Requirements for intelligent a.c. mitigation devices, that minimize the negative effects of electromagnetic interferences on pipelines

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Abstract

Pipelines are often influenced by interference voltages from various sources such as traction power supply systems, high voltage lines, earth faults and lightning effects. These interference voltages can occur in form of transient, temporary or steady state overvoltage. The effect of it can be a.c. corrosion, damage of parts of the pipeline or damage to persons. These multiple interferences and protection goals make high demands on decoupling devices, that should discharge these voltages and currents to a defined earth-termination system, without negatively affecting the cathodic protection potential. The sources of influences are discussed and the resulting requirements for a.c. decoupling devices are presented. Moreover, an example of a possible solution is given.

1. Interference voltages on cathodically protected pipelines

Since pipelines are widely distributed and highly networked, they are often influenced by interference voltages from various sources such as parallel high-voltage lines, traction power supply systems, earth fault currents and lightning effects. Interference voltages are non-system voltages which can occur in the form of transient, temporary or long-duration overvoltage depending on their duration. They can enter a system, for example an insulated pipeline, by means of galvanic, inductive or capacitive coupling and frequently cause damage to installations, parts thereof and persons. Special surge protection solutions allow to reduce these interference voltages to values below defined/uncritical limit values. In addition, a.c. corrosion can occur as a result of a.c. voltage interference [1]. The interference voltages described below may cause personal injury, material damage and, in case of long-duration interference, a.c. corrosion in certain circumstances [2], [3].

1.1 a.c. interference caused by high-voltage lines

High-voltage lines generate electromagnetic fields which may be inductively coupled to parallel pipelines and often occur in the form of permanent interference voltage. This interference may present a safety hazard to persons due to impermissibly high touch voltages and a.c. corrosion. In case of coating defects (damage), current can travel from the pipeline to the ground during the anodic half-wave and can lead to corrosion of the pipeline under certain circumstances.

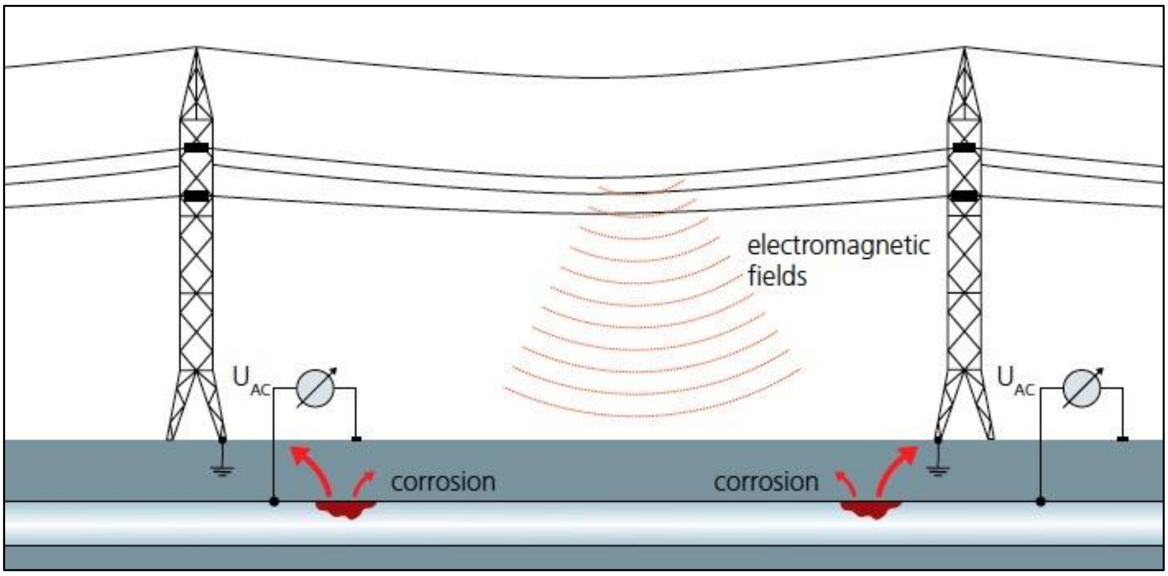


Figure 1: a.c. corrosion resulting from parallel high-voltage lines

1.2 Earth faults

An earth fault causes a potential gradient area in the surrounding soil whose potential affects pipelines located in this area. This potential gradient area thus spreads over to the relevant pipeline network as interference voltage. This interference voltage occurs for a short period of time (up to about 200 ms) and can present a safety hazard to persons or/and exceed the insulation strength of equipment connected to the pipeline (e.g. insulating joints).

