare signals)	Update of PFM monitoring systems, so that the configuration is consistent with current topology. Definition of procedure to update them in case of modifications in the network topology	Finished	PFM systems have been updated		J. Smit	R. Garmers	D. Jonis DigiSilent	None
12	February 7th Recommendations	PFM no accessible and/or did not capable of recording all events of interest	PFM shall be accessible remotely and configured to assure that all relevant events in the system are recorded, which will support the analysis of future events	In Progress	Various actions are taking place		J. Smit	R. Garmers	D. Jonis DigiSilent	Aqualectra IT-Department
13			Ensure correct labels to signals in PFM	Finished	All Labels are correct		J. Smit	R. Garmers	DigiSilent	None
14			Ensure accessibility to all PFM systems	In Progress	Outside stations Tera Cora and Playa Canoa are being worked on. all other stations are online		J. Smit	R. Garmers	DigiSilent	None
15			Install alarm monitoring system for functionality of the PFM system	In Progress			J. Smit	R. Garmers	DigiSilent	DigiSilent
16										
17										
18	⊞ December 7th Recomendations	Change in operation mode of various diesel plants in power plants Dokweg IIA and Dokweg IIB from isochronous to constant output active and reactive power operation (08:07:41-08:16:24). Engine manufacturer Wartsila claims that this caused overloading in other diesel units, which eventually led to the isochronous to constant output active and reactive power operation.	AQ claims that the operators have experienced in the past sudden disconnections of diesel units due to overloading, at times when the engines were operating close to the rated output power in isochronous mode. That explains the switch on the operation mode from isochronous to constant output active and reactive power operation	Finished	The operators changed the operation mode of the plant causing the system reverting to the default setpoint. this setpoint was lower than the demand causing an instability		J. Granger	R. Garmers	D. Jonis Investigative Committee	Wärtsilä
24	⊞ December 7th Recommendations	Disconnection of wind farms Playa Canoa and Tera Cora I (08:18:00- 08:20:00) in the postfault phase, presumably due to under voltage, which caused additional loadshedding and increased the difficulty of the power system to recover. Similarly, their reconnection approximately 10 minutes later, when the system was still operating with significant frequency and voltage deviations, affected system stability negatively. this behavior has been observed as well in the analysis of past events , such as the blackout on the11th of February, 2020 [2].	It is recommended to discuss with the windfarm operators/owners if the protection settings in the windfarms Playa Canoa en Tera Cora I can be modified to resemble those in winfdarm Tera Cora II (which did not disconnect for the came events), with the objective of a more resilient operation in case o grid faults	Finished			J. Smit	R. Garmers	D. Jonis Investigative Committee	DigiSilent Wärtsilä
27	⊟ After blackout event issues	Actions to stabilize grid and plant								

	Action Type	Conclusion for action	Action describtion	Status	Statius describtion	Due-date for action	Responsable	Accountable	Informed	Consulted
28	After blackout event issues	Unload 66 kV cable DW-II ISLA	Energize the Parera Transformer	Finished	Caused overloading of the DW plants - ISLA		J. Smit	R. Garmers	D. Jonis Investigative Committee	DigiSilent K-Line Schneider
29	⊟ After blackout event issues	66 / 30 kV protection system analysis					J. Smit	R. Garmers	D. Jonis	DigiSilent
30	After blackout event issues	Root Cause analysis high voltage 66 kV	Analysis of the events and find correlations between events	Finished	Blackout report has been submitted by Managmenment		R. Garmes	D. Jonis	None	DNV-GL DigiSilent
31	After blackout event issues	Perform VAr study	Analyze the way of dispatching the Reactive Power	In Progress	DNV-GL has been contracted for further analysis		R. Garmes	D. Jonis	None	DNV-GL DigiSilent
32	After blackout event issues	Investigate Ebbler system for proper working	Ebbler system is functional	Finished	66 kV transformers are		A. Guillermo	J. Smit	D. Jonis R. Garmes	Eberle GmbH Schneider
33	⊟ After blackout event issues	Ensure proper working and understanding of Isochronous operating system					J. Granger	R. Garmers	D. Jonis	Wärtsilä
34	After blackout event issues	Obtain system manual	Functional working of the Isochronous	In Progress						
35	After blackout event issues	Ensure proper settings for system operations	Based on the protection study it will be necessary to adapt the operational settings							