

Electrical Safety Aspects of AC Interference on Pipelines

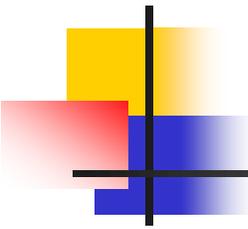
By
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UKOPA 16th May 2018

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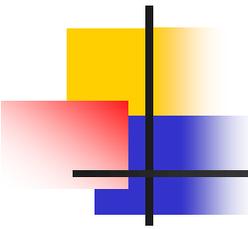
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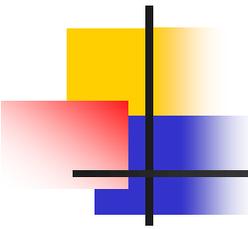
AC Interference on Pipelines

- AC interference on pipelines can cause AC corrosion under certain conditions, which can affect pipeline integrity and result in high rates of corrosion on pipelines that have effective levels of CP.
- However, AC interference on pipelines can also have consequences for personnel safety by creating a touch and step potential electrical shock risk during pipeline construction, operation, maintenance and repair
- It can also affect pipeline CP system operation and the ability to conduct over the line surveys



Presentation Aims

- **Identify the electrical risks associated with working on pipelines in close proximity to overhead powerlines, which should be considered during design, construction and operation.**
- **Provide clarity and guidance on the permissible long term and short term voltage levels and identify deficiencies in existing standards in relation to permissible voltage levels.**
- **Discuss specific situations that may give rise to risk e.g. incendive ignition risks in AGIs at IJs, use of surge protection , proximity distances between electrical power sources and pipelines etc**
- **Identify applicable reference standards**



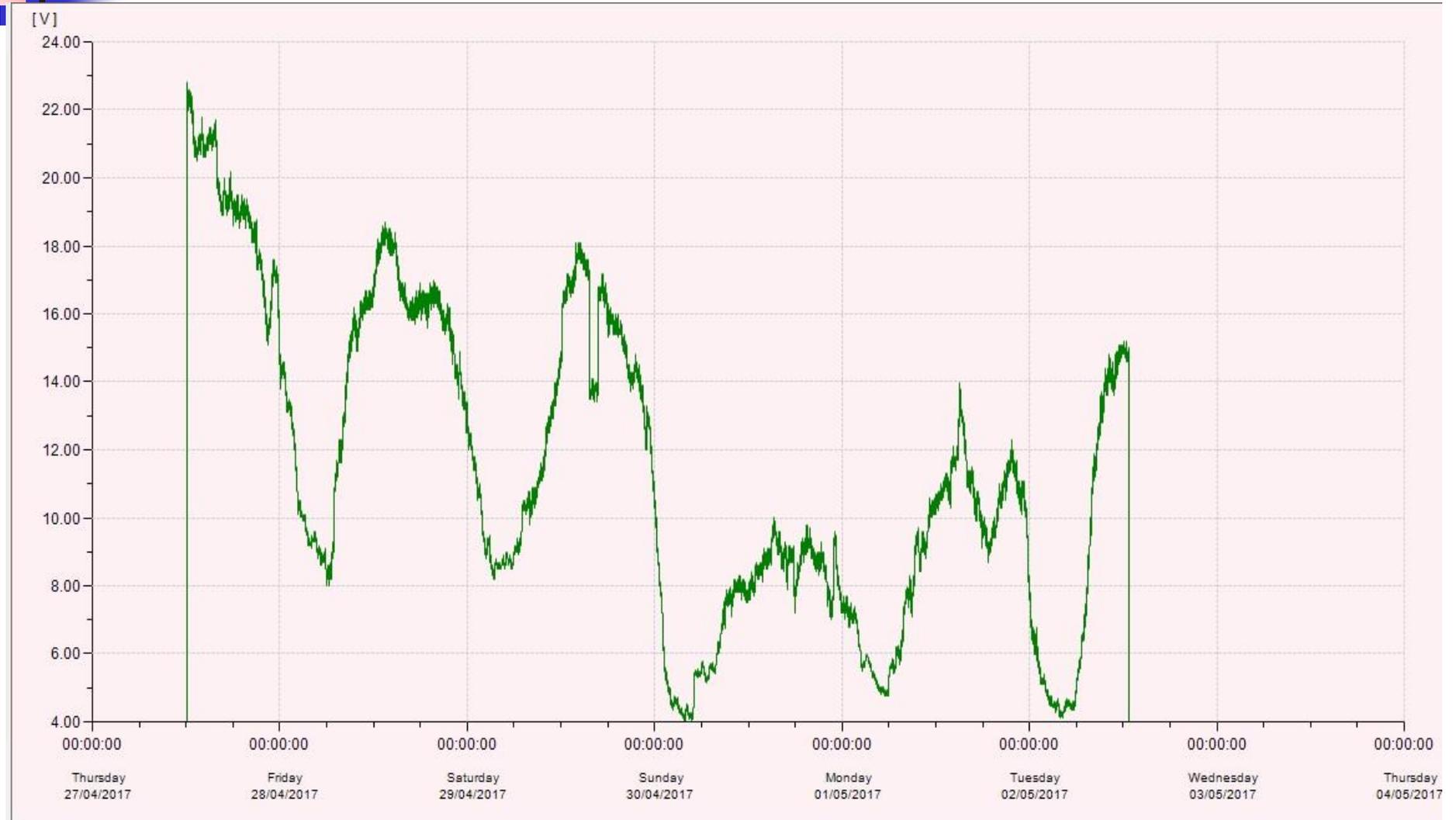
Pipeline AC Interference

- There are two main types of AC interference on pipelines which occur from coupling either inductive, resistive or capacitive between powerlines and pipelines.
- **Long term interference** i.e. AC voltages induced on pipelines routed close to powerlines via low frequency induction (LFI) that may result in varying voltages on a pipeline between 0 to 100Vrms. The voltage limit may be present for prolonged periods of time i.e. greater than 24 hours
- **Short term voltage** i.e. voltage transferred to pipeline via resistive/inductive coupling could approach a few thousand volts and would be present for the period of time it takes the fault to clear generally less than 200ms for HV systems up to 132kV or longer up to 1 second for lower HV voltage sources

Long Term Electromagnetic Inductive Coupling



Long Term Voltage Levels



AC Transmission Fault Conditions

- **When fault conditions occur on a transmission line, voltages and currents can be induced on buried pipeline systems with values up to 2000V or greater possible for the duration of the fault in very close proximity to a pylon**



Pipeline CP System Transformer Rectifier (TR) Unit



TR Unit After Lightning Hits Pipeline

The photograph shows the condition of a CP TR unit after the pipeline it was protecting was hit by a voltage surge.

The CP TR negative cable is connected directly to the pipeline

This photo helps to demonstrate the fact that during fault conditions there is a considerable amount of energy available.

If anyone was working on the TR or the pipeline at the time of the fault they could have suffered serious injury even death



