P2029
Security of Supply in Curaçao's Electricity System

Analysis of Grid Events - 07.12.2020

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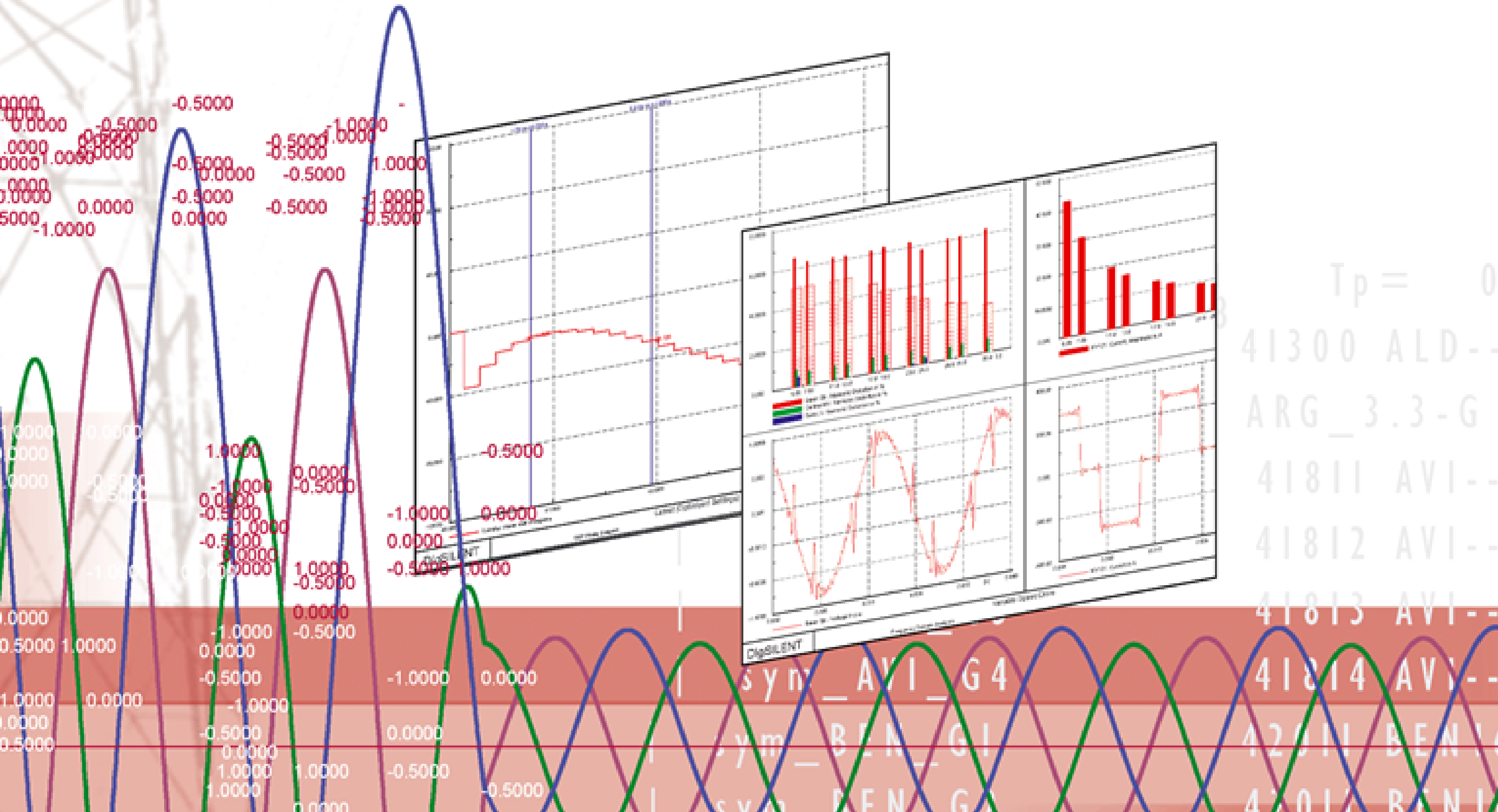

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01	First Version	P2029_Aqualectra_Event-Analysis-20201207_REPTRIP01_R01_V01.docx	21.12.2020	J. Gómez

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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