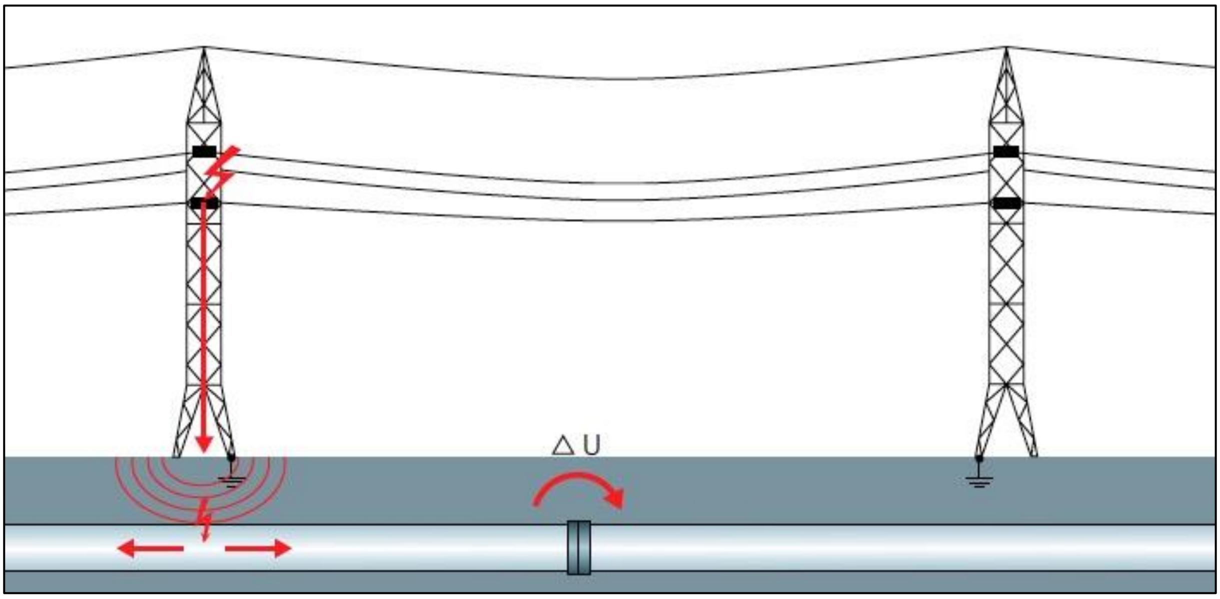


Figure 2: Interference voltage caused by earth faults

1.3 Electric railways

Electric railways produce galvanically coupled stray currents which travel through the ground and transfer to the pipeline through coating defects, thus changing the potential of the pipeline by means of interference voltages. The low-impedance connection via the pipeline serves as a parallel path for the traction return current back to the source. Also in this case, corrosion will occur at the points of current exit.

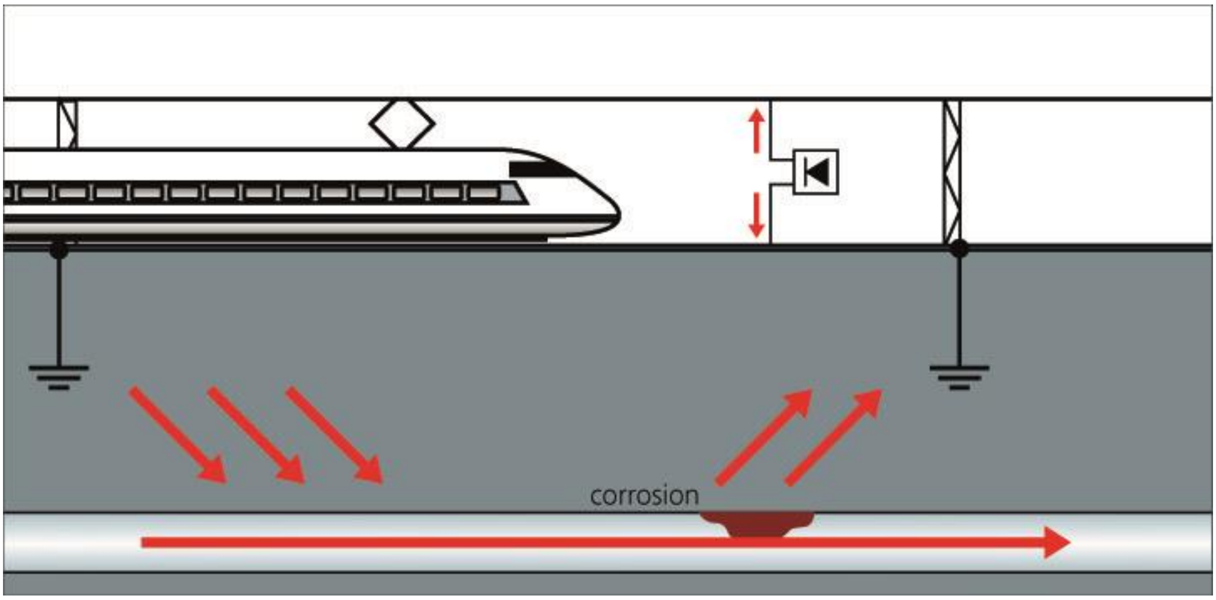


Figure 3: Corrosion resulting from stray currents caused by electric railways

1.4 Lightning strike

Lightning generates transient interference voltages against uninfluenced metal systems. Injected via a potential gradient area, it spreads over the entire pipeline network. The insulation strength of the insulating joints, which are installed on the pipeline to electrically isolate the pipeline sections, would be exceeded. Consequently, flashover occurs and the insulating joint is damaged.

