Technical Report

Network fault with supply interruption

on 2nd September, 2004

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1 Summary

On Thursday, 2nd September, 2004, a network fault occurred at 16:51 hours in the transmission grid of RWE Transportnetz Strom GmbH with a subsequent supply interruption. Areas in Rhineland-Palatinate and the public power supply of Luxembourg were affected (see Figure 1).

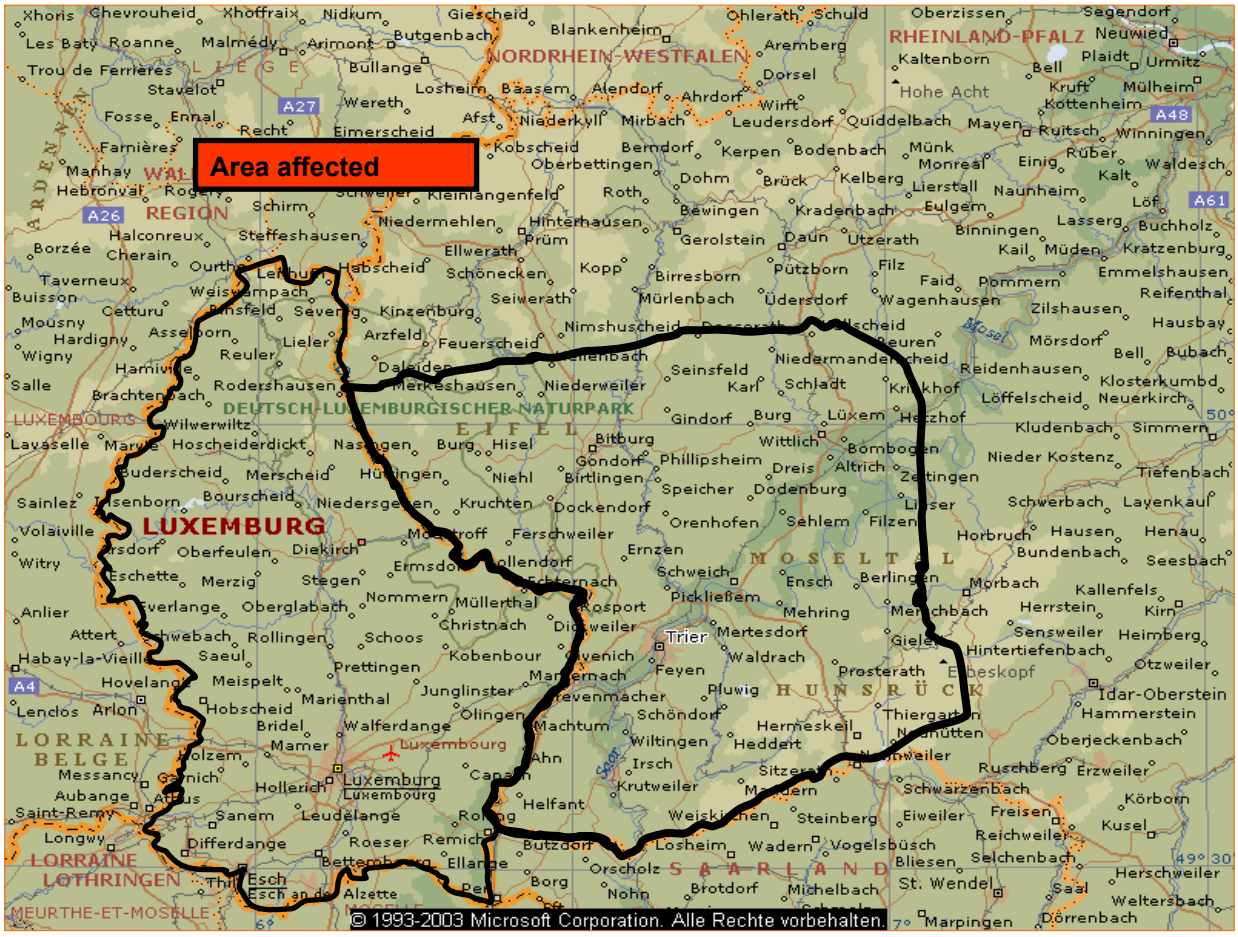

Figure 1 : Area affected by the network fault

Following an evaluation of the data and a comprehensive analysis, two independent events could be determined as the fault's cause. There was initially a short-circuit between two overhead cables ("2-phase fault), the cause of which could not be determined, in the 220 kV line (kV = kilovolts) "Saar Nord" from Diefflen to Trier in a 10 km section near Merzig (Saarland). This was aggravated by the overfunction of a protective device in the 220 kV "Osburg" line from Uchtelfangen to Trier in the Trier-Quint station, which led to tripping of the Osburg line. During the overfunction the protection equipment did not return to its steady state after it had started due to a power oscillation instead, it switched the line off; the cause of the overfunction could not be clarified despite intensive examination in the laboratory.

As maintenance work on the 380/220 kV transmission transformer 41 in the Niederstedem station near Bitburg, that had been planned well in advance, was being carried out at the time of the network fault, there was an overload on the last remaining 220 kV line "Kondelwald" from Weißenthurm to Niederstedem after the failure, which then failed too.

The 220 kV network in the Trier region and in Luxembourg was thus without voltage and the power supply was interrupted. On the whole, the power failure on German territory was approx. 380 megawatts (MW) and in Luxembourg approx. 480 MW.

The analysis of the load situation carried out during troubleshooting showed that the network, with a total of three available 220 kV lines, was in an (n-1)-safe state even when the transmission transformer was switched off before the occurrence of the fault on 2nd September, 2004 at 16:51 hours. This is confirmed by both on-line calculations and the recordings.

The network fault in the transmission grid was remedied at 17:23 hours when the Kondelwald line was connected. The Osburg line was re-connected at 17:43 hours. Following an inspection of the Saar Nord line, that showed no optical findings, this line was connected back to the grid at around 21:13 hours. Thus, all 220 kV lines were again live and the normal 220 kV network was restored.

The supply to the distribution networks in Luxembourg was restored thanks to a different security concept when the network fault in the transmission grid was remedied at 17:23 hours. Starting at 17:23 hours, the distribution network transformers in Trier and the Eifel region were gradually switched back on. This was partly carried out manually with the support of the local control stations in the transformer stations. The complete restoration of supplies to all customers was completed at around 21:24 hours.

CEGEDEL and RWE Transportnetz Strom discovered no conceptional or operational defects in the grid management following an analysis of the disturbance. However, the fault does give us a cause to increase soon the security reserves and operational flexibility in the affected distribution network region with the support of the measures already planned on the basis of the forecast load increase in Luxembourg. This is why top priority is being given to the planned enhancement of the grid through a further transmission transformer in Niederstedem. Furthermore, CEGEDEL is also checking whether an altered network

topology by interconnecting the CEGEDEL and SOTEL networks in Luxembourg could contribute to an increase in the supply security.

The analysis of the network restoration showed that in such a situation the automatic voltage control through the grading of transformers can delay the restoration process. To avoid a run-through of the step switch with an automatic stop in future, the remote control functions will be extended in order to provide for the possibility to block the automatic transformer graduation as required.

2 Course of the fault

2.1 Network status before the fault

Before the fault, the power supply in the region around Trier and Luxembourg (network group Trier) was provided by the following 220 kV lines:

- Saar Nord line from Diefflen (Saarland) to Trier
- Osburg line from Uchtelfangen (Saarland) to Quint
- Kondelwald line from Weissenthurm (Rhineland Palatinate) to Niederstedem

A further possibility of supplying the network group Trier, a feed via the 380/220-kV transformer 41 in Niederstedem, was not available before the fault since this was out of operation between 30.08.2004 and 10.09.2004 due to maintenance work that had been planned long in advance. The 380/220 kV network interconnection here was open during this scheduled disconnection.

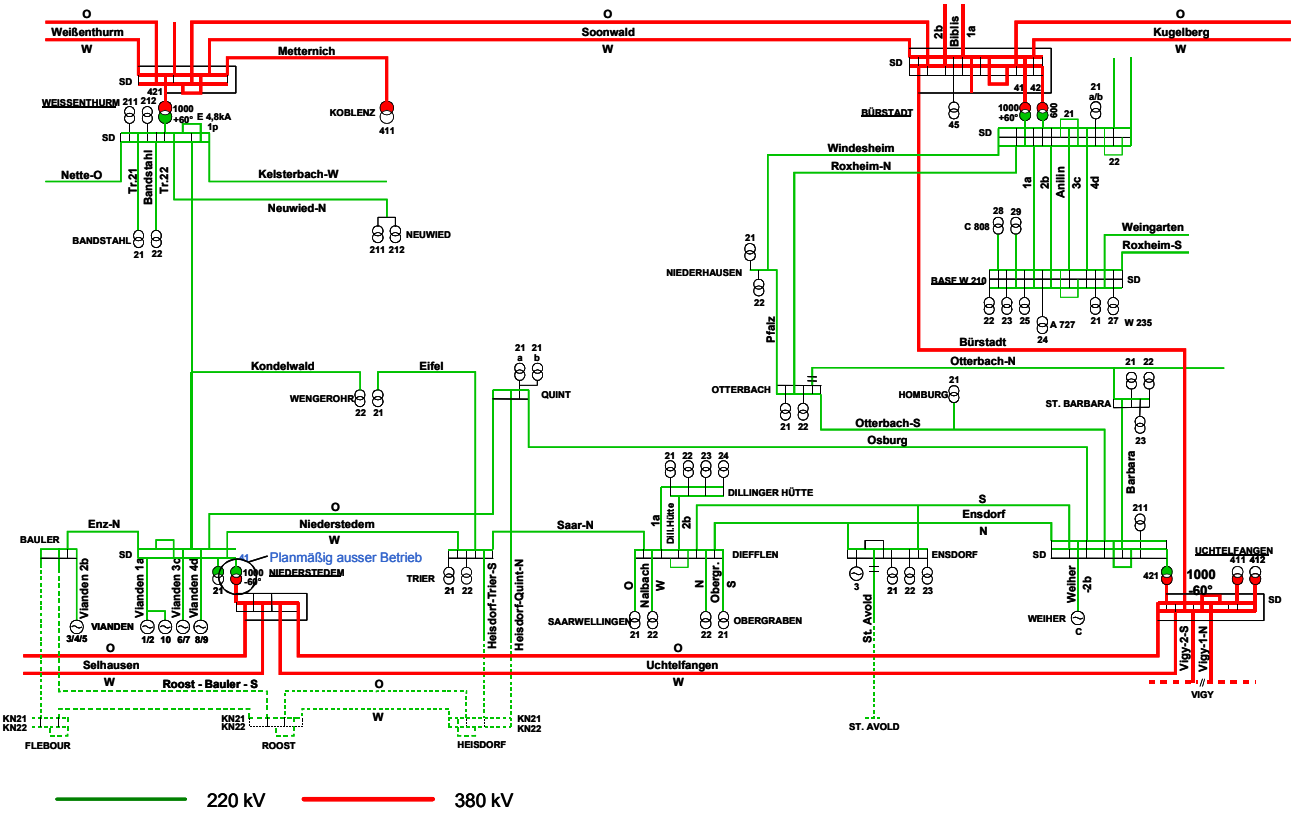

Figure 2: Network topology before the start of the fault (source: RWE)

In addition, there was the possibility to unburden, if necessary, the aforementioned 220 kV lines through a direct feed into the network region from Vianden power plant in order to

ensure (n-1) security. This feeding to Niederstedem transformer station was contractually agreed.

Before the fault Luxembourg was supplied from the RWE transmission grid via the following 220 kV lines:

- line from Trier to Heisdorf
- line from Quint to Heisdorf
- line from Bauler to Flebour
- line from Bauler to Roost

The network topology of the transmission grid in this region before the fault is shown in Figure 2.

2.1.1 Use of operating resources (power plants in operation)

Prior to the fault, network group Trier was supplied as follows (cf. Figure 2):

At the transformer stations Weissenthurm and Uchtelfangen, power was fed in from the 380 kV level by means of a transmission transformer with a rated output of 1000 MVA. The 220 kV plant in Uchtelfangen was supplied with an output of 583 MVA from Weiher power plant (rated active power: 640 MW). In addition, Ensdorf power plant (rated active power: 300 MW) fed an output of 210 MVA to the Ensdorf plant which is looped into the double line between Uchtelfangen and Diefflen.

At the time of the fault, one machine was in pumping mode and six machines in phase shift mode at Vianden power plant[1]. No machine was in generator mode.

[1] Phase shift mode is the mode of operation for a machine whereby the generator generates reactive power (inductive or capacitive) to support the voltage.

The individual machines in the Vianden power plant were in the following operating conditions at 16:51 hours :

on line 1a:	M1 in standby
	M2 in phase shift with 57 MVAr
	M10 at standstill (commissioning of the new transformer)
on line 2b:	M3 in pumping mode with 68 MW; 53 MVAr
	M4 in phase shift with 58 MVAr
	M5 in phase shift with 43.5 MVAr
on line 3c:	M6 in phase shift with 52 MVAr
	M7 in phase shift with 62 MVAr
on line 4d:	M8 in phase shift with 46 MVAr
	M9 in standby

Thus, Vianden power plant fed a reactive power of 217 MVAr directly to Niederstedem. Vianden power plant obtained a rated active power of 68 MW from the network via Bauler plant, where the line Vianden 2b (machines 3, 4 and 5) is looped in, and generated an inductive reactive power of 58 + 43.5 – 53 = 48.5 MVAr.

2.1.2 Load distribution before the fault

Before the fault, the following power flows were measured on the lines available to supply the network group Trier in view of the operating resources status and load situation (data from the SCADA system at RWE):

Line Saar Nord: Current = 630 A; voltage = 233 kV. This corresponds to an apparent power of 254.2 MVA at an active power of 254.0 MW.

Line Osburg: Current = 775 A; voltage = 243 kV. This corresponds to an apparent power of 326.2 MVA at an active power of 323.0 MW.

Line Kondelwald: Current = 591 A; voltage = 238 kV. This corresponds to an apparent power of 243.6 MVA at an active power of 242.2 MW.

The following power flows were measured on the tie lines from RWE to CEGEDEL before the fault (source: CEGEDEL; recordings on digital data recorder LEM; Figures see Annex 1):

Trier – Heisdorf line: Current = 375 A, voltage = 232 kV. This corresponds to an apparent power of 150 MVA at a measured active power of 148.4 MW

Quint – Heisdorf line: Current = 412 A; 445 A, 450 A, voltage = 232 kV. This corresponds to an apparent power of 175 MVA at a measured active power of 171.4 MW

Bauler – Flebour line: Current = 315 A, voltage = 234 kV. This corresponds to an apparent power of 127 MVA and a measured active power of 94 MW.

Bauler – Roost line: Current = 240 A, voltage = 233 kV. This corresponds to an apparent power of 96.5 MVA at a measured active power of 64 MW.

This results in a total specific apparent power of 550 MVA. The total specific active power in Luxembourg was consequently 477.8 MW. The measured data correspond to the data recorded at 16:50 hours in the central network control station system at CEGEDEL (SCADA system, see table) and were also confirmed by subsequent load flow calculations.

Line	Active power	Reactive power	Apparent power
Trier – Heisdorf	152 MW	18 MVAr	153.1 MVA
Quint – Heisdorf	179.5 MW	41 MVAr	184.1 MVA
Bauler – Flebour	85.5 MW	78 MVAr	115.7 MVA
Bauler – Roost	65 MW	65 MVAr	91.9 MVA
Total:	482.0 MW	202 MVAr	526.8 MVA

Table 1: Power flows on the tie lines from RWE to CEGEDEL

The differences between the measured values for the SCADA and the LEM-system of CEGEDEL are due to measuring inaccuracies.