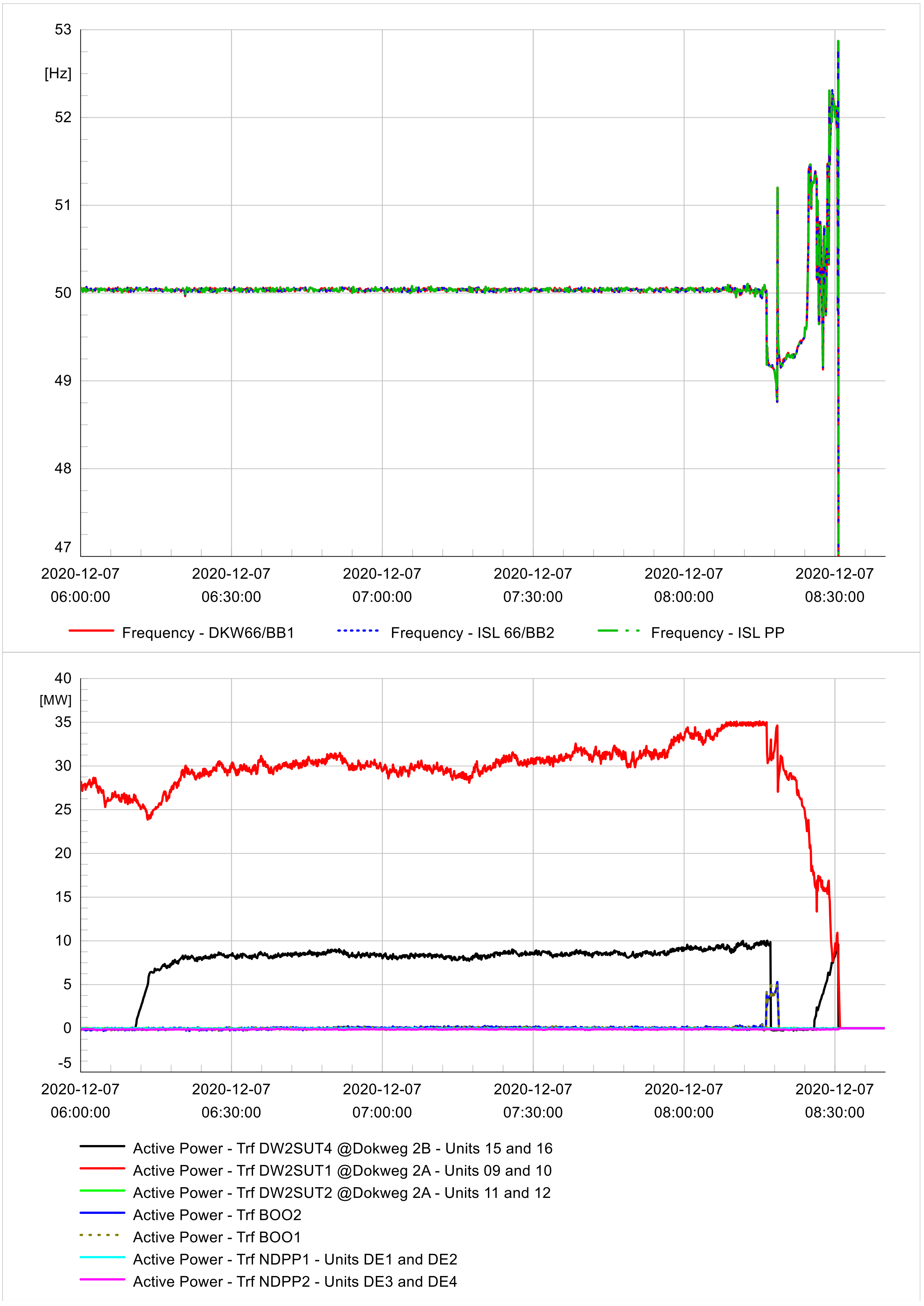
