An algorithm for CP effectiveness evaluation: the Italian KT and its possible application in other countries

I.MAGNIFICO
Automa S.r.l. – Via Casine di Paterno, 122/A – 60131 Ancona - Italia
ivano.magnifico@byautoma.com

ABSTRACT:

Remote monitoring for cathodic protection introduces the possibility of performing a detailed investigation on cathodic protection, by obtaining measurement every second during the whole days and the whole weeks, thus allowing to monitor potentials evolution in real time on many points at the same time in a CP system.

This means that cathodic protection technicians have to deal with a huge amount of data: for this reason, a software able to analyze all these data and automatically highlight critical conditions for CP is fundamental to obtain the best benefits from remote monitoring.

In this perspective, an algorithm able to give a global evaluation for cathodic protection effectiveness of a CP system, resulting in a simple number for the whole system, would be very useful to have a general understanding of CP behavior and identify possible critical condition without having to analyze any single measure received by any single remote monitoring device.

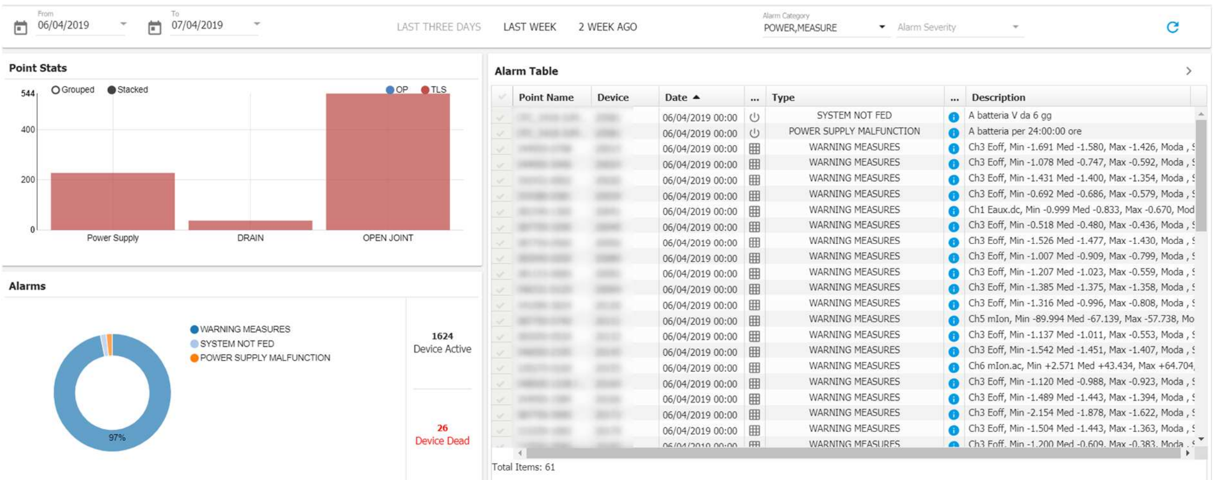
In Italy, all gas distribution and transmission companies have to demonstrate every year to National Authority the effectiveness of the CP applied to their pipelines by calculating the "KT" evaluation.

In this paper, the main principles of Italian KT will be presented, and the possibility of its application also to other countries will be discussed.

INTRODUCTION

The introduction of remote monitoring in cathodic protection has brought the advantage of being aware about what happens on pipelines in terms of variation of the electrical parameters measured with a daily update.
Remote monitoring allows to know exactly what happens on pipelines (thanks to DC and AC On Potentials, Off Potentials and IRFree potentials measures) as well as be informed almost in real time of any CP equipment failure thanks to the monitoring of other parameters like output current and voltage from the rectifiers, drained currents from AC and DC drainages and so on.

On the other hand, all this information results in a huge amount of data (particularly taking into account very large pipelines extensions with hundreds or thousands of installed dataloggers) that can be very difficult to check daily by cathodic protection technicians: for this reason a software able to filter all this data is fundamental to just highlight all that conditions like in the example below, where from a global installation of more than 1600 dataloggers with an average of 5 measuring channels enabled for each datalogger, 61 anomalous condition are automatically identified and highlighted from the system, considering measures out of the defined thresholds, main power supply failure on rectifiers, etc…:



It is evident how much easier can be to focus directly on the anomalies instead of looking daily (in this case) on the 1600*5= 8000 measure reports received every day.