2.2 Network restoration

The Kondelwald line could be successfully reconnected at 17:23 hours. This remedied the fault in the transmission grid; all 220 kV systems were live. This also restored the power supply in Luxembourg. At 17:43 hours Osburg line was also put back into operation by the local control station.

The distribution network transformers of the RWE network group Trier which had previously been disconnected from the transmission network were then successively reconnected. Partly this was done manually with the support of the local control stations in the transformer stations. This gradual restoration of the supply was completed around 21:24 hours (see further details in Chap. 3.9).

Following an inspection of the Saar Nord line, that brought no apparent findings, this line was reconnected to the grid at around 21:13 hours. Thus, all 220 kV lines were live and the normal 220 kV network restored.

2.3 Temporal sequence of events during the power fault

The following table summarises the course of the fault and the restoration of the power supply in chronological order (explanations see Chap. 3):

Time	Event	Remarks
16:35 hours	Triggering of the cyclic network security calculation (SIRE) in the dispatching centre Brauweiler (HSL)	Result: no findings
16:39 hours	Start of a pump in the Vianden power plant; parallel to this four machines in phase shift operation	Pumping output: 68 MW
16:44 hours	Start of two further machines in phase shift mode in the Vianden power plant	Support for the 220 kV mains voltage and reduction of the conduction currents
16:51:11 Uhr	Saar Nord line tripped at both ends in Diefflen and Trier	Short circuit with two-phase fault; fast tripping (0.1 s)
16:51:15 Uhr	Osburg line tripped at one end in Quint	Tripped in reverse end time (2.6 s)

Time	Event	Remarks
16:51:24 Uhr	Kondelwald line tripped in Weißenthurm	Tripped after overcurrent starting
From 16:51:24 hours	Disconnection of the RWE network group Trier and the CEGEDEL network from the national grid; disconnection of the machines in the Vianden power plant from the network	Mains failure and supply interruption in Luxembourg and area around Trier
16:53:06 Uhr	On request by telephone, CEGEDEL was informed of the supply interruption	
16:57:51 hours	Reconnection of the Kondelwald line	Supply restored to area without voltage
16:57:58 hours	Attempt to reconnect the Osburg line	Unsuccessful due to fault in the remote control device
16:58:00 hours	Machine 3 run up from standstill in the Vianden power plant	Purpose: Relief for the Kondelwald line
From 16:58:00 hours	Step up of the distribution network transformers through automatic voltage control in the network group Trier	Step-up on the 20 kV side of the 110/20 kV distribution network transformers
17:00:58 hours	Bauler-Roost line tripped in Bauler	Cause so far not clarified
17:01:07 hours	Kondelwald line tripped in Niederstedem	Cause: undervoltage and overcurrent starting
17:02:00 hours	Machine 3 in the Vianden power plant in Niederstedem switched off after unsuccessful attempt at synchronisation	
17:03:28 hours	Attempt to reconnect the Kondelwald line	Unsuccessful; immediate tripping through undervoltage and overcurrent starting
From 17:03:28 hours	Preparation of the network for a successive mains restoration	Distribution network transformer of the RWE network group Trier switched off on the secondary side
17:07:06 hours	A CEGEDEL power supply is connected to the SOTEL network	Supply of approx. 100 MW in the CEGEDEL network from Belgium

Time	Event	Remarks
17:23:34 hours	Reconnection of the Kondelwald line after the distribution network was switched off	Energising of the no-voltage 220-kV network; thus supply restored to the remaining network in Luxembourg
From 17:23:34 hours	Successive reconnection of the distribution network transformers in the RWE network group Trier	Partly manual reconnection using local control stations
17:43:35 hours	Reconnection of the Osburg line	Reconnection with the support of the local control station in Quint
From 17:45:00 hours	Physical inspection of the Saar Nord line	Visual check of the line with the goal of determining the cause of the short circuit and ruling out a mechanical damage
20:06:23 hours	Circuit for returning the Belgium-supplied part of the CEGEDEL network to the RWE network	Restoration of normal supplies in Luxembourg
21:13:00 hours	Reconnection of the Saar Nord line	After check with no findings
By approx. 21:24 hours	Start-up of all distribution network transformers in the RWE network group Trier	Conclusion of restoration of supply to all customers

2.4 Flow of information between RWE and CEGEDEL

After the Kondelwald line tripped at 16:51 hours the region shown in Figure 1 was without voltage. Since there was no fault in the CEGEDEL network, a large number of secondary error messages were received in the central network control station in Heisdorf. There were, however, no alarm messages since the no-voltage state did not involve a shutdown of 220-kV network elements in the CEGEDEL network.

By request of the CEGEDEL dispatching centre in Heisdorf at 16:53:06 the centre was informed of the interruption of supplies by the dispatching centre of the RWE Transportnetz Strom in Brauweiler. Reference was hereby made to a problem in the 220-kV network of RWE Transportnetz Strom. RWE Transportnetz Strom promised CEGEDEL to restore the voltage as quickly as possible.

Between 16:59:41 hours and 17:00:36 hours RWE Transportnetz Strom, in response to an inquiry from the CEGEDEL dispatching centre, confirmed that the Kondelwald line was once again carrying voltage after the first reconnection attempts and that RWE Transportnetz Strom would take the necessary measures to further stabilise the network.

Between 17:32:19 hours and 17:34:36 hours RWE Transportnetz Strom informed CEGEDEL of the successful restoration of supplies.

3 Technical analysis of the events

3.1 Development of the network situation immediately before the fault

The network group Trier including Luxembourg was supplied by the 220 kV network of RWE Transportnetz Strom, which was under a higher load than usual on account of the missing feed from the 380/220 transmission transformer 41 in Niederstedem.

The network security calculation (SIRE) carried out at 16:35 hours by Brauweiler dispatching centre of RWE Transportnetz Strom (HSL) showed no findings that were relevant for security (no so-called I-findings, cf. Chap. 4). This means that there was no undershoot of the specified security margins to the maximum permissible operating current in the RWE network group Trier at this time; the network was in an (n-1) secure condition. The further analysis of the network situation at this point in time also showed that the connection of a pump turbine in the Vianden power plant (68 MW) was possible without permissible operating limits being exceeded since two further machines in Vianden were started at the same time to support the network in phase shift mode to compensate the additional current load caused by the pump turbine in the 220 kV network. Moreover, a significant drop in the mains load could be expected at the end of normal working hours.

Taking these circumstances into account, pump turbine 3 was connected to the mains at 16:39 hours after approval by the dispatching centre at the request of the power plant operator. At 16:44 hours two further machines went into operation in phase shift mode at the request of the HSL dispatcher.

The resulting network condition after these measures was recorded and saved at 16:45 hours during the cyclic archiving. This data record forms the basis for the further technical analysis.

3.2 Tripping of the Saar Nord line

At 16:51 hours the Saar-Nord line tripped simultaneously in the transformer stations Diefflen and Trier. The recordings show a two-phase short circuit with no earth contact between phases L2 and L3 (see Figure 5). The time of fault according to the recordings of the fault recorder in the protection equipment was 16:51:10,921 hours. Tripping occurred in the first time stage with a 100 milliseconds delay (= fault duration) after 150 milliseconds (50

milliseconds = switch response time). The recordings of the digital fault recorder clearly show the temporal sequence of the fault and the starting of the protection equipment in transformer stations Diefflen and Trier.

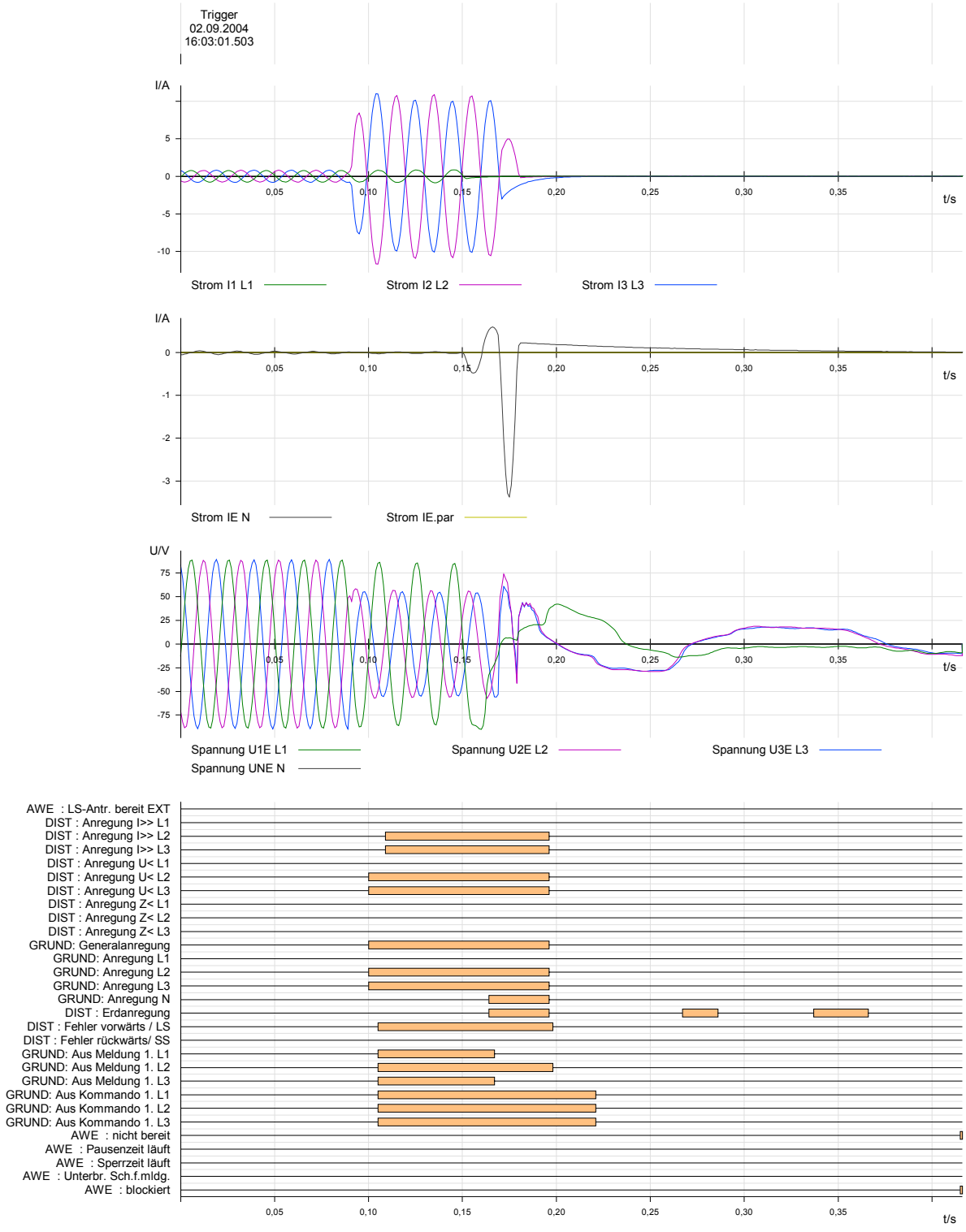

Figure 3: Print-out of the fault recorder for the Saar Nord line at Diefflen station (source: RWE)

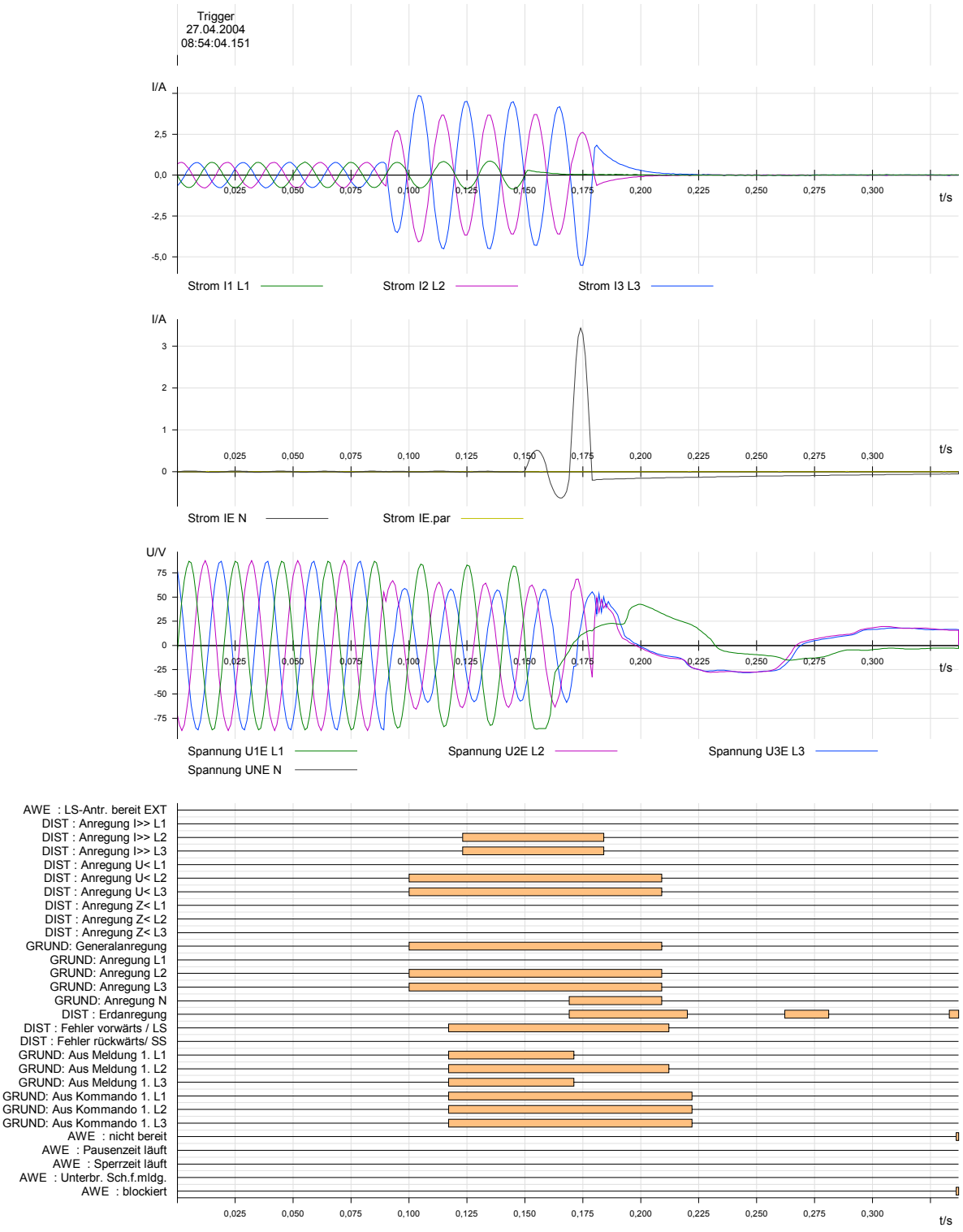

Figure 4: Print-out of the fault recorder in the Saar Nord line at Trier station (source: RWE)

The protection equipment installed at Diefflen and Trier are digital devices with a starting value of 1,500 A each.