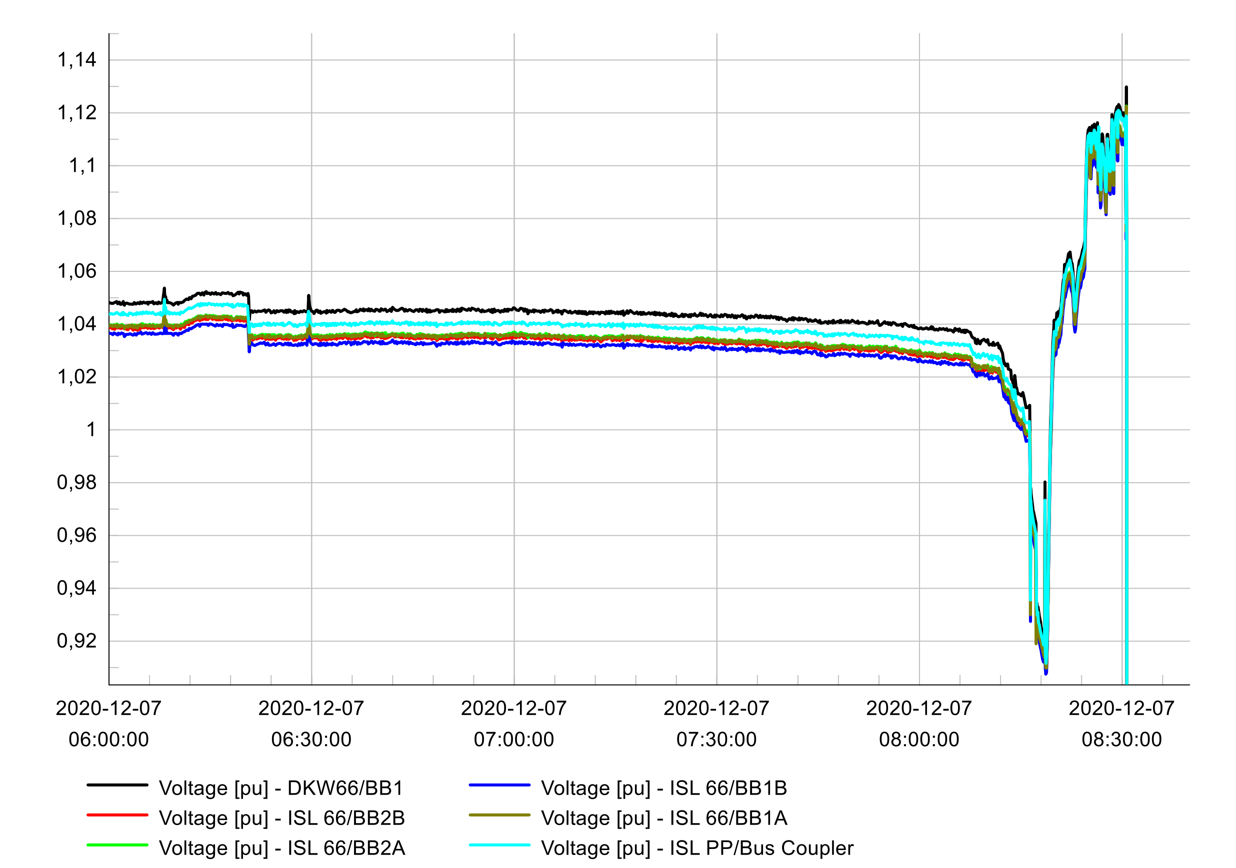


