Special Publication

Operation and Monitoring of MSCDN-Systems

The popularity of Mechanical Switched Capacitor with Damping Network (MSCDN) systems in German transmission grid is growing massively. This is especially caused by the changing tasks of transmission grid due to the fact of increased utilization, not only during peak periods and the loss of regionally distributed reactive power generation capability from fossil fuels or nuclear power stations as voltage backup. In addition, the relatively simple structure of the systems also meets the demand for cost-effective operation.

Because of the increasing number of MSCDN-systems, reliable ways for monitoring their operation and thus methods for the early and as accurate as possible detection of faults in the systems had to be found. Especially regarding the large number of implemented individual capacitors. Here the operational information system for MSCDN-systems cooperatively developed by TenneT TSO GmbH Bayreuth (TenneT) and A. Eberle GmbH & Co. KG Nuremberg takes effect.

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TenneT is Europe´s first cross-border grid operator for electricity. With approximately 20.000 kilometres of (Extra) High Voltage lines and 36 million end users in the Netherlands and Germany we rank among the top five grid operators in Europe. Our focus is to develop a north-west European energy market and to integrate renewable energy.

1 MSCDN-Systems

Since 2008/2009, TenneT has been operating three MSCDN-systems along the north-south corridor between Hamburg and Kassel. Currently there are two more systems between Kassel and Ingolstadt under construction, which should go into operation in march 2013. The primary task of the mechanically switched capacitor bank is the feeding of reactive power into the power grid. The objective is on the one hand to maintain the voltage under heavy load and on the other hand to protect against overvoltage at low loads due to the automatic, voltage-dependent activation and deactivation of the compensation system.

Through the structure‘s auxiliary capacitor series-connected coil and a resistor connected in parallel with the auxiliary capacitor and the coil, the inrush current during power-up can be reduced, a network damping created and harmonics filtered (c-type filter). In addition to voltage stabilisation, MSCDN-systems also contribute to improve the grid dynamics.

Detailed information on the operation and construction of the systems can be obtained from the publications „Kompensationsanlagen im 380-kV-Netz“ [I] and „Mehr Energie von Nord nach Süd“ [II]. An example of an MSCDN-system is shown in Figure 1.

Figure 1: 300 Mvar / 380 kV MSCDN-System

-L1: Filter circuit reactor
-R1: Filter circuit damping resistor
-T12 and -T13: Unbalance current transformer
-C1: Main capacitor
-C2: Auxiliary capacitor
-Q52: Earthing switch
-T1: Primary current transformer
-Q0: Circuit breaker

1.1 Capacitor bank

The main focus on these systems is the main and auxiliary capacitor ($-C_1$ or $-C_2$). For a better comprehension, these definitions must be used in the following description:

- Capacitor element: A component consisting of two electrodes separated by a solid dielectric.
- Capacitor unit: An arrangement of one or more capacitor elements in a housing filled with liquid dielectric and insulated lead-out terminals („pot capacitor").
- Capacitor rack: A rack is a mechanical structure in which all of the capacitor units have the same electrical potential.
- Capacitor stack: A mechanical structure consisting of multiple capacitor racks at different potentials and on separate insulators.
- Capacitor bank: Capacitor network of capacitor stacks with the main capacitor $-C_1$ and the auxiliary capacitor $-C_2$.

The TenneT MSCDN-systems have, with one exception, a power of 300 Mvar at a voltage of 380 kV. This reactive power is supplied through the $-C_1$ with 6.61 µF main capacitor. This capacity can, at a voltage up to 440 kV (t ≤ 30 min.), only be guaranteed by a combination of capacitor units connected in series and in parallel. Within a capacitor unit there are also multiple capacitor elements, which are aligned in a in series and in parallel sequence. Figure 2 shows an example of the construction of a capacitor unit.