The advantage of receiving and storing all this data, becomes really evident at the moment of checking the anomalies: the possibility of analyzing all the historical data to understand how that signal moves to an anomalous condition allows to perform consistent assumptions and easily identify in most cases the causes for solving the issue.

Anyway, this are just corrective actions, taken into consideration only after an anomaly has occurred.

A different approach could be creating a global indicator that takes into account entirely a cathodic protection system, with all its installations and measures, returning, through a calculation, just a single number indicating the state of the effectiveness of cathodic protection on that system: by analyzing this numbers and their trends could be possible to realize if something is happening on a CP system before it would lead to some anomalous condition, without really checking any single measure by the CP technicians and, in this way, starting to move the analysis from a corrective one to a predictive one.

A first step to analyze an algorithm like this, could be to check what already exists and how it works, and then try to generalize it to a global application.

In Italy already exists and is applied an algorithm like this, performed on yearly base, called KT.

THE ITALIAN KT [1,2,3]

Every year in Italy, the gas distribution and transmission companies have to demonstrate to ARERA (Autorità di Regolazione per Energia Reti e Ambiente, a national independent body set up by the task of protecting the interests of consumers and to promote competition, efficiency and deployment of services with adequate levels of quality, through regulation and control activities) their efforts on keeping safe and in good state the gas pipelines by presenting the KT calculation performed on every single Cathodic Protection system, to demonstrate the effectiveness of CP applied.

The final KT obtained through a specific algorithm is a number from 0 to 100, where 60 is the minimum accepted value to consider effective the CP applied to that specific CP system.

Before describing the algorithm and the calculation, it is necessary to define some concept.

Definitions

- *Cathodic Protection System (CPS)*: is a portion of the gas pipeline network, cathodically protected independently of the other systems, from which it is electrically isolated.
- *Remotely monitored CPS*: it is a CPS where all the rectifiers, all the drainages, all the railway crossings or parallelism and an additional number of selected measuring points (whose minimum number is defined according to CPS length and stray current influence) are equipped with a datalogger.
- *Variability*: it refers to electric field variability for a CPS, it measures the stray current influence on the CPS.

In the KT calculation the following measurements are considered:

- *Short term measurements*: acquisition of electrical parameters carried out by an operator in the field having a maximum duration of 5 minutes with restitution of a single value or statistical values (minimum, average, maximum)
    - *Compliance:* a short term measurement is compliant if **all** the values are more negative than the ones indicated as maximum threshold from CP criteria
- *Intensive measurements*: acquisition of electrical parameters with a duration of 24 hours performed by dataloggers with sampling time ≤1 s. The acquisition returns a graphical plot of the measured values.
    - *Compliance:* an intensive measurement is compliant if the values are more negative than the ones indicated as maximum threshold from CP criteria except for a maximum interval of 3600 seconds (non-continuous).
- *Daily Report*: acquisition of electrical parameters with a duration of 24 hours performed by dataloggers with sampling time ≤1 s. The acquisition returns statistical values of the 86400 measurements:
    - *Minimum value*
    - *Average value*
    - *Maximum value*
    - *Mode*
    - *Standard Deviation*
    - *Variability*
    - *Total time (seconds) below the minimum threshold during the day*
    - *Total time (seconds) above the maximum threshold during the day*
    - *Total number of minimum threshold trespassing during the day*
    - *Total number of maximum threshold trespassing during the day*
        - *Compliance:* a daily report is compliant if the total time above the maximum threshold is less than 3600 seconds (non-continuous).

According to the measurement described above, a measuring point equipped with remote monitoring can be considered compliant (over a 365 days period) if it has at least 300 compliant daily reports.

Variability

Electric field variability of a CPS requires some preliminary measurement to be evaluated:

- on all the selected measuring point of the system, an intensive measurement is performed, with **no** CP applied;
- for each measuring point, variability is calculated as follows:
    - arithmetic average X is calculated from the 86400 values of the intensive measurement;
    - then variability is:
        - *Low*: if more than 95% of the values of the intensive measurement lays in the interval of ±10% of X

        - *Medium*: if more than 95% of the values of the intensive measurement lays in the interval of ±25% of X
        - *High*: if less than 95% of the values of the intensive measurement lays in the interval of ±25% of X
- the CPS variability then corresponds to the highest variability detected on the selected measuring points.

Once defined variability for the CPS, then the **minimum** number of selected point to be equipped with remote monitoring is known automatically:

- Low: a point every 10km of CPS length
- Medium: a point every 6,5km of CPS length
- High: a point every 5km of CPS length

Example: for a 21 km long CPS with low variability, 3 points as minimum (10+10+1 Km) must be equipped with remote monitoring.

KT algorithm and calculation

Once defined variability and identified the points to be equipped with remote monitoring, all the parameters to perform calculation are known:

- Calculation parameters of the cathodic protection system
    - L_{SPC}: length of the CPS (in meters)
    - N_{PM}: total number of the measuring points present in the CPS
    - ΔE: variability of the CPS
    - N_{AF}: number of measuring points corresponding to crossing or parallelism with railway lines present in the CPS
    - N_{IPC}: total number of rectifiers, drainage systems (unidirectional or mixed) and bonding with foreign structures present in the CPS
    - N_{PMC}: number of selected measuring point identified and equipped with remote monitoring
- Calculation parameters of the controls with remote monitoring
    - N^{TLS}_{PM}: total number of compliant measuring points equipped with remote monitoring present in the cathodic protection system (among N_{AF} , N_{IPC} and N_{PMC})
    - N^{TLS}_{MBD}: total number of compliant short-term measurements performed by operators in the field in the measuring points of the CPS except those considered in N^{TLS}_{PM}
    - N^{TLS}_{MR}: sum of the number of intensive measurements performed by operators in the field and / or obtained from the remote monitoring system in the measuring points of the CPS except those considered in N^{TLS}_{PM}

The KT calculation is as follows:

$$KT = (K_1 * \sqrt{\frac{K_2}{70}} + K_2)$$

Where

- K_1 is the coefficient related to the **design** of the CPS and it is a value that can reach a maximum of 30
- K_2 is the coefficient related to the **measures** performed on the CPS and it is a value that can reach a maximum of 70

The K_1 coefficient is the parameter to evaluate the design features of each CPS, since it considers both the length of the CPS (K_{11}) and the measuring points (K_{12}) present in the same CPS:

$$K_1 = 30 * (\frac{1}{3}K_{11} + \frac{2}{3}K_{12})$$

Where

- K_{11} depends from the length of the CPS (L_{SPC}): considering an ideal system of maximum 20Km, it has a maximum value of 1 if $L_{SPC} \leq$ 20Km, and decrease with quadratic law as larger than 20 Km the SPC is.
- K_{12} depends from the number of measuring points designed in the CPS (N_{PM}): it depends also from SPC length, and its ideal value considers an average spacing between two followings measuring points of 1,5Km (L_{SPC}/N_{PM}); for this reason it has a maximum value of 1 if the spacing is 1,5Km or lower, and decrease with quadratic law as larger than 1,5Km as the spacing is.

The coefficient K_2 is related to the management of the CPS and must express the evaluation on the management and operation of the cathodic protection, intended as a verification of the reliability and effectiveness of the CPS:

$$K_2 = 70 * \sqrt{(K_2^{TLS})^3}$$

Where K_2^{TLS} is the result of a calculation that takes into account all the evaluation on the compliance of the measures performed on the measuring points of the CPS.

The KT cathodic protection indicator can be expressed as:

- insufficient (value < 60): value taken by the indicator in conditions of ineffective application of cathodic protection.
- standard (value ≥ 60): value taken by the indicator in conditions of effective application of cathodic protection.

Indicator values between 60 and 80 normally correspond to situations in which the effectiveness of cathodic protection is assured. The range of twenty points of the indicator, between 60 and 80, considers the different operating conditions.
Indicator values greater than 80 corresponds to situations where checks and controls have been intensified due to the magnitude and variability of the interfering electric fields.

Examples

The Italian KT indicator, is based on the measures performed during a year, so from January 1st to December 31th.

Here below an example of KT calculation on many CPS for 2018, with indicated also all the sub-elements of the calculation.

SYSTEM	YEAR	VARIABILITY	L-SPC	KT	K1	K2	K11	K12	N-PM	N-IPC	N-AF	N-PMC	N-PM-TLS	PM-TLS-UNI	N-MR-TLS	N-MBD-TLS
[illegible]	2018	B	14,608	100,00	30,00	70,00	1,00	1,00	11	2	0	3	2	2	20	2
[illegible]	2018	B	19,122	99,62	29,62	70,00	1,00	0,98	11	1	0	3	3	1	4	1
[illegible]	2018	B	14,781	100,00	30,00	70,00	1,00	1,00	10	1	0	2	2	1	4	1
[illegible]	2018	B	13,132	86,66	30,00	59,09	1,00	1,00	9	1	0	2	1	1	9	2
[illegible]	2018	B	13,347	99,09	29,09	70,00	1,00	0,95	7	1	0	2	3	1	0	0
[illegible]	2018	B	12,669	99,41	29,41	70,00	1,00	0,97	7	1	0	2	3	1	0	0

It is also possible to check KT evolution year by year, to verify the effects of the management on the CPS:

System	Year	V	KM	F-TLS	C	KT	KT=60	Calculated on
[illegible]	2010		26,080			98,70		Thu, 3 Mar 11 11:20
[illegible]	2011		28,515			97,72		Fri, 30 Mar 12 08:51
[illegible]	2012		28,591			97,69		Fri, 15 Mar 13 03:16
[illegible]	2013		29,690			98,54		Mon, 31 Mar 14 17:27
[illegible]	2014		29,690			98,54		Fri, 27 Mar 15 16:16
[illegible]	2015		29,784			98,51		Tue, 1 Mar 16 13:01
[illegible]	2016		29,784			98,51		Fri, 10 Mar 17 12:53
[illegible]	2017		28,309			98,94		Wed, 21 Mar 18 17:29
[illegible]	2018		28,309			98,94		Thu, 14 Mar 19 14:46

NEDGIA NATURGY GROUP KT

An important European gas distribution company, the Spanish NEDGIA NATURGY GROUP, after discovering the Italian KT, liked so much the idea to develop an own KT algorithm, adapting and improving it to better fit with their internal processes of control of cathodic protection.

In this case the calculation is no more performed yearly on a fixed temporal period, but monthly, taking into account the last 12 months, so on a mobile windows that allows to better appreciate KT evolution by updating the value every month.

The final value obtained must be checked to decide if some action must be taken or not:

- $K_T < 65$: Level of effectiveness and efficiency of CPS inadequate, within 1 month a detailed assessment of the CPS must be carried out in order to perform an in-depth analysis of it.
- $65 \leq K_T < 75$: Level of effectiveness and efficiency of the CPS is adequate, but within a period of less than 3 months a detailed assessment of the CPS must be carried out in order to perform an in-depth analysis of it.
- $K_T \geq 75$: Level of effectiveness and efficiency of the CPS is adequate, no action required.

KT algorithm and calculation

They develop so their algorithm as follows:

$$K_T = K_R + K_I + K_M$$

where:

- K_R is the network index: it is related to the length of the CPS, and can assume a maximum value of 5;
- K_I is the installations index: it is related to the number of measuring points presents in the SPC, and can assume a maximum value of 10;
- K_M is the measures index: it is related to the measures performed on the CPS.

The network index K_R depends from the length of the CPS: considering an ideal system of maximum 20Km, it has a maximum value of 5 if the length is ≤ 20Km, and decrease with quadratic law as larger than 20 Km the CPS is.

The installation index K_I depends from the number and the type of measuring points designed in the CPS and it depends also from CPS length. The measuring points in K_I calculation have different weight according to their type:

- rectifiers,
- measuring points equipped with remote monitoring,
- measuring points equipped with coupon,
- furthermore three different category are defined for measuring points.

This index can reach a maximum value of 10.

The measures index K_M depends from three main elements:

- evaluation of the effective working time of the rectifiers,
- evaluation of the measures obtained by remote monitoring
  - instant off measures on coupon have higher influence on final value
- evaluation of the measures obtained by operators in the field

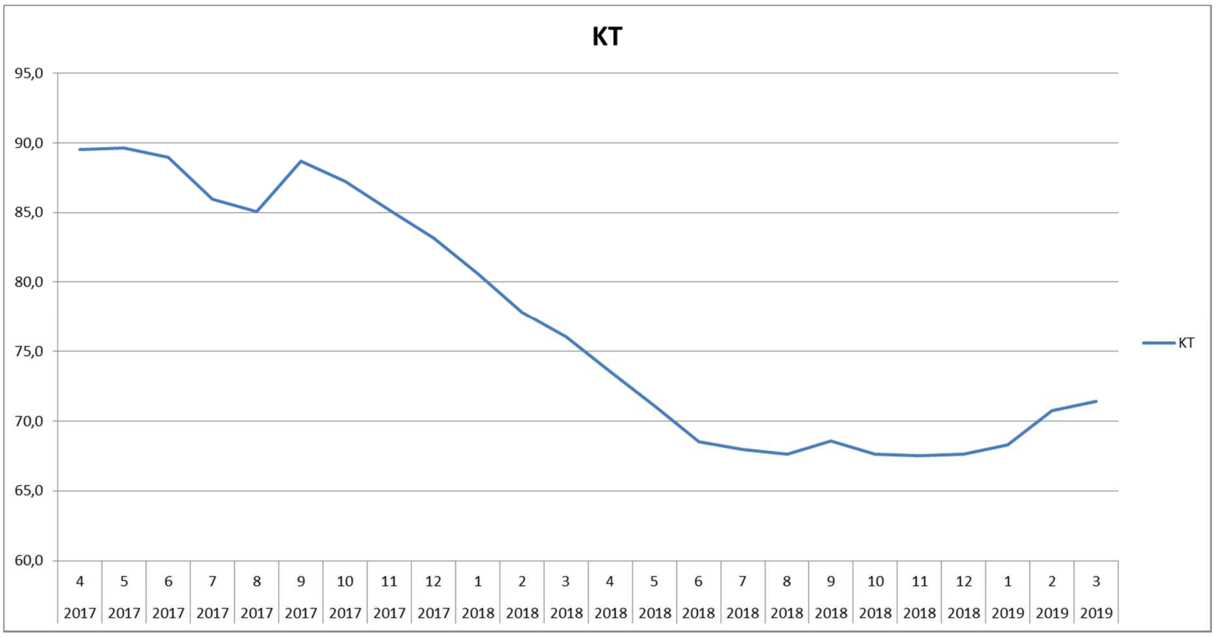
This index can reach a maximum value of 85.

Examples

Here below an example of a KT calculation on a CPS over a period of 12 months, with indicated also all the sub-elements of the calculation.

				INSTALACIONES													INDICES KT			INDICES MEDIDAS			EPC-DF	
				EPC-DF		TP-C1		TP-EP		TP-C2		TP-C3		TPC		KT								
ZPC	KM	AÑO	MES	N	T	N	T	N	T	N	T	N	T	N	T	TPC	KR	KI	KM	KM-DF	KM-TL	KM-OP	HR	HT
[illegible]	26,251	2017	4	1	1	6	3	6	3	23	22	0	2	7	4	89,5	4,7	10,0	74,8	16,1	36,2	22,4	8732	8760
[illegible]	26,251	2017	5	1	1	6	3	6	3	23	22	0	2	7	4	89,6	4,7	10,0	74,9	16,2	36,4	22,4	8733	8760
[illegible]	26,251	2017	6	1	1	6	3	6	3	23	22	0	2	7	4	88,9	4,7	10,0	74,2	15,4	36,5	22,4	8309	8760
[illegible]	26,251	2017	7	1	1	6	3	6	3	23	22	0	2	7	4	86,0	4,7	10,0	71,3	14,0	34,9	22,4	7566	8760
[illegible]	26,251	2017	8	1	1	6	3	6	3	23	22	0	2	7	4	85,1	4,7	10,0	70,3	12,9	35,0	22,4	6995	8760
[illegible]	26,251	2017	9	1	1	6	3	6	3	23	22	0	2	7	4	88,7	4,7	10,0	74,0	12,9	36,0	25,0	6995	8760
[illegible]	26,251	2017	10	1	1	6	3	6	3	23	22	0	2	7	4	87,2	4,7	10,0	72,5	12,9	34,6	25,0	6995	8760
[illegible]	26,251	2017	11	1	1	6	3	6	3	23	22	0	2	7	4	85,2	4,7	10,0	70,5	12,9	32,5	25,0	6995	8760
[illegible]	26,251	2017	12	1	1	6	3	6	3	23	22	0	2	7	4	83,2	4,7	10,0	68,5	12,9	30,5	25,0	6995	8760
[illegible]	26,251	2018	1	1	1	6	3	6	3	23	22	0	2	7	4	80,6	4,7	10,0	65,9	12,9	28,0	25,0	6995	8760
[illegible]	26,251	2018	2	1	1	6	3	6	3	23	22	0	2	7	4	77,8	4,7	10,0	63,1	13,0	25,1	25,0	7020	8760
[illegible]	26,251	2018	3	1	1	6	3	6	3	23	22	0	2	7	4	76,0	4,7	10,0	61,3	13,0	23,3	25,0	7020	8760