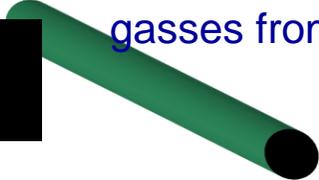
AC Discharge Through Ionised Gases



Ionised air path due to hot gasses from heath fire



Damage to buried pipe by arc



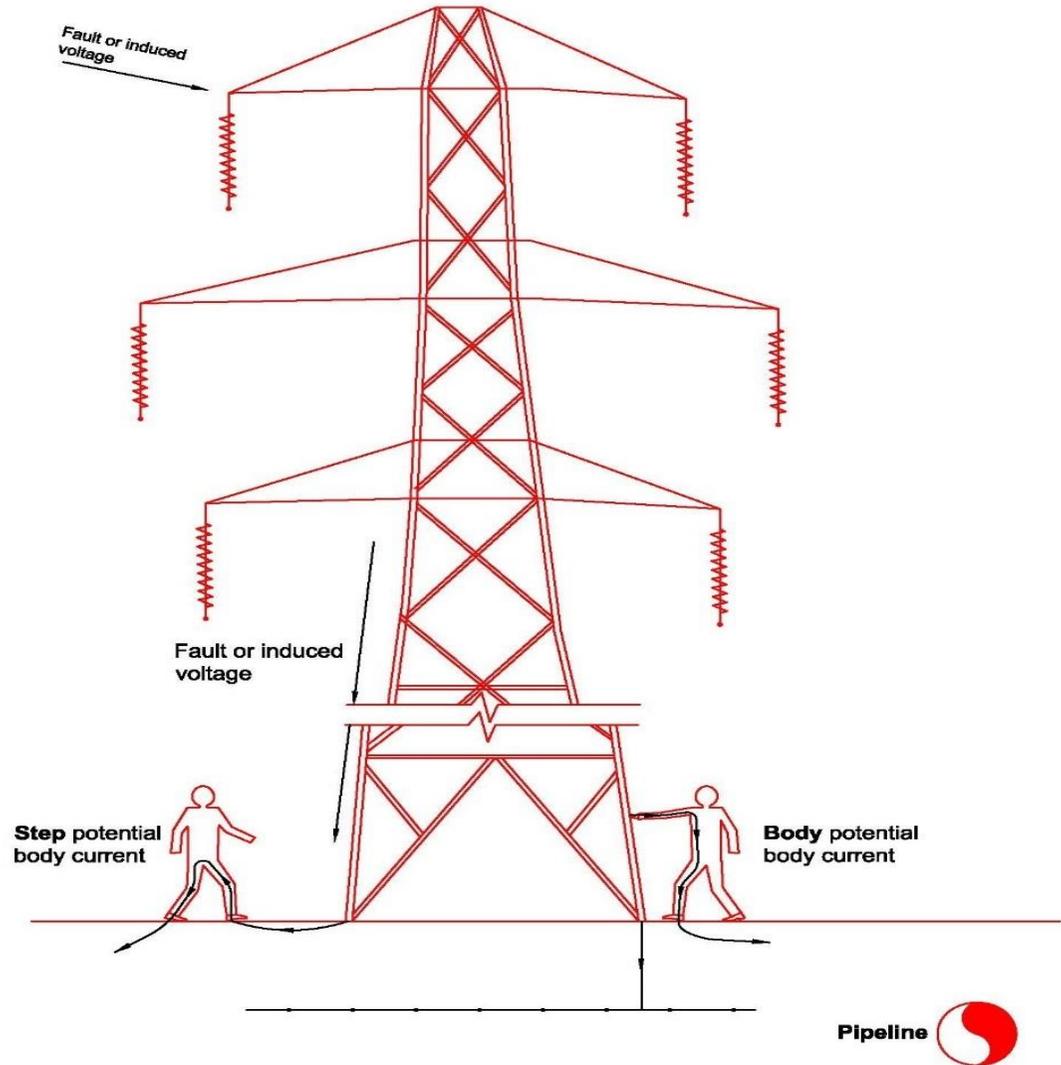
M28 Posts



**M28 Post studs sometimes not insulated from reinforcing within the CP post, which acts as an earth. Current may discharge and cables appear burnt
Any operative making contact with the post at the time would be exposed to risk.
Operators need to ensure test equipment adequately protected from short circuit**

Step and Touch Potential

- During fault conditions on overhead pylons high voltages can be transferred to pipelines if they are routed close a pylon.
- This risk often not considered during route selection.
- Touch potential is the voltage between the energized object and the feet of a person in contact with the object. In the case of pipelines, it is the voltage between the pipeline and the feet of anyone making electrical contact with the pipeline in contact with the ground.
- The step potential is the voltage difference across the ground that would occur when fault current flows. Step potential is the voltage between the feet of a person standing near an energized grounded object.



Touch and Step Potential- BS EN 50522

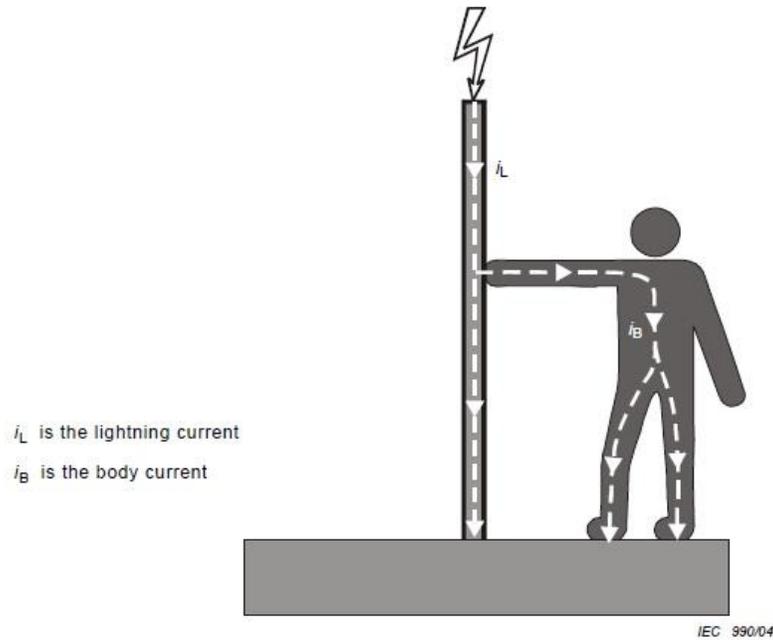


Figure A.3 – Touch voltage

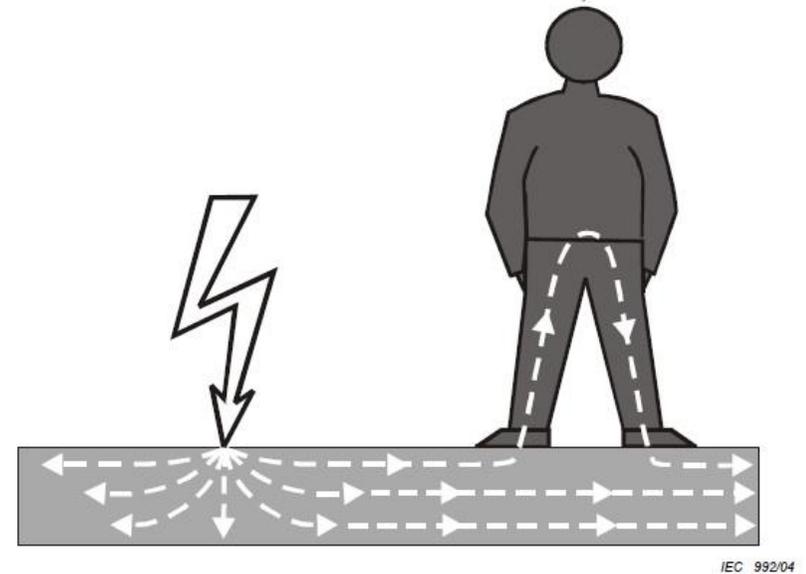


Figure A.5a – Step voltage

Overhead Pipelines Close to Powerlines

- Capacitive coupling can induce AC voltages on above ground pipelines.
- Above ground pipelines need to be effectively earthed so that if overhead power cables fall onto a pipeline then the protective devices can operate and AC voltages are safely discharged to earth.



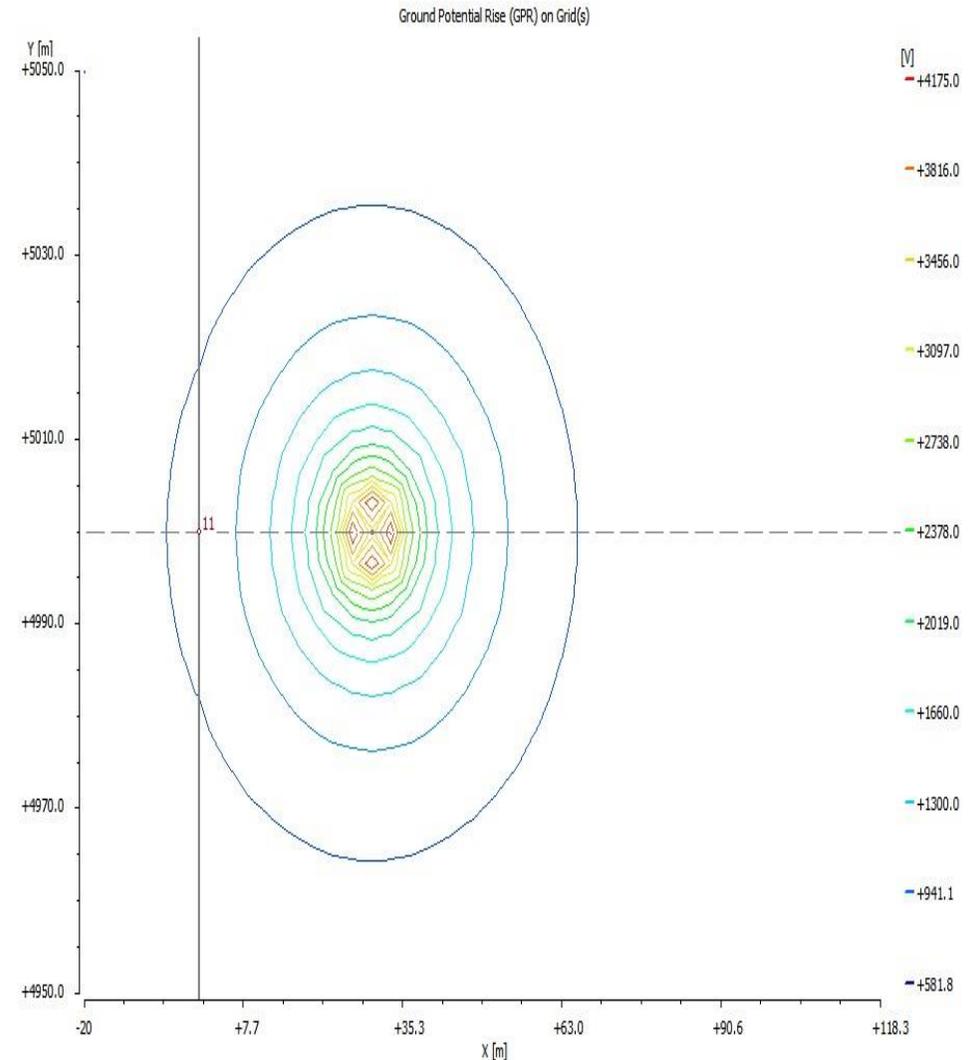
Pipelines Close to Powerlines

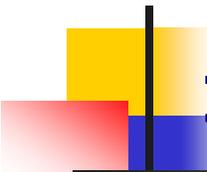
- Pipelines are often routed close to powerline pylons
- There are a large number of these locations around the country.
- For any work on the pipeline system seen on the picture on the right then the touch potential risk during fault conditions should be considered
- Voltage contours during faults can be distorted and hazardous voltages can spread some distance along a pipeline from the fault location
- Operators should establish high risk touch potential locations