Figure 1: PFM Recordings - Frequency and Active Power – From 6:00:00 to 08:31:00 hours



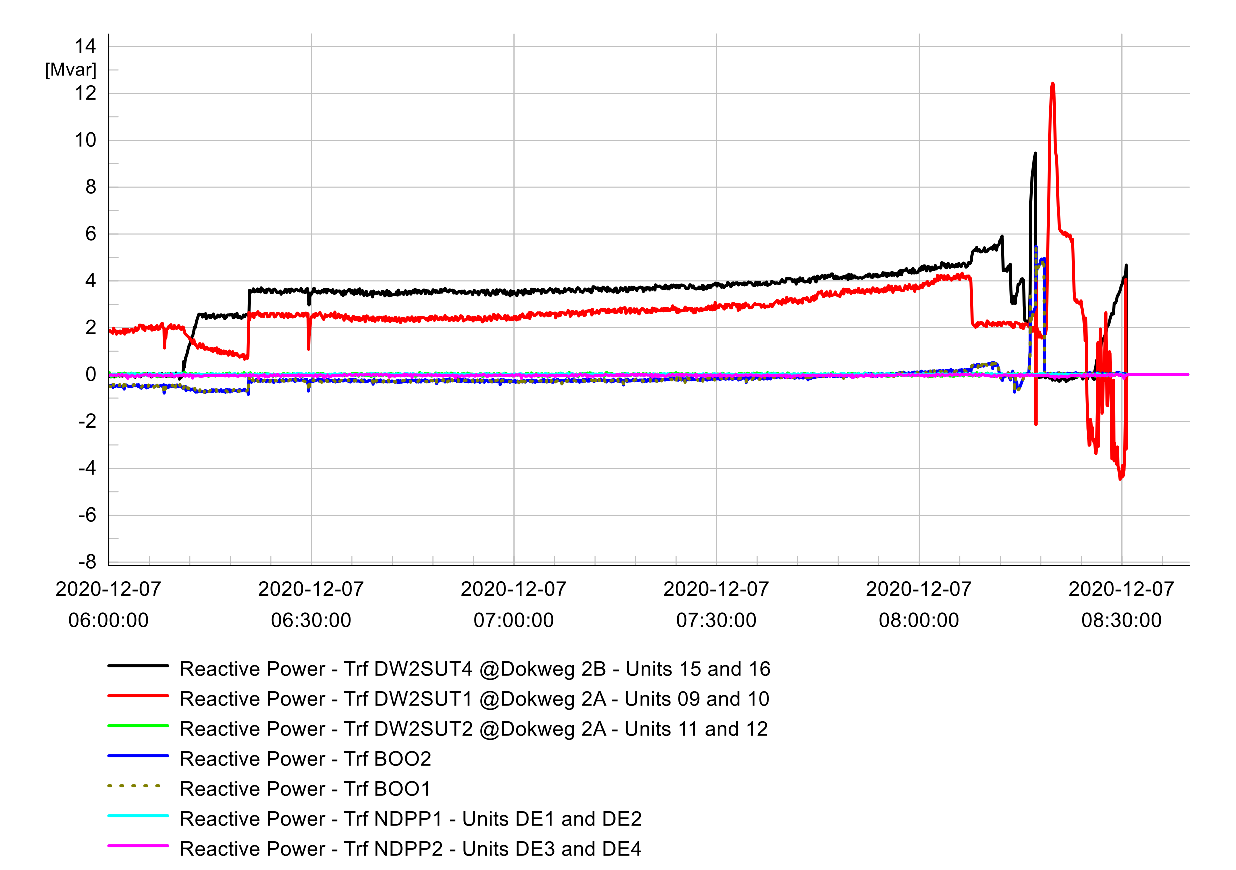


Figure 2: PFM Recordings - Voltage and Reactive Power – From 6:00:00 to 08:31:00 hours