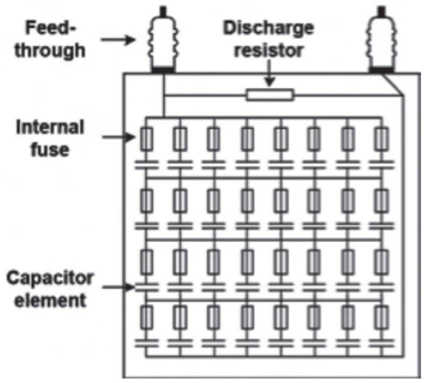


Figure 2: Construction of a capacitor unit

The task now is to detect faulty capacitor units. To this end, both the main capacitor and the auxiliary capacitor are constructed as an H-bridge circuit, each with an unbalance current transformer (–T12 and –T13). If you consider one phase of the main capacitor, depending on the manufacturer, there are approximately 200 capacitor units, each with 50 capacitor elements in multiple capacitor racks, which are arranged into a sub-group of capacitor stacks. The failure of one of these approx. 10,000 capacitor elements per phase, depending on where it is installed, results in a change in the unbalance current of approx. ± 50 mA. The loss of a single element does not lead to a system shutdown, since multiple elements in a capacitor unit can fail before an unacceptable voltage load occurs. Individual failures must however be logged, because the failure of elements in different bridge arms can neutralize themselves. If there is continuous monitoring, sign changes or jumps in the unbalance current are recognisable and can easily be recorded.

2 Protection - Monitoring Barrier

In terms of protection, differential, overcurrent and circuit breaker failure protections are provided for the whole system. Individual components, especially the capacitors and resistors are also equipped with additional protective equipment such as capacitor-unbalance, overvoltage, fundamental oscillation overcurrent, RMS-overcurrent, thermal overload and phase unbalance protection. These protection functions are sufficient for guaranteed operation of the system, but not for early fault detection, monitoring component loads and their trend documentation, as well as the shown problems of unbalance current. The already mentioned MSCDN monitoring was developed for this.

3 Monitoring

As well as the mandatory monitoring of the unbalance value of the main and auxiliary capacitor for monitoring the capacitor elements and the fault location described in Section 2, the following functions are integrated:

- Verifying the functionality of the synchronised on and off switching
- Recording the on and off switching operations
- Recording the maximum current amplitude during power-on
- Monitoring the load on the filter resistors
- Logging of the entire duty cycle and the reactive energy produced in the process

In order to realize these functions a minimum of three voltage and eleven current inputs are required. The exact allocation of the individual channels and the connection principle of the monitoring system are given in Section 3.1 with Figure 3.2.

3.1 Connections

The signals for the voltage measurement are connected by the busbar voltage replication because there are no voltage instrument transformers installed in the MSCDN-bay. Standard inductive or capacitive types are sufficient due to the fact that the focus for the monitoring is not on power quality measurements.

In addition to the operational currents I_{L1T1} to I_{L3T1} other currents such as the unbalance current in the main and auxiliary capacitors I_{L1T12} to I_{L3T12} and I_{L1T13} to I_{L3T13}, the transient current in the resistor branch of the phase L_2 I_{L2T14} and I_{L2T10}, and the current in the 50 Hz oscillating circuit are set as input signals. All current signals come from the field of the MSCDN-system. To trigger the on and off switching operations in the system, the following binary signals are also set:

- Main protection triggering
- Backup protection triggering
- ON command
- OFF command