Pylon Earth Fault Voltage Contour Plot

- Voltage contour diagram for fault current of 10 kA within 50m of a pylon in soil of resistivity 100 ohm m
- Transfer voltage on a pipeline would be about 580V at a distance of 40m from the pylon but within 10m of the pylon the voltage would be about 2,300V.
- Higher soil resistivity, higher fault current then the larger the voltage contour distance.





Issues Associated with Pylons Close to Pipeline

- During fault conditions high voltages can be induced on a pipeline close to a pylon.
- These voltages could damage the pipeline coating and present a hazard to personnel working on pipelines and are dependent upon fault current, local soil resistivity and pylon to pipeline separation distance.
- Voltages in excess of 2,000V on a pipeline can damage IJs
- Personnel safe short term voltage levels vary dependent upon contact impedance and contact surface area. They also vary from nature of contact e.g. hand to foot or hand to knee
- The voltage limit may be less in certain instances and varies in different standards.
- Power system operators should ensure that fault currents will not create a **HOT** site in terms of electrical safety i.e. > 650V see ENA TS 41-24.
- Need to ensure personnel are aware of issues associated with work on pipelines near pylons and substations.
- Permissible voltages based upon current levels for heart fibrillation given in IEC 60479-1 now PD IEC 60479-1
- If genuine earth fault then auto reclose function means there will be 3 faults in quick succession.

Pylon Powerline Separation

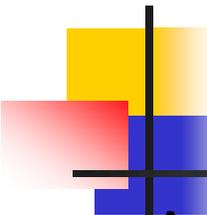
Fault Current A	Separation required (m) for two different soil resistivity values	
	100 Ω .m	500 Ω .m
1000	60	310
3000	190	940
6000	380	1900
10000	635	>3500

Separation distance for a touch voltage of 220V for UK requirements distance would be a lot lower because of higher permissible limits- Data from Australian Standards

Pylon Powerline Separation-650V Contour Rough Data

Fault Current A	Separation required (m) for two different soil resistivity values	
	100 Ω .m	500 Ω .m
1000	7	35
3000	15	70
6000	25	120
10000	35	180

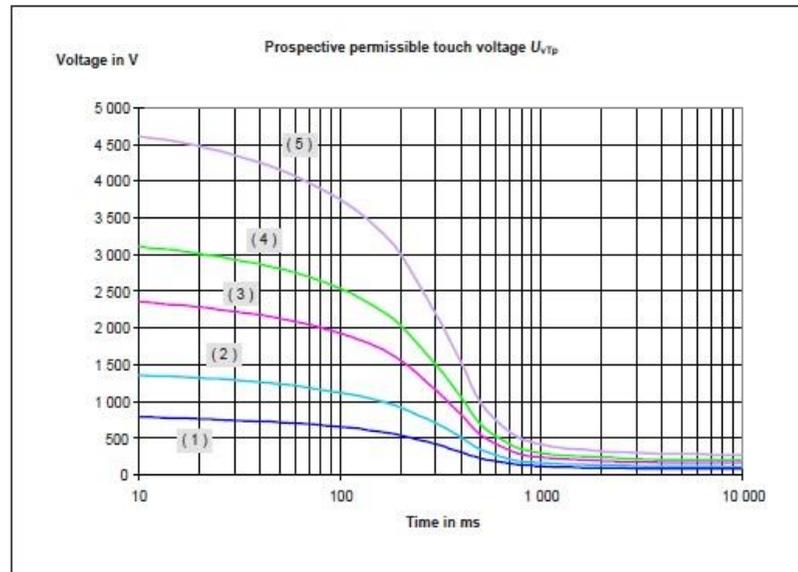
Data above gives an approximate separation distance for a touch voltage of 650V. Values are approximate estimates accurate values will be included in the AC GPG



What is the Effect of a High Touch Voltage ?

- An unexpected low voltage electrical shock can result in an involuntary action e.g. loss of balance, dropping objects or slip.
- It is the surprise in receiving an electrical shock that can cause concern and alarm.
- It is unlikely to be fatal if less than 50V for prolonged periods or result in serious injury but can be unpleasant.
- However, the effect of the voltage will be greater if the hands are wet and personnel are not insulated from the ground.
- Hand to hand and hand to knee contact not good as low contact resistance with ground lower voltage limits.
- Step potential limits dependent upon person's weight, protective clothing and varies from person to person.

Safe Touch Potential – BS EN 50222



- (1): Permissible touch voltage according Figure 4
- (2): $R_F = 750 \Omega$ ($R_{F1} = 0 \Omega$, $\rho_s = 500 \Omega m$)
- (3): $R_F = 1750 \Omega$ ($R_{F1} = 1000 \Omega$, $\rho_s = 500 \Omega m$)
- (4): $R_F = 2500 \Omega$ ($R_{F1} = 1000 \Omega$, $\rho_s = 1000 \Omega m$)
- (5): $R_F = 4000 \Omega$ ($R_{F1} = 1000 \Omega$, $\rho_s = 2000 \Omega m$)

NOTE $R_{F1} = 1000 \Omega$ represents an average value for old and wet shoes. Higher values of footwear resistance may be used where appropriate.

Figure B.2 - Examples for curves $U_{vTP} = f(t_f)$ for different additional resistances $R_F = R_{F1} + R_{F2}$

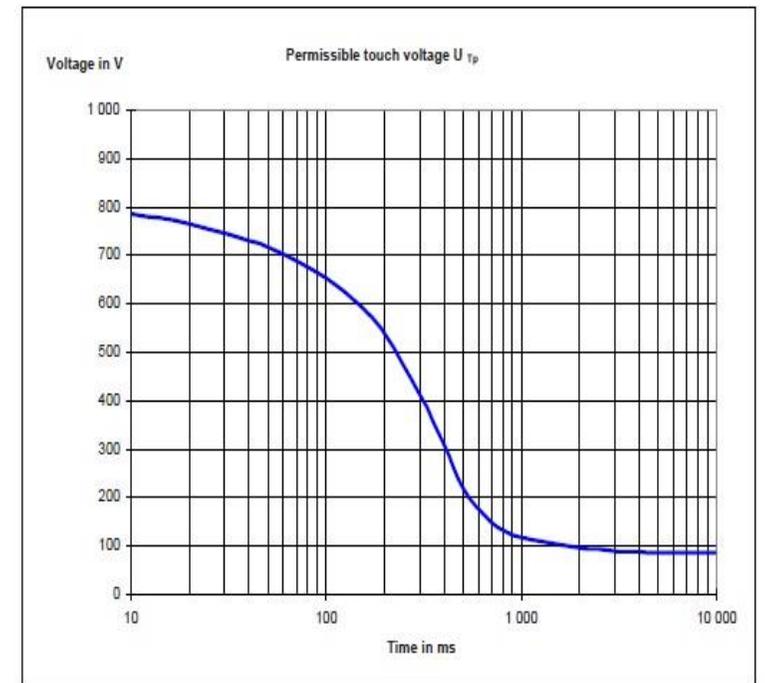


Figure 4 - Permissible touch voltage

NOTE For duration of current flow considerably longer than 10 s a value of 80 V may be used as permissible touch voltage U_{TP} .