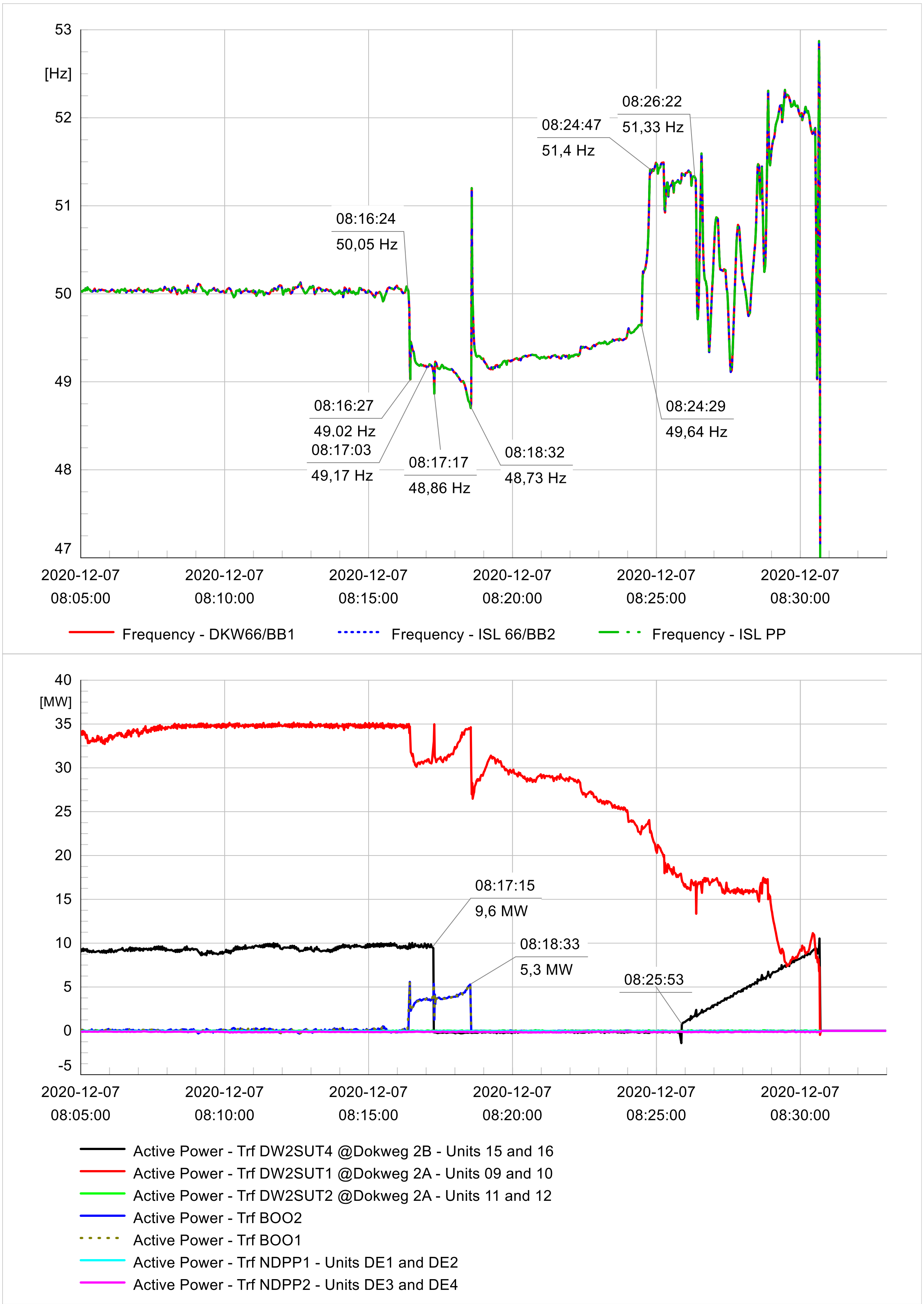


Figure 3: PFM Recordings - Frequency and Active Power – From 8:05:00 to 08:33:00 hours