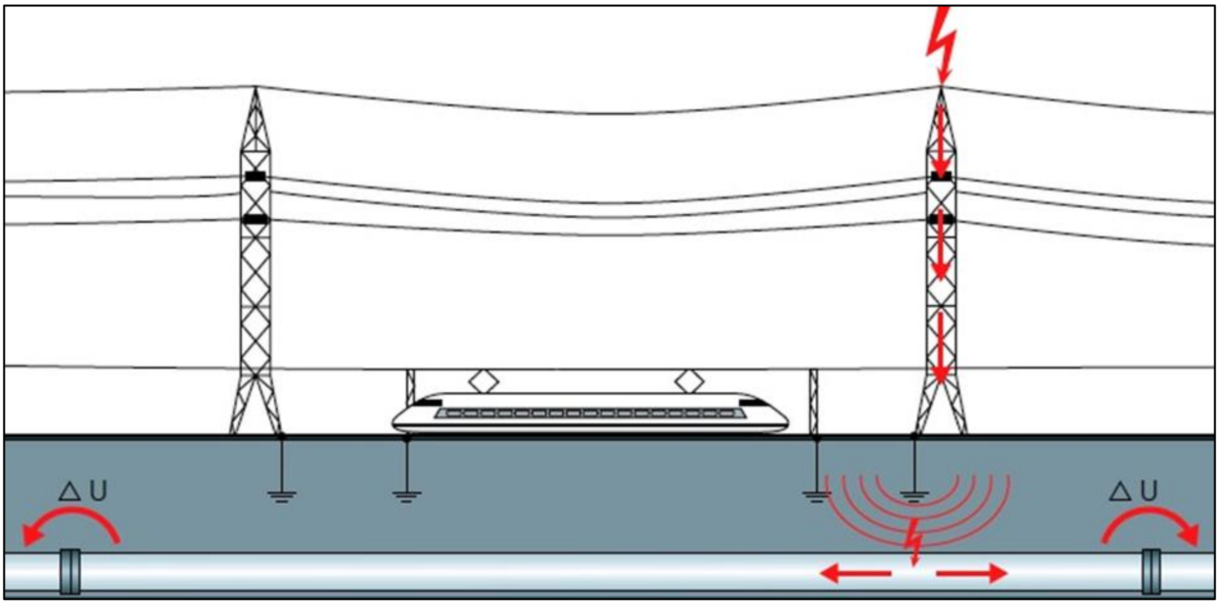


Figure 4: Interference caused by direct and indirect lightning strikes

2. Requirements from a safety point of view

These interferences, described above, are the source of different negative effects and damages on the pipeline as well as safety hazards for persons. These hazards and risks lead to following protection goals:

- Personnel protection in case of temporary and long-term overvoltages
- Protection against a.c. corrosion
- Protection of devices and components connected to the pipeline as well as protection of the isolation of the pipeline

This means, measures must be taken, that reduce the negative effects of interferences and should meet these protection goals to ensure a safe and economic operation of the pipeline system.

2.1 Personnel protection

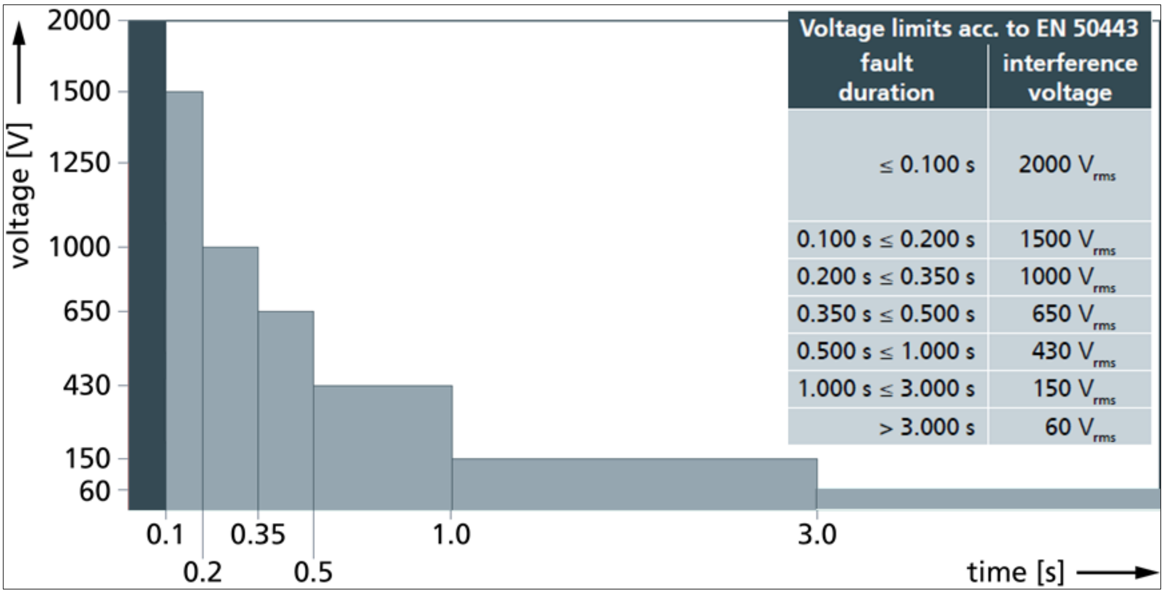
In case of possible temporary and long-term overvoltages, personnel safety hazards are present during pipeline construction and maintenance, and during normal steady state operation.

The threshold for an acceptable touch voltage is described in different national and international standards:

a) The Canadian Standards Association (CSA) [5] and NACE International (NACE) [6] have published standards, which recommend reducing the steady state touch and step potential **below 15 volts** at any location where a person could touch the pipeline or any electrically continuous appurtenanace.

b) The german AfK Recommendation Nr. 3 [7] defines two thresholds for a different period of time:
short term influence: **below 1000 volts**
and long term influence: **below 60 volts**
These values are valid for 16.7 Hz and 50 Hz systems

c) EN 50443 [3] gives following detailed recommendations



Voltage limits acc. to EN 50443

fault duration	interference voltage
≤ 0.100 s	2000 V_{rms}
0.100 s ≤ 0.200 s	1500 V_{rms}
0.200 s ≤ 0.350 s	1000 V_{rms}
0.350 s ≤ 0.500 s	650 V_{rms}
0.500 s ≤ 1.000 s	430 V_{rms}
1.000 s ≤ 3.000 s	150 V_{rms}
> 3.000 s	60 V_{rms}

Figure 5: Voltage limits acc. to EN 50433

These examples show, that different standards and recommendations are available with varying requirements for permissible interference voltages on the pipeline.
To decide if a mitigation measure meets the appropriate requirements, the documentation of this device should give detailed information about its limitation behaviour.

2.2 Protection against a.c. corrosion

If the risk of a.c. corrosion on a.c. influenced pipeline is present or not, several parameters has to be determined:

- a.c. voltage on the pipeline
- a.c. current density
- turn-on / turn-off potentials
- relationship between a.c. and d.c. current density
- specific soil resistivity
- geometry and electrode resistance of the holiday

The risk of a.c. corrosion is low in following cases [1]:

- a.c. current density $J_{ac} \leq 30\ Am^{-2}$, or
- d.c. current density $J_{dc} \leq 1\ Am^{-2}$, or
- relationship between a.c. (50 Hz) and d.c. current density $J_{ac}/ J_{dc} \leq 3$

This shows that a realistic estimation for the risk of a.c. corrosion is not easy and is only possible, if several field measurements are performed. So, a generally threshold value for the maximum acceptable a.c. voltage on a pipeline does not exist [1]. It rather depends on several different parameters.
This means, that an a.c. mitigation device, which has to be installed on different places and need to be used in different applications, should have an adjustable

threshold voltage for steady-state influences from a low level of a few volts up to about 50 volts.

2.3 Protection of devices and components connected to the pipeline as well as protection of the isolation of the pipeline

For protection of electronic equipment as well as isolation joints or the isolation of the pipeline itself, transient and temporary overvoltages must be taken into consideration.

The minimum withstand voltages of these components are

- isolating joints: 2.5 kV rms / duration 1 min.
- electronic equipment: 1.5 kV (1,2/50 µs)
- pipeline isolation: depending on the coating: 4 kV – 20 kV

One requirement for mitigation devices out of this is, that the device has to limit transient overvoltages due to lightning effects and earth faults to an acceptable level.

2.4 Summary

All these voltage limits described above are values found in different standards and recommendations and makes no claim to completeness but is instead intended to give a rough indication.

Following table is a short summary:

Protection goals	**Duration**		
	Transient ≤ 1ms	**Temporary 1ms – 3s**	**Long duration > 3s**
Personnel protection	2 kV	150 V – 1.5 kV	15 V – 60 V
Protection against a.c. corrosion	n.A.	n.A.	2 V – 30 V
Protection of pipeline and equipment	1.5 kV – 4 kV	1.5 kV – 4 kV	n.A.

Table 1: Voltage limits

3. Discharge capability

One of the main functions of a mitigation measure is to discharge foreign currents on a pipeline, which could have negative effects on the same or to connected structures, to a grounding system. To achieve above described protection goals the mitigation measure is reducing the voltage on a pipeline via a defined short-circuit between pipeline and ground.

We have to take into account, that the different sources of influences make different demands on the discharge capability of a mitigation device.

But not only the mitigation device has to fulfill these requirements, but also the complete mitigation system, including the grounding system as well as all connection parts.

3.1 Transient influences

The source of transient influences are lightning strikes, direct or indirect on the pipeline. This influence occurs within a time period of up to 1ms. Direct lightning currents are represented by a test pulse with a wave form of 10/350µs. Indirect lighting influences with a test pulse of 8/20µs. The following graph shows the difference between a 10/350µs and 8/20µs pulse.

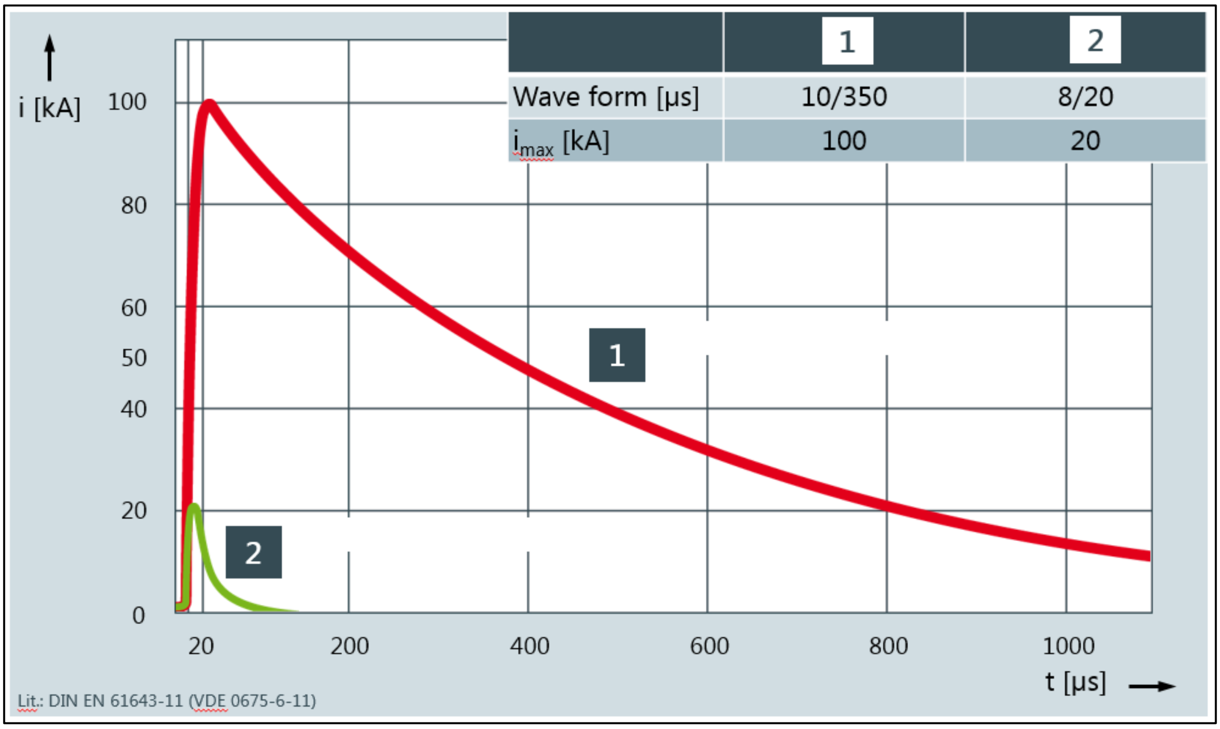


Figure 6: Difference between 10/350µs and 8/20µs pulse

According to IEC 62305-1 [8] the maximum value of i_{max} of a 10/350µs pulse is 200kA. For this the maximum lightning current on a pipeline would be 100kA 10/350µs in case of a direct lightning strike.

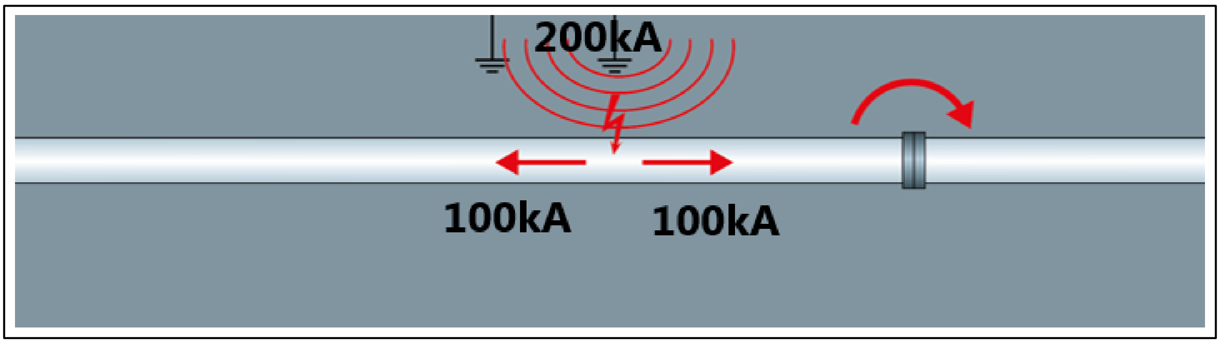


Figure 7: current division on a pipeline during lightning influence

3.2 Temporary influences

In case of an inductive interference by a single-phase short-circuit to earth current of a high-voltage overhead line operated with a solid neutral earthing, decouplers for fault currents have the task of automatically establishing a low impedance current carrying connection between the pipeline and a defined earth electrode before dangerously high voltages between the pipeline and the earth can occur.

A typical duration of such earth faults is 200ms.

Following basic requirements should be considered when selecting a mitigation device, according to AfK 3 [7]:

- Decisive factors when configuring and selecting decouplers are the maximum technical alternating current to be discharged and the duration of current flow (max. disconnecting time)
- In case of correspondingly permissible steady-state current, the disconnection device must remain in high impedance state.
- After clearing the earth short-circuit the disconnection device must return to the high impedance state, regardless of the residual steady-state current voltage on the pipeline.

3.3 Steady-state influences

When configuring and selecting decouplers the maximum technical alternating current to be discharged for steady-state current is decisive. Should, in addition, inductive fault current also be possible due to the mode of operation of the interfering high-voltage transmission lines, this load should also be considered when selecting and dimensioning, as should the fact that capacity is reduced by the bias current load (due to the permanently discharged steady-state current).

Following basic requirements should be considered when selecting a mitigation device, according to AfK 3 [7]:

- The disconnection device may not, whether under normal operating conditions or in the event of a fault, cause serious damage to the cathodic corrosion protection.
- The functionality of the device may not be dependant on the permanent availability of an unsecured, external auxiliary power (e.g. 230 V AC).
- Permanent earthing on cathodically protected pipelines generally requires the use of decouplers, which may neither significantly influence the operation of the cathodic corrosion protection nor the measurements which prove its existence.

3.4 Summary

There are different requirements for transient, temporary and steady-state influences.

- For temporary and steady-state influences the max. discharge current at the place of installation has to be determined via a high-voltage survey and/or calculated via a simulation software.
- Transient influences due to lightning strikes will induce a current of several 10kA with a wave-form 10/350µs.

All these influences can occur at the same time, e.g. a steady-state induced current from a HV-AC line and a lightning strike in the mast of a nearby HV-mast. This

means, that a mitigation device should be a complete tested solution to ensure that the discharge capability will be not exceeded in case of simultaneous occurrence of different influences.
Finally, the grounding system and all connection parts should be able to carry the same discharge parameter as the mitigation device.

4. Additional requirements

Beside the limiting behavior and the discharge capability, there are some more additional requirements for mitigation devices, which should be mentioned:

4.1 Environmental requirements

- Local temperatures and weather conditions may not lead to faults and should be considered when selecting, for example, the degree of protection of the device.

4.2 Requirements for a safe operation

- In case of an overload, the device should switch into a safe and defined state, which ensures personnel protection.

4.3 Requirements for the use on cathodic protected pipelines

- The device may neither significantly influence the operation of the cathodic corrosion protection nor the measurements which prove its existence.
- The device should block the DC potential on the pipeline up to several volts.

4.4 Requirements for the use with remote monitoring systems

- In case of an overload the device should have a possibility to give an alarm.
- Possibility of switching on and of the device remotely for maintenance purposes, for example in case of d.c. or a.c. voltage gradient surveys (DCVG/ACVG survey)
- Transfer of operational parameter like voltage between earth and pipeline, discharge current, etc.

4.4 Maintenance and testing requirements

According to EN 12954 [9] the test intervals for d.c. decoupling devices and earth-termination systems should be every year or more often, depending on operational requirements.
Here the device should:

- display its actual state directly (normal operation, discharge mode, fault mode, etc.)
- have the possibility to switch it on and of directly
- have an implemented easy to use test procedure

5. Example of a possible solution

The above described requirements are only achievable using a device with different functional units. One solution is the VCSD 40 IP65, which is shown in Figure 8.

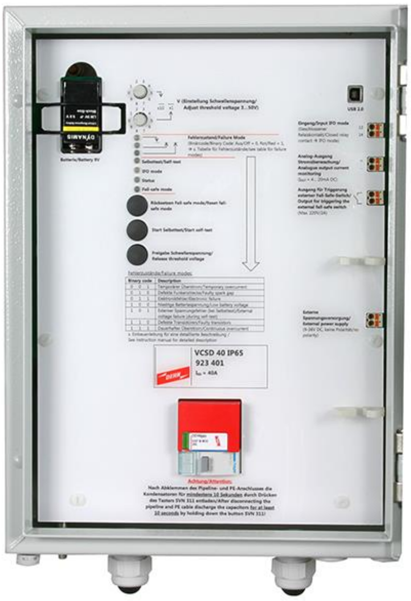


Figure 8: Intelligent decoupling device VCSD 40 IP65 with open enclosure

5.1 Principle function

This device evaluates different sensor signals via a control unit, thus coordinating the interaction of the individual functional units consisting of power electronics (power unit (PU)) and a spark gap (transient unit (TU)) as depicted in Figure 9. Transient overvoltage of wave form 10/350 µs or 8/20 µs is discharged via the spark gap of the TU, 16.7 Hz or 50/60 Hz temporary and long-term overvoltage is dissipated to the ground along the parallel path via the power electronics of the PU. Thus, the VCSD allows coordinated and tested protection against transient, temporary and long-term overvoltage.

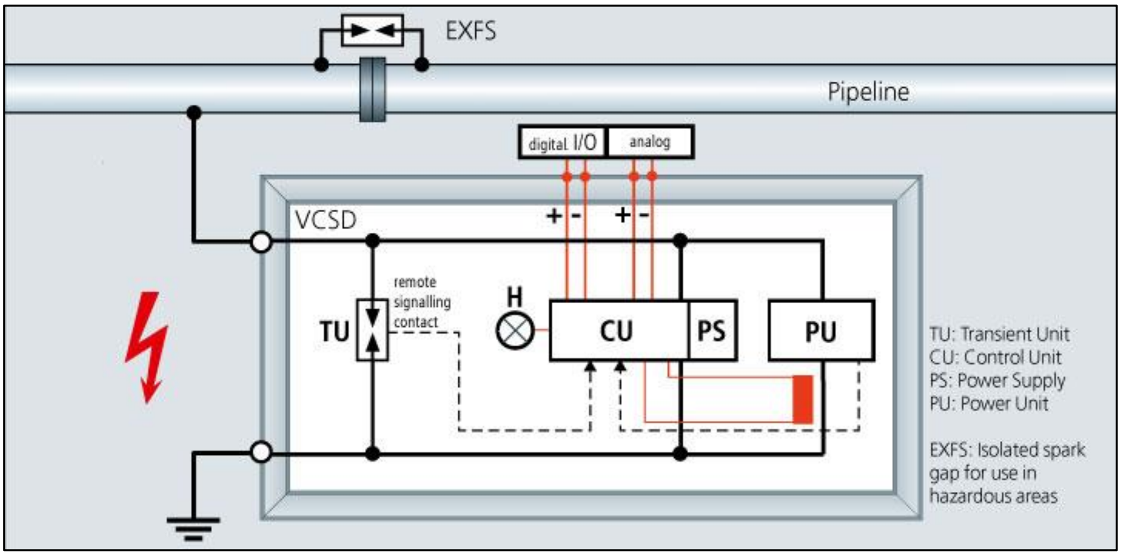


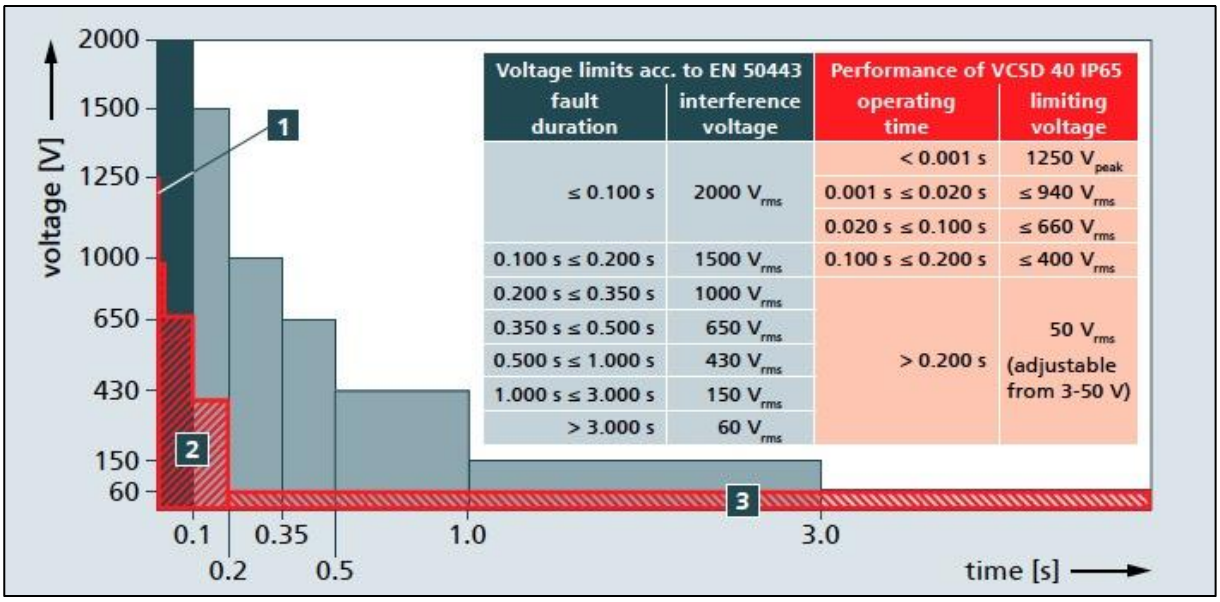
Figure 9: Design and functional units of the intelligent decoupling unit VCSD 40 IP65

5.2 Limiting behavior

The following protection goals can be achieved:

- Personal protection in case of temporary and long-term overvoltage
- Protection against a.c. corrosion
- Protection of the devices and components of system parts connected to the pipeline

This is achieved via following limiting behavior:



Voltage limits acc. to EN 50443		Performance of VCSD 40 IP65	
fault duration	interference voltage	operating time	limiting voltage
≤ 0.100 s	2000 V_{rms}	< 0.001 s	1250 V_{peak}
		0.001 s ≤ 0.020 s	≤ 940 V_{rms}
		0.020 s ≤ 0.100 s	≤ 660 V_{rms}
0.100 s ≤ 0.200 s	1500 V_{rms}	0.100 s ≤ 0.200 s	≤ 400 V_{rms}
0.200 s ≤ 0.350 s	1000 V_{rms}	> 0.200 s	50 V_{rms} (adjustable from 3-50 V)
0.350 s ≤ 0.500 s	650 V_{rms}		
0.500 s ≤ 1.000 s	430 V_{rms}		
1.000 s ≤ 3.000 s	150 V_{rms}		
> 3.000 s	60 V_{rms}		

Figure 10: Limiting behavior of the VCSD depending on the duration of the overvoltage event

5.3 Interfaces and voltage supply

In addition to the main connections to the pipeline and the earth-termination system, the VCSD has about 5 other interfaces which are illustrated in Figure 11 and Figure 12.

The digital input ‘digital in‘ allows to switch the VCSD on and off via remote control (e.g. from the process control system in the pipeline control center). This is particularly required for measurements on the pipeline, for example d.c. or a.c. voltage gradient surveys (DCVG/ACVG survey). For this purpose, the VCSD is switched off (high impedance) to ensure that the pipeline capacity is not negatively affected by the decoupling unit and that the measurement results are not distorted. Consequently, the device does not have to be mechanically disconnected which is a considerable advantage over conventional solutions.
The digital output ‘digital out‘ is activated in case of a function-critical device error. This error can, for example, be displayed in the control system or an external fail-safe switch (short-circuit contactor) can be activated to galvanically earth the pipeline.
The USB interface is used by the manufacturer for programming the control unit.