The following proportionate fault currents and voltage drops were measured at the transnational lines between CEGEDEL and RWE during the fault duration of 100 ms (see also the graphic depiction in Annex 2):

On the Heisdorf - Trier line:

In phase L1: current (375 A) 400 A; voltage drop to (231 kV) 211 kV
In phase L2: current (375 A) 758 A; voltage drop to (231 kV) 160 kV
In phase L3: current (375 A) 1200 A; voltage drop to (231 kV) 202 kV

On the Heisdorf - Quint line:

In phase L1: current (445 A) 492 A; voltage drop to (231 kV) 211 kV
In phase L2: current (405 A) 392 A; voltage drop to (231 kV) 160 kV
In phase L3: current (410 A) 437 A; voltage drop to (231 kV) 202 kV

On the Flebour - Bauler line:

In phase L1: current (320 A) 415 A; voltage drop to (234 kV) 215 kV
In phase L2: current (320 A) 441 A; voltage drop to (234 kV) 168 kV
In phase L3: current (300 A) 367 A; voltage drop to (234 kV) 207 kV

On the Roost - Bauler line:

In phase L1: current (245 A) 323 A; voltage drop to (234 kV) 212 kV
In phase L2: current (235 A) 383 A; voltage drop to (234 kV) 162 kV
In phase L3: current (240 A) 360 A; voltage drop to (234 kV) 206 kV

Based on the protection equipment recordings displaying different starting times the fault could be localised to be in a ten kilometre section near Merzig (Saarland) of the 59 km line (approx. nine kilometres from Diefflen and 40 kilometres from Trier).

Despite several thorough visual inspections of the line, including a flight inspection with a helicopter and a check of the line with a line trolley, there has as yet been no indication that the short-circuiting of the two overhead cables was caused by an electric arc. Burn marks, molten extraneous material or cracks, which would be typical for short circuits, could not be found in the aluminium shell of the two affected phases L2 and L3.

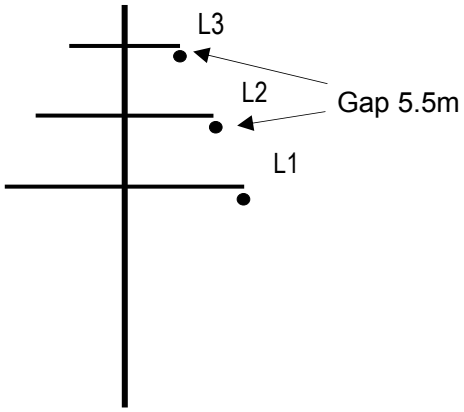

Figure 5: Schematic view of the line near Merzig showing arrangement of phases

Damage to the line was not discovered and can be ruled out as a cause of the short circuit after re-commissioning of the line on the day of the power failure. As this was a two-phase fault between phases L2 and L3 (see Figure 5), an earth fault, in other words a current between an overhead cable and the earth caused e.g. by a tree growing near the line, can also be ruled out as cause of the damage.

After checking the weather data based on information from the German Weather Service for the time in question, atmospheric influences through lightning or wind can also be ruled out as cause of the short circuit.

RWE brought charges against unknown persons on 10.9.2004 after several identical statements from witnesses had been received indicating external interference to the line close to pole 8 near Merzig. The DPP in Saarbrücken closed investigations on 17.11.2004 with no results. No interference by third parties could be proven.

3.3 Tripping of the Osburg line

3.3.1 Description of the protection equipment

Protection equipment serves to protect persons and network elements against excessively high currents, e.g. due to short circuits. An overcurrent starting value is set at the protective device depending on the design of the network element. If this starting value is exceeded the protection equipment initially starts; a timer begins to run. Whether the protection equipment then leads to tripping of the line or not depends on the course of the current within a certain period – 2.0 seconds for rectified starting, 2.6 seconds for non-directional starting. If the current drops back below a typical device release value before the end of the time the protection equipment is released and the line does not trip. If, after starting, the current does not fall below the release value by the end of the time the protection equipment sends a tripping command to the power switch; the line is disconnected.

The protection equipment for the Osburg line installed in Quint at the time of the fault was an electromechanical-analogue model of the type AEG SD324. The pre-set starting value for this device and thus the short-term permissible current load on the Osburg line was 1,500 amperes (A). The release value for the current starting in the aforementioned type of device is 85 % of the starting value. If this value is exceeded the current then has to drop back below the release value of 85 * 1,500 A = 1,275 A within 2.0 seconds (or 2.6 seconds with non-directional starting) so that the protective device does not trip.

The laboratory test of the protective device carried out after the fault and replacement of the device by RWE Rhein-Ruhr Netzservice (see Annex 4) showed that the actual starting value determined in the fault simulation was 1,440 A, and thus 60 A below the pre-set value of 1,500 A. An actual release value of 1,242 A was also determined in the laboratory (see Annex 4, Chapter 6).

The protective device installed in Uchtelfangen at the other end of the Osburg line was a digital model of the type Alsthom, Type P 437. The overcurrent starting value was also set to 1,500 A in Uchtelfangen. The release value for this type of device is 95% of the starting value, thus in this case 1,425 A.

As an analogue mechanical protective device, the protection equipment in Quint recorded no fault, unlike the digital device in Uchtelfangen. The reconstruction and analysis of the course of the fault is thus based in particular on the following available sources:

- information from the control system of the dispatching centre,
- recordings from the available digital protection equipment and fault recorder and
- recordings of the current flows in Luxembourg.

3.3.2 Starting of protection through power oscillations on the Osburg line

Directly after the Saar Nord line had tripped, a power oscillation with a frequency of approx. 1 Hz, i.e. an oscillation duration of 1 second, was excited by the dynamic behaviour of the nearby Ensdorf and Weiher power plants. This oscillation affected the current flow on the Osburg line. The current on this line hereby fluctuated around the new stationary value of the operating current that was present in the line after the change in the network topology due to the failure of the Saar Nord line in the new state.

Such a dynamic oscillation around a stationary value does not lead to tripping of the protection equipment based on its design since the current frequently drops below the release limit at a frequency of 1 Hz before expiry of the non-directional end time of 2.6 seconds and the protection should thus be safely released after any starting caused by the oscillation.

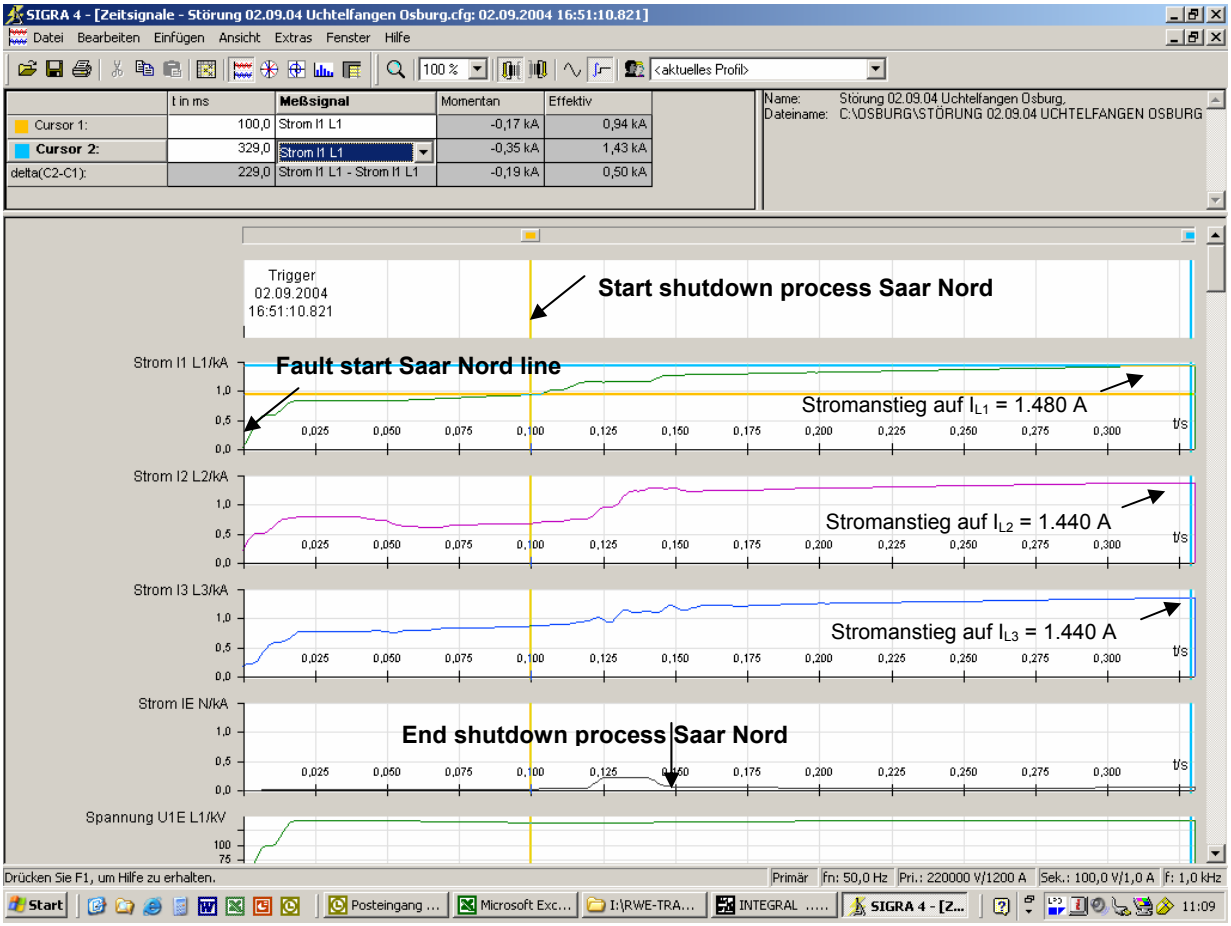

Figure 6: Pendulum current on the Osburg line, values measured by the digital protection equipment in the Uchtelfangen station (source: RWE)

The current on the Osburg reached its new stationary value of 1,212 A as a result of the shift in load flow within 0.15 seconds of the occurrence of the fault on the Saar Nord line. On account of the power oscillation, the increase in current in the first half-wave of the oscillation persisted and reached the following values in phases L1, L2 and L3 approx. 0.325 seconds after the occurrence of the fault at the end of recording (see Figure 6):

I_{L1} = approx. 1480 A -> I_{L1max} = approx. 1512 A

I_{L2} = approx. 1440 A -> I_{L2max} = approx. 1468 A

I_{L3} = approx. 1440 A -> I_{L3max} = approx. 1468 A

The protection equipment in Quint started when the actual starting value of 1,440 A was exceeded during the first half-wave of the oscillation. This occurred 0.4 seconds after the fault on the Saar Nord line and 0.25 seconds after the end of the shutdown process for the Saar Nord line at the peak of the first half-wave (duration of shutdown process on Saar Nord: 0.15 seconds = 0.1 seconds fault duration + 0.05 seconds switch response time). With a

tripping time of 2.6 seconds after non-directional starting – the protection equipment on the Osburg line in Quint registered a current flow in a reverse direction (towards Quint) – and a switch response time of 0.04 seconds for the protection equipment in Quint, the Osburg line tripped 3.04 seconds after the occurrence of the fault on the Saar Nord line. These times were confirmed by the recordings at CEGEDEL.

At the same time the protection equipment in the opposite station Uchtelfangen also started, but was released again after the value fell below the release value in the second, negative half-wave according to the design.

3.3.3 Tripping of the Osburg line through overfunction of the protection equipment

Within 2.6 s of starting due to the increased current caused by the mains oscillation the protection equipment in Quint led to tripping of the Osburg line on one side.

An actual current release value of 1,242 A was determined in the laboratory tests. This means that when the current fell below this value on the Osburg line the protection equipment should have been released. Although the current strength theoretically fell below this value in both a stationary state (1,212 A) and during the second, negative half-wave of the mains oscillation the starting remained and the protection equipment led to tripping of the Osburg line on expiry of the end time (overfunction of the protection equipment). A dynamic simulation of these processes carried out by RWE Transportnetz Strom based on the calculated and measured current shows the path of the current in the Osburg line. The results of this simulation shown in Figure 7 clearly show that the value repeatedly fell below the release value for the protection equipment determined in the laboratory.
The practical evaluation of the malfunction recording showed a current increase in phase L1 to a maximum of about 1512°A. The peak amplitude of the pendulum current determined on the basis of the recordings on the Osburg line was approximately 278 A. The minimum value of the pendulum current thus dropped to 1234 A, corresponding approximately to the measured drop of 1242 A. Whether this drop was actually undershot remains open due to possible measurement inaccuracies, reading errors and modelling inaccuracies in the theoretical calculations.
The laboratory tests (see Enclosure 4) attempted to simulate the overfunction of the protection equipment to determine its cause. In laboratory tests the protection equipment functioned correctly and was released after starting when the value fell below the release value of 1,242 A, as designed. Relevant damages to the protection equipment were not

determined. The protection equipment was serviced regularly every two years according to the state-of-the-art. The last service in February, 2003 resulted in no anomalies.

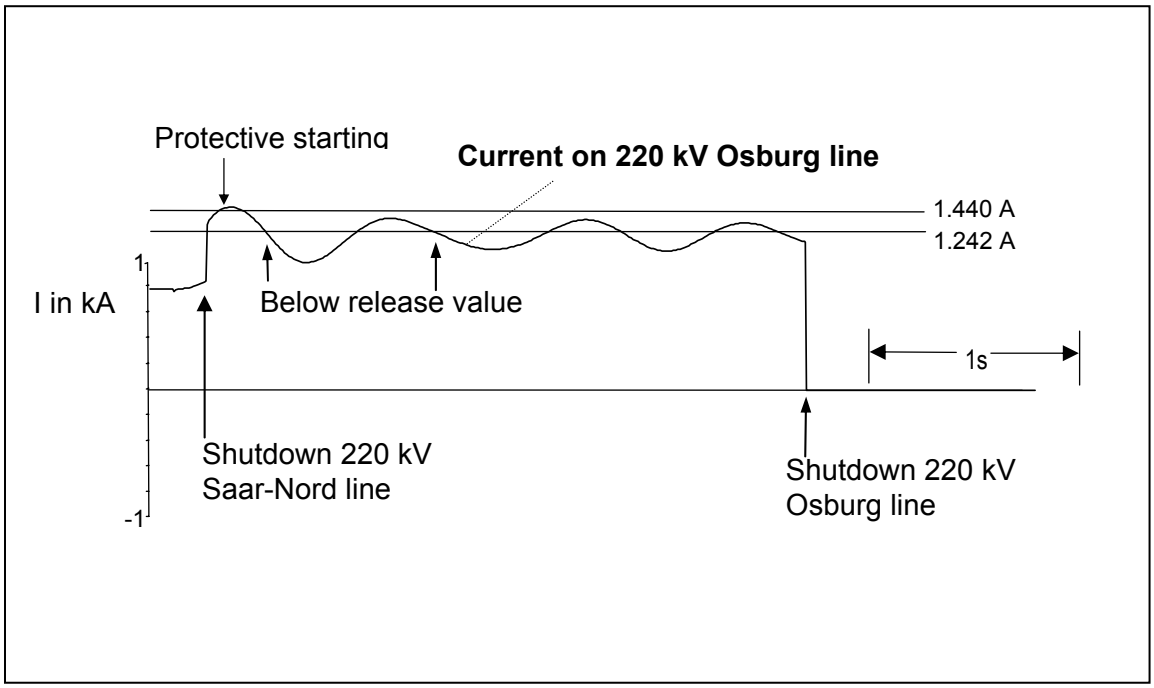

Figure 7: Simulation of the current on the 220 kV-Osburg line after tripping of the 220 kV Saar Nord line (source: RWE)

3.4 Tripping of the Kondelwald line

After the Osburg line had tripped in Quint, there was an (n-2)-case. This was not protected by the mains by the system management in accordance with the security standards in the UCTE national grid operation (cf. UCTE Operational Handbook; VDN Transmission Code 2003). The overload that occurred on account of the (n-2)-case after the failure of the Saar Nord and Osburg lines led to tripping of the remaining Kondelwald line due to an overload in accordance with the security concept.