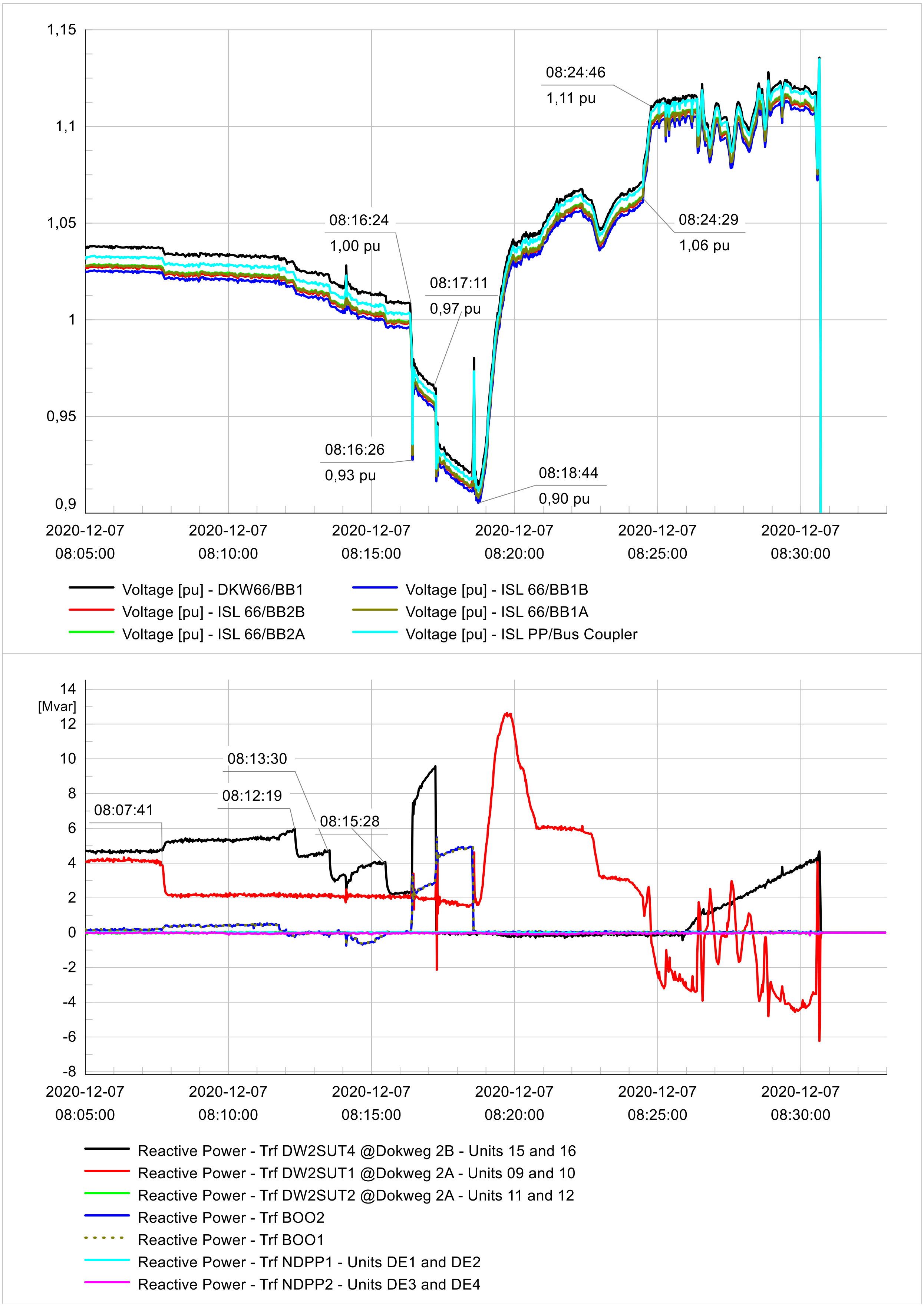


Figure 4: PFM Recordings - Voltage and Reactive Power – From 8:05:00 to 08:33:00 hours