With a more frequent update of the KT, it is also possible to generate graph for its trend:



KT GENERAL KEY POINTS

A global indicator that can give, from a single number, an overview of the effectiveness of the cathodic protection from the data received by remote monitoring can be very useful especially when dealing with very large networks.
In this way it can be possible to have a rapid overview of the whole network, and just focusing attention on those CPS where the KT is too low.
Furthermore, a frequent update of the KT allows to detect also a sudden decrease of the value before it would fall under the threshold value, thus giving the opportunity to analyze the CPS and if necessary implement corrective actions before the presence of e real alarm.

For this reason is very important to have a reliable algorithm, taking into account all the main aspects of a CPS.

Design of the CPS: it is a fundamental element in the algorithm, and it must take into account both the length of the CPS and the number of measuring points present in it. It needs to have the right weight in the global evaluation so that in case of a poor design, a stronger effort on the measure part must be necessary to reach compliance.
The most significant points of the CPS needs to be remotely monitored: rectifiers, drainages, AC/DC decoupling devices, railway crossings or parallelisms, at least the measuring points with most positive and more negative potentials. This can be set or on design side, giving higher evaluation if this point is respected, or on measures side, giving a higher weight to the measures received by these kinds of measuring points and lower to the remaining ones.

The minimum number of measuring point to be equipped with remote monitoring, should also be related to the presence and the effects of stray current in the CPS: for example the variability calculation could be a good tool to evaluate it.

Measurements: on the measurement must be taken into account different aspects, for this reason it is normally the more articulated part of the algorithm.
As a first step, must be identified a compliance evaluation criteria for the measures received daily (respect of specific thresholds, establish a daily maximum admitted time out of protection,…).
As a second step, must be identified which kind of measures must be taken into account in the evaluation, eventually assigning a different weight for IRFree/Off Potential with respect to On Potential.
As specified in the previous point, a higher importance in the evaluation should be given also to the measures received from the most significant points in the CPS.
Another interesting element that could contribute to this part of the KT index, could be the evaluation of the hours of the rectifiers activity, like implemented in Nedgia Naturgy Group KT.
In the index calculation, must be also taken into account the possibility of evaluating eventual integrative measurements performed in field by operators on non-remotely controlled measuring points.

Temporal period: the temporal interval over which consider the measures to calculate the KT index must be defined also. A window of 12 months, really allows the index to be general and not affected for example from seasonal variation (humidity, temperature,…): under this conditions a variation in the index will depend only from changes in cathodic protection behavior.

KT Index update: the update frequency of the index is related to the desired reactivity to detect any change on the index. At least a monthly update can give a good overview of the CP evolution, while for faster reaction it could be updated for example also every week.

CONCLUSIONS

A global index able to put together all the information received by remote monitoring and to give an evaluation of cathodic protection effectiveness can be a very helpful tool to perform a fast check if everything is working correctly or if there is some variation in the CP behavior.

To obtain this, a reliable remote monitoring system is fundamental to achieve the best results from KT calculation.

The application both in Italy (intended more as a final reporting activity) and in Nedgia Naturgy Group (here really intended as a follow-up of the Cathodic Protection evolution) shows very good results when applied to well defined CPS.
It could be very interesting to evaluate how to apply KT index also in other conditions, for example where large pipelines networks are interconnected without insulating joint so that maybe in these cases a "geographical" grouping or some

other separating criteria could be applied to identify the areas to be evaluated independently.

The possibility of having a single number to evaluate and monitor over time the CP effectiveness in a CPS or area, and to analyze its evolution, can be a strong help for the technicians involved in cathodic protection.

Thanks to the analysis of KT evolution, it can be possible to realize if something is happening on the CP system before the cause of its variation would develop into a more serious problem that could lead to a real corrosion issue: this means evolving the analysis from a corrective type to a predictive one.

[1] APCE - Associazione per la Protezione dalle Corrosioni Elettrolitiche, "Linea Guida PC Distribuzione GAS", ed.5 rev.1 (2015)
[2] UNI 11094 "Criteri generali per l'attuazione, le verifiche e i controlli ad integrazione della UNI EN 12954 anche in presenza di correnti disperse"
[3] UNI 10950 "Telecontrollo dei sistemi di protezione catodica"