3.4.1 Protective reactions/recordings

The recordings for the protection equipment on the Kondelwald line in the Weissenthurm and Niederstedem plants show the course of the fault.

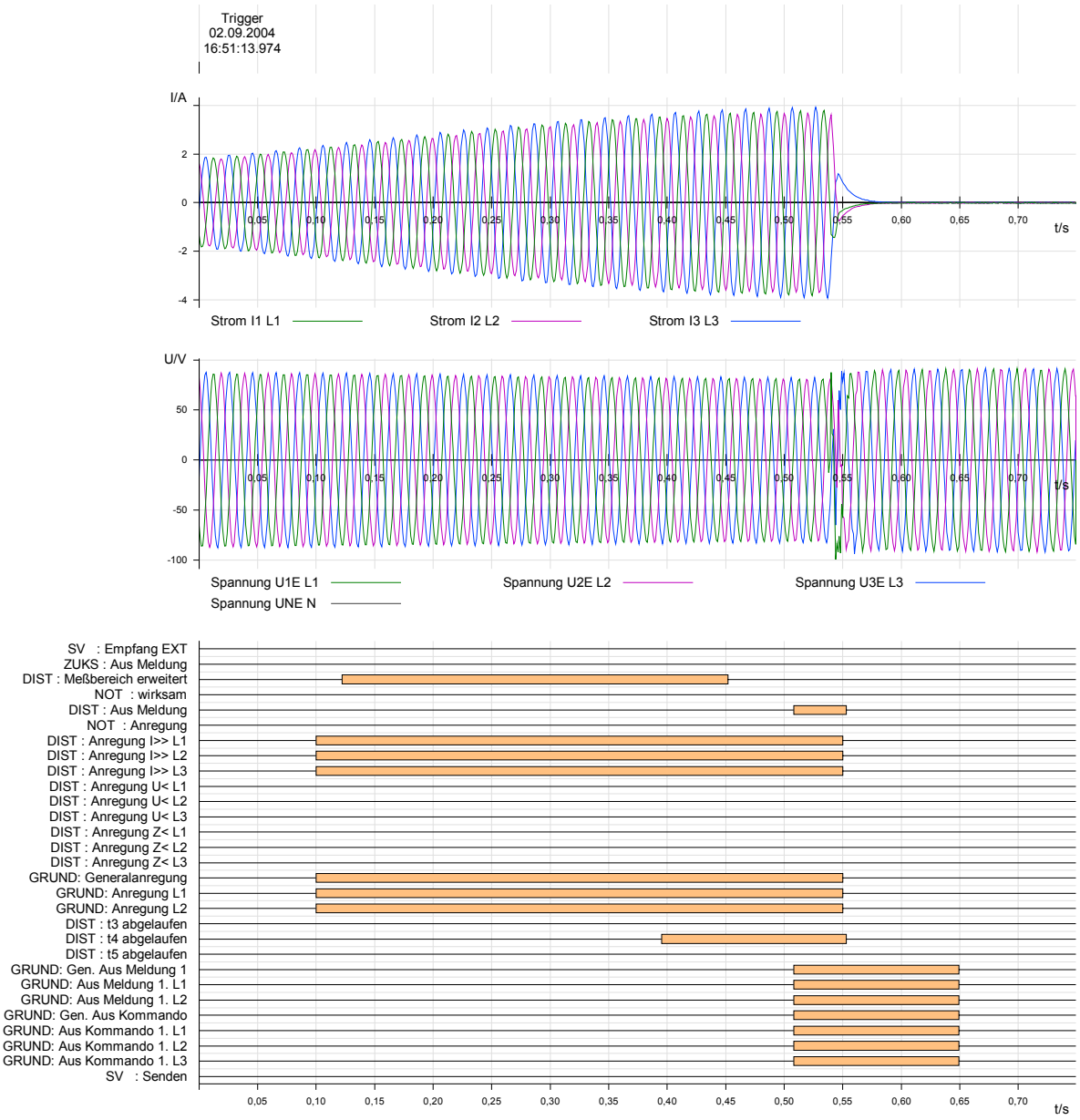

Figure 8: Print-out of the fault recorder for the Kondelwald line in the Weissenthurm station (source:RWE)

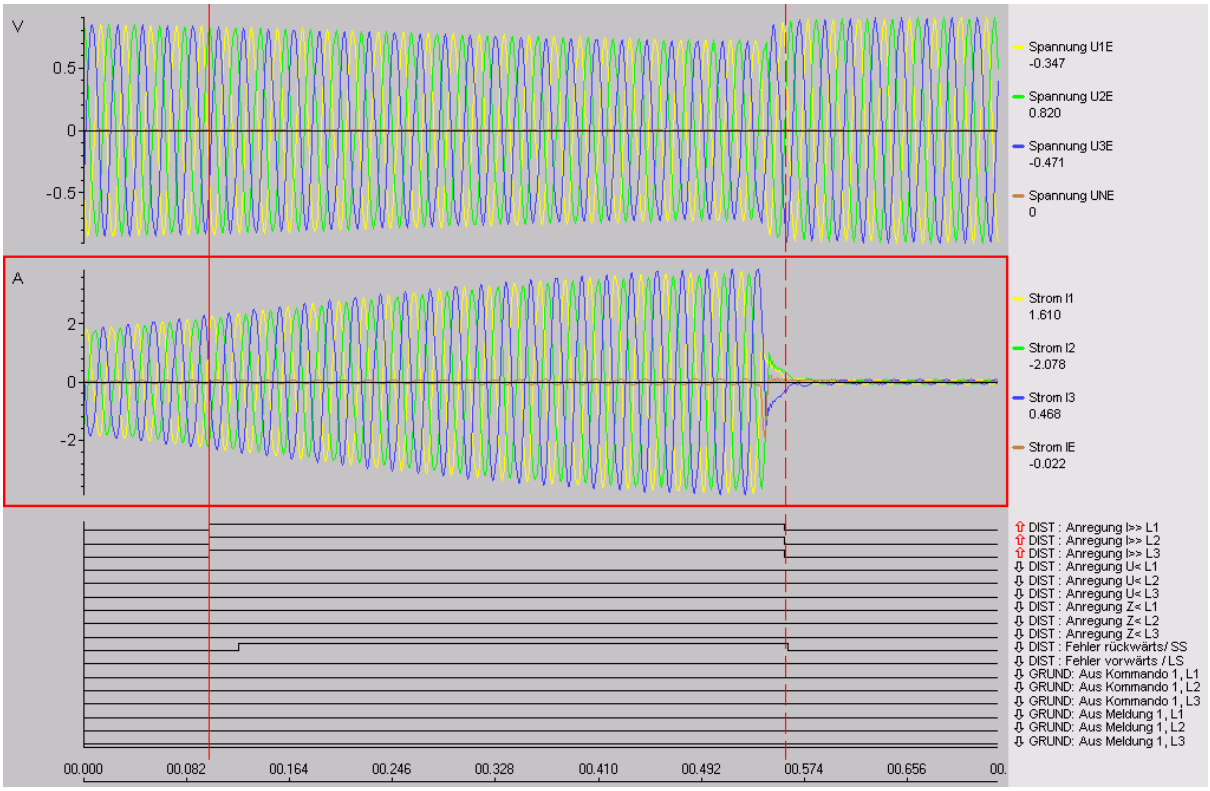

Figure 9: Print-out of the fault recorder for the Kondelwald line in the Niederstedem station (source: RWE)

After the tripping of the Kondelwald line the CEGEDEL network and the consumers connected to the transformer stations in Trier, Quint and Wengerohr via the distribution network were no longer supplied with energy from the national grid. The turbines in Vianden that were in phase shift mode had no mechanical drive torque. They delivered their rotational energy to the network and were braked. This resulted in a drop in frequency and the decay processes in the current and voltage that were recorded by the LEM measuring devices in the CEGEDEL network. The machines were finally disconnected from the network due to underfrequency and undervoltage protection and were run down to a standstill. The Vianden power plant was supplied after this tripping by the Lohmühle generator in standalone operation. These events occurred with no damage to the machines in the Vianden power plant.

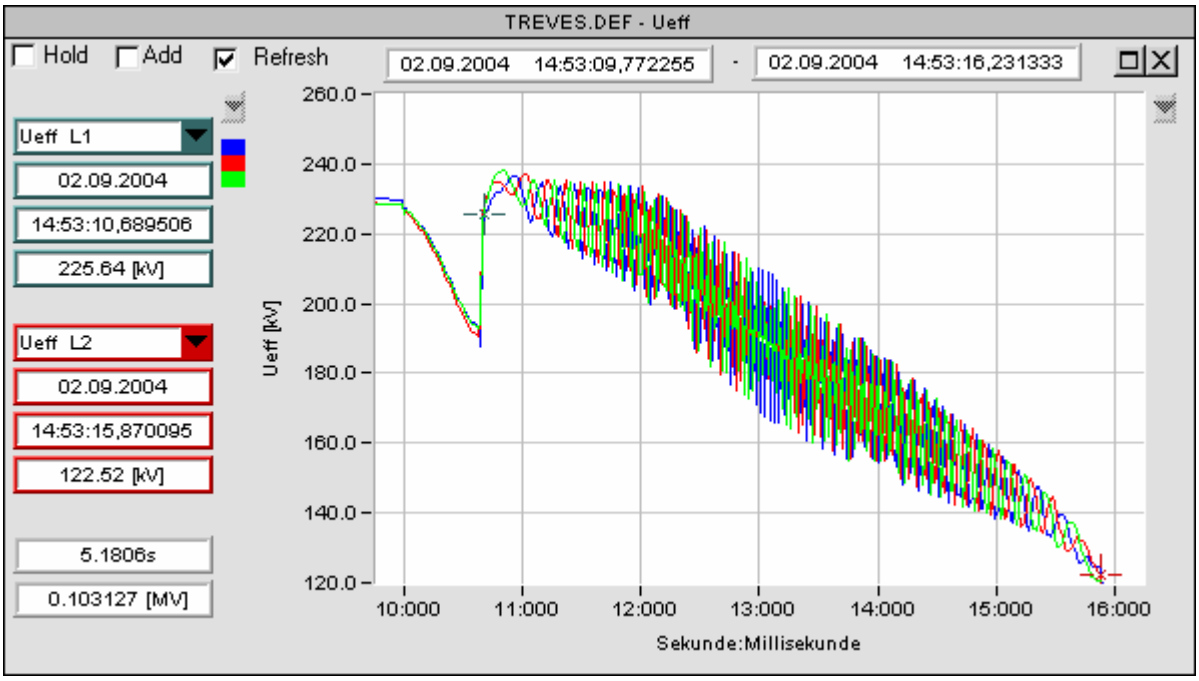

Figure 10: Voltage curve during shutdown of the machines in Vianden (source: CEGEDEL)

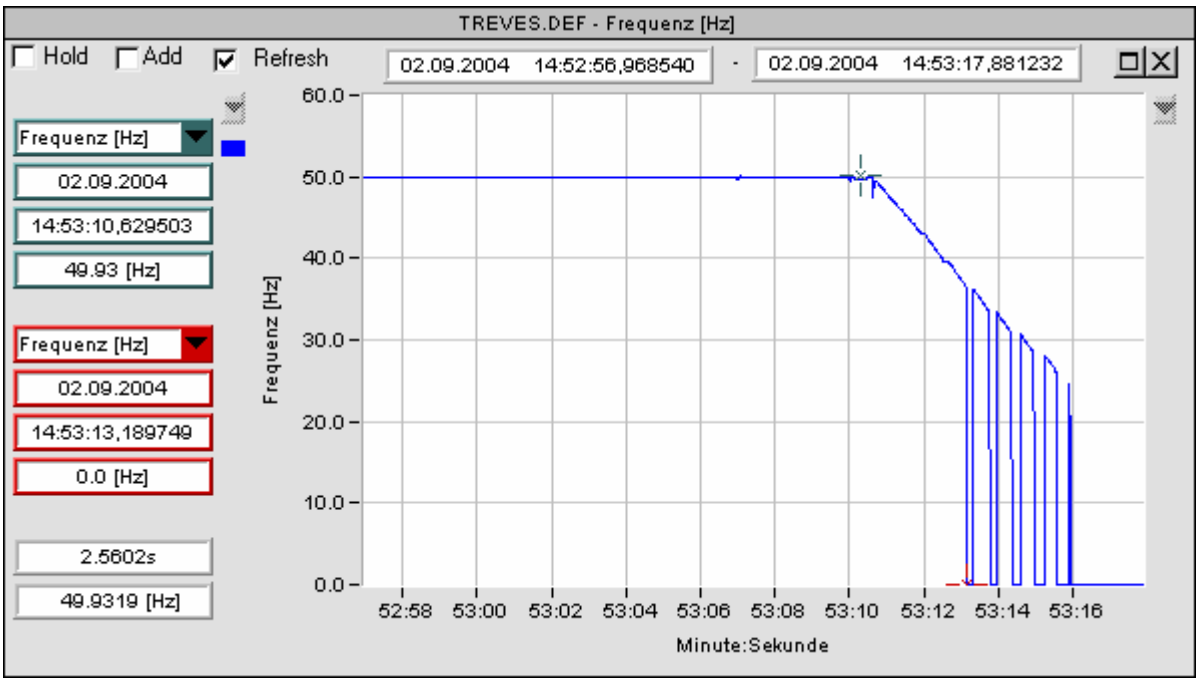

Figure 11: Frequency fall-off after shutdown of the Kondelwald line (source: CEGEDEL)

3.5 First attempt at reconnection

At 16:57 hours an initially successful attempt to reconnect the Kondelwald line was carried out. Owing to an error in the remote control unit of the Quint plant, before a successful start of the Osburg line and synchronisation of a machine in Vianden the Kondelwald line tripped once again due to the high load from a sub-impedance starting. This meant that the Trier region and Luxembourg were once again without voltage.

3.5.1 Current flows/voltage curve

The voltage in the Heisdorf plant rose to around 217 kV when this was switched on. The voltage dropped slowly on account of the making current and the increasing load current. After 3 minutes 18 seconds the voltage had dropped to 172 kV and the Kondelwald line was once again disconnected by the protection equipment.

A voltage breakdown occurred here on account of the weak connection via the Kondelwald line. The voltage on the secondary side was kept almost constant due to the automatic stepping of the transformers that fed the medium voltage. As soon as an undervoltage on the 220/110 kV level is compensated by this transformer control the current rises in the 220/110 kV network. On account of this higher current, the voltage drop in the upstream network increases significantly with a weak network connection so that the transformer control is re-activated immediately. This process is accompanied by a decreasing voltage and increasing current and is repeated until the current on the feeding line exceeds the protection starting value and the line trips (see Figures 12 and 13). Due to the delay in the voltage regulators and consequently the delayed rise in current, the shutdown was only carried out after 3:18 minutes.