- Guidance on the effect current has on the human body is given in PD IEC 60749-1.
- The effects are related to current and the duration of the current flow.
- The body impedance or resistance to current flow is also dependent upon the voltage magnitude
- Higher the voltage lower body impedance it also varies across the population as well
- e.g at 200V 5% of population will have impedance of 3,500 ohms but 95% of population it will be 8,650 Ohms for wet conditions hand to hand low contact
- Dry conditions at 25V impedance 11,125 ohms but at 200V it is 1,375 ohms for medium contact hand to

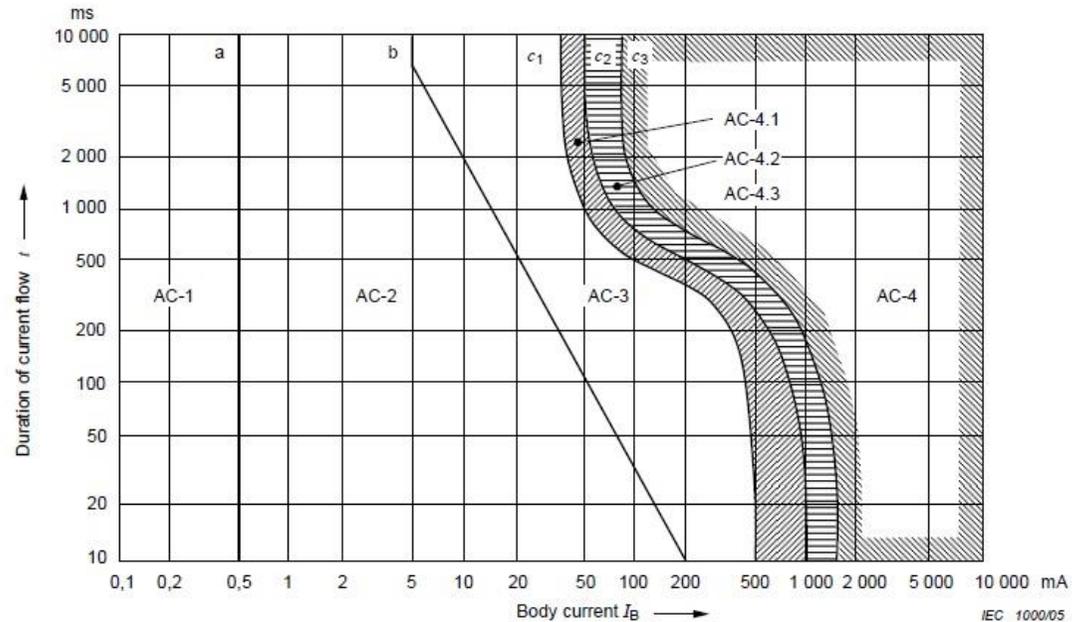
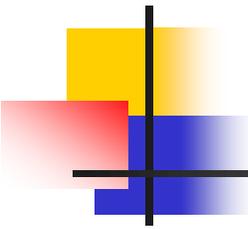


Figure 20 – Conventional time/current zones of effects of a.c. currents (15 Hz to 100 Hz) on persons for a current path corresponding to left hand to feet (for explanation see Table 11)

Current Ranges –PD IEC 60749

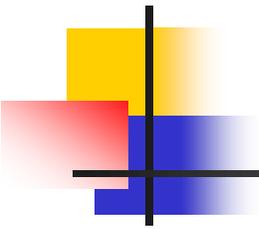
Table 11 – Time/current zones for a.c. 15 Hz to 100 Hz for hand to feet pathway – Summary of zones of Figure 20

Zones	Boundaries	Physiological effects
AC-1	Up to 0,5 mA curve a	Perception possible but usually no 'startled' reaction
AC-2	0,5 mA up to curve b	Perception and involuntary muscular contractions likely but usually no harmful electrical physiological effects
AC-3	Curve b and above	Strong involuntary muscular contractions. Difficulty in breathing. Reversible disturbances of heart function. Immobilization may occur. Effects increasing with current magnitude. Usually no organic damage to be expected
AC-4 ¹⁾	Above curve c_1 c_1-c_2 c_2-c_3 Beyond curve c_3	Patho-physiological effects may occur such as cardiac arrest, breathing arrest, and burns or other cellular damage. Probability of ventricular fibrillation increasing with current magnitude and time AC-4.1 Probability of ventricular fibrillation increasing up to about 5 % AC-4.2 Probability of ventricular fibrillation up to about 50 % AC-4.3 Probability of ventricular fibrillation above 50 %
<p>¹⁾ For durations of current flow below 200 ms, ventricular fibrillation is only initiated within the vulnerable period if the relevant thresholds are surpassed. As regards ventricular fibrillation, this figure relates to the effects of current which flows in the path left hand to feet. For other current paths, the heart current factor has to be considered.</p>		



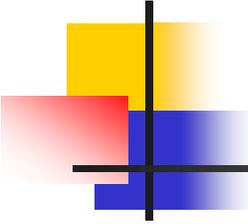
15V AC Limit on Pipelines

- The shock hazard arising from induced AC voltages has been widely recognized for many years in North America and Internationally, where the NACE SP0177 standard stipulates that an AC voltage of 15 Vrms or greater between a pipeline appurtenance and ground, which could expose a person to a touch voltage, is considered a shock hazard.
- *This requires that the touch voltage be reduced to a safe level or the pipeline be treated as a live electrical conductor. The 15 V limit was determined by multiplying 15 mA (considered the current limit below which a person could let go when grasping an electrified conductor) and 1000 Ohm (conservatively considered the human body impedance assuming a contact resistance of zero ohms).*



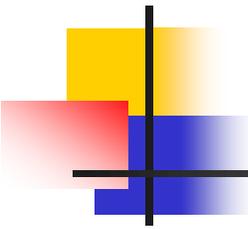
Touch Potential Voltage Limits

- Guidance on touch potential limits for pipelines in the UK is given in BS EN 50443.
- BS EN 50443 *electromagnetic interference on pipelines caused by high voltage a.c. electric traction systems and/or high voltage a.c. power supply systems* gives guidance on maximum touch potential limits but the levels quoted for pipelines are quite high.
- Indeed, touch potential limits in BS EN 50443 for pipelines are higher and different to the guidance adopted by other industries. Rail and telecoms industries require lower touch voltage limits.



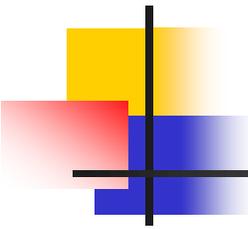
BS EN 50443 Limitations

- Only standard to give specific guidance for pipelines on short and long term touch potentials is BS EN 50443.
- For short term interference for disconnection time of protective devices less than 200ms it is 1,500V, less than 1 second it is 430V.
- For long term interference it is 60V !!!
- BS EN 50443 voltage levels are possibly too high and are based upon electrically instructed personnel working on pipeline with a contact resistance of 3,000 ohms.
- These high voltage limits can affect personnel safety and pipeline operation. **We should not accept for pipelines in UK that a long term voltage of 60V is acceptable under any circumstances.**
- For short term interference BS EN 50122-1 for railway systems gives the touch voltage for disconnection time of protective devices less than 200ms as 645V, for disconnection times less than 1 second it is 80V.
- NACE standard for pipelines is 15V long term. BS EN 15280 for AC corrosion is risk is also maximum 15V rms.



BS EN 50443 Requirements

- The voltage values in BS EN 50443 refer to instructed persons with common clothing, without particular individual protection means other than shoes with an insulating resistance not less than 3,000 Ω .
- In case of use of individual protection means a specific study shall evaluate the admissible values for the interference voltages, which can be higher than the ones given in 10.2.2 and in 10.2.3.
- Section 10.2.2 means long term voltages above 60V and 10.2.3 means voltage less than 1,500V for a disconnection time of less than 200ms.



BS EN 50443 Requirements

- *In case of more severe situations (wet conditions, narrow working space, repairing operations, etc.) or where common people (i.e. neither electrically instructed nor skilled persons) may come in contact with the pipeline in operating conditions, additional precautions should be taken into consideration (e.g. reduce admissible voltage, use of insulating coverings, special instruction to personnel, etc).*
- *for danger to persons who come in direct contact or in contact through conductive parts with the metallic pipeline system or to the connected equipment, the voltage to earth of the pipeline and the voltage difference on the insulating joints shall be evaluated in normal operation and in fault conditions;*

Short Term Voltage Limit 200ms

Standard	Value	Comment
NACE SP 0177	Not Given	Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems
CAN/CSA-C22.3 No. 6-M91	Not Given	Principles and Practices of Electrical Coordination Between Pipelines and Electric Supply Lines
BS EN 15280	Does not cover safety	Evaluation of a.c corrosion likelihood of buried pipelines- Application to cathodically protected pipelines.
BS EN 50443	1,500 Vrms	Effects of electromagnetic interference on pipelines caused by high voltage a.c. electric traction systems and/or high voltage a.c. power supply systems
BS EN 50122-1	645 V rms	Railway applications. Fixed installations. Electrical safety, earthing and the return circuit. Protective provisions against electric shock
BS EN 50222	1,570 Vrms	Earthing of power installations exceeding 1 kV a.c
ENA TS 41-24	650V hot site 430V cold site	Guidelines for the design, Installation, Testing and Maintenance of Main Earthing Systems in Substations