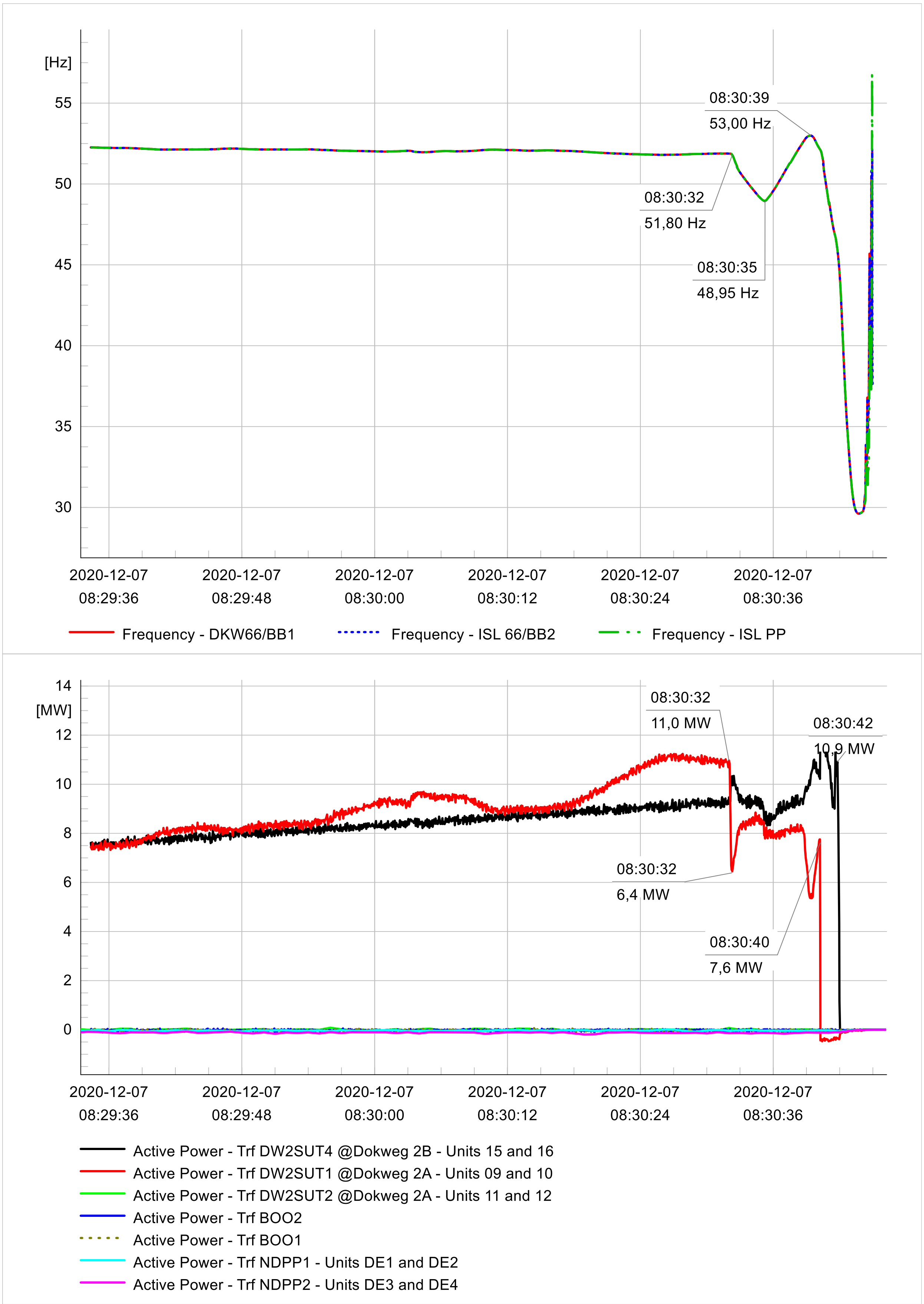


Figure 5: PFM Recordings - Frequency and Active Power – From 8:30:00 to 08:31:00 hours

