LIGHTNING AND HIGH-VOLTAGE INTERFERENCE PROTECTION ON PIPELINES

The most important protection measure for maintaining the functionality and ensuring safe operation of these systems is to protect buried pipelines against corrosion. However, pipelines are also influenced by external factors such as lightning discharge and high-voltage systems and therefore adequate protection measures are required. This article deals with solutions for protecting pipelines in case of lightning and high-voltage interference.

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Passive corrosion protection is achieved by coating or painting the pipeline. This non-conducting insulating coating is supposed to prevent that current flows from the steel of the pipeline to the ground. In practice, however, it is to be expected that coatings are damaged. This leads to different free corrosion potentials at the different defect locations due to the different soil conditions. A corrosion current may flow from the pipeline to the ground even in case of a difference of a few hundred millivolts in the different free corrosion potentials, thus causing material degradation.

Therefore, corrosion effects caused by different soil conditions in the soil surrounding the pipeline can hardly be prevented by passive corrosion protection alone.

Another reason why metals corrode in the soil is their different free corrosion potential in the soil. Due to these different potentials, there is a risk of corrosion when the pipeline contacts a reinforced concrete foundation. Measured using a copper/copper sulphate electrode (Cu/$CuSO_4$), steel in a concrete foundation has a free corrosion potential of-200 mV to -400 mV. Steel in soil, in contrast, has a free corrosion potential of -500 mV to -800 mV [1]. In this case, this potential difference causes material degradation/corrosion at the damaged coating of the pipeline. To ensure corrosion protection, it is therefore imperative to electrically isolate the buried pipeline from the reinforced concrete foundation.

In case of electric d.c. traction systems, the tracks are used as return circuit. Since these tracks are not completely isolated from the ground, a part of the return current flows from the rolling stock through the ground back to the traction substation as stray current. If a pipeline runs in parallel to this path, the stray current will flow through it back to the traction substation. If the coating of the pipeline is damaged, defect locations with small surfaces have a high the current density, resulting in corrosion effects at the pipeline.

Due to building regulations, pipeline sections are often installed in parallel with high-voltage lines electrified railway routes. This proximity poses the risk that a.c. voltage transfers to the pipeline.

To prevent possible corrosion effects caused by

- Different soil conditions,
- Different free corrosion potential of different metals,
- Stray currents resulting from d.c. traction systems and
- Induced a.c. voltages,

the electrochemical corrosion process can be stopped by cathodic protection measures. This is achieved by galvanic anodes (sacrificial anodes) or impressed current systems which prevent the gradual material degradation at the steel surface by shifting the metal/medium potential to more negative values and at the same time considerably reducing the corrosion rate. Cathodic protection requires permanent monitoring of the pipeline. To this end, the voltage level at the pipeline is detected at defined measuring points along the pipeline and, if necessary, the intensity of the protective current is adapted. For this purpose, the pipeline is divided into individual segments which are electrically isolated from one another by insulating couplings (mainly underground) and insulating flanges (aboveground) (Figure 1).

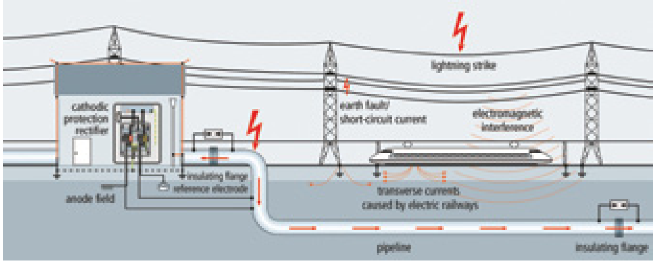

Figure 1 *Possible interference of pipelines.*

LIGHTNING INTERFERENCE

Lightning overvoltage caused by a lighting strike to exposed parts of pipeline systems almost always exceed the dielectric strength of insulating joints, resulting in open sparking or destruction of the insulating joint. Faulty insulating joints significantly compromise the efficiency of cathodic protection. The resulting necessity of exchanging the insulating joint entails high repair and downtime costs for the system.

Therefore, the German Technische Regel GW 24 of DVGW [2] dictates that isolating spark gaps must be used for protecting the insulating joints from destruction caused by lightning-related voltages and currents.

Isolating spark gaps are components used for lightning equipotential bonding according to EN 62305-3 [3] and must fulfil the test requirements of IEC 62561-3 [4]. When used in potentially explosive atmospheres, isolating spark gaps additionally have to be explosion-proof and ATEX-certified at the place of installation according to the Ex zone.

To ensure that the isolating spark gaps are used for their intended purpose, the electrical properties of the insulating clearance of the insulating joint must be coordinated with the electrical data of the spark gap which is connected in parallel. Coordination of these two components must ensure that the electric equalising process after a lightning discharge along a pipeline is performed via the spark gaps instead of the insulating clearances of the insulating couplings or flanges. To this end, the isolating spark gap must be tripped by a voltage below the dielectric strength of the insulation of the insulating joint.

According to [2], the insulation strength of insulating joints is verified by applying an a.c. test voltage (U_{PW}) of 50 Hz. In this context, a distinction is made between two classes:

- Class 1: $U_{PW} = 5\ kV_{rms}$
- Class 2: $U_{PW} = 2.5\ kV_{rms}$

In case of these voltage levels, no puncture or flashover may occur at the insulating joints.

The isolating spark gap must therefore trip below the above mentioned values to ensure insulation coordination. To determine the sparkover behaviour of the isolating spark gap, a standardised lightning impulse voltage of 1.2/50 µs wave form is used [5]. The voltage value (U_{as}), which 100% trips the spark gap in a defined test series, is specified in the data sheet of the spark gaps. If the value of the 100 % lightning impulse sparkover voltage (U_{as}) fulfils the condition

$$U_{as} \le U_{PW}/2,$$

the relevant isolating spark gap can be used to protect the insulating joints. Thus, the lightning impulse sparkover voltage of the isolating spark gaps for protecting the insulating joints must fulfil the following requirements:

- For class 1 insulating joints: $U_{as} \le 2.5$ kV (1.2/50 µs)
- For class 2 insulating joints: $U_{as} \le 1.25$ kV (1.2/50 µs)

Figure 2 *Isolating spark gap for insulating joints.*

Figure 2 shows an isolating spark gap for class 1 and 2 insulating joints in hazardous areas.

INSTALLATION OF ISOLATING SPARK GAPS

In addition to the electrical data of the isolating spark gap, its protective effect heavily depends on the type of installation at the installation location. When the lightning impulse sparkover voltage is exceeded, the voltage across the spark gap breaks down to some 10 V (red curve in Figure 3). This value depends on the arc voltage U_{bo} of the spark gap. After the spark gap has tripped, lightning currents starts to flow, causing voltage drops at the impedances of the connecting cables of the isolating spark gap. Since the lightning current is a short-term current impulse with a high rate of current change (di/dt), not only the ohmic, but also the inductive component of the impedance of the connecting cable must be considered when assessing the voltage drop.

The voltage drop of the connecting cable U_L is therefore calculated as follows:

$$U_L = I_{imp} \cdot R_L + L \cdot \frac{di}{dt}$$

where

R_L is the ohmic resistance of the connecting cable,
L is the inductance of the connecting cable,
I_{imp} is the value of the lightning impulse current and
$\frac{di}{dt}$ is the steepness of the lightning impulse current.

According to the spark gap arrangement in Figure 3, the maximum voltage (U_{max}) for the spark gap and the connection system during the discharge occurrence is calculated as follows:

$$U_{max} = U_{L1} + U_{L2} + U_{bo}$$

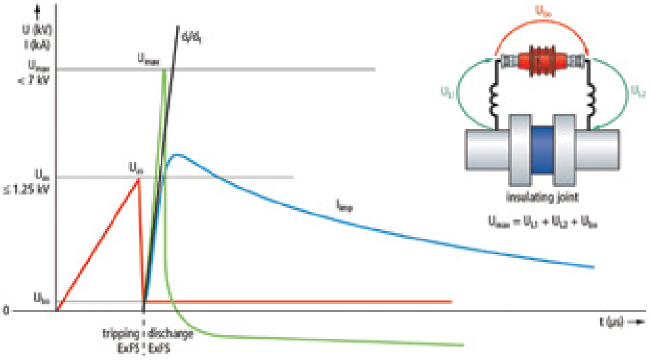

Figure 3 *Schematic voltage curve at an isolating spark gap and an insulating joint in case of lightning interference*

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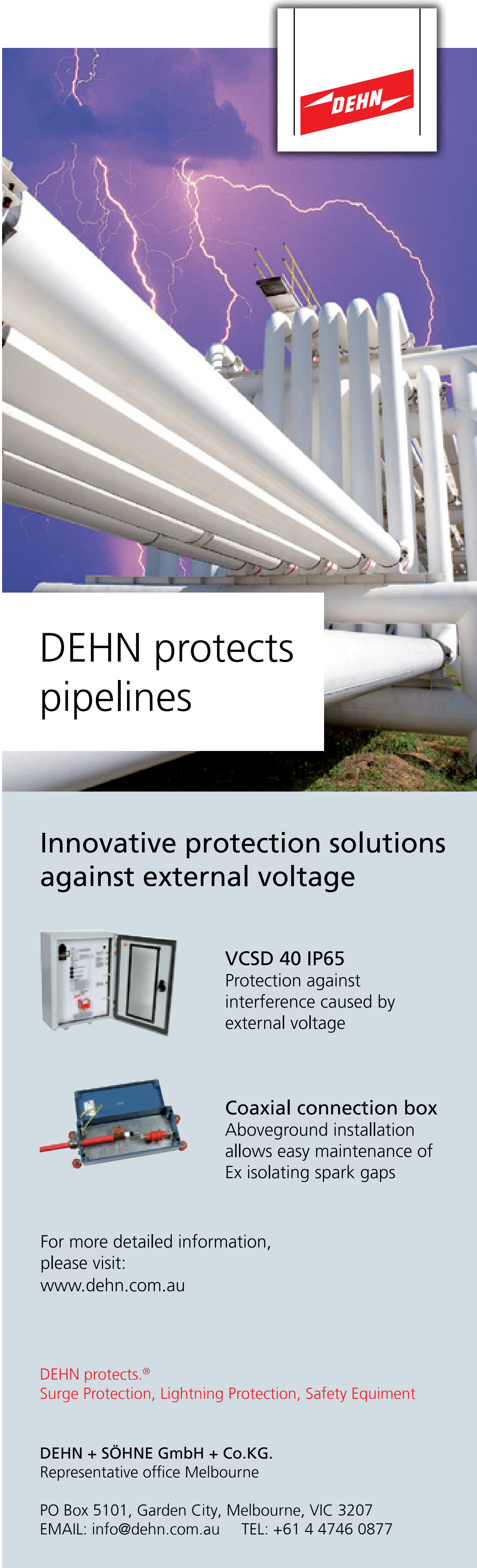

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To ensure safe operation, the value of U_{max} must not exceed the peak value of the test voltage (U_{PW}) used to verify the insulation strength of the insulating joints. In Figure 3 this is shown for a class 1 test. In this case, U_{max} must fulfil the following condition:

$U_{max} < \sqrt{2} \cdot 5$ kV

$U_{max} < 7.07$ kV

CASE 1

To illustrate this, the example in Figure 4 should be discussed. There you can see a buried insulating joint. The associated isolating spark gap should be installed aboveground so that it can be easily accessed for regular inspection. For this arrangement, coordination between the spark gap installation and the insulating joint is to be assessed in all phases of the lightning-related discharge process.

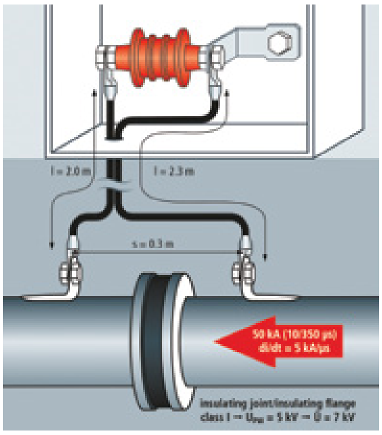


Figure 4 *Connection of the isolating spark gap by means of a round conductor*

In this context, the following parameters are assumed:

1. Spark gap
   $U_{as} \leq 1.25$ kV
   $U_{bo} = 30$ V
2. Connecting cable
   Copper 25 mm² (round conductor)
   Length of outgoing and return conductor: 4 m
   $R_L = 0.712$ mΩ / m
   $L = 1$ µH / m
   Distance between the connection points at the pipeline: 0.3 m
3. Lightning current parameters (Table C.2 in [2])
   $I_{imp} = 50$ kA (10/350 µs)
   $\frac{di}{dt} = 5$ kA/µs
4. Insulating joint
   Class 1
   $U_{PW} = 5$ kV
   $U_{max} < 7$ kV

The results of the calculation of the voltage drop of the overall arrangement using copper conductors (round) with a cross-section of 25 mm² are summarised in Table 1.