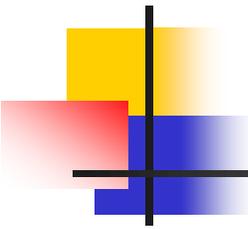
Voltage Limit Long Term > 3s

Standard	Value	Comment/Title
NACE SP 0177	15V rms	Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems
CAN/CSA-C22.3 No. 6-M91	15V rms	Principles and Practices of Electrical Coordination Between Pipelines and Electric Supply Lines
BS EN 15280	15V rms	Evaluation of a.c corrosion likelihood of buried pipelines- Application to cathodically protected pipelines.(Not safety related)
BS EN 50443	60 Vrms	Effects of electromagnetic interference on pipelines caused by high voltage a.c. electric traction systems and/or high voltage a.c. power supply systems
BS EN 50122-1	60 V rms	Railway applications. Fixed installations. Electrical safety, earthing and the return circuit. Protective provisions against electric shock
BS EN 50222	65 V rms	Earthing of power installations exceeding 1 kV a.c
ENA TS 41-24	Not Given	Guidelines for the design, Installation, Testing and Maintenance of Main Earthing Systems in Substations
Low Voltage Directive – Directive 2014/35/EU	50Vrms	Not mentioned but some condition apply extra low voltage where 25V applied for hazardous conditions
BS 7671 Extra Low Voltage Systems	25Vrms	For use in specific conditions where Extra low voltages circuits where Regulation 414.4.5 does not require basic protection against electric shock for SELV and PELV circuits at less than 25 V a.c. in dry conditions or 12V a.c. for any condition. SELV is Safety extra-low voltage and PELV is Protective extra-low voltage.
CCN	15V	15V

Comparison of Touch Potential Limits

Power System Fault Duration Time (seconds)	BS EN 50443 Safe Voltage Limit (Volts)	BS EN 50122-1 Safe Voltage Limit (Volts)
< 0.1	2 000	865
0,1 < to 0,2	1 500	785
0,2 < to 0,35	1 000	645
0,35 < to 0,5	650	480
0,5 < to 1,0	430	220
1 < to 3	150	75
$t > 3$	60	60

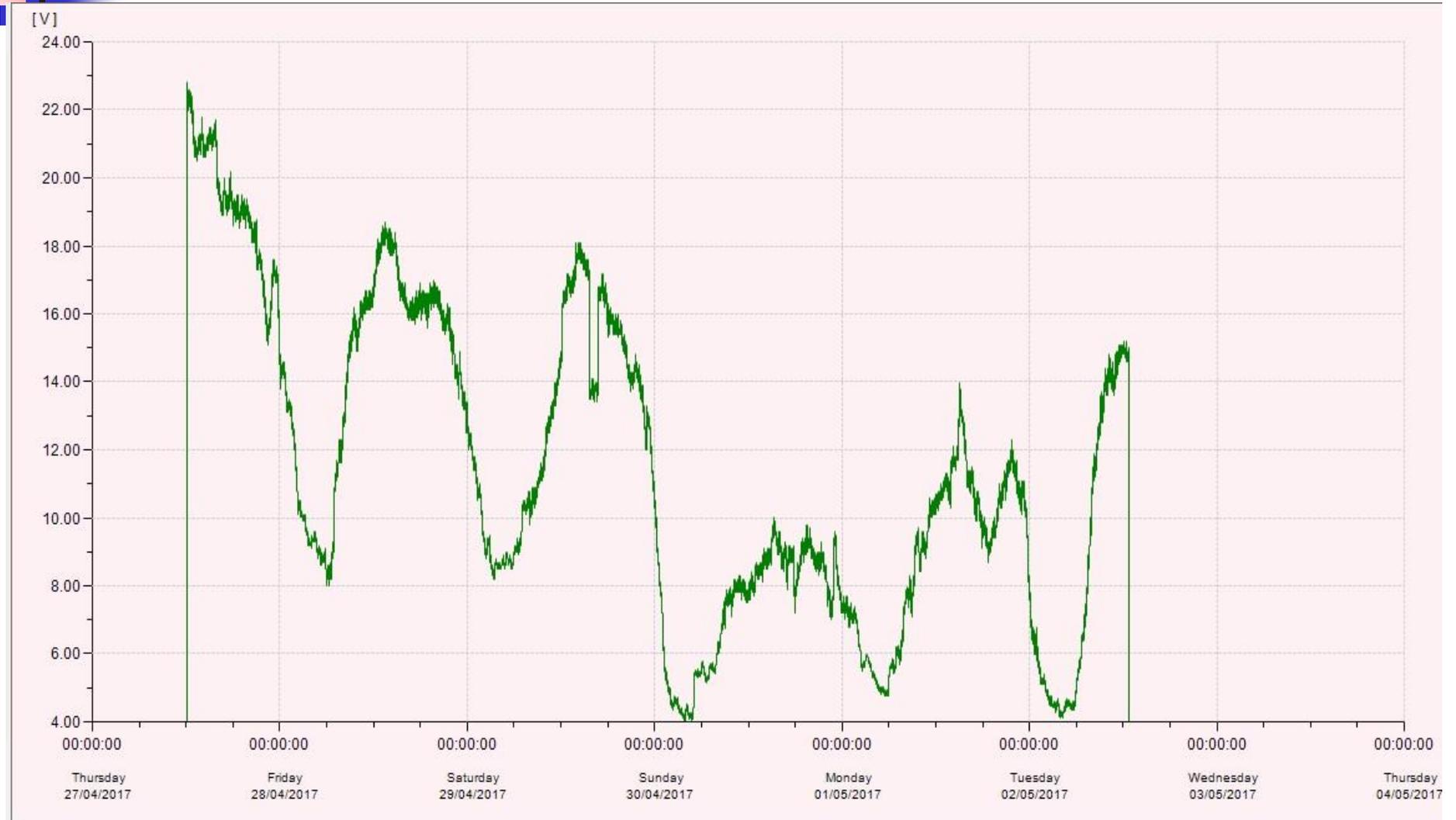
BS EN 50443 is the EN standard for Voltage Limits on Pipelines and BS EN 50122-1 those that the Rail Authorities require. BS EN 50443 although supposedly for pipelines imposes limits for electrical instructed personnel with a contact resistance of 3,000 Ohms . These insulation values are not applicable to most pipeline operatives or working conditions. Not sure how much UK involvement in BS EN 50443 standard development

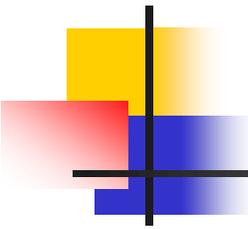


Recommended Short Term Touch Potential Limits BS EN 50122-1

Power System Fault Duration Time (seconds)	BS EN 50122-1 Safe Voltage Limit (Volts)
< 0.02	865
0.05	835
0.10	785
0.20	645
0.30	480
0.40	295
0.50	220
0.60	155
0.70	90
0.80	85
0.90	80
1.0	75

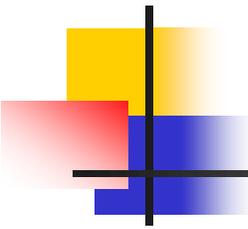
Long Term Voltage Levels





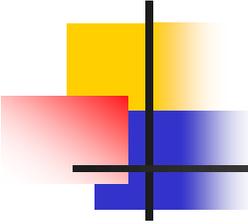
Pipelines and Touch Voltages

- BS EN 15280 on AC corrosion limits maximum voltage to 15V rms
- BS EN 50443 gives touch voltage of 60V for periods greater than 3 seconds but this is for fault conditions. However, the standard does state that the 60V is acceptable long term.
- Long term interference AC voltage present for 24 hours a day 7 days per week on pipeline hardly fault conditions so 60V should not be accepted by the UK pipeline industry.
- Pipelines with voltages greater than 50V would be classed as live conductors under the IET wiring regulations. Yet to comply with BS EN 50443 60V is permitted? It does not make sense !
- Extra low voltages circuits where Regulation 414.4.5 of BS 7671 does not require basic protection against electric shock for SELV and PELV circuits at less than 25 V a.c. in dry conditions or 12V a.c. for any condition. SELV is Safety extra-low voltage and PELV is Protective extra-low voltage . Voltage limit here is 25V



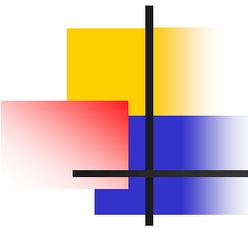
Touch Potentials for Low Voltages

- For pipelines close to power cable systems < 66 kV where the disconnection time is less than 1 second then the maximum touch potential should be lower than the 650V limit given in ENA TS 41-24
- The maximum touch potential should be based upon BS EN 50122-1 for less than 1 second it is 80V.
- Expert guidance should be sought for new installations