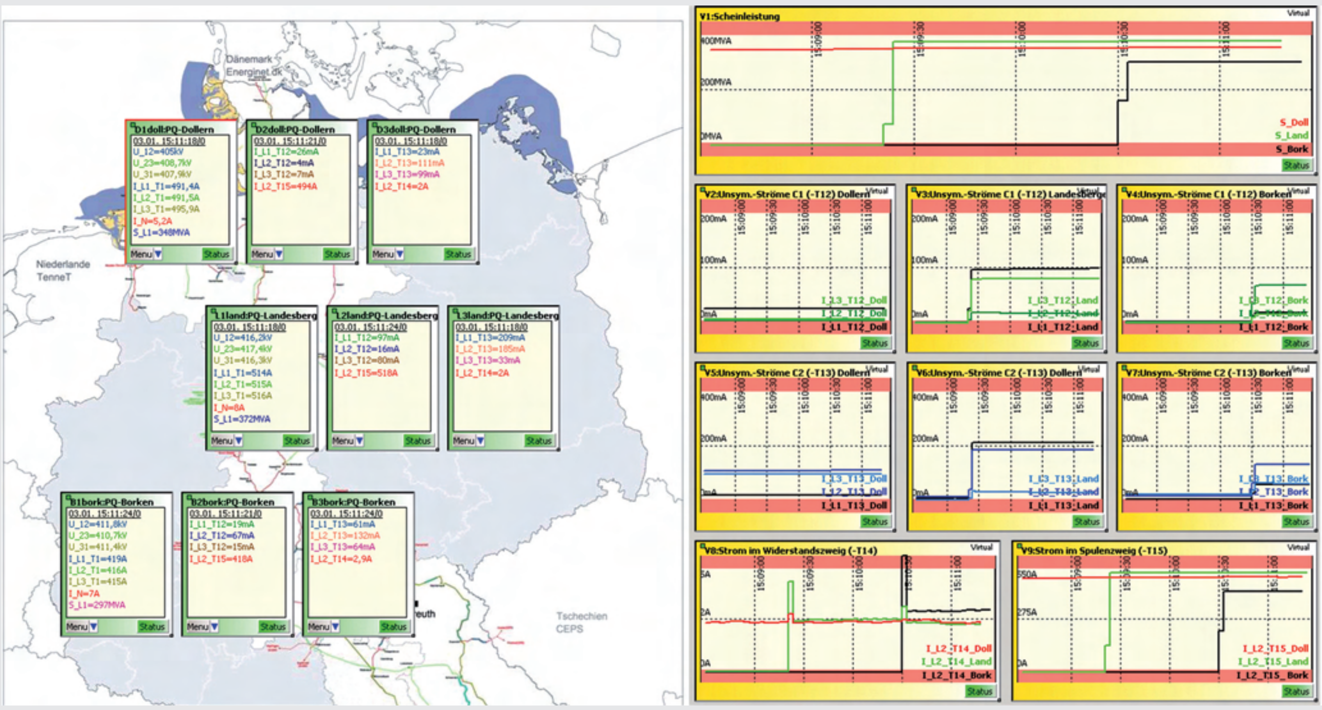
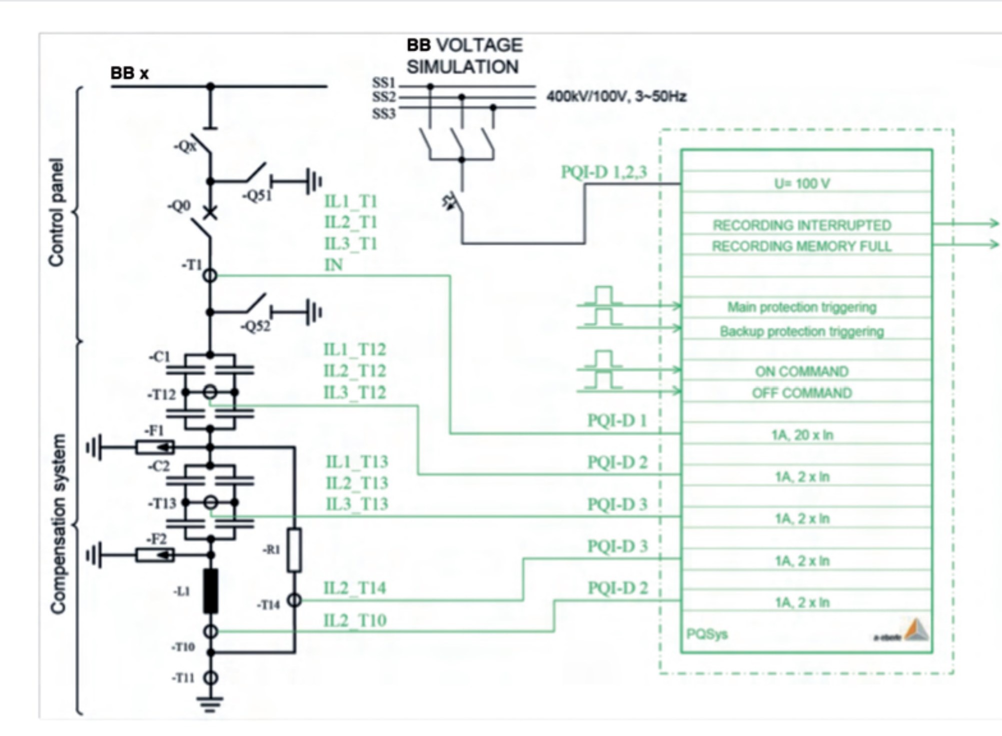


Figure 3.1: Main screen of the monitoring system with alphanumerical and graphical real-time display (3-second average value)



SSx: Busbar No. x (x=1…3)
-Qx: BB Disconnecting switch No. x (x=1…3)
-Q51: Earthing switch
-Q0: Circuit Breaker
-Q52: Earthing switch
-T1: Primary current transformer
-T12, -T13: Unbalance current transformer
-C1: Main capacitor
-C2: Auxiliary capacitor
-L1: Filter circuit reactor
-R1: Filter circuit damping resistor
-Fi: Overvoltage arrester

Figure 3.2: Single line diagram of an MSCDN system with connection principle I monitoring system PQSys (3 x PQI-D (3 x U, 11 x I) and REG-COM (TCP/IP))

3.2 Device selection

Due to the special application area, very flexible parameterizable measuring instruments and a clear, customer-specific, but also customizable application software must be used for monitoring the MSCDN-system. In addition, all the requirements for the use of the devices in energy installations must be met. All devices must have centralised data storage with a remote reading capability and remote parameterization capability connected to it using the TCP/IP protocol. The required number of input channels inevitably leads to the use of multiple PQI-D devices for a single MSCDN-system that have an internal trigger and timing bus so that the signals from different devices can be used together. Furthermore, the construction of the unit must be very compact (Figure 3.3).

Figure 3.3: PQSys monitoring system (3 x PQI-D and REG-COM (TCP/IP))

3.3 Parameterization

Remote parameterization is generally used; time synchronization is done using an NTP server over the IP-network. To obtain long-term sustainability of the monitoring functionality, a suitable selection of the hardware-based functions and memory on the PQI-Ds and a reasonable server selection must be made. Because some of the data for the automated MSCDN report is only available for a certain time in the PQSys detection system, part of the analysis is already carried out in the device. Special evaluation algorithms are required that are not part of the standard measurement device, but which will be executed simultaneously with the data becoming available online. These algorithms are available as free programs stored directly in the measurement system and run continuously in the background. The calculated data is stored in the event memory of the device with other parameters and are still available after several months.

In principle, all necessary device data is transferred immediately to an SQL database, where the information is then saved and available virtually for an unlimited period.

In the following table examples of some of the important measurements and their evaluation are described.

Examples for the evaluation of the parameters needed for the MSCDN monitoring automated report

Operating current I_{T1}	Used to determine the duty cycle of the system. The measured value is obtained from the 3-second averages of the device. When exceeding and falling below a threshold, the switch-on and switch-off will be registered.
Reference current I_{L1T1}	The phase of the operating current I_{L1T1} is used as a reference for evaluating the phase angle in the main and auxiliary capacitor.
Maximum current I_{T1max}	The largest 10-minute average during each duty cycle.
Reactive power Q	The average calculated from the 10-minute averages during the whole duty cycle.
Reactive energy WQ	Calculation of the difference between the reactive power when switched off compared to the switching-on point (these values are exact to the second recorded by the so-called background programs (MSCDN-specific programming) detailed above).
Maximum Amplitude of the transient response I_{T1peak}	The maximum value of the current of an oscilloscope fault recorder (10.24 kHz sampling frequency) across all phases at the moment of switching on. This recording is triggered by a binary input.

3.4 Functional Description

In principle, all the hardware and software functions of the PQI-D devices and WinPQ software such as fault record capture, RMS recorder, storage and display of 3 s-, 10 min average values, etc. can be used for monitoring. In addition, the main events and relevant operating data relating to an arbitrary starting date will be evaluated weekly, monthly, semi-annually or annually, depending on the required parameters, the information is obtained from the SQL database on the server or the hardware-based event list (see Table 1). As a result, the user receives a PDF-file that can be created manually or by an automatic Windows task at any intervals, stored and sent via e-mail (see Section 3.4.3). For further explanation of the selected functions the following section gives example descriptions.