On account of the low voltage in the 220 kV network, the automatic voltage regulators of the 220/65 kV transformers in the CEGEDEL network and the 110/20 kV transformers at RWE adjusted the step switches to their end positions (automatic voltage regulation).

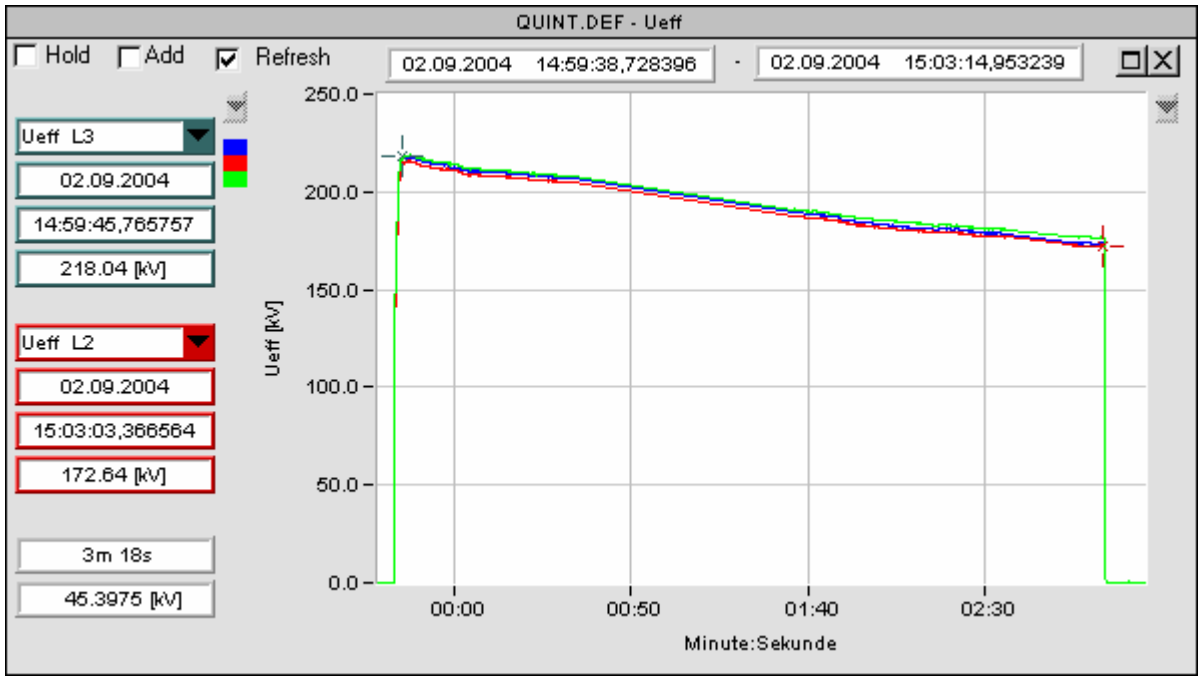

Figure 12: Voltage curve in Heisdorf after the first attempt at reconnection (source: CEGEDEL)

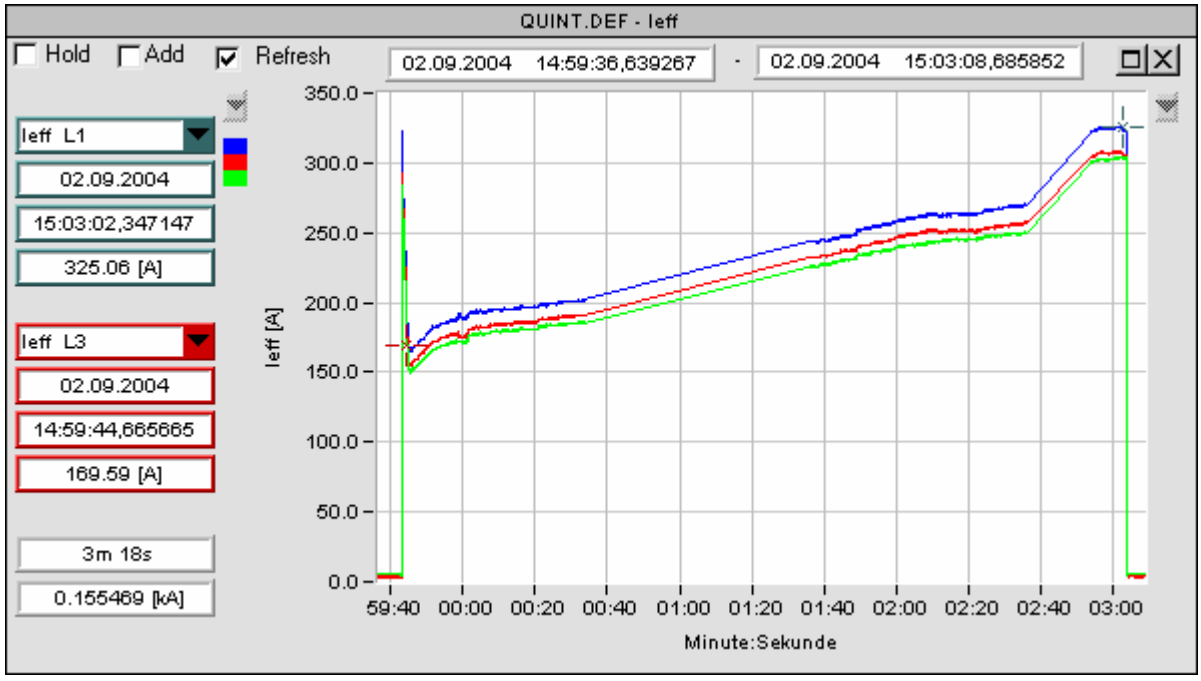

Figure 13: Current flow in the Heisdorf - Quint line after the first attempt at reconnection (source: CEGEDEL)

3.5.2 Vianden power plant and Osburg line during the attempt at reconnection

Immediately after the successful connection of the Kondelwald line, the command was given to switch on the Osburg line at 16:57 hours so that the affected region could be supplied by two lines. This connection attempt failed due to a faulty connection in the remote control unit of the Osburg line in the Quint plant. The remote control unit is buffered by a battery should the transformer lose its voltage. This battery was not fully connected to the remote control device, as on-the-spot tests discovered, so that there was no conceptual emergency supply to the control device with d.c. voltage. A cyclic check and maintenance of the battery within the scope of an emergency supply concept is planned and was carried out. The simulation of a no-voltage plant condition is, however, not scheduled at RWE within the scope of cyclic maintenance work.

Machine 3 in Vianden was run up in generator mode to increase the feed to the network group Trier at 16:58 hours. Before this machine could be synchronised and switched into the network group to support the Kondelwald line via Niederstedem, the protection in the Kondelwald line tripped once again in Weissenthurm.

3.6 Second attempt at reconnection

A second attempt at reconnecting the Kondelwald line at 17:03 hours was also unsuccessful.

Since the step switches of the transformers were already in the end position during this connection attempt, there was immediately a higher current on the Kondelwald line, leading to an overcurrent starting of the protection equipment and the shutdown of the line. Due to the short connection time, neither the available machines in Vianden nor the Osburg line in Quint could be connected.

A current of 426 A was recorded on the Heisdorf - Quint line. This value was above the current of 325 A that had been measured immediately before shutdown during the first connection attempt. As a result of the high current, the line protection equipment led again to tripping of the line after an overcurrent starting on expiry of the end time of 2 s.

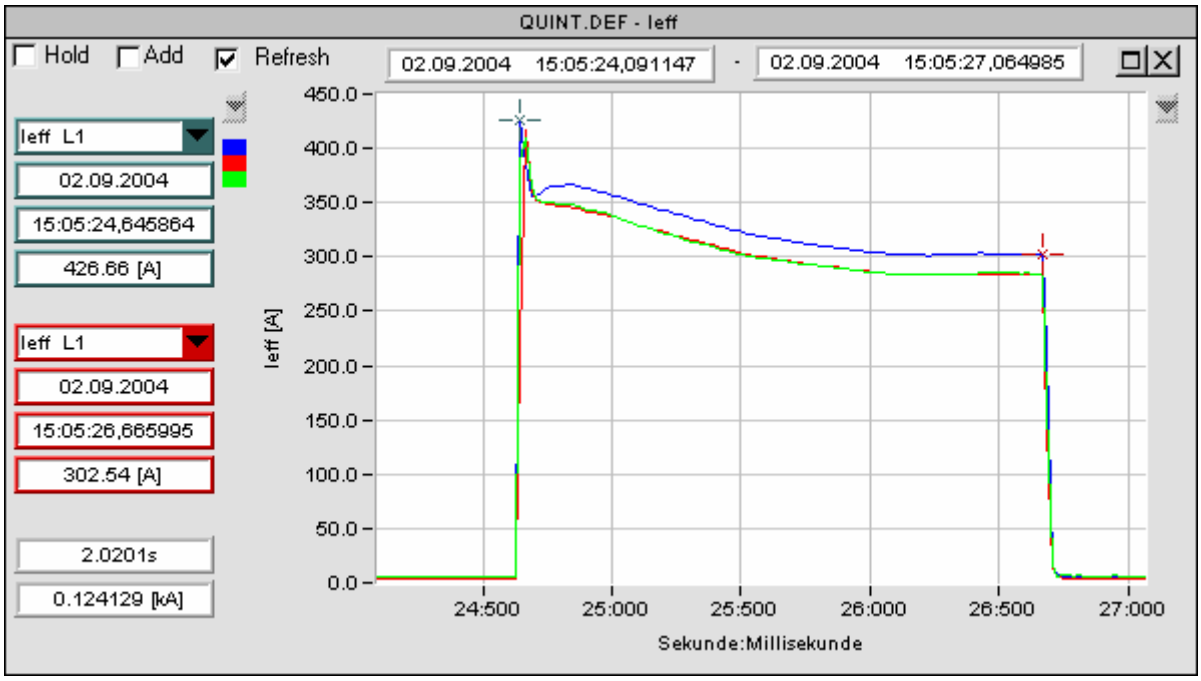

Figure 14: Current flow on the Heisdorf - Quint line during the second connection attempt (source: CEGEDEL)

The voltage in the Heisdorf plant only reached 171 kV.

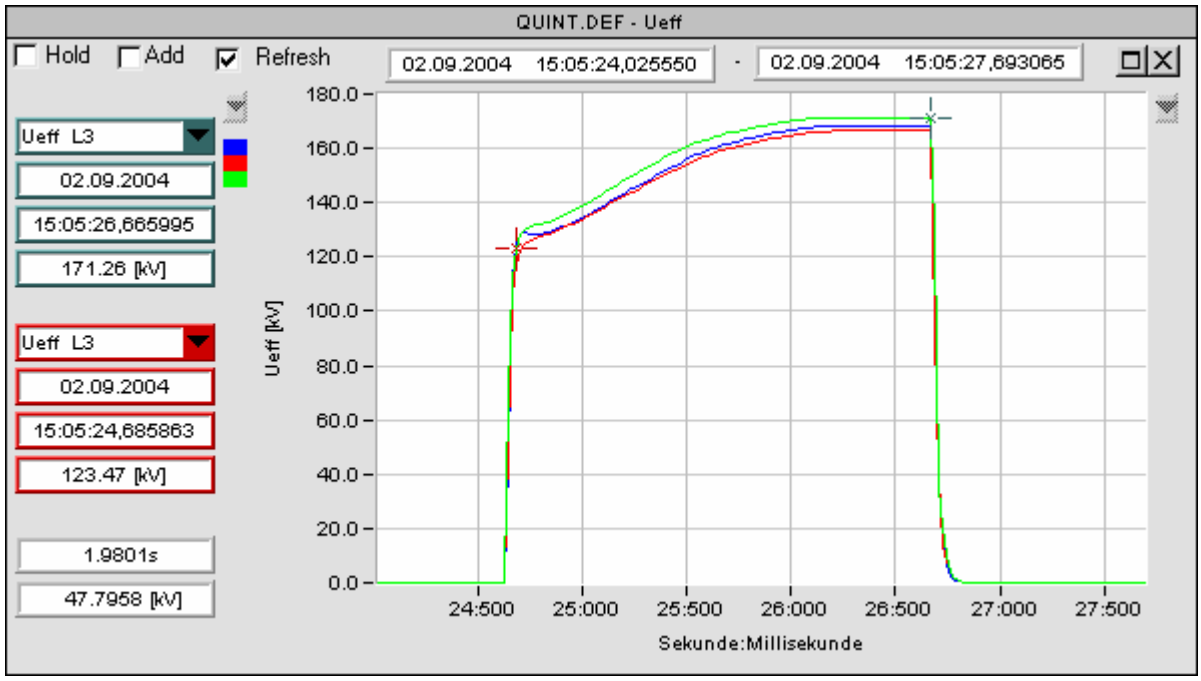

Figure 15: Voltage curve in Heisdorf during the second connection attempt (source: CEGEDEL)

3.7 Measures taken by CEGEDEL to secure the supply

3.7.1 Contacts with RWE

At 16:51:21 the Kondelwald line tripped and the aforementioned network region was without voltage.
Since the loss of voltage was not related to any shutdown in the CEGEDEL network, no direct alarm message occurred.

Betweem 16:53:06 and 16:53:32, the technician on duty at the dispatching centre in Heisdorf inquired in Brauweiler about the cause of the loss of voltage.
He was informed of a supply interruption triggered by a problem in the 220-kV network of RWE. RWE announced that it would specify voltage for CEGEDEL as soon as possible.

Between 16:59:41 and 17:00:36 following the first attempt at reconnection the technician called RWE and received confirmation that voltage was present and that RWE was in the process of further stabilising the network.

Between 17:32:19 and 17:34:36 a call occurred from RWE reporting on the successful restoration of voltage at the CEGEDEL. Information on the cause of the malfunction could not be provided at this point in time.

3.7.2 Emergency power supply via SOTEL

At 16:56:12 hours (duration 57 seconds) the CEGEDEL dispatching centre called SOTEL to request an emergency feed from the SOTEL/ELIA network to part of the CEGEDEL network, thus restoring at least part of the power supply to Luxembourg. SOTEL promised to check this emergency feed internally.

At 17:02:47 hours (duration 7 minutes 2 seconds) the CEGEDEL dispatching centre asked SOTEL whether the emergency feed had been approved. At this point in time SOTEL was prepared to provide 100 MW of power. The corresponding dispatching actions to establish the emergency feed of 100 MW via the SOTEL network from the network of the Belgian transmission network operator ELIA were carried out during the telephone call.

Part of the CEGEDEL network was connected within the scope of the emergency feed via the line from the TWINerg power plant to Schifflingen. For this purpose the power switch in

theTGV-TWINerg plant was closed in the direction of Schifflingen at 17:07:06 hours. Power was thus restored to the OXYLUX plant of CEGEDEL (CFL and parts of Esch/Alzette) after around 16 minutes.

The 220/65 kV transformers in Schifflingen were connected between 17:10 hours and 17:11 hours. This meant that power was restored to the Esch/Alzette, Bascharage, Biff, Lamadelaine, Paafewee, Woiwer, Sanem WSA, Galvalange, Dudelange, Riedgen, Trefilarbed, Bettembourg and SIDOR plants after around 20 minutes. Luxguard Bascharage and TDK were then connected at around at 17:14:21 hours via Bascharage.

3.7.3 Contacts to TWINerg

Between 17:11:07 hours and 17:12:02 hours the control station at TWINerg asked the CEGEDEL dispatching centre who was responsible for the emergency power supply to the power plant after it had noticed that the voltage was missing from the feed. CEGEDEL informed TWINerg about the power failure in the entire network region of CEGEDEL.

The TWINerg power plant, that normally feed the Belgian network, was already feeding at its rated output and could not have fed any additional energy to the CEGEDEL network. On account of the higher outdoor temperature and thus the temperature of the air supply, the maximum power that could be generated was slightly lower during the afternoon than at night.

3.7.4 Restoration of the normal connection between CEGEDEL and SOTEL

After the RWE Transportnetz Strom network had once again been safely connected, the area fed by SOTEL was switched back to the RWE Transportnetz Strom network. Both networks were connected in parallel at 20:05:58 hours after a comprehensive correction of the phase angle between both networks in Schifflingen. At 20:06:23 hours, parallel operation was once again cancelled in the TWINerg plant by opening the switch in the direction of Schifflingen. All CEGEDEL customers were thus once again supplied from the RWE Transportnetz Strom network.

3.8 Restoration of the CEGEDEL supply

At 17:23 hours, voltage was restored to the Niederstedem plant through the Kondelwald line and thereby also to Luxembourg. Osburg line was reconnected at 17:43 hours so that Luxembourg could now also be supplied via the Quint-Heisdorf line.

On account of the low voltage level that arose during the first reconnection attempt, the step switches of the transformers moved towards the end position. Due to the partially missing load from customers on the one hand and the end position of the step switch on the other, there could have been excessive voltages in the CEGEDEL network after final restoration by RWE of the normal operating voltage. This effect was compensated by RWE initially only supplying a voltage of 210 kV which was then gradually increased to between 225 and 230 kV. The voltage regulators of all transformers adjusted the voltage correctly thanks to their automatic high-speed circuits.

3.9 Restoration of supplies in the Trier / Eifel region

The 220 kV network was prepared for reconnection to restore supplies to the Trier region and Luxembourg from 17:03 hours onwards. In accordance with the network restoration concept of RWE Transportnetz Strom, the 220/110 kV transformers that feed the 110 kV Trier group were switched off. This reduced the load on the 220 kV network for reconnection, which in turn allowed a successive connection of the no-voltage parts of the 220 kV network. In the cascaded network, work began on connecting parts of the 110 kV network group to the neighbouring 110 kV network group. Furthermore, the 110/20 kV transformers had to be readjusted by hand and on the spot in the transformer stations to their normal position according to the network restoration concept after they had been adjusted to their end positions by the voltage regulators on account of the low voltage in the 220 kV network.

The reconnection of the distribution network transformer and thus the restoration of supplies to customers was carried out according to the following table (source: RWE).

Station	Field or tap	Load [MW]	Supply restoration time
Blankenrath	Transformer 11	3.6	17:28
Sohren	Transformer 11	5.0	17:28
Sohren	Transformer 12	1.9	17:28
Quint	own requirements	1.0	18:50
Moselstahlwerk	Transformer 11	12.0	18:50
Moselstahlwerk	Transformer 12 a/b	1.0	18:50
Saarburg	Transformer 11	2.0	18:53
Saarburg	Transformer 12	5.5	18:53
Wengerohr	Transformer 13	4.0	19:06
Wengerohr	Transformer 12	31.3	19:06
Niederstedem	own requirements	1.0	19:06
Sinspelt	Transformer 11	1.5	19:14
Sinspelt	Transformer 12	2.3	19:14
Laufeld	Transformer 11	4.0	19:24
Morbach	Transformer 11	5.2	19:25
Morbach	Transformer 12	22.3	19:25
Grüneberg	Transformer 11	0.2	19:30
Grüneberg	Transformer 12	1.5	19:30
Bekond	Transformer 11	6.8	19:41
Bekond	Transformer 12	5.5	19:41
Bitburg	Transformer 11	16.7	19:43
Bitburg	Transformer 12	5.5	19:43
Bernkastell	Transformer 11	1.0	19:54
Grosslittgen	Transformer 11	2.9	19:54
Bernkastell	Transformer 12	7.0	19:54
Tobiashaus	Transformer 11	5.2	19:55

Station	Field or tap	Load [MW]	Supply restoration time
Welschbillig	Transformer 11	2.8	19:58
Welschbillig	Transformer 12	2.4	19:58
Keltenweg (SWT)	Transformer 12	14.0	20:00
Tarforst	Transformer 11	no data	20:00
Tarforst	Transformer 12	7.5	20:00
Keltenweg (SWT)	Transformer 11	no data	20:00
Beilingen	Transformer 11	7.1	20:09
Beilingen	Transformer 12	5.4	20:09
Kyllburg	Transformer 11	3.9	20:10
Ehrang (SWT)	Transformer 11	13.6	20:15
Ehrang (SWT)	Transformer 12	10.0	20:15
Kuhnenstr. (SWT)	North (Transformer 12)	7.4	20:15
Kuhnenstr. (SWT)	South (Transformer 11)	14.0	20:15
Hermeskeil	Transformer 11	4.5	20:16
Hermeskeil	Transformer 12	2.1	20:16
Mandern	Transformer 11	3.0	20:18
Mandern	Transformer 12	3.2	20:18
Gusterath	Transformer 11	1.0	20:19
Gusterath	Transformer 12	2.7	20:19
Wintrich	Transformer 12	no data	20:25
Wintrich	Transformer 11	4.8	20:25
Konz	Transformer 11	4.4	20:59
Konz	Transformer 12	7.8	20:59
Thalfang	Transformer 11	5.6	21:01
Trier	Transformer 12	9.8	21:19
Trier	Transformer 13	14.5	21:19
Trier	Transformer 11	no data	21:19
Detzem	Transformer 11	1.0	21:24

After a thorough check of the Saar Nord line, which led to no apparent findings, the line was successfully connected at 21:13 hours. The supply was finally restored to the Trier region on the downstream distribution network level at around 21:24 hours.

4 Compliance with (n-1)-security

The (n-1)-criterion is normally applied as a security standard in UCTE national grid operation (cf.: UCTE Operational Handbook; VDN TransmissionCode 2003). This principle states that an individual network element may fail without this failure disturbing the safe operation of and supply to the overall network. The principle is applied throughout the world and is state-of-the-art in order to guarantee an adequate supply security.

In the event of the failure of any operating resource the stationary operating currents on the remaining network elements are decisive for (n-1)-security. On the basis of the loads and power supplies at the time of the fault, a stationary current flow of 1,212 A was calculated for the Osburg line in the event of a failure of the Saar Nord line (RWE load flow calculation using the archived data record of Thursday, 02.09.2004, 16:45 hours). This value correlates with the measurements of the protection equipment in Uchtelfangen after tripping of the Saar Nord line (see Fig. 6). This value is lower than both, the pre-set release value for the Osburg line of 1,275 A and the actual release value of 1,242 A. The calculations and measurements of the protection equipment in Uchtelfangen thus prove that the network was in an (n-1) secure status with respect to the failure of the Saar Nord line.

Nor is there any violation of the (n-1) security with the second calculated variant, the failure of the Osburg line that can carry a higher load.

The simulation for the failure of the feeder transformer in Uchtelfangen also shows non-critical results since the load for the 220 kV group can be largely covered by an infeed from the two power plants in Ensdorf and Weiher. Nor do the failure calculations for the transformer in Weissenthurm come up with any critical results.

The relevant failure simulations thus prove that, before the fault, there was operational (n-1)-security for the 220 kV network group Trier as regards the relevant failure scenarios - in particular with respect to the failure of the Saar Nord line. A dynamic consideration is not needed as, with a stationary operating current below the release value, the current would fall below this value during network oscillations within the second half-wave of the oscillation.

The results of these subsequent calculations of the (n-1)-security are also confirmed by the results of the online security calculations (SIRE) that are carried out regularly at the

dispatching centre . The compliance with specified security margins to the limits of the (n-1)-security is checked within the scope of these calculations. SIRE determines the current system condition (topology, feed of active and reactive power), then simulates the "failure" of all individual network elements in succession and finally calculates the current in the remaining current circuits with the held of a load flow calculation. These simulated load flows (active power, reactive power, current and voltage) are then compared with a list of the limits set in the SCADA system. A so-called specific I-finding is given if a current occurs in one of the remaining network elements that is greater than the respective limit value set in the SCADA system after a simulated failure of an operating resource. This value is below the maximum permissible operating current and is an early warning indicator that the current has dropped below a set reserve margin to the permissible operating limits of the network and thus to the (n-1)-security. An I-finding is thus a warning for the operational management engineer in the dispatching centre that the line is still within the safe range but is being operated with only a small reserve. In the event of an I-finding it is the responsibility of the line manager to assess the current network situation and if necessary prompt preventive measures to guarantee the network security and increase reserves.

As concerns the Osburg line, this max. permissible operating current is 1,275 A, whereas the limit value for an I-finding as set in the SCADA system is 1,200 A. While the SIRE initiated at 16:35 hours showed no I-finding, the next cyclic SIRE initiated at 16:50 hours would have resulted in an I-finding for the Osburg line on the basis of the data record archived at 16:45 hours due to a slight transgression of the limit value (transgression of the aforementioned limit value by 12 A). This violation of the security margin would have been cause enough for the dispatching centre to take suitable measures to enlarge the security reserves, e.g. a change in the machine employment in the Vianden power plant. All the same, the (n-1)-criterion would not have been violated even without these measures.

5 Immediate measures taken and further consequences

The following prompt action was taken and further investigations initiated on the basis of the analysis of the course of the fault and network restoration:

- RWE Transportnetz Strom replaced the corresponding protection equipment in Quint with digital protection equipment as an immediate measure directly after the fault.

- The planned additional transmission transformer in Niederstedem, whose installation began in August 2004, will be given priority according to the resolved network concept. Apart from safeguarding the forecast increase in load in Luxembourg in the long run, this will also mean a greater operational flexibility for network operation.

- At the initiative of the Department of Economic Affairs in Luxembourg, a study group was commissioned to investigate whether a significant improvement in supply security could be achieved by interconnecting the CEGEDEL network with the neighbouring networks. This study group is also investigating whether the mutual assistance between SOTEL and CEGEDEL in the event of a fault can be improved.

- The automatic stepping of transformers in weakened or high-load networks can increase the risk of a voltage breakdown. Investigations are being carried out into how the step switch could be blocked from a central station to prevent a possible voltage breakdown.

- Based on the experience gathered during the fault, the existing RWE-internal communication and co-ordination processes will be expanded and intensified.

- Further experience such as the partial collapse of the mobile phone network during the fault have prompted RWE Transportnetz Strom to investigate the communication technology in the event of faults.

6 ANNEXES

Annex 1: Power flows on the tie lines from RWE to CEGEDEL (recordings from the digital data recorder LEM)

Annex 2: Proportional fault currents and voltage drops on the lines between CEGEDEL and RWE

Annex 3: Report on the use of the Vianden power plant

Annex 4: RWE: report on laboratory tests of the protection equipment “Osburg line”

Annex 1: Power flows on the tie lines from RWE to CEGEDEL (recordings from the digital data recorder LEM)[2]

Line Trier – Heisdorf:

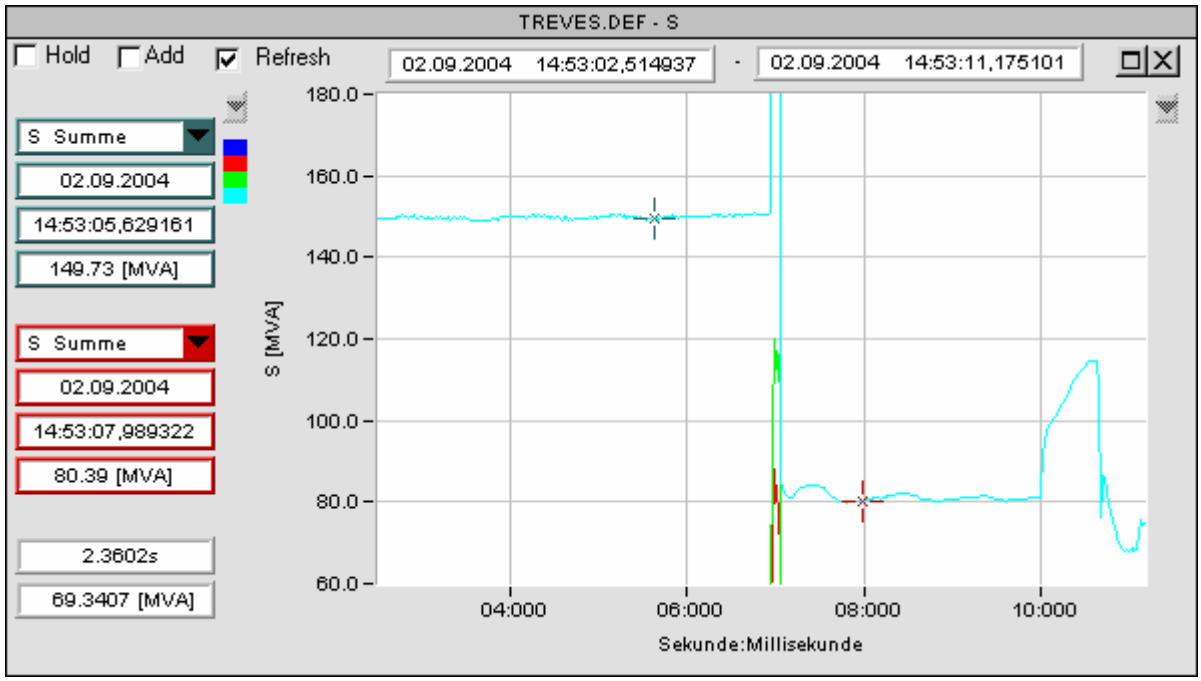

Figure 1: Apparent power on the Trier – Heisdorf line

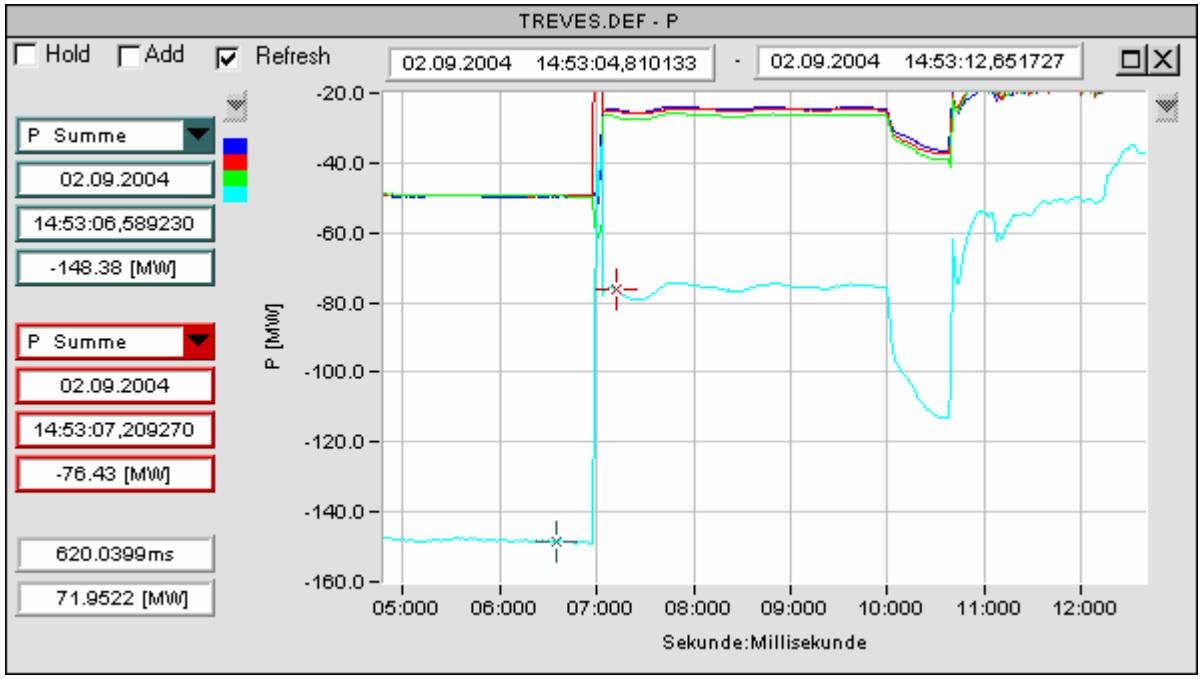

Figure 2: Active power on the Heisdorf - Trier line

[2] The time in the diagrams is not synchronised; data in UCT

Quint – Heisdorf line:

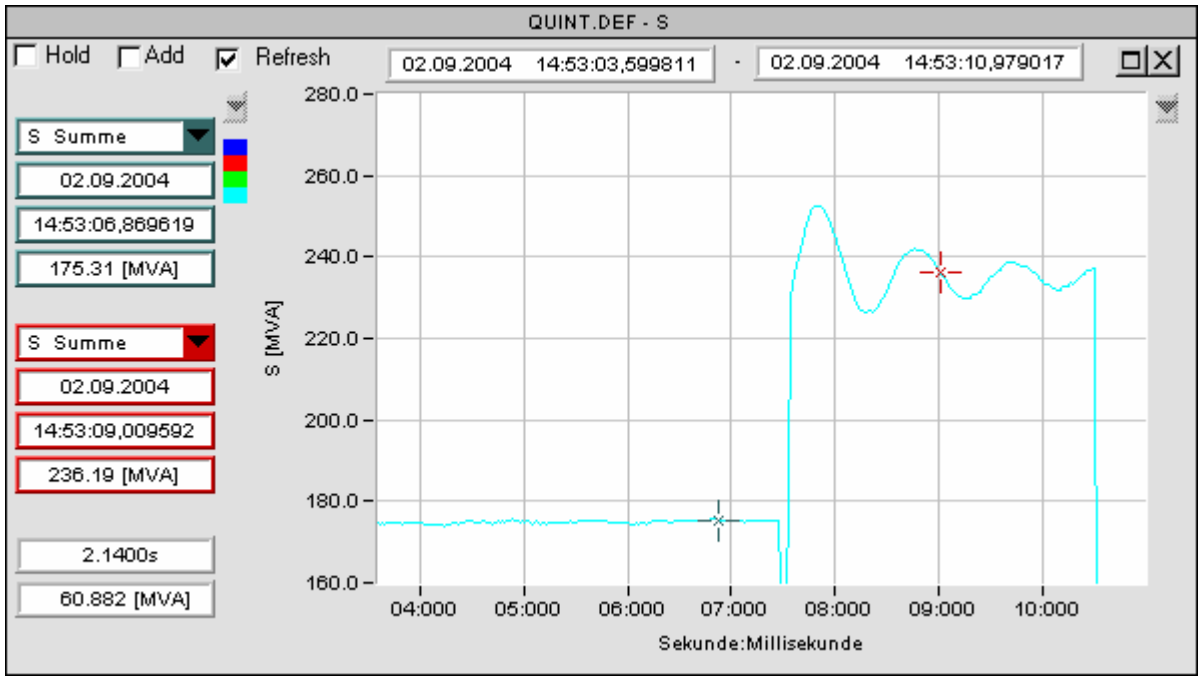

Figure 3: Apparent power on the Heisdorf - Quint line

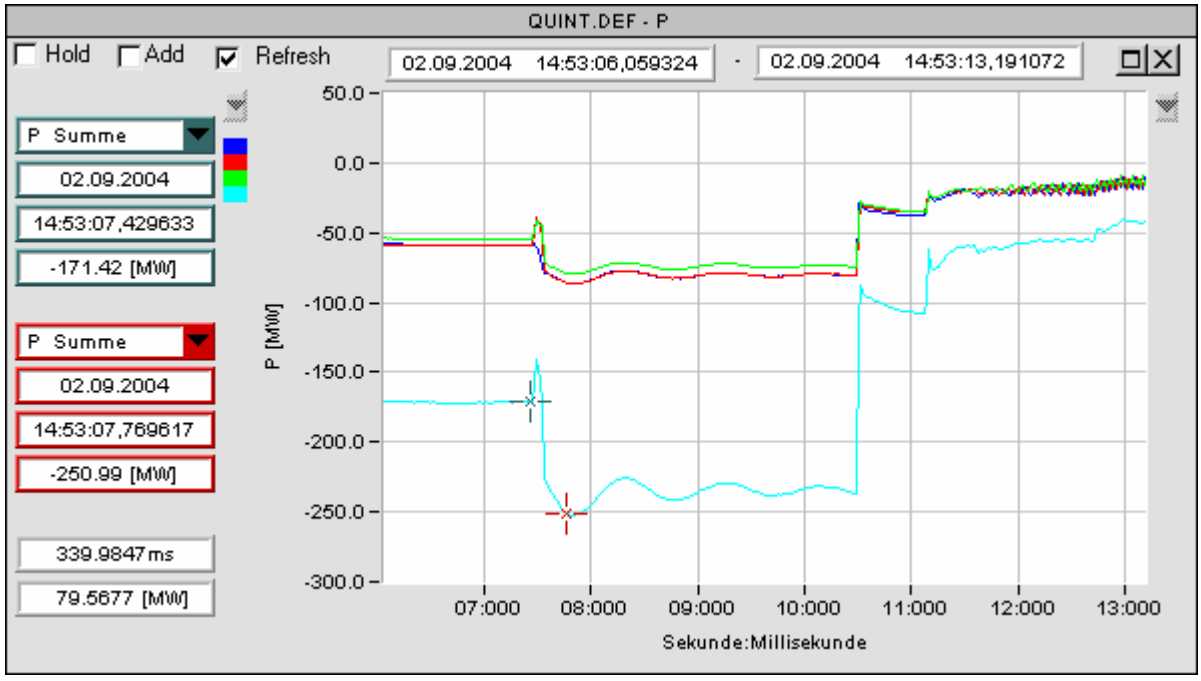

Figure 4: Active power on the Heisdorf - Quint line

Bauler – Flebour line:

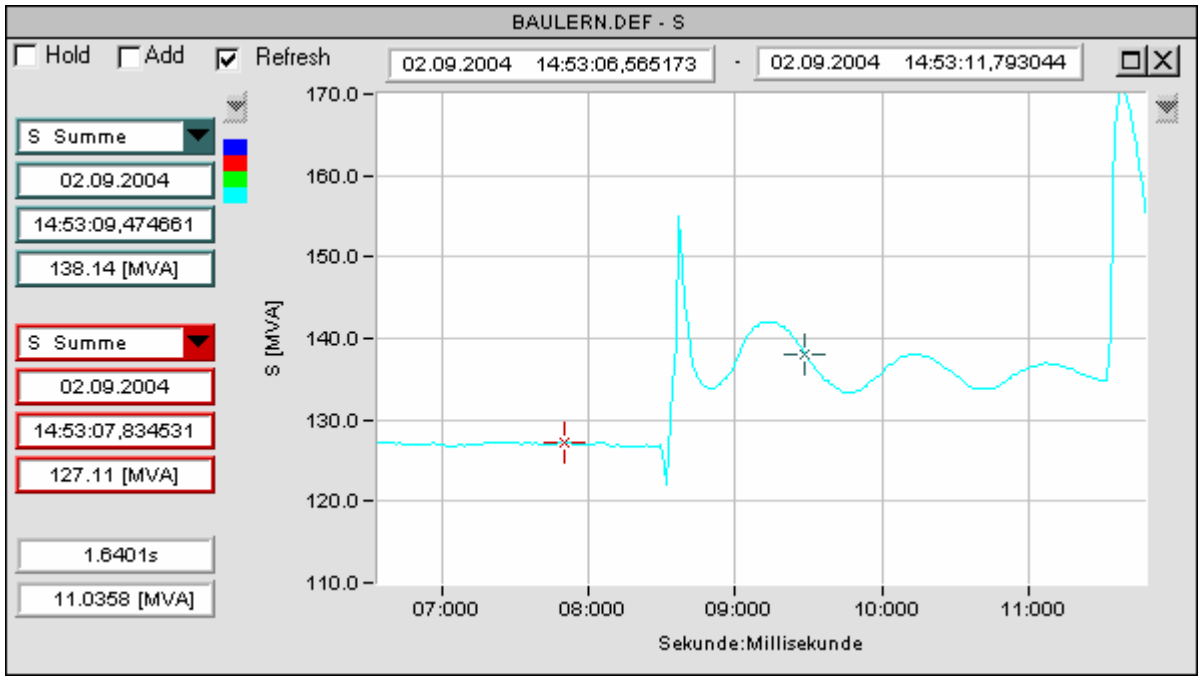

Figure 5: Apparent power on the Bauler - Flebour line

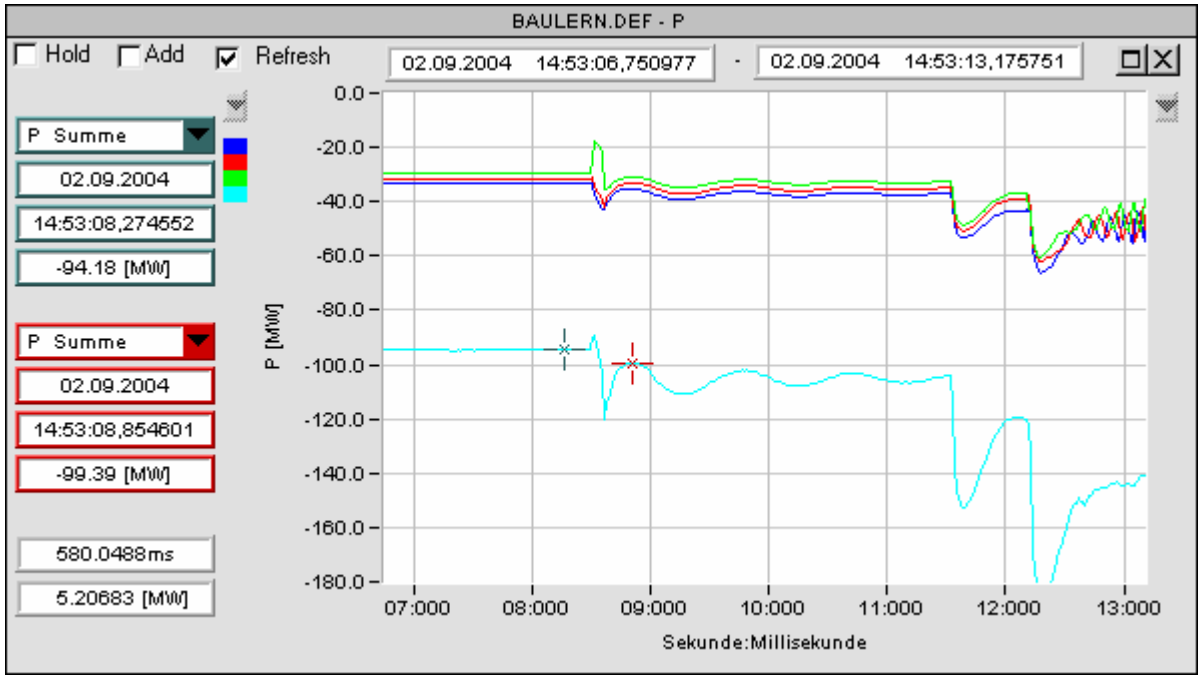

Figure 6: Active power on the Bauler - Flebour line

Bauler – Roost line:

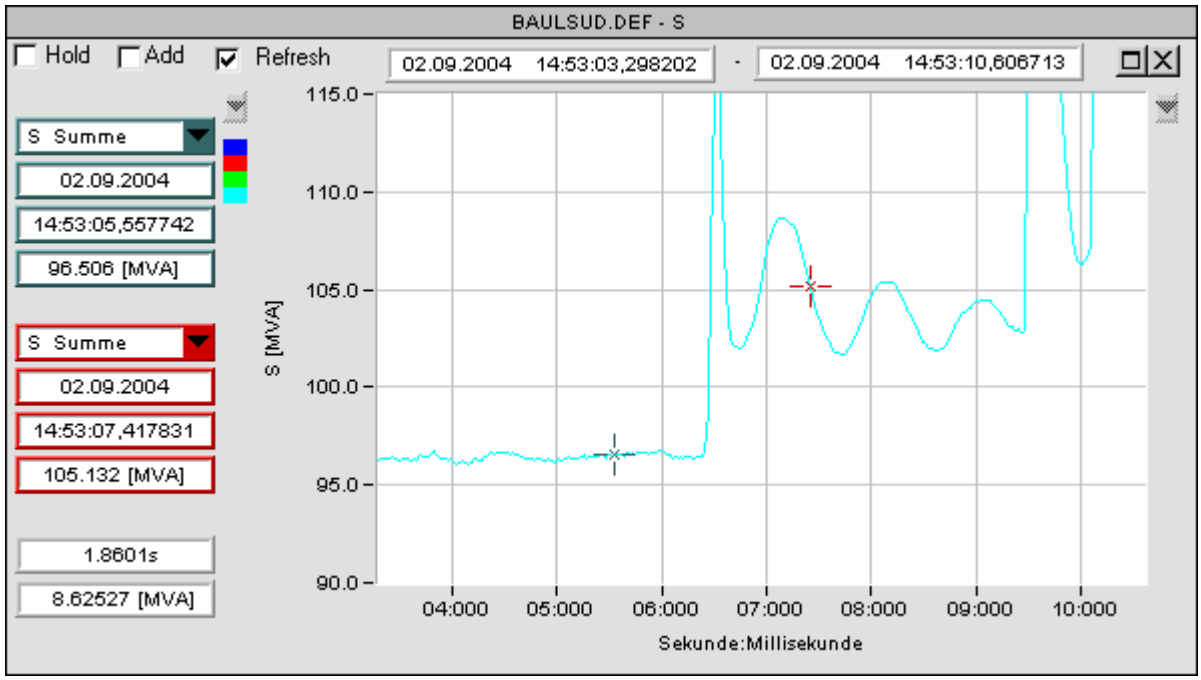

Figure 7: Apparent power on the Bauler - Roost line

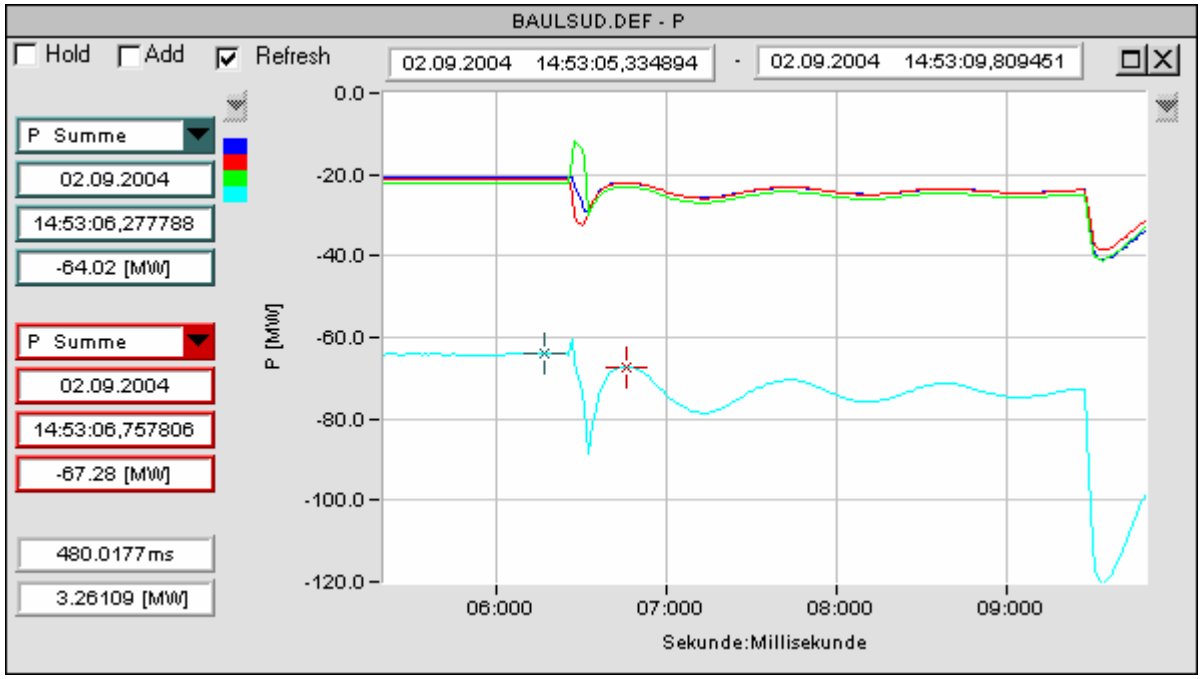

Figure 8: Active power on the Bauler - Roost line

Annex 2: Proportional fault currents and voltage drops on the lines between CEGEDEL and RWE

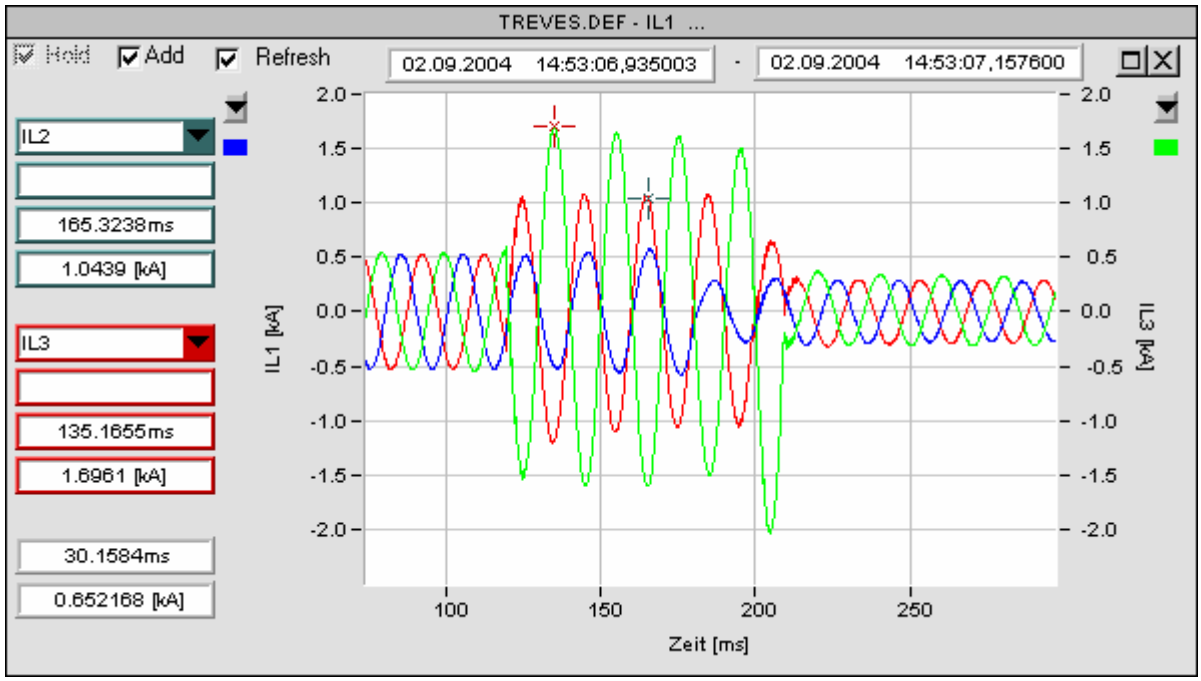

Figure 9: Short-circuit currents on the Heisdorf - Trier line

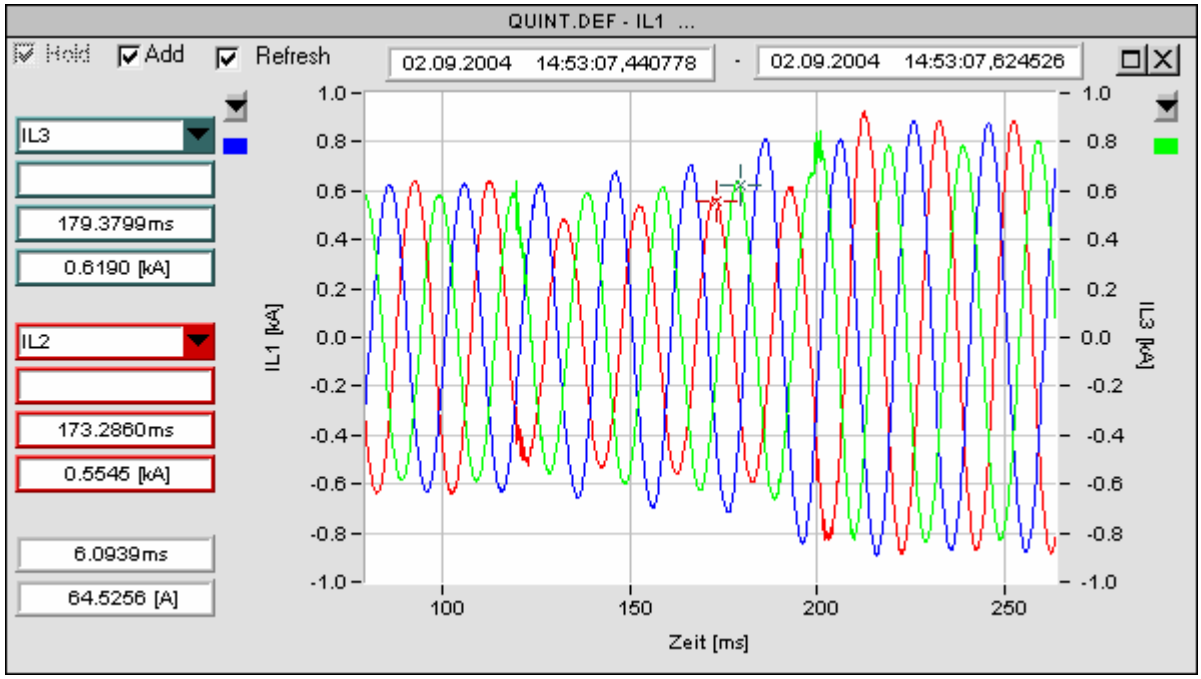

Figure 10: Short-circuit currents on the Heisdorf - Quint line

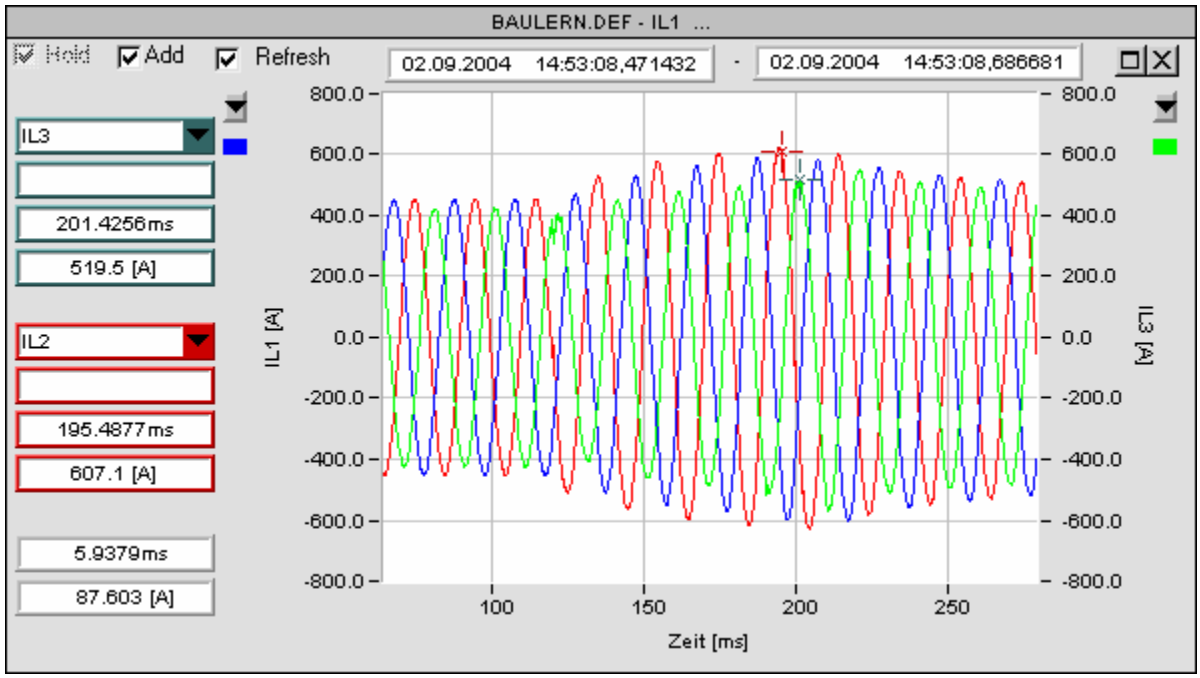

Figure 11: Short-circuit currents on the Flebour - Bauler line

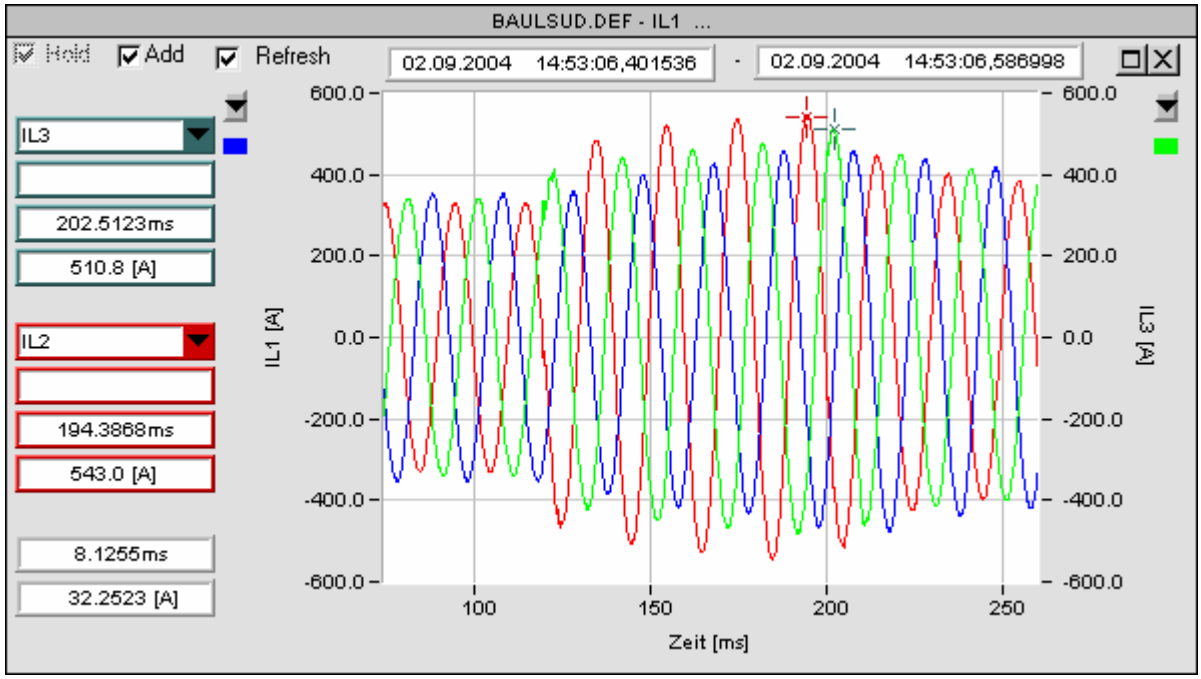

Figure 12: Short-circuit currents on the Roost - Bauler line

Annex 3: Report on the use of Vianden power plant

SOCIETE ELECTRIQUE DE L'OUR Vianden, 07.09.04
Centrale de Vianden
3109-3/FA

Report on fault in RWE network on 02.09.2004

At the time of the fault on 02.09.04 at 16:51 hours, the machines at Vianden power plant were in the following operating states:

On line 1a:	M1 in standby
	M 2 in phase shift mode 57 MVAr
	M 10 (at standstill, commissioning of the new transformer)
On line 2b:	M 3 in pumping mode 68 MW, 53 MVAr
	M 4 in phase shift mode 58 MVAr
	M 5 in phase shift mode 43.5 MVAr
On line 3c:	M 6 in phase shift mode 52 MVAr
	M 7 in phase shift mode 62 MVAr
On line 4d:	M 8 in phase shift mode 46 MVAr
	M9 in standby

At 16:45 hours, machine 2 was started on line 1a and machine 8 on line 4d in the phase shifter on the instructions of the system managment Networks at Brauweiler.
Machine 3 was run down to a standstill at 16:51:14.836 hours due to underfrequency at 49.6 Hz (normal stoppage). There was also a normal shutdown command at 16:51:19.333 hours through a drop in voltage (70% Un, 0.5 sec delay, only applies for pumping mode).
Machines 2, 4, 5, 6, 7, 8 were run down to standstill at 16:51:19.742 hours through a drop in voltage. The 4 220 kV lines were without voltage at this time.
A few minutes after the fault the 2nd dispatcher in Brauweiler informed us that the 220 kV lines would soon be carrying voltage and asked whether a turbine could be provided on line 2b.
The 1st control station officer then requested the mechanic in the cavern to make machine 3 ready for operation again over the paging system.

At 17:02 hours machine 3 was once again ready for operation and was started up in TU mode. At 17:04 hours the generator was live, but the parallel switchgear did not switch because the 220 kV voltage was no longer available at this point in time.
The machine was then stopped again on the instructions of the 2nd dispatcher.
At 17:25 hours machine 3 was run up in phase shift mode, at 17:28 hours in TU mode with 100 MW. At 17:30 hours machine 7 was also run up in TU mode to 100 MW.
At the time of the fault the two machines in Lohmühle supplied the 6 kV own requirements network with full power. The 13.8/6 kV power switch for the own requirements feed tripped at 16:51:15.151 hours due to an underfrequency.
The two machines in Lohmühle took over the own requirements supply for the power plant with no problems. The two house machines were also started for security reasons.
At 22:21 hours the own requirements feed was switched back to line 2b.

SOCIETE ELECTRIQUE DE L'OUR
Centrale de Vianden
Signed

Fernand Zanter Francis Angelsberg

Annex 4: RWE: report on laboratory tests of the protection equipment “Osburg line”