Touch Potential Limits

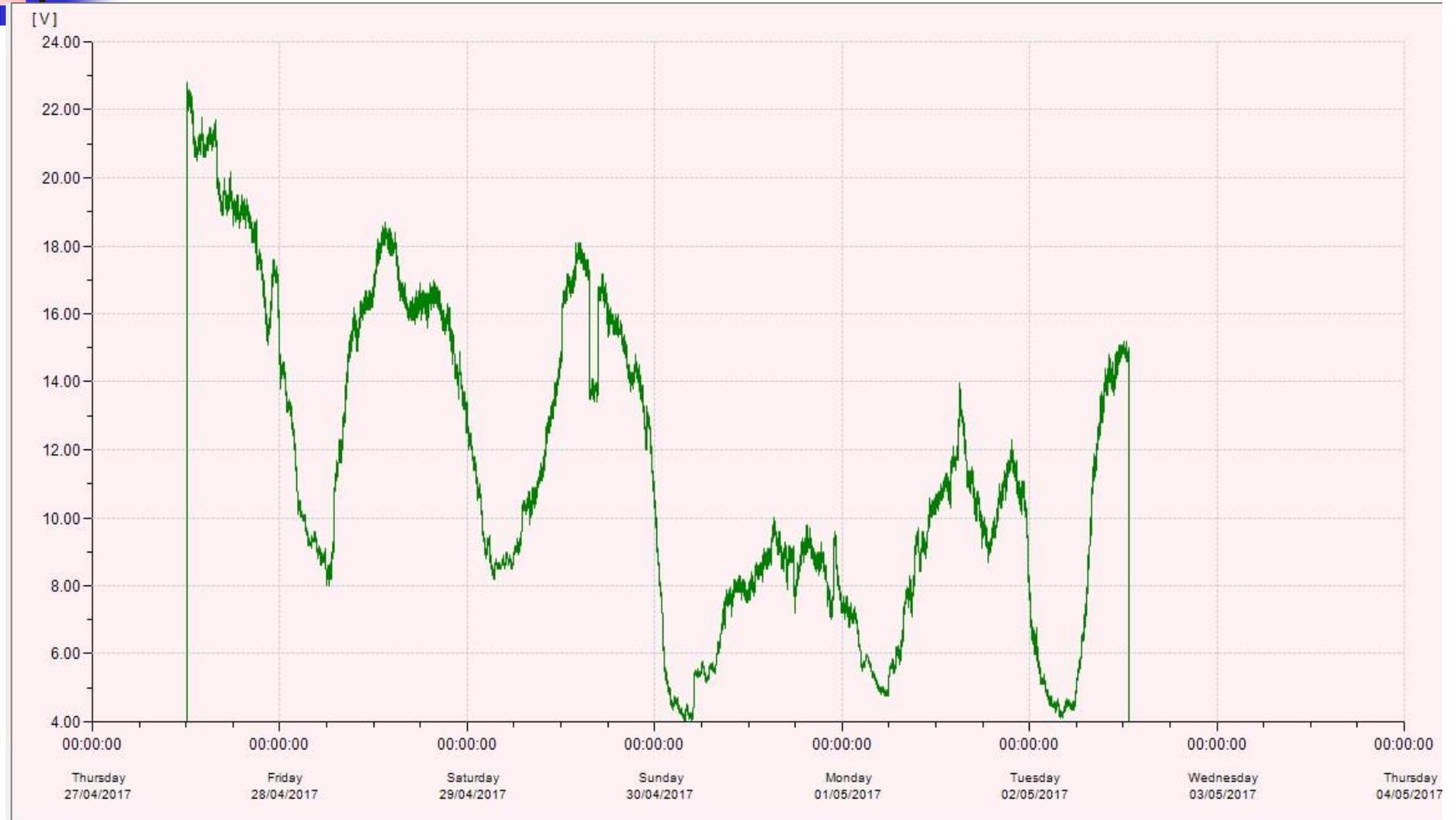
- Internationally 15V rms is the AC touch voltage limit for pipelines.
- *15V is the long term limit in BS EN 15280 but that standard does not relate to safety but AC corrosion risk.*
- BS/EN touch potential standards relate to safety provide higher values up to 60V
- There is a need for clarity on the permissible levels of touch voltage

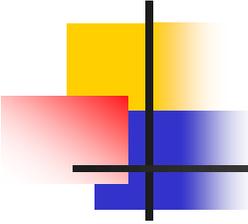


Why Keep AC Voltage on Pipelines Low ?

- 15V on pipeline would not create a hazardous situation in terms of electrical shock but could result in an involuntary action i.e. slip/trip or fall.
- General public can come in contact with pipeline appurtenances
- AC present on pipelines can be rectified by variac controlled TR units and produce a fluctuating DC current and pipe to soil potential. 15V present would cause fluctuating potentials but if 60V was present there would be more DC current produced by TR units and significant changes in pipe potential.
- CIP surveys can be affected by AC interference, as AC rejection ability on CIP data loggers can vary and give misleading survey results
- 15V also historically used as maximum touch potential as if 15V was measured one day at a CP post it could be different the next day. The fact that high voltage was measured indicates a risk and if 15V is used as the base level and the voltage levels increase there is some safety tolerance
- AC corrosion could occur at voltages .Soil resistivity can vary quite considerably along pipeline route. BS EN 15280 requires AC voltage to be less than 15V to mitigate AC corrosion risk

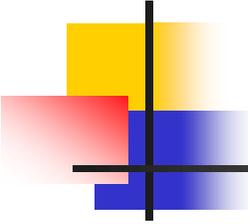
Long Term Voltage Levels



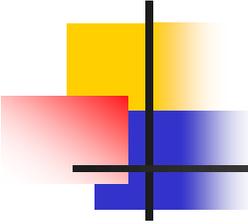


Summary Touch Potentials

- Pipeline industry needs clarity on safe values to adopt for both short term and long term voltage levels as there is not clarity in existing BS/EN standards.
- Existing BS/EN standards have been developed by electrical engineers without taking cognisance of other associated effects from AC interference on pipelines and give relatively high and varying touch potential limits.
- Most likely that there a number of locations on many existing pipeline systems where touch potentials during fault conditions exceed safe limits.
- The number of such locations could run into a few hundred or more

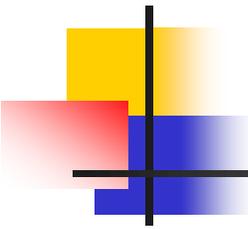


Safety Issues and Specific Situations



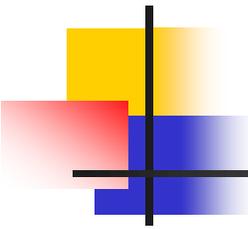
Aspects Associated with AC on Pipelines

item	Topic	Comment
1.0	AC voltage difference each side of IJ or IF	If Polarisation Cell Replacements (PCR)s not employed at I/Js then there could be a spark hazard if insulating device e.g. IF/IJ accidentally short circuited. This could create incendive ignition risk if short circuited as available current could be quite high
2.0	High AC voltage can affect control of CP TR units	Higher AC voltage present on pipeline greater variation in DC current out from CP TR units so problems associated with control of CP systems increase with increase in AC voltage
3.0	Pipe location	Pipe depth and location by radio frequency devices difficult near overhead power lines if high levels of AC present can assist with location but also interfere with location
4.0	Over the line CIP surveys and routine monitoring	High levels of AC can affect data obtained especially if AC rejection capability not sufficient on measuring device
5.0	Pigging operations	Need to review risks with ILI vendor possible spark risk when inline inspection vehicle crosses IJ or when scaffolding is erected and if AC voltages can affect PIG data
6.0	AC corrosion	At high AC voltages higher risk of AC corrosion especially when soil resistivity data is not accurately known along whole of pipeline



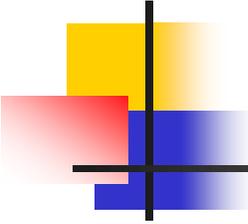
Assessment of High Risk Locations

- Can actually check AC potentials at CP test posts. This is not always carried out during routine CP checks by some operators
 - Should assess pipelines at risk of AC interference and corrosion
 - Measurement of AC voltage at CP posts may not identify high risk locations these can be at intermediate locations between CP posts
 - Can undertake mathematical modelling to determine touch potential high risk locations from long term interference.
- **FIGURE REMOVED**



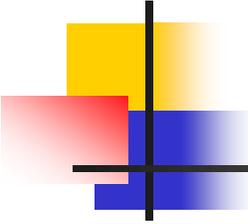
Voltage on Pipeline

- AC voltage on pipeline will vary based upon load on powerline
- If powerline operator decides to increase load on powerlines e.g. new circuits from offshore windfarms added or new power station constructed then induced AC voltage on affected pipelines will increase.
- This will affect both touch potential and AC corrosion risk
- Pipeline operators need to be aware that situations may change over time and should therefore regularly monitor and assess AC interference levels and risks