In this sample arrangement, the coordination requirement for tripping the spark gap is fulfilled since U_{as} of the spark gap of 1.25 kV is below the required limit value of less than 2.5 kV for a class 1 insulating joint. When considering the overall arrangement when the spark gap trips, it can be seen in Table 1 that in this case a voltage drop of 21.7 kV is to be expected. This value is significantly above the permissible value U_{max} of 7 kV. Consequently, the solution in Figure 4 cannot be used in practice under these conditions. In this case, the main problem is the inductive voltage drop of the connecting cables.

CASE 2

When using low-inductance connecting cables, the inductive voltage drop of the installation arrangement in Figure 4 could be reduced to such an extent that the permissible value $U_{max} < 7$ kV is no longer exceeded. Figure 5 shows such a solution with a coaxial connecting cable. It includes the isolating spark gap according to Figure 2 in combination with a medium-voltage line of type N2XSY 01x35/16 6/10 kV.

Now the following parameters are assumed:

1. Spark gap
   $U_{as} \leq 1.25$ kV
   $U_{bo} = 30$ V

	Distance between connections s [mm]	Cable length l [m]					
		1.0	1.5	2.0	3.0	4.0	5.0
Voltage drop (U_{max}) in kV at 5 kA/µs	300	6.6	9.1	11.6	16.6	21.7	26.7
	500	7.6	10.1	12.6	17.6	22.7	27.7
	1000	10.1	12.6	15.1	20.2	25.2	30.2
	1500	12.6	15.1	17.6	22.7	27.7	32.8
	2000	15.1	17.6	20.2	25.2	30.2	35.3

Table 1 *Voltage drops at round conductors 25 mm2 according to calculation as per GW24 [2].*

	Distance between connections s [mm]	Cable length l [m]					
		1.0	1.5	2.0	3.0	4.0	5.0
Voltage drop (U_{max}) in kV at 5 kA/µs	300	3.8	4.4	4.9	5.7	7.9	8.6
	500	6.0	6.6	7.1	8.1	10.2	10.9
	1000	8.9	9.7	10.5	11.5	13.2	14.1
	1500	11.1	11.6	12.1	13.2	14.3	15.5
	2000	17.3	17.6	18.6	20.3	20.5	20.6

Table 2 *Excerpt from installation instructions [6].*

2. Connecting cable
   Medium-voltage line of type N2XSY 01x35/16 6/10 kV
   Length: 2 m
   Distance between the connection points at the pipeline: 0.3 m
3. Lightning current parameters (Table C.2 in [2])
   $I_{imp} = 50$ kA (10/350 µs)
   $\frac{di}{dt} = 5$ kA/µs
4. Insulating joint
   Class 1
   $U_{PW} = 5$ kV
   $U_{max} < 7$ kV

The supplier of the solution in Figure 5 measured the relevant voltage drops for different configurations and documented them in the installation instructions of this solution [6]. Table 2 shows an excerpt of the values which are required for reconsidering the sample application.

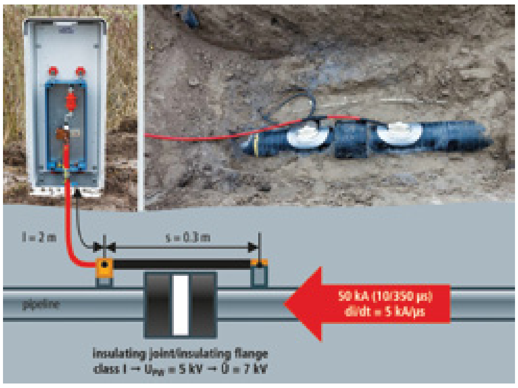


Figure 5 *Isolating spark gap with coaxial connection system.*

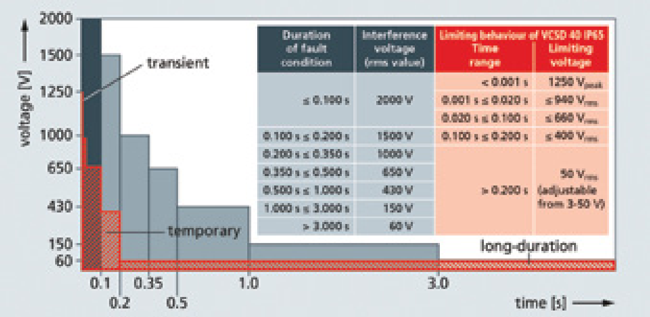
In this improved sample arrangement in Figure 5, the coordination requirement for tripping the spark gap is fulfilled since U_{as} of the spark gap of 1.25 kV is below the required limit value of less than 2.5 kV for a class 1 insulating joint. When considering the overall arrangement when the spark gap trips, it can be seen in Table 2 that in this case a voltage drop of 4.9 kV is to be expected. This value is now considerably below the permissible value U_{max} of 7 kV.

When using specifically tested new connection systems like the solution for connecting the isolating spark gap shown in Figure 5, the isolating spark gaps can now be easily and correctly arranged aboveground for test purposes.

REQUIREMENTS ON THE CONNECTION SYSTEMS

All connection systems must be

- Capable of carrying lightning current,
- Non-sparking (in case of a simultaneously occurring hazardous potentially explosive atmosphere),
- Arranged in parallel with and close to the insulating joint,
- Connected in the shortest possible way,
- Protected against accidental bridging (e.g. caused by tools)



Duration of fault condition	Interference voltage (rms value)	Limiting behaviour of VCSD 40 IP65	
		Time range	Limiting voltage
≤ 0.100 s	2000 V	< 0.001 s	$1250\ V_{peak}$
		0.001 s ≤ 0.020 s	$\leq 940\ V_{rms}$
		0.020 s ≤ 0.100 s	$\leq 660\ V_{rms}$
0.100 s ≤ 0.200 s	1500 V	0.100 s ≤ 0.200 s	$\leq 400\ V_{rms}$
0.200 s ≤ 0.350 s	1000 V	> 0.200 s	$50\ V_{rms}$ (adjustable from 3-50 V)
0.350 s ≤ 0.500 s	650 V		
0.500 s ≤ 1.000 s	430 V		
1.000 s ≤ 3.000 s	150 V		
> 3.000 s	60 V		

Figure 6 *Voltage values.*

Welded lugs or pins and threaded holes in the flanges are adequate connection points to pipelines.

Connection via clamps is only permitted if it is verified in tests that lightning currents do not produce ignition sparks.

All screw connections must be secured against working loose e.g. by inserting a spring washer. Toothed lock washers have not proven adequate in practice (sparking in case of lightning currents).

TESTING THE ISOLATING SPARK GAPS

If Ex isolating spark gaps (ExFS) are used in potentially explosive atmospheres, they have to be tested after three years at the latest according to IEC 60079-17 [7]. Tests for ExFS and its connection systems always consist of a visual inspection and a measurement. The ExFS and its connection systems are visually inspected for

- Damage to the housing of the ExFS
- Correct installation position according to the manufacturer's installation instructions
- Insulation of the connection cables
- Loosening of the connecting cable
- Testing the contact stability
- Soiled ExFS installation
- Suitability for use in potentially explosive atmospheres

The ExFS must be tested for short-circuits and sufficient insulation strength according to the relevant manufacturer's and test instructions. Electrical tests must be carried out outside of hazardous areas when the ExFS is removed. If an electrical test is to be carried out in hazardous areas, this test may only be performed in agreement with the operator.

Figure 7 *Voltage-controlled short-circuiter VCSD 40 IP65.*

LIMIT VALUES IN CASE OF HIGH-VOLTAGE INTERFERENCE

Pipelines are not only affected by lightning interference, but also by high-voltage lines or traction current systems as described at the beginning of this article. In this context, a distinction must be made whether this interference is permanent (long-duration) or short-term (temporary). In both cases, an a.c. voltage is induced in the pipeline system. According to the German AfK recommendation No. 3 [8], max. 60 V are allowed in case of permanent interference (long-term) and up to 0.2 s in case of short-time interference (temporary) to ensure touch protection. These limit values for ensuring touch protection in case of a.c. interference (16.7 Hz or 50 Hz) cannot be reached by using isolating spark gaps. Nevertheless, isolating spark gaps must have an a.c. discharge capacity (e.g. 500 A for 0.2 s) to carry the short-term alternating currents without destruction after being ignited by a.c. voltages at about 500 V. Therefore, other measures than isolating spark gaps are required to ensure touch protection at pipelines affected by a.c. voltage. EN 50443 [9] provides more detailed information about the limit values for ensuring electric safety of persons in conjunction with interfered pipelines. The values stated in this standard refer to parts of metal pipelines or connected devices and installations which are accessible to (electrotechnically) instructed persons. In Figure 6 the limit values for the interference voltages are marked in grey and are also shown in grey in the diagram.

If laymen contact pipelines, [9] requires that the permissible voltage be further reduced without stating specific values.

VOLTAGE-CONTROLLED SHORT-CIRCUITER

The voltage-controlled short-circuiter depicted in Figure 7 allows to reduce a.c. voltages at pipelines to values below the limit values of the EN 50443 standard. This intelligent decoupling device is a short-circuit switch activated by overvoltage which limits long-term, temporary and transient overvoltage. All interference voltages are discharged and limited to a preset value without negatively affecting the d.c. voltage (cathodic potential) to ensure cathodic protection. The limiting behaviour of this device is shown in red in Figure 6.

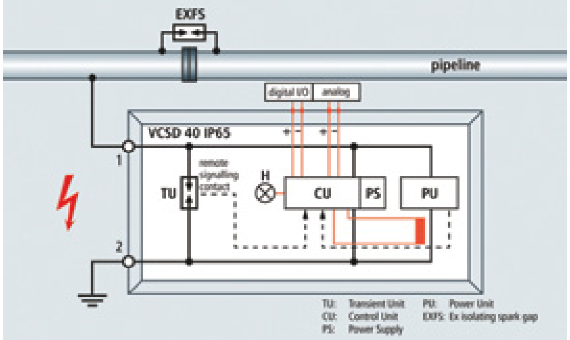


Figure 8 *Use and circuit diagram of VCSD 40 IP65.*

As can be seen in the figure, the voltage-controlled short-circuiter limits the interference voltages at the pipeline below the limit values of AfK recommendation No.3 [8] and EN 50443 [9]. Figure 8 shows the use and functional principle of the voltage-controlled short-circuiter.

CONCLUSION

The protection measures and protective devices presented in this article are an important factor for ensuring cathodic protection for pipeline systems affected by transients such as lightning strikes and temporary or long-term a.c. interference caused by high-voltage systems. An important protection goal when operating pipeline systems is to limit impermissibly high touch voltages to ensure personal protection.

Safe and undisturbed operation of pipeline systems is only possible if

- Corrosion protection
- High-voltage interference
- Lightning protection

is seen in the overall context since the individual aspects of the different protection measures may influence one another. Interdisciplinary cooperation of these areas is therefore the prerequisite for a comprehensive protection concept.

References

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[2] Arbeitsblatt GW 24: 2014-02: Kathodischer Korrosionsschutz in Verbindung mit explosionsgefährdeten Bereichen. (textgleich mit der AfK-Empfehlung Nr. 5). Bonn: DVGW 2014.

[3] EN 62305-3. Protection against lightning - Part 3: Physical damage to structures and life hazard.

[4] IEC 62561-3: Lightning protection system components (LPSC) - Part 3: Requirements for isolating spark gaps (ISG).

[5] IEC 60060-1: High-voltage test techniques - Part 1: General definitions and test requirements

[6] Installation instructions, coaxial connection box, coaxial connection of EXFS100. Publication No. 1846/UPDATE 07.14, Neumarkt: DEHN+SÖHNE

[7] IEC 60079-17: Explosive atmospheres - Part 17: Electrical installations inspection and maintenance

[8] German AfK recommendation AFK 3: Maßnahmen beim Bau und Betrieb von Rohrleitungen im Einflussbereich von Hochspannungs-Drehstromanlagen und Wechselstrom-Bahnanlage (textgleich mit DVGW-Arbeitsblatt GW 22 und der Technischen Empfehlung Nr. 7 der Schiedsstelle für Beeinflussungsfragen) 2014.

[9] EN 50443: Effects of electromagnetic interference on pipelines caused by high voltage a.c. electric traction systems and/or high voltage a.c. power supply systems