

# AC corrosion as a result of differing methods of DC stray current protection measures

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## **Abstract:**

A gas pipeline installed close to a direct current (DC) voltage operated railway is affected by stray currents. Differing measures are used to protect pipelines from stray currents. The most common solution is a unidirectional drainage bond. Since this is often not sufficient, it was also necessary to create a forced drainage, usually referred to as 'soutirage'.

This paper describes a case where a gas pipeline has interference due to stray currents. There are several cathodic protection (CP) stations, a rectifier with anodebeds, drainage and soutirage. This pipeline also runs in the vicinity of high voltage power lines.

Stray currents cathodically interfere with the pipeline so that  $E_{on}$  fluctuates to very negative values. Several changes have been made in the CP system. The aim was to have as little interference of stray currents as possible.

The aim of installing ER coupons was to evaluate DC or alternating current (AC) corrosion. Data analysis shows a high corrosion rate of the ER coupon. AC corrosion was dependent on different connections of CP stations. As a consequence, this has led to modification of the CP system.



### *1.1. Cathodic protection system*

Cathodic protection has been implemented since the beginning of construction. Some problems occurred at the beginning because the operator has no experience with influence of stray currents.

The cathodic protection system has been improving all the time. An old T/R rectifier was changed with automatic controlled rectifiers, automatic controlled soutirages (forced drainage) and unidirectional drainage. Remote monitoring of the cathodic protection system was installed in 2005. The first coupons were used in 2007.

Today, a cathodic protection system consist of 95 CP stations. Out of this, 18 are soutirages and 13 unidirectional drainages, the remaining 64 are T/R CP stations. Rectifiers and soutirages work in automatic mode to control the ON potential. Drainages are a simple CP station, where a high power diode and wire resistor are used. A wire resistor is used to reduce a current. The rail voltage can fluctuate from a few volts up to one hundred volts in positive or negative. This causes very high currents, which is also the case at soutirages. Approximately 30% of the entire pipeline system is affected by stray currents.

In order to have as stable ON potential as possible, a drainage station was disconnected and soutirage was changed to T/R rectifier connected to anode groundbed. This paper presents this method.

Steel casing pipes make a short connection between gas pipelines and casing. These short connections can be either metallic-galvanic or electrolytic. All gas operators have problems with non-piggable pipelines, especially in urban areas where above-ground inspections are limited (excavating, DCVG, etc.). Underground pipe inlets over concrete walls are also critical points. Connected pipes in shafts where there is water also presents a problem. If there is an insulating joint, it make corrosion cell, meaning that corrosion can easily occur.

Special attention is paid to pipelines attacked by stray currents. As far as possible their influence should be eliminated. In a real situation it is difficult to complete useful measurements. Installed ER coupons are the most common solution to verify the CP system.

As in all other countries there is some interference caused by high voltage electric power transmission lines. The Slovenian high voltage transmission network is composed of facilities on three voltage levels: 400 kV, 220 kV and 110 kV. Among the transmission facilities there are transmission lines, substations and switching substations. The transmission network consists of 2,843 kilometres on all voltage levels. Many of the pipelines run close to this network, so risks of AC corrosion and overvoltage influence must be taken into consideration.

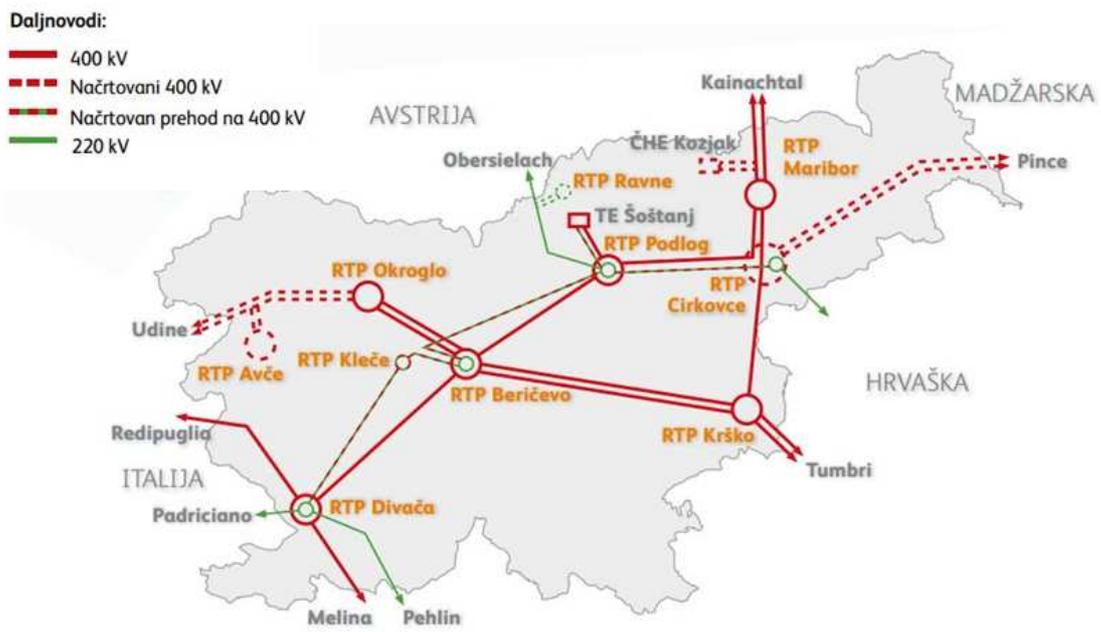


Figure 2: The Slovenian power system

## 2. DC-operated electric traction system

In Slovenia there is a DC-operated electric traction system. Slovenian railways are composed of 1,229 kilometres of main and regional rails. There are single and double track rails, but DC-operated rails are less than half, 504 kilometres. The graphic below shows DC-operated rails as red lines.

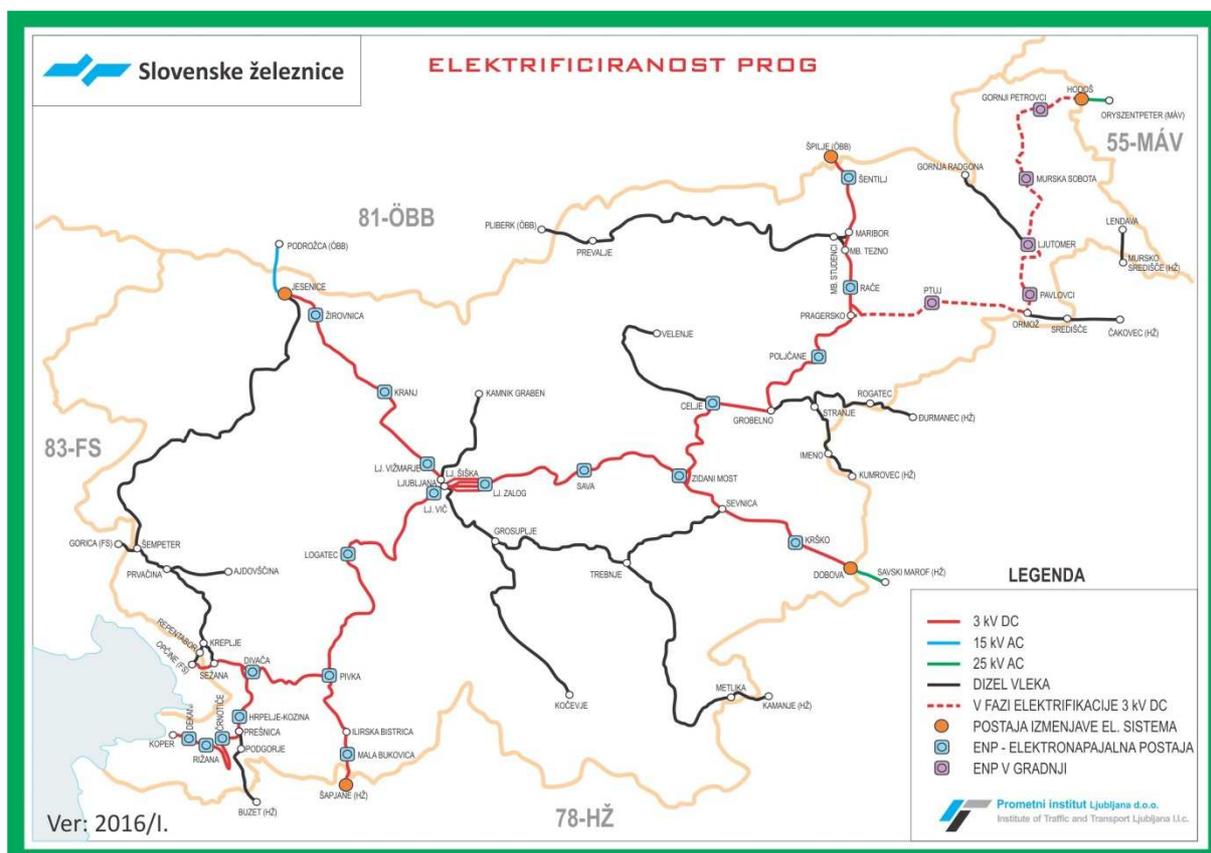


Figure 3: Rail system and traction power substations

Slovenia's neighbouring countries, except Italy, have different electric power systems. Austria has 15 kV, 16 2/3 Hz, and Croatia has 25 kV, 50 Hz. In the network there is a connection with Hungary, which also has a 25 kV, 50 Hz power traction system.

A 3 kV DC-operated electric traction system is connected to 18 traction power substations (TPS). They are located close to the rail, typically at between 15 to 40 kilometre intervals.

Most of these TPS were built in the period from 1964 to 1976, when the electrification process began. The first was built in 1936. As previously mentioned, a new track will be implemented with an electric traction system, and there will be another five traction power substations.

A traction power substation typically consists of two DC power units, a transformer and a rectifier. Each unit can be overloaded by 50% for at least 2 hours and at 200% for one minute. This is needed in case one unit is out of service. The nominal power of one unit is from 2.25 MW to 6.8 MW. The current limitation is set according to the nominal power; the maximal current limitation is 2400 A.

The electric traction system is always powered from two sites, except at the ends where the interconnection is made.

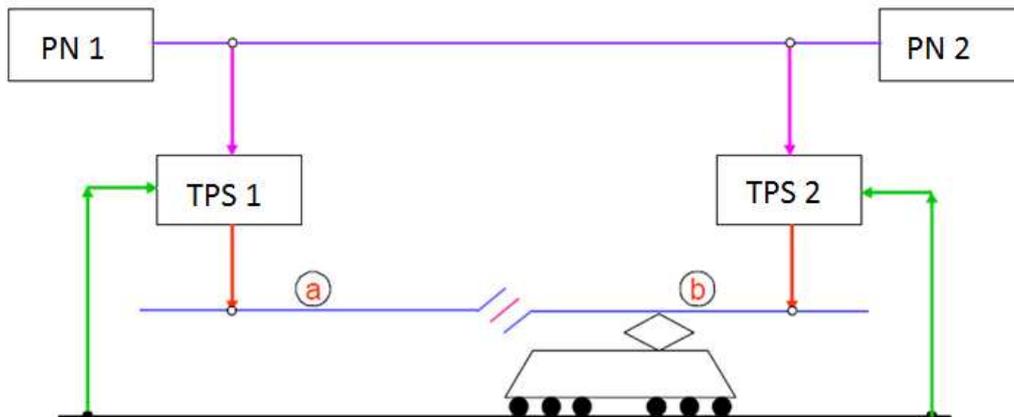


Figure 4: TPS connection

The nominal voltage level is 3000 V, but this voltage is not fixed. It can vary from -33% to +20% of the nominal value. Therefore, the voltage can be from 2000 V – 3600 V. Voltage fluctuates due to the situation on the rails as it depends on the consumption of trains, however, braking systems on trains act as generators.

### 2.1. Stray currents

Dual overhead power lines are connected through a switch-over at railway stations. This means that currents can only flow over that connection and at traction power substations.

Stray currents tend to be very dynamic in nature, with the magnitude varying with usage of the transit system and relative position and degree of acceleration of the electrified vehicles. Direction of current depends on whether trains consume or generate power.

This means that direction, height and distribution of current cannot be predicted.

The negative pole of the electric traction system is the rail. Rail is not completely isolated from soil and it is connected with the ground in several places. This causes stray currents.

Fundamentally, the following factors all have an effect on the severity of stray currents:

- magnitude of propulsion current
- substation spacing (rail length)
- substation grounding method
- resistance of the running rails
- usage and location of cross bonds and isolated joints
- track-to-earth resistance
- voltage of the traction power system.

In the most common situation, where there are two traction substations, power consumption is divided between them. This means that stray currents will distribute to each traction substation. For example, with a 6 MW rail vehicle, 30 km length of rail, the specific soil resistance of the rail bed  $5000 \Omega\text{m}$ , and specific soil resistance of the soil  $50 \Omega\text{m}$ . A calculation was made and the results of the specific rail resistance are  $0.48 \Omega/30\text{km}$ , and grounding resistance of the rail  $0.7 \Omega$ . From this equation it can be concluded that stray currents are 41% of the nominal current of the rail vehicle, equating to around 20% for 15 km of rail, and around 200A for each traction substation. The highest value of stray currents is when the rail vehicle is in the middle between two traction substations.

In practice, the real values are much lower, however, the most important factors are length of the rail and specific soil resistance.

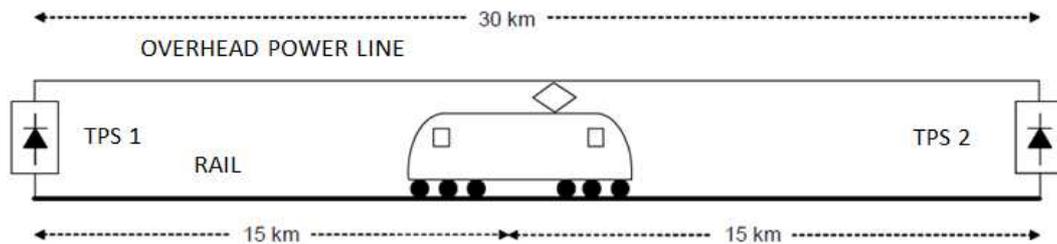


Figure 5: Stray current calculation

### 3. Case study

This study presented a case where a gas pipeline suffers interference from stray currents. There is a 15 km gas pipeline, DN 150, with an operating pressure of 10 bars. It is located close to the city, there is a DC-operated traction system and high voltage AC transmission power lines. The pipeline coating is polyethylene. The pipeline was built in 1978 and crosses a railway, running in parallel with three 2x110 kV power lines. There is a gas substation. At this location there is a CP station installed. At the point of crossing, there is a drainage station.



*Figure 6: Location overview*

Cathodic protection consists of one unidirectional drainage station, one soutirage station and two T/R stations connected to an anode groundbed. The drainage station makes high fluctuations of  $E_{on}$  potential. Changes in the potential were significant when diodes conducted current, interfering with cathodic direction. Attempts were made to eliminate this influence. It was predicted that the soutirage station would protect the pipeline, especially as there are also two T/R. ER coupons were installed next to the drainage station.

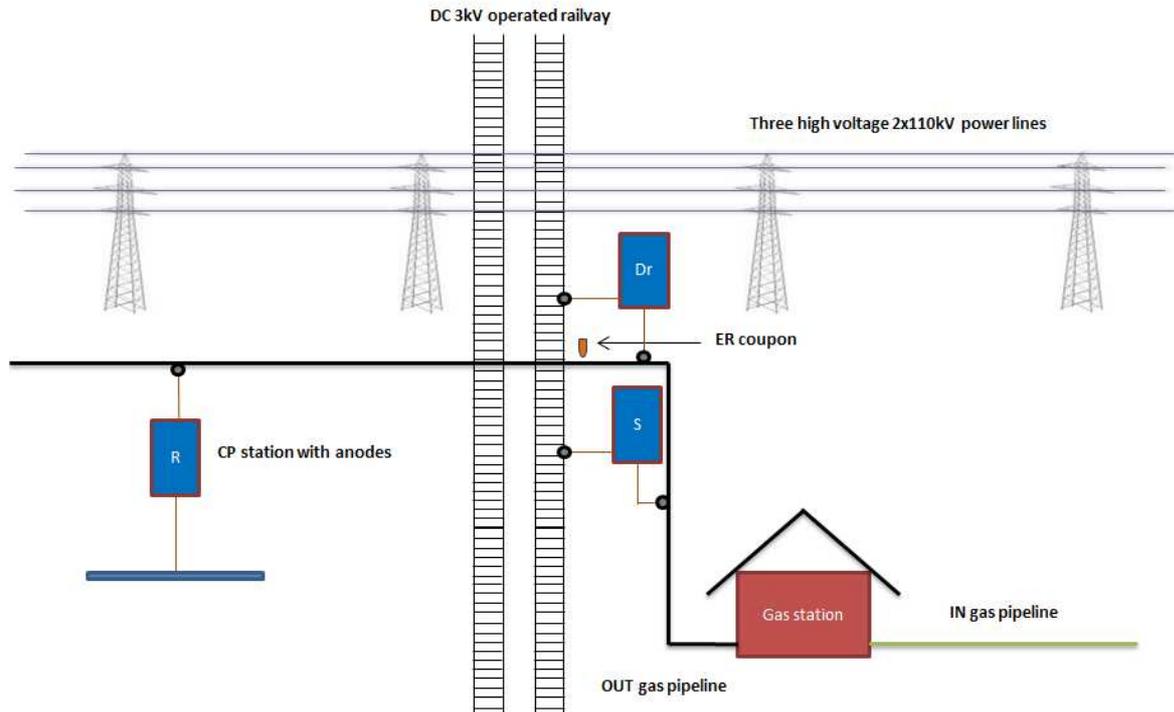


Figure 6: Situation and CP connection overview

The cathodic protection system was changed in a few steps:

- disconnection of the drainage station
- reduction of the  $E_{on}$  potential of the soutirage
- reconnection of the soutirage to anodes
- AC diverter installation

Initially, when the drainage station was disconnected, there was no cathodic interference, and the  $E_{on}$  potential became more stable. A soutirage also causes some interference, so the reference potential was reduced -  $E_{ref}$ . It was planned that the soutirage would be changed to the T/R station, however, because the anode groundbed was under construction, the change was not possible.

All CP stations connected to rail cause huge interferences to pipeline potential. This can lead to overprotection and its consequences. Drainage current can be reduced with resistors or other electrical elements, however, this is usually a very exacting piece of work, and some cathodic interference will still remain.

Two T/R stations connected to an anode groundbed are dislocated from the point of interest by 1 km and 11 km. Both CP stations feed a small current so they do not have a significant impact on the protection potential.

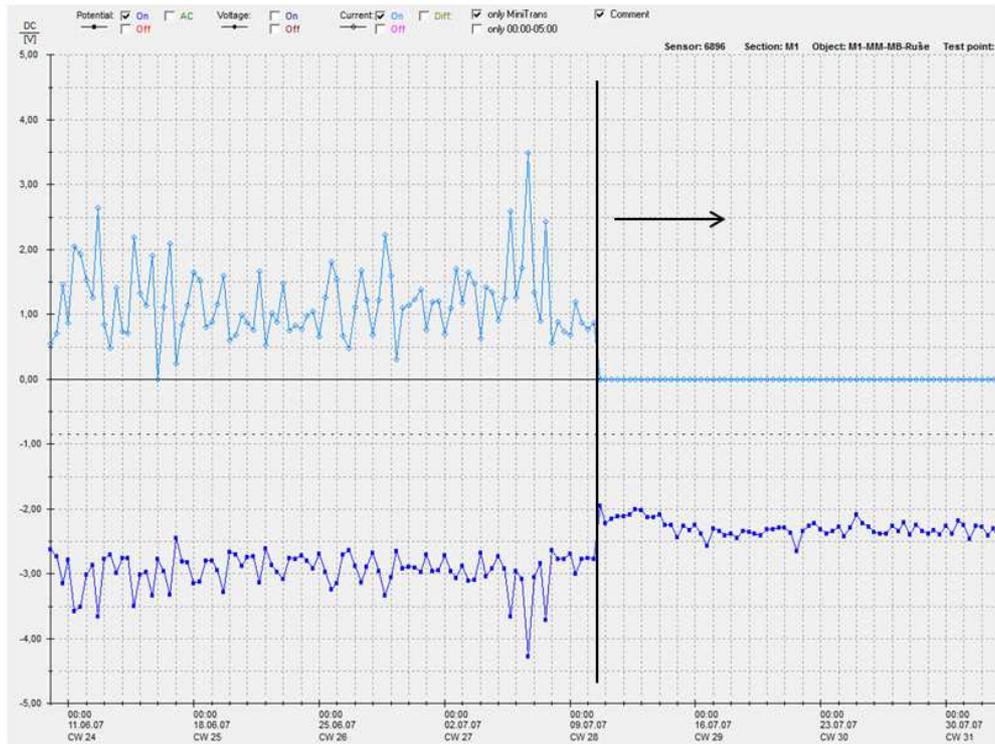


Figure 7: Drainage station parameters

Figure 7 shows the protection potential and drainage current at a drainage station. There is a time when the drainage station was switched OFF. The graph clearly shows what effect the cathodical interferences have on drainage and the change in protection potential. When drainage is switched OFF the  $E_{on}$  protection potential is less negative and more stable. It is obvious that this  $E_{on}$  protection potential is far from the  $E_{IRfree}$  potential.

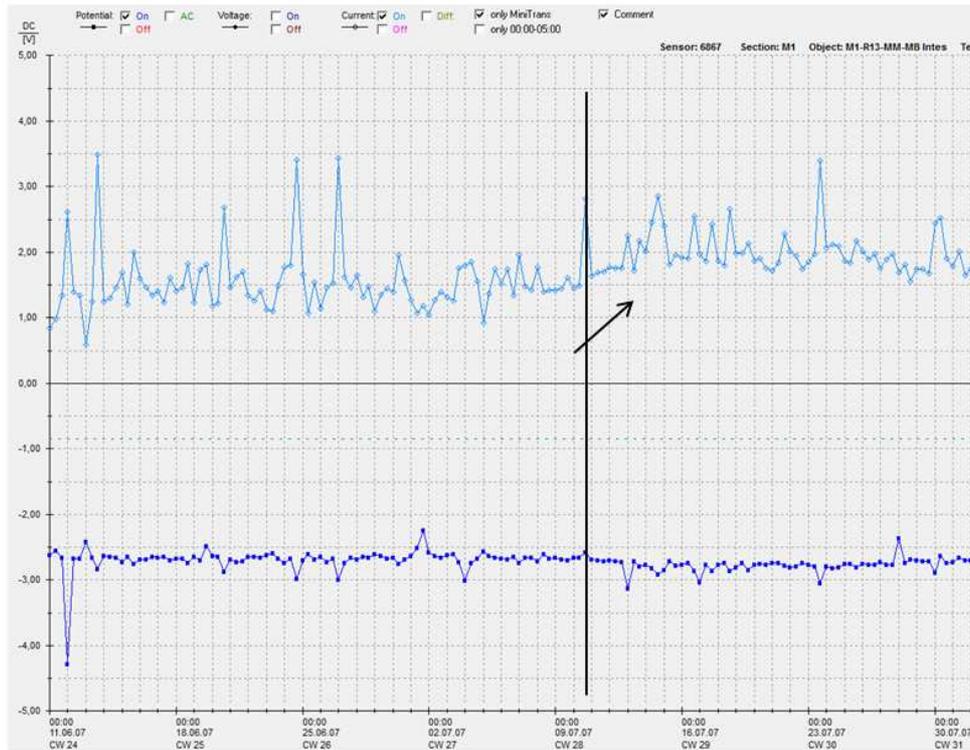


Figure 8: Soutirage station parameters

At the same time as the drainage station was switched off, it can be seen in figure 8 how the protection current of the soutirage increased.

In order to take a closer look at this situation, two ER coupons were installed next to the drainage station. The ER coupons are produced by Metricorr. The data was also analysed by their software tools. One ER coupon of 500  $\mu\text{m}$  and one of 100  $\mu\text{m}$  were used for a surface area of 1  $\text{cm}^2$ . The 100 $\mu\text{m}$  coupon suffered corrosion very quickly, which was quite surprising.

For the next step it was necessary to analyse the situation and try to find the reasons for this high corrosion rate. Figure 9 shows the corrosion rate of the 500 $\mu\text{m}$  coupon in a time period of five months. Seven marked time periods were analysed. The same diagram shows the status of CP stations. The CP system was changed in increments. The relationship between the status of the CP station and the corrosion rate provided interesting information.

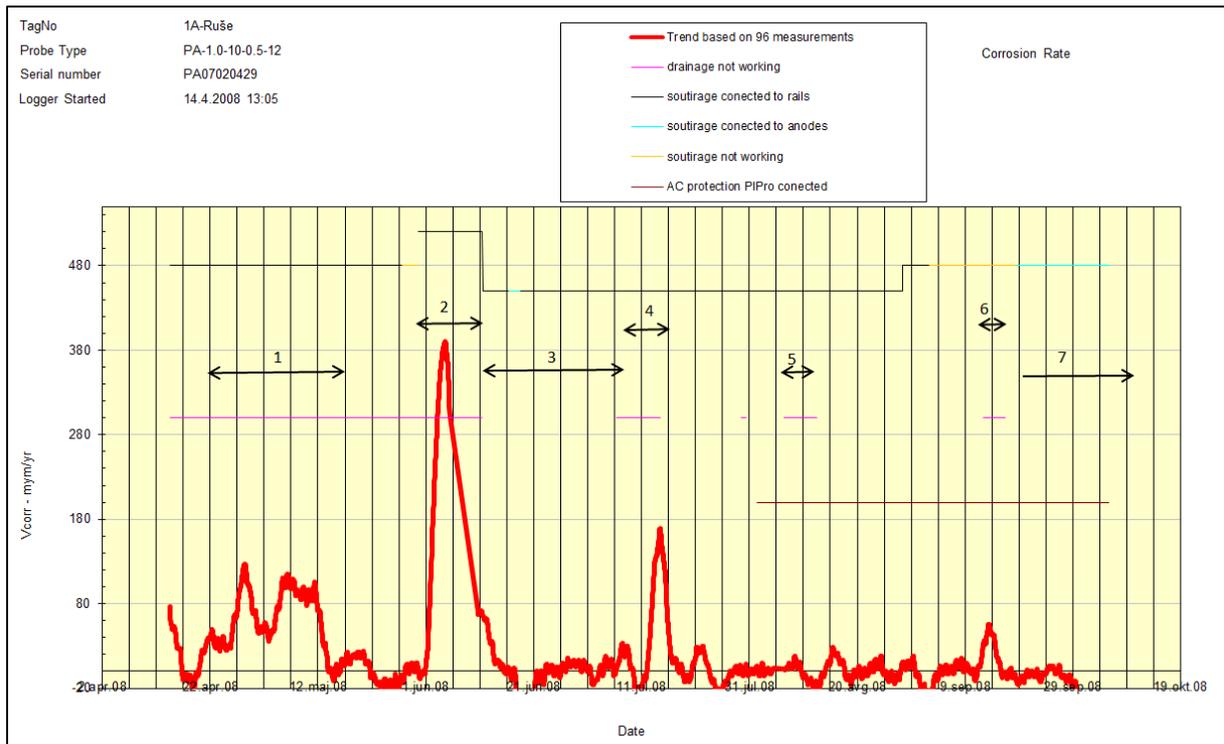


Figure 9: Corrosion rate in time

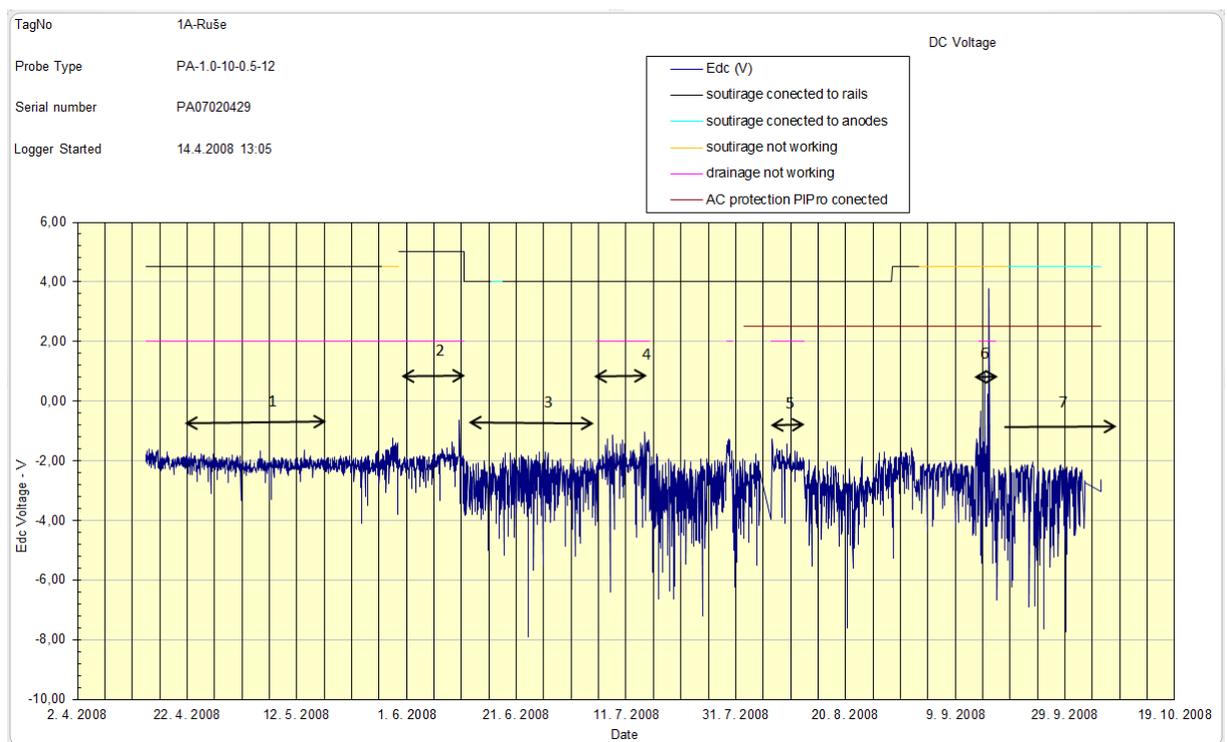


Figure 10:  $E_{on}$  in time

Figure 10 shows the same time period with protection potential. For example, in time period 3, influences can be seen when drainage is working; similar in time period 6 where drainage and a soutirage station is not working. The status of CP stations and the corrosion rate for the seven periods were used for this calculation.

CP station	1	2	3	4	5	6	7
<b>DRAINAGE</b>	OFF	OFF	ON	OFF	OFF	OFF	ON
<b>SOUTIRAGE</b>	normal	high	low	low	low	OFF	ANODES
<b>AC filter</b>	OFF	OFF	OFF	OFF	YES	YES	YES
<b>corrosion</b>	midle	high	min	midle	min	low	min

Figure 11: Table of CP status

Key parameter	1	2	2-1	3	4	4-1	5	6	7
<b>J<sub>DC avg</sub>(A/m<sup>2</sup>)</b>	-5,8	-8,1	-10,0	-13,9	-5,5	-6,9	-6,1	-4,1	-7,7
<b>U<sub>AC avg</sub>(V)</b>	5,0	6,9	13,3	4,3	4,9	5,5	5,7	1,6	3,6
<b>J<sub>AC avg</sub>(A/m<sup>2</sup>)</b>	31,6	70,3	129,5	44,4	36,4	55,3	43,1	9,2	16,6
<b>Corrosion rate</b>	73	91	2743	-6	25	296	3	56	-4
<b>V<sub>corr</sub>(µm/y)</b>									
<b>Ratio J<sub>AC/DC</sub></b>	5	9	13	3	7	8	7	2	2

Figure 12: Table of parameters

Abbreviated status of CP status means:

Drainage:

- drainage station is working – ON
- drainage station is not working – OFF

Soutirage:

- soutirage station is working in normal mode – normal
- soutirage station is working as usual - normal
- soutirage station is feeding increased current - high
- soutirage station is feeding small current - low
- soutirage station is not working - OFF
- soutirage station is connected to anode groundbed - ANODES

AC diverter:

- device connected to pipe and grounding to drain AC current – ON
- no device to drain AC current – OFF

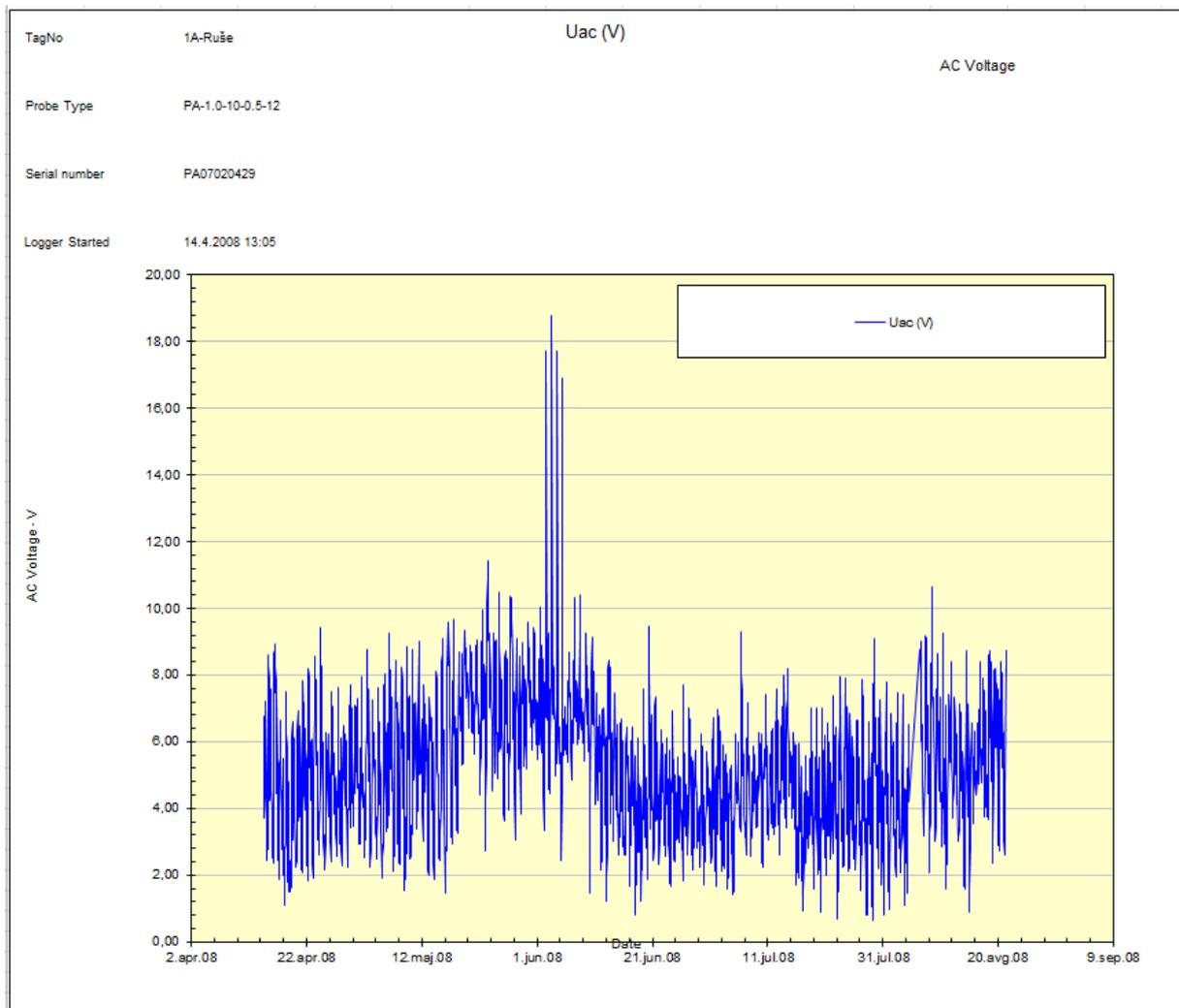


Figure 13: AC voltage in time

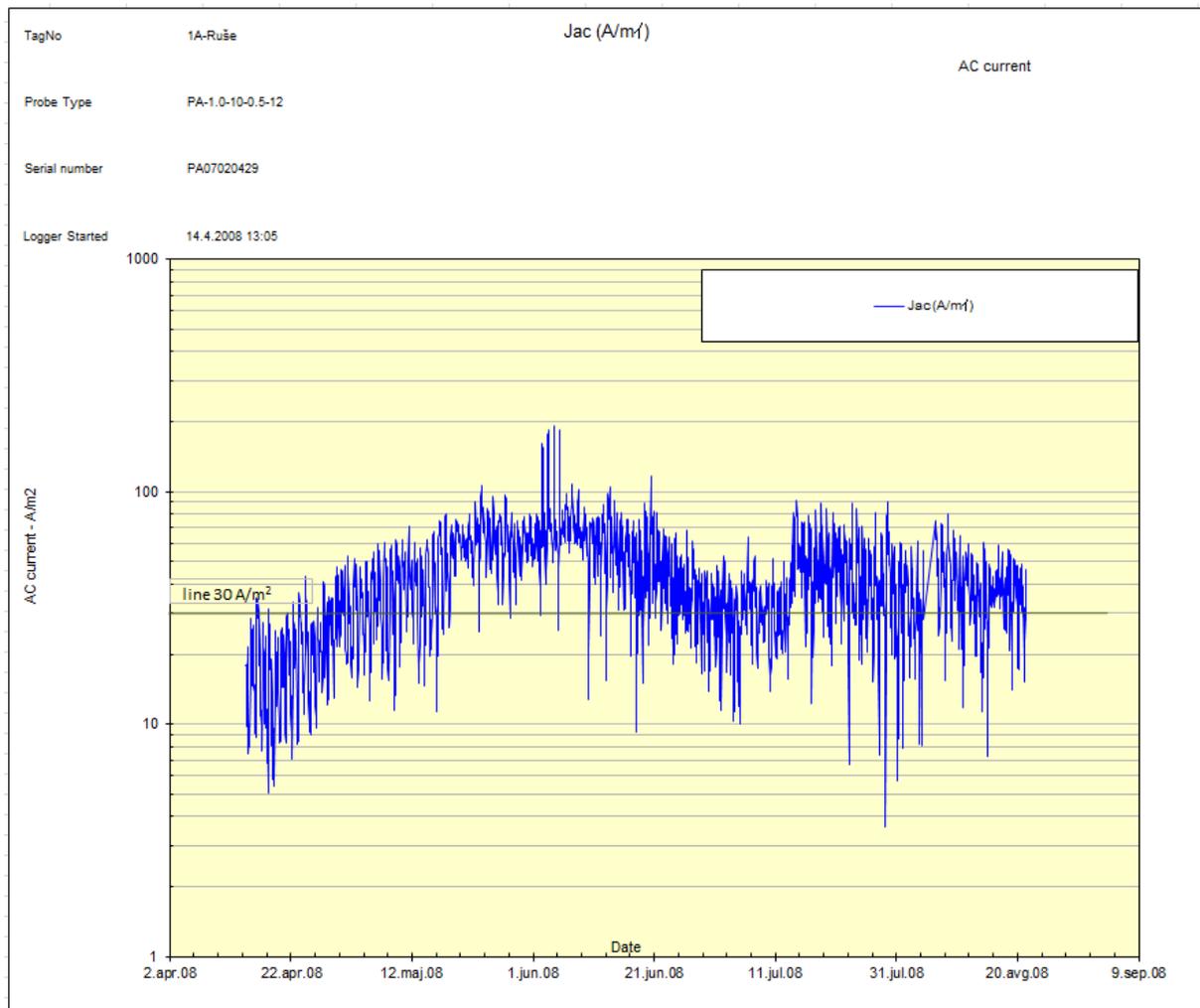


Figure 14: AC current density in time

In figures 13 and 14 the induced AC voltage  $U_{AC}$  (V) on the pipeline and the AC current density  $J_{AC}$  (A/m<sup>2</sup>) on the ER coupon can be seen.

### 3.1. Analysis

The induced AC voltage  $U_{AC}$  (V) in a time period of five months did not exceed 20 V, most of the time it was below 10V. The specific soil resistivity in a particular location is close to 100  $\Omega$ m. According to CEN/TS 15280, for the specific soil resistivity over 25  $\Omega$ m, induced AC voltage should not exceed 10V to prevent AC corrosion.

The current density was, most of the time, over 30 A/m<sup>2</sup>, so according to the standard there is a medium likelihood of corrosion. When the current density exceeded 100 A/m<sup>2</sup>, there was significant corrosion (time period 2-1). In this time period (2-1) in 3 days ER 100  $\mu$ m coupon corroded.

Other conclusions can be drawn from figure 12. In time period 6, where the drainage and soutirage station was not working, there was quite a strong cathodic polarisation ( $J_{DC} = -4,1$  A/m<sup>2</sup>), but not enough to protect the EC coupon.

The  $E_{ON}$  criterion protection potential is not sufficient, as is clear and well-known. Some operators try to eliminate cathodic shifts by minimalising cathodic interferences.

However, strong cathodic polarisation, in combination with AC interferences, leads to corrosion (time period 2, 2-1).

Time period 7 is the present state of the cathodic protection system. The soutirage station was reconnected to the anode groundbed, thus behaving as an T/R station. The drainage station is constantly functioning. In order to reduce the AC voltage there was installed two AC diverters. This situation is shown in figure 15. Over a longer time period it can be observed and confirmed that there is very low, or negligible, corrosion rate of  $V_{corr} < 10 \mu\text{m}/\text{year}$ .

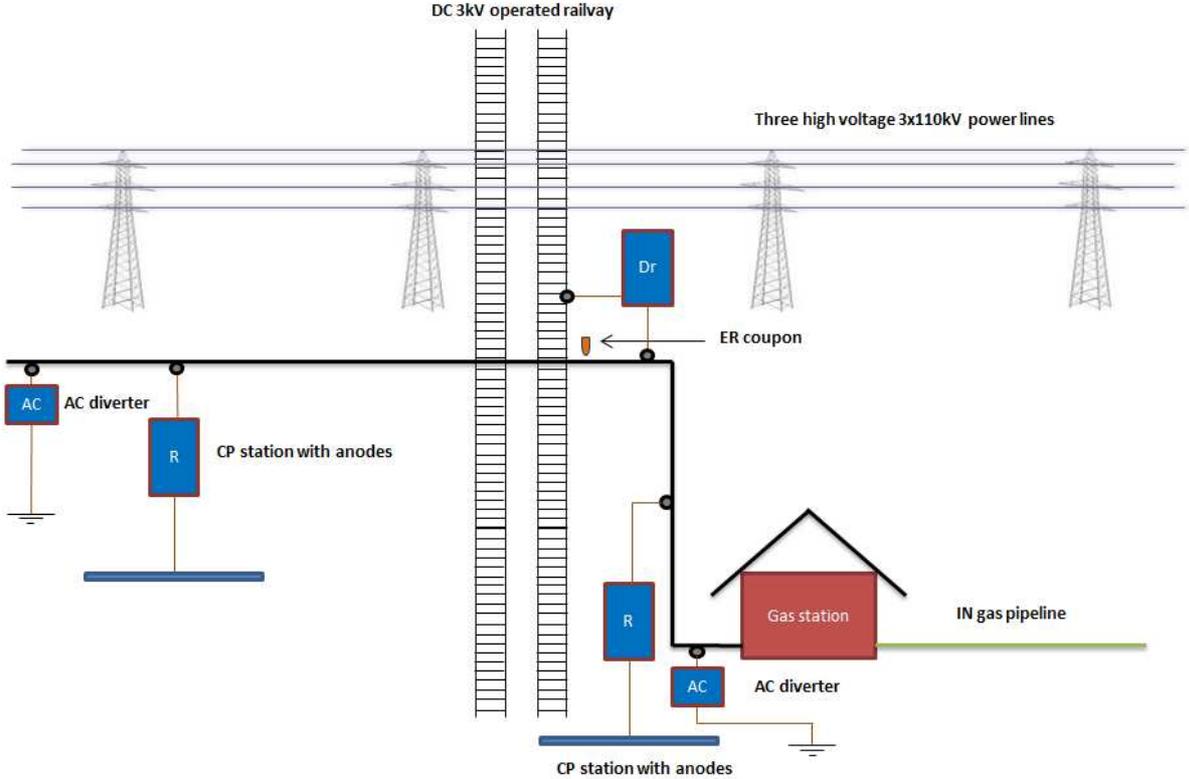


Figure 15: Situation and CP connection overview after modification

#### 4. Conclusion

The drainage station has a strong impact on the  $E_{ON}$  protection potential and the DC current density of  $J_{DC} > 10 \text{ A/m}^2$ . When the drainage station was working, in time period 3 and 7, there was negligible corrosion. The same situation occurred when the drainage station was switched off, but the AC diverter was connected. It seems that the unidirectional drainage bond drains AC voltage. It acts as a rectifier or AC diverter, thus preventing AC corrosion.

In the paper we could have done a more sophisticated analysis. The intention was to present a simple and practical point of view. This presents a theoretical view, however, in a real situation it is very important that quick and right decisions are made.