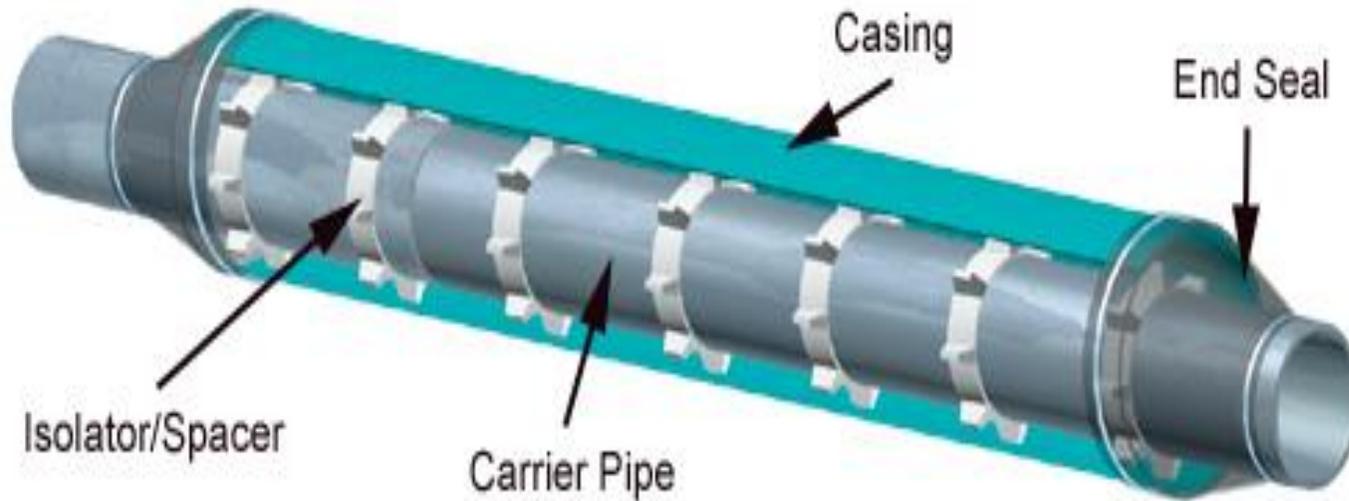
Topics for discussion

item	Topic	Comment
1.0	AC spark risk carrier pipelines in casing	There is guidance given in NACE Standard SP0177
2.0	High AC voltage can affect control of CP TR units	Higher AC voltage present on pipeline greater variation in DC current out from CP TR units
3.0	Lightning and arc risk	Risk of damage to pipelines by arcing and also when fires light under powerlines
4.0	AC voltage and ability to perform CIPS and routine CP surveys	High levels of AC can affect data obtained especially if AC rejection capability not sufficient on measuring device
5.0	Where to obtain guidance on construction near powerlines	Detail reference documents will be provided
6.0	Spark risk on testing IJs and current flow in pipelines	AC spark risk certain situations
7.0	Surge protection devices and earthing systems	Current risk and affect of decoupling devices on earthing systems
6.0	Earth faults through groundbeds and AC mitigation earths	Personnel often do not consider that groundbeds can discharge fault current off pipelines



Pipeline In Casing

Pipeline In Sleeve



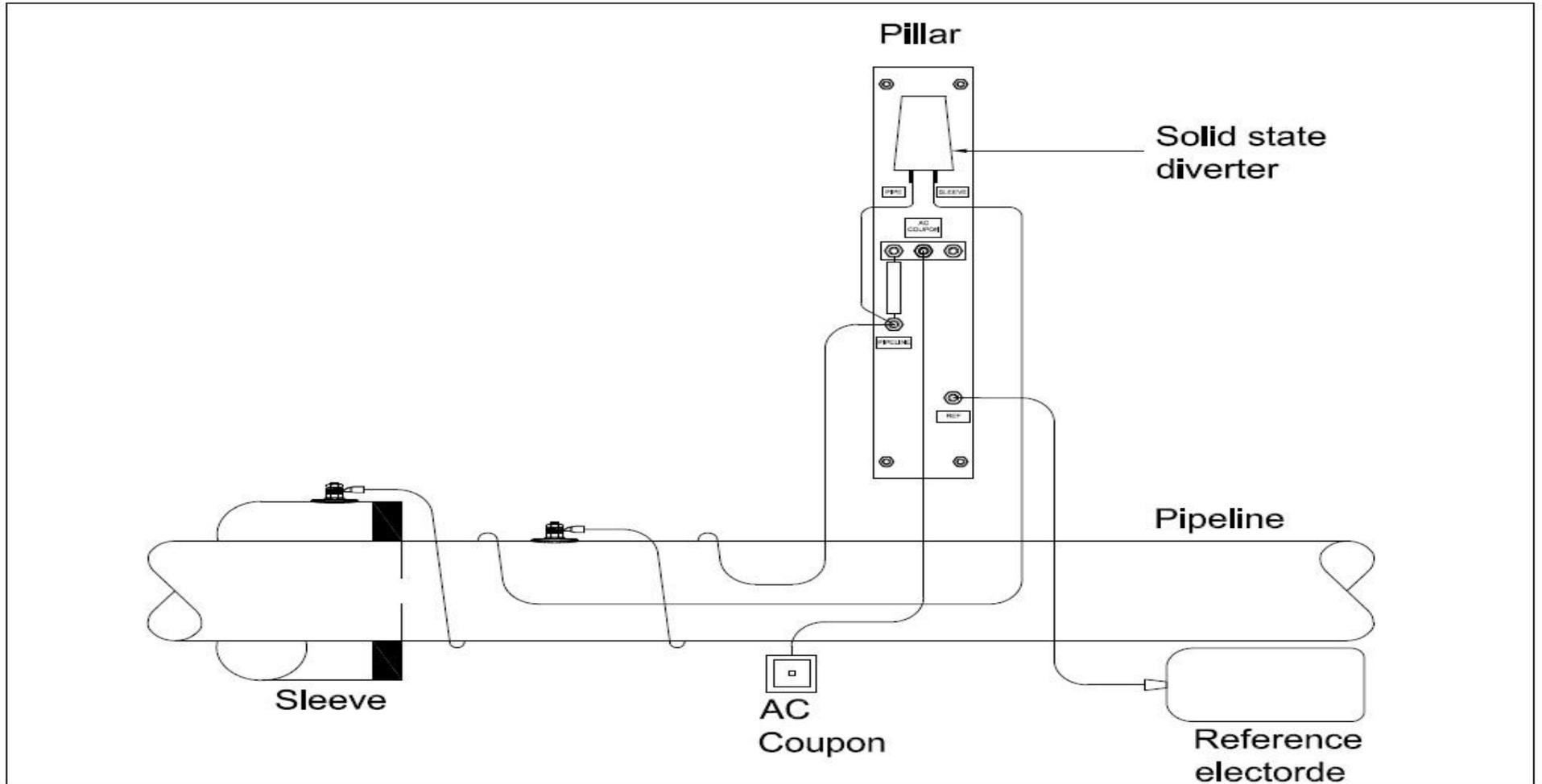
NACE Standard SP 0177 also identifies arc risk on carrier pipeline within sleeve. If carrier pipe exposed to high voltage due to HV or lightning strike there could be an arc within the sleeve as the casing would act as an earth. Use of decoupling devices between sleeve and carrier pipe could be considered to reduce arc risk. Carrier pipes with low wall thickness are at greater risk of damage by arc can also have AC corrosion on carrier pipe within casing

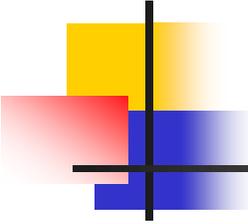
Carrier Pipe in Sleeve

- Carrier pipe if exposed to high voltage could arc to casing.
- Could be perforation of carrier pipe especially if low wall thickness
- Casing if uncoated could be low resistance discharge path for fault current