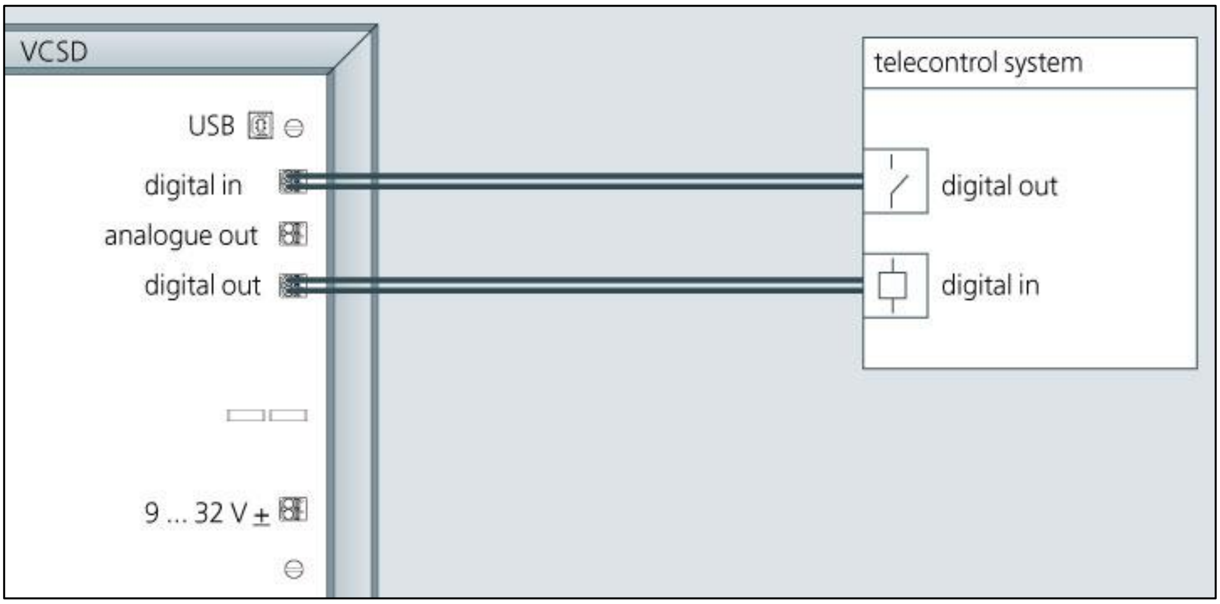


Figure 11: Connection of the digital interfaces

The instantaneous value of the discharge current can be provided through the analogue output as a 4-20 mA signal (scaled to 0-40 A). Consequently, a trend statement concerning the interference of the pipeline can be made in the control center for an extended period of time (e.g. for a year).

The VCSD uses the a.c. interference voltage on the pipeline to supply the control unit and ensure proper operation. If the pipeline is not influenced by a interference voltage at a certain time, the VCSD is in standby mode and is supplied via the integrated battery.
A 9-32 V d.c. external voltage supply is only required to perform a self-test and to supply the 4…20 mA analogue output.

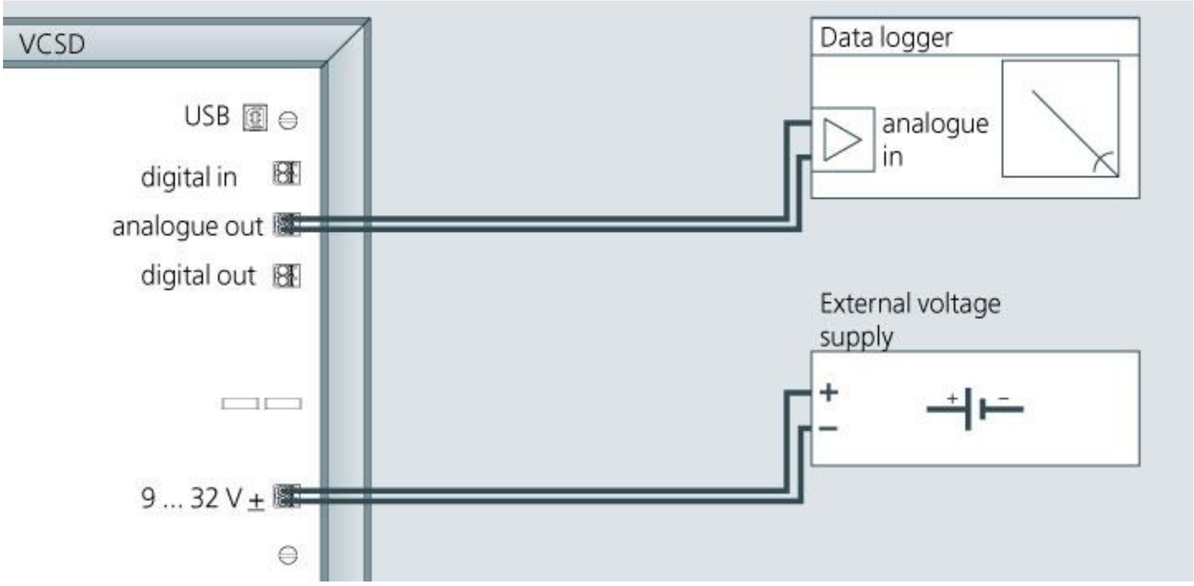


Figure 12: Evaluation of the analogue signal and external power supply

5.4 User benefits compared to conventional mitigation units

Up to this point, different technologies such as polarization cells, capacitive decoupling units, series resonant circuits, a.c. compensation systems or the like have been used to discharge transient and long-term interference voltage. These technologies have individual advantages and disadvantages depending on their purpose of use. Compared to conventional decoupling units, modern system solutions such as the VCSD offer decisive benefits for the operator, for example:

- Remotely controllable from the control center: Connection/disconnection in case of DCVG / ACVG measurements is not required
- Monitoring function (measurement of the actual discharge current) allows conclusions to be drawn to the interference situation of the pipeline
- High discharge capacity and excellent limiting behavior
- No negative effects on the cathodic protection potential (d.c. potential) whilst d.c. currents are blocked
- Manufacturer-tested all-in-one system for transient, temporary and long-term interference voltages
- Easy testing by means of integrated self-test routine
- No hazardous electrolytes required thanks to fully electronic design

6. Conclusion

The selection of an appropriate mitigation solution depends on different factors. For example, the necessary discharge parameter at a particular point of installation must often be evaluated via calculations based on site surveys and measurements. This means, that for this complicated application “pipelines influenced by external voltage” there is no solution fitting to all situations.

On the other hand, intelligent functionalities should be considered to ensure a safe and efficient operation during the whole life cycle of the pipeline.

7. Literature

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[5] CAN/CSA-C22.3 No.6-M91: Principles and Practices of Electrical Coordination Between Pipelines and Electric Supply Lines

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[8] IEC 62305-1: Protection against lightning - Part 1: General principles

[9] EN 12954: Cathodic protection of buried or immersed metallic structures - General principles and application for pipelines

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