9 Annex C: SCADA Recordings

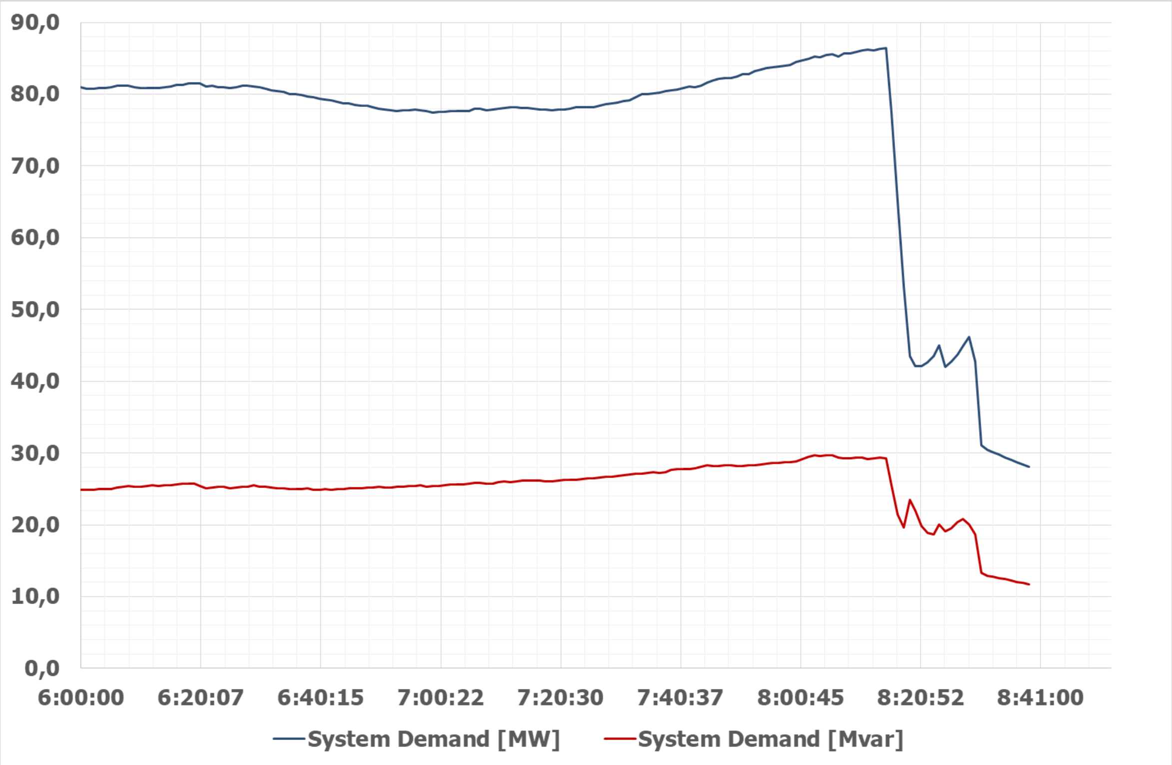


Figure 6: SCADA Recordings – System Demand– From 6:00:00 to 08:41:00 hours

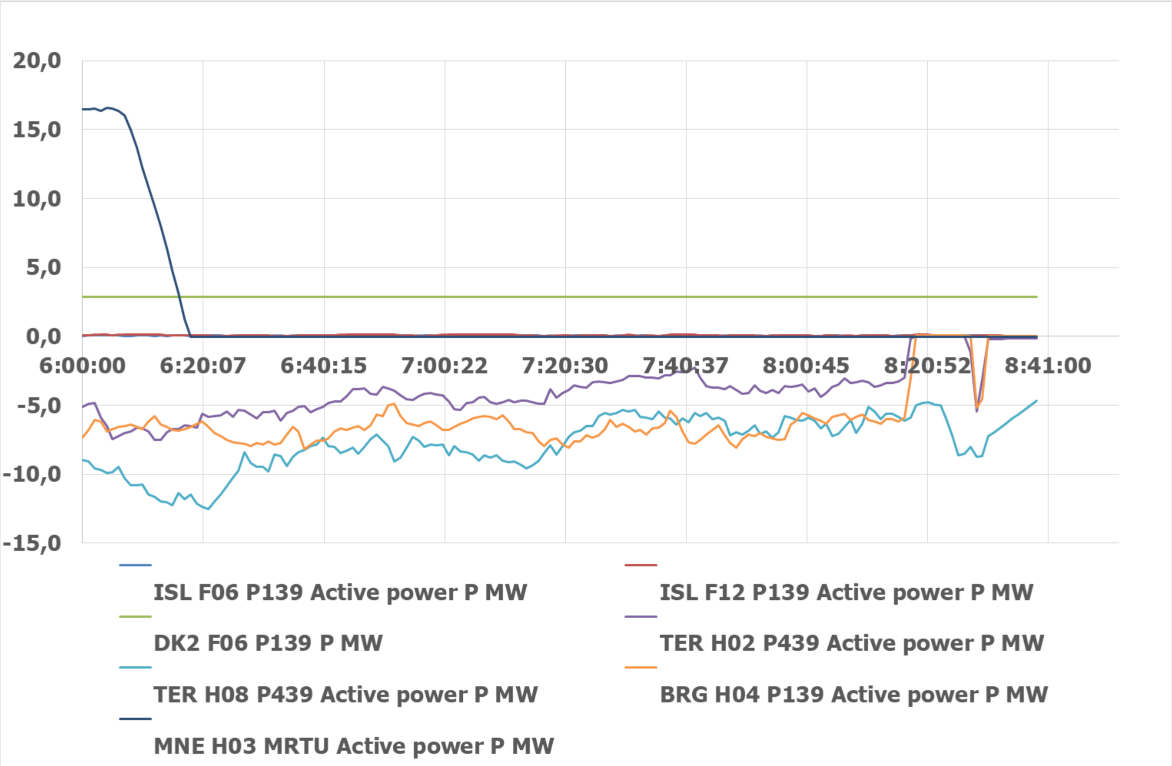


Figure 7: SCADA Recordings – Generation Output Power [MW]– From 6:00:00 to 08:41:00 hours