3.4.1 Oscilloscope Function

First of all, the activation and deactivation of the MSCDN-system is recorded using the binary signals received from the system control in the PQSys system oscilloscope record at a sampling rate of 10.24 kHz (100 µs). However, any other event (dU/dt, dI/dt, df/dt, overcurrent, overvoltage, etc.) can be set as a trigger. All the signals produced in the monitoring will be recorded. As an example, the operating current at switching on is shown in Figure 3.4. It is well recognized that phase selectively and synchronously with the aid of a circuit breaker - synchronous switching device, shortly after the zero crossing of the voltage, the amplitude of the current increases. The activation delay is also immediately apparent through the running times and synchronous switching device, if the binary signal of the command is also considered.

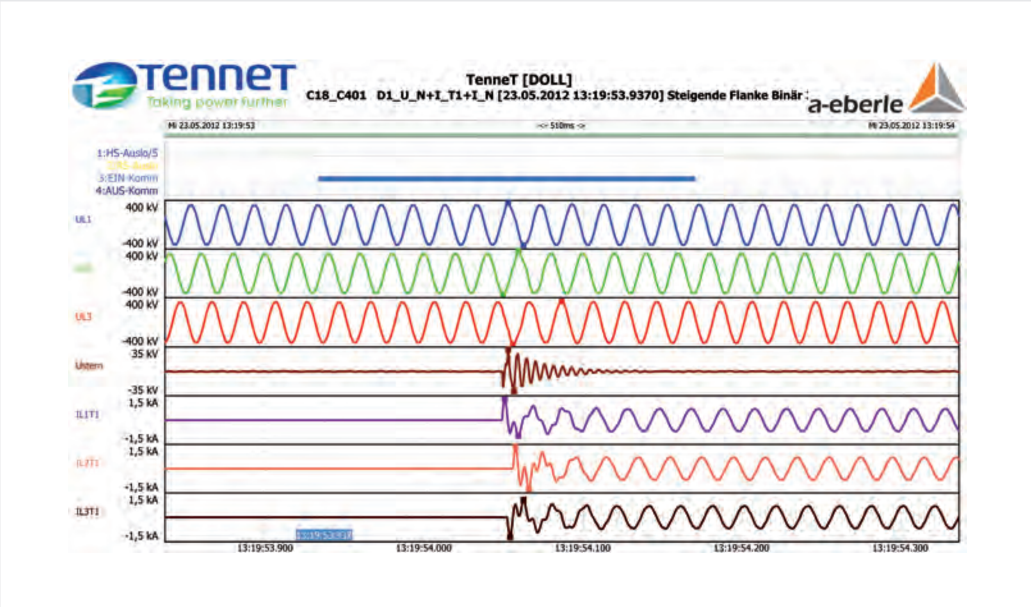


Figure 3.4:
Typical switch-on operation of an MSCDN-system (WinPQ visualization)

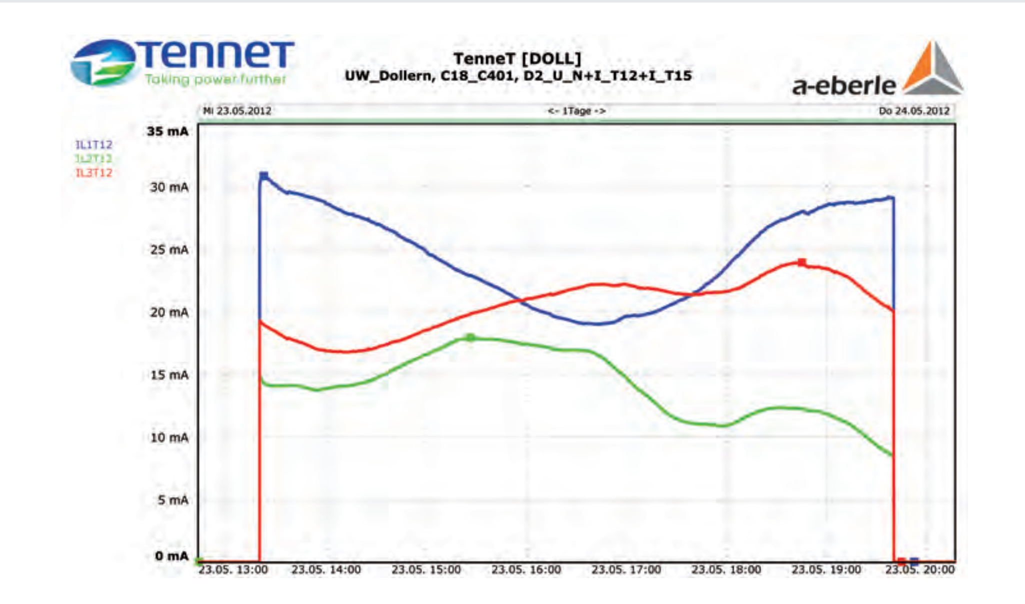


Figure 3.5:
Typical behaviour of the unbalance current in the main capacitor (WinPQ visualization)

3.4.2 Permanent recording

(3 s / 10 min average values)

In addition to the oscilloscope, a permanent record is realized. The 3 s- and 10 min-mean values are selected which, depending on the server capacity, can be stored for several years. Again, all of the signals connected to the monitoring system are recorded. Figure 3.5 shows an example of a typical history of the unbalance current in the main capacitor. This can run completely separately as long as no jumps of several mA occur (failure on a capacitor element). The change in the current over time is mainly dependent on the operating voltage and the heating of the capacitors and thus on the harmonics and the environmental conditions (sun, wind and rain).

3.4.3 Automated MSCDN Report

(operating data analysis)

This function can be used manually or automatically, starting from an arbitrary starting date over flexible evaluation periods. The main functions are the recording and trend monitoring of the unbalance currents of the main and auxiliary capacitor, the fault location and monitoring the maximum transient oscillation amplitude (monitoring of the synchronized switching). All operational events are clearly displayed in graphical and tabular form, so the essential information about the operating status of the system can be obtained in no time.

These and other functions are shown in Figure 3.6 and Figure 3.7.

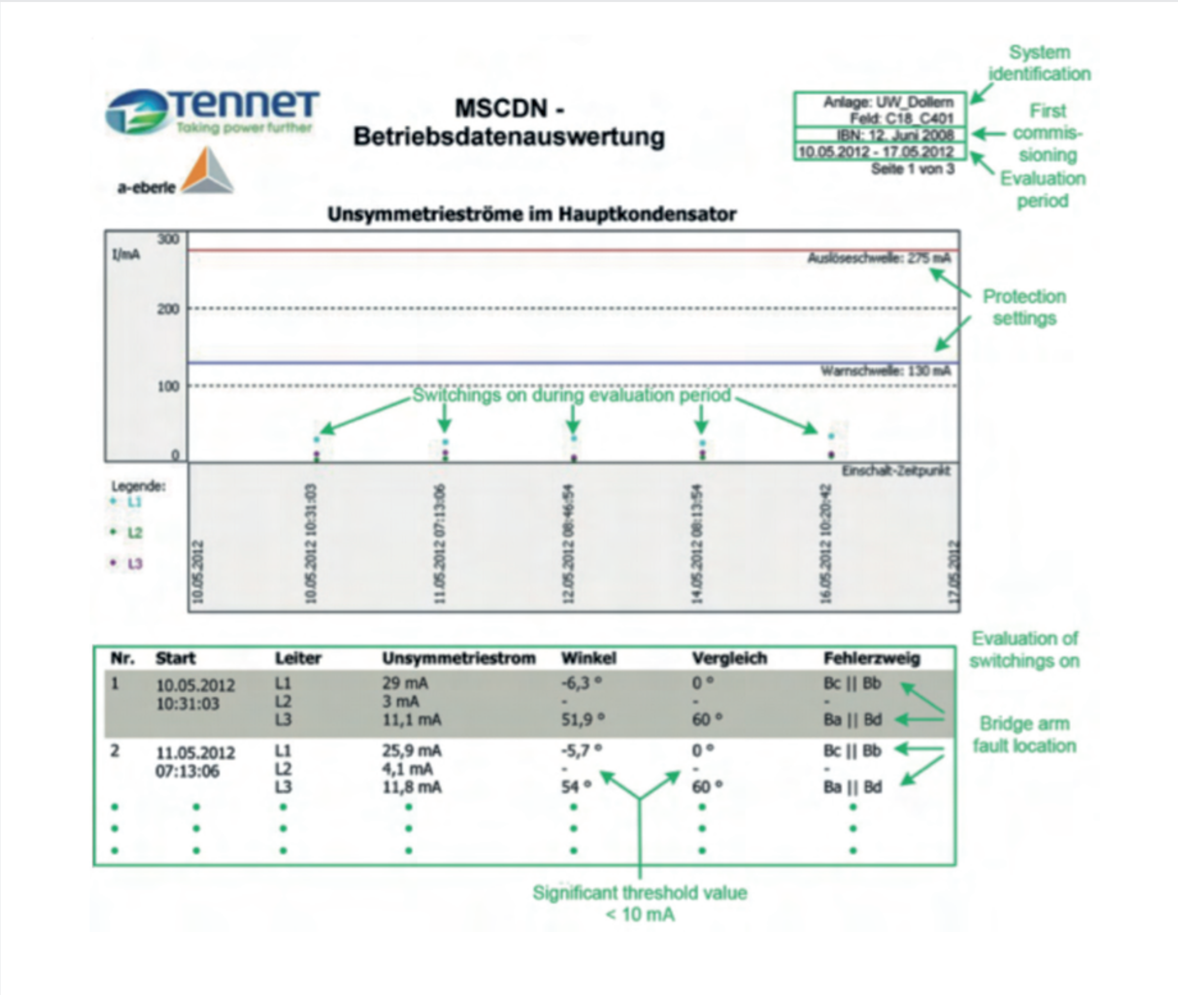
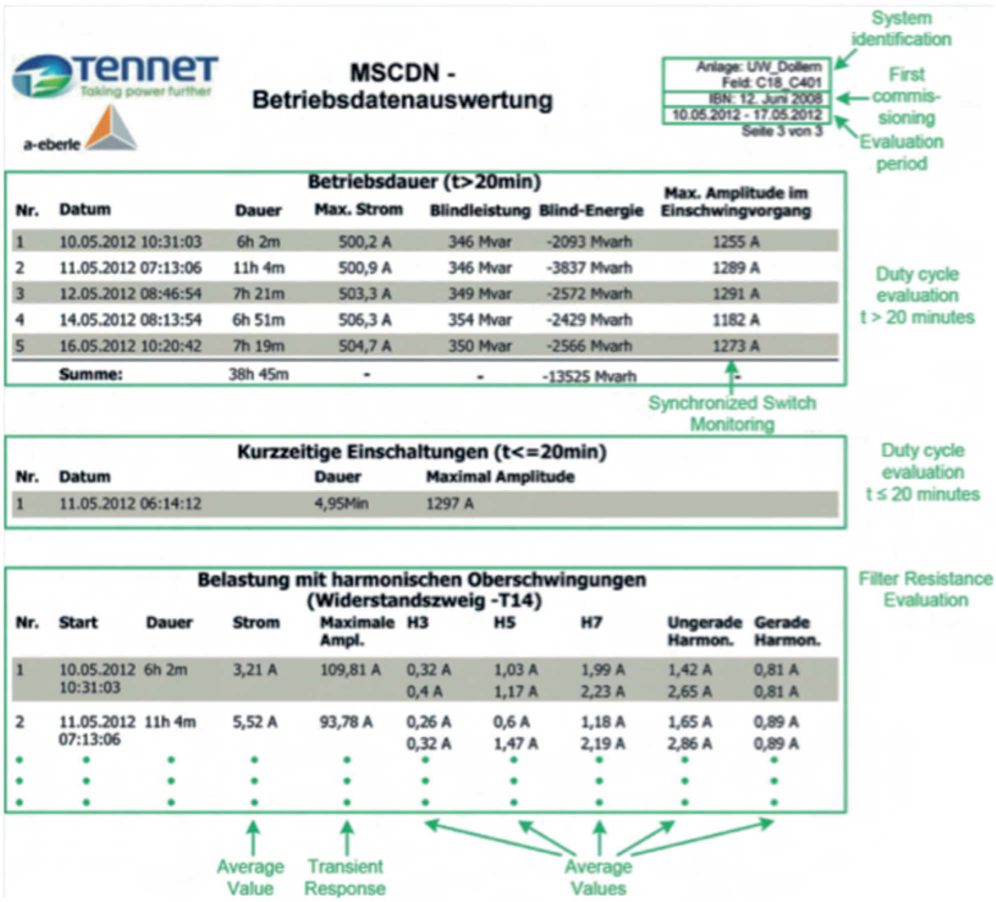


Figure 3.6: Graphical and tabular analysis of the natural unbalance C_I, example from the automated MSCDN Report (Visualization software WinPQ)



MSCDN - Betriebsdatenauswertung

Anlage: UW_Dollern
Feld: C18_C401
IBN: 12. Juni 2008
10.05.2012 - 17.05.2012
Seite 3 von 3

Betriebsdauer (t>20min)

Nr.	Datum	Dauer	Max. Strom	Blindleistung	Blind-Energie	Max. Amplitude im Einschwingvorgang
1	10.05.2012 10:31:03	6h 2m	500,2 A	346 Mvar	-2093 Mvarh	1255 A
2	11.05.2012 07:13:06	11h 4m	500,9 A	346 Mvar	-3837 Mvarh	1289 A
3	12.05.2012 08:46:54	7h 21m	503,3 A	349 Mvar	-2572 Mvarh	1291 A
4	14.05.2012 08:13:54	6h 51m	506,3 A	354 Mvar	-2429 Mvarh	1182 A
5	16.05.2012 10:20:42	7h 19m	504,7 A	350 Mvar	-2566 Mvarh	1273 A
	Summe:	38h 45m	-	-	-13525 Mvarh	-

Kurzzeitige Einschaltungen (t<=20min)

Nr.	Datum	Dauer	Maximal Amplitude
1	11.05.2012 06:14:12	4,95Min	1297 A

Belastung mit harmonischen Oberschwingungen (Widerstandszweig -T14)

Nr.	Start	Dauer	Strom	Maximale Ampl.	H3	H5	H7	Ungerade Harmon.	Gerade Harmon.
1	10.05.2012 10:31:03	6h 2m	3,21 A	109,81 A	0,32 A 0,4 A	1,03 A 1,17 A	1,99 A 2,23 A	1,42 A 2,65 A	0,81 A 0,81 A
2	11.05.2012 07:13:06	11h 4m	5,52 A	93,78 A	0,26 A 0,32 A	0,6 A 1,47 A	1,18 A 2,19 A	1,65 A 2,86 A	0,89 A 0,89 A

Figure 3.7: Evaluation of the MSCDN activations, example from the automated MSCDN Report (Visualization software WinPQ)

Summary

The increase in installed capacitive reactive power from MSCDN-systems requires an efficient maintenance concept. The MSCDN monitoring described in this article makes a contribution to this.

Through continuous monitoring and the early detection of failures of individual capacitor elements, downtime can be minimized through targeted exchange during routine inspections, thus reducing maintenance costs. The limitation of the fault location by monitoring the direction of the unbalance current halved the measurement time due to the containment of potentially faulty capacitors. The automatically generated report enabled the operating personnel to perform a very fast analysis of the most important functions of the entire MSCDN-system. The variety of other evaluation functions that monitoring provides can be used to analyse other functions such as the phase-selective and synchronous switching of the power circuit breaker, the behaviour of the filter and the load on the resistor arm. Because of the careful choice of sources, parameters and data needed for evaluations and analyses the gathered information can subsequently be used for years, if there should be a failure of the system. Monitoring is thus one of the vital components that are necessary for a basis of efficient, cost-effective and failure-free operation of the system.

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[III]IEC TS 61000-6-5 Generic
standards – Immunity for power
station and substation environments

[IV] www.tennettso.de

[V] www.a-eberle.de

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