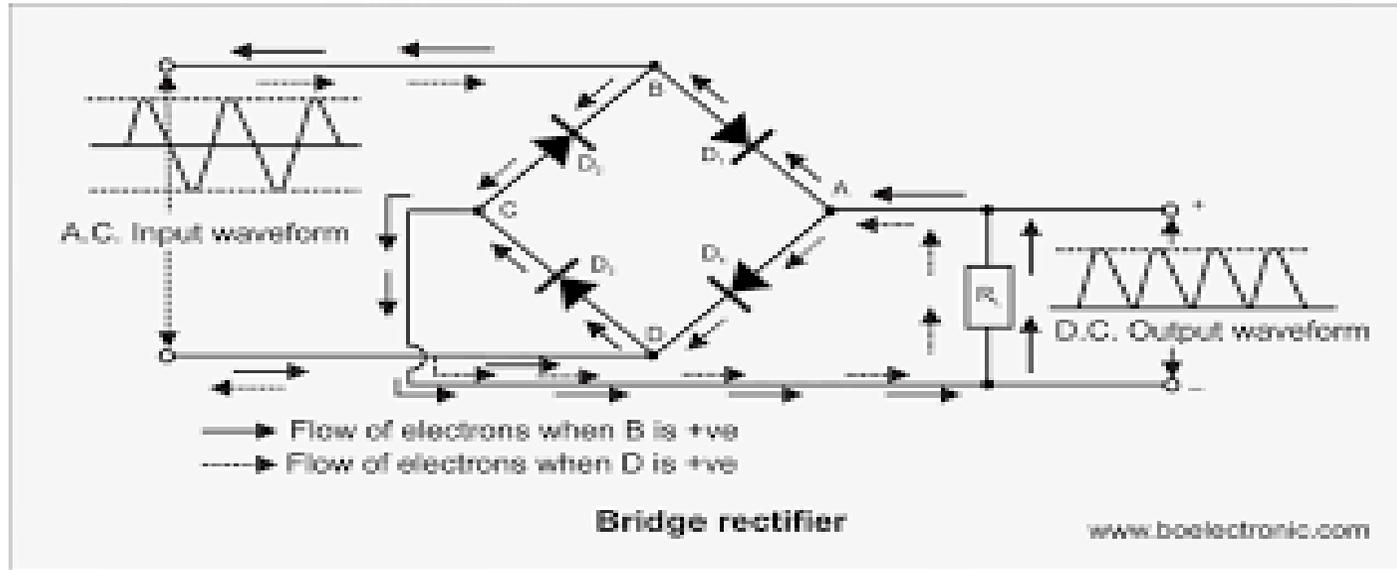
Prevention of Arcing





Rectification of AC on Pipeline

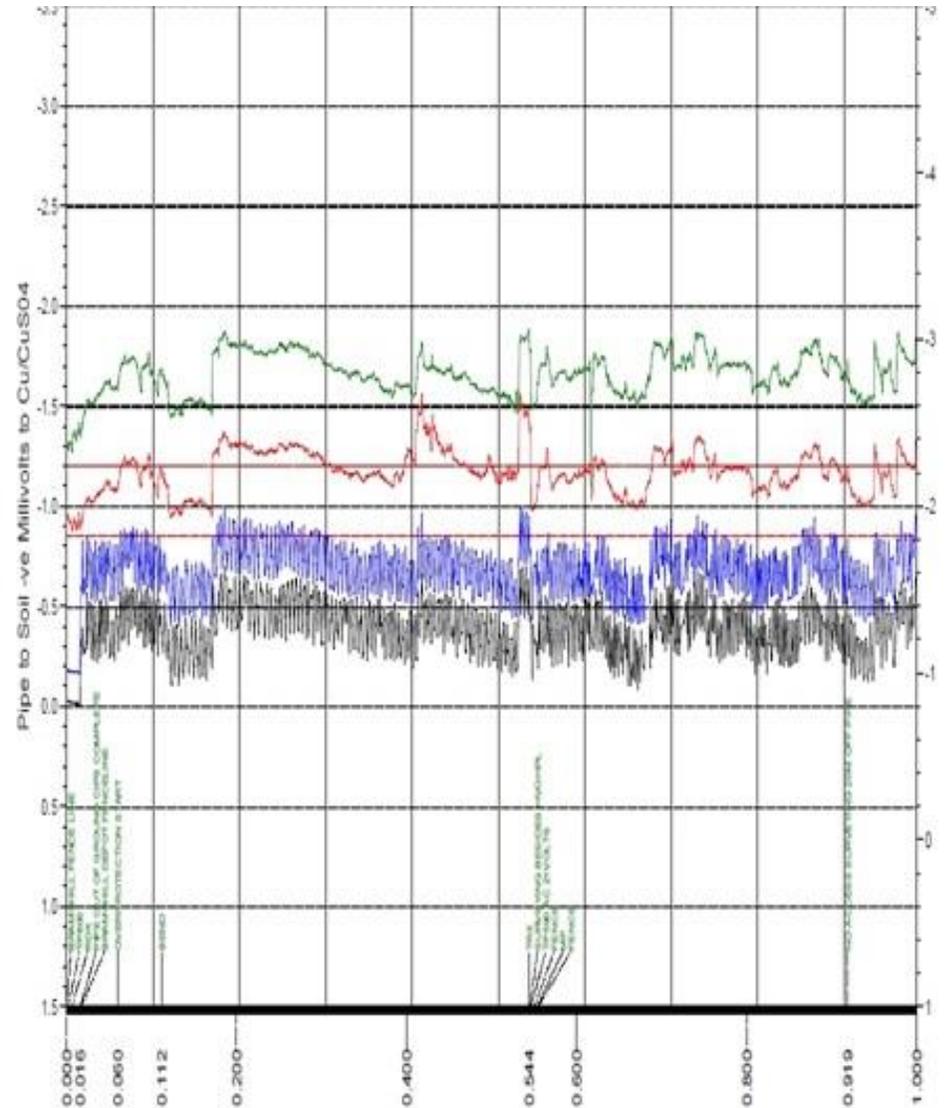
Current Flow Through TR Unit

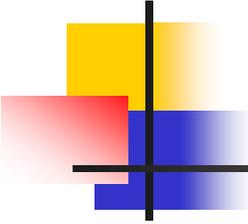


AC voltage across DC output can be rectified by rectifier bridge to produce DC current . The DC current levels can fluctuate. Use choke in negative and or different TR unit construction

CIP Survey on Pipeline Affected by AC

- The fluctuating CIP plot is due to a fluctuating DC current because the TR unit is rectifying the AC current present on the pipeline.
- It is not actually as a result of DC interference
- This can be seen from the static data logger CIP plot as the AC voltage increases so does pipe to soil potential
- If we permit higher voltages than 15V on pipelines this effect will only get worse i.e it wont be possible to maintain a stable pipe to soil potential





Lightning Risk

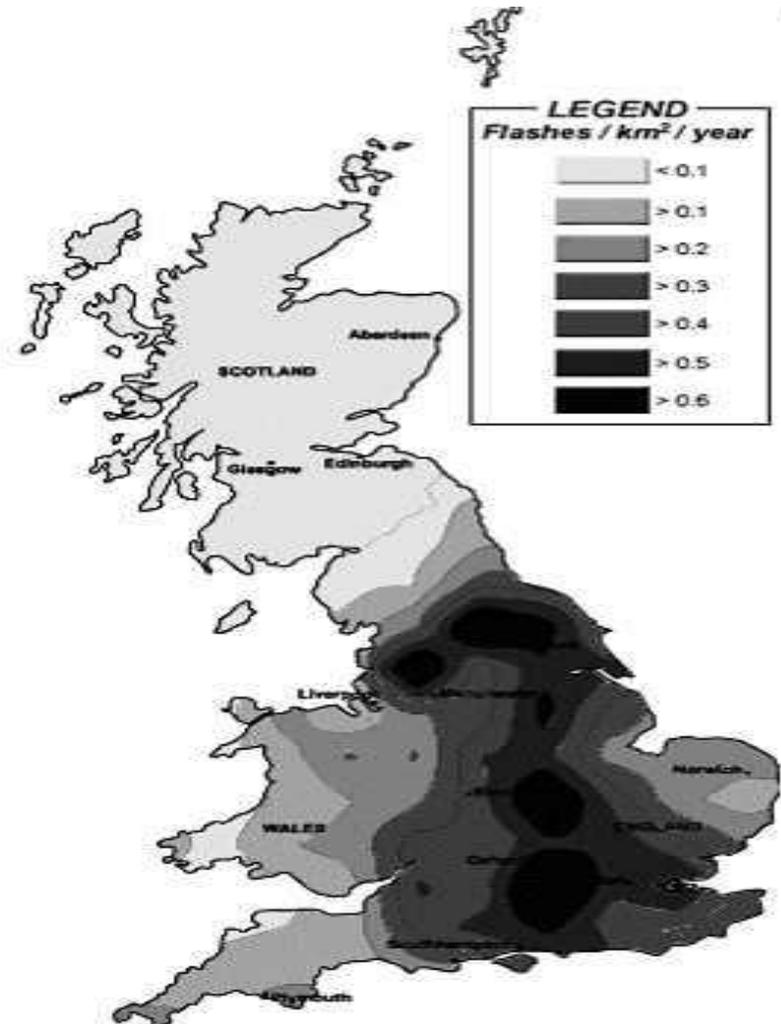
Unfavourable Weather Conditions



- Lightning strikes and unfavourable weather conditions can initiate fault conditions on a power transmission system. This can cause very high voltages to be induced on the pipeline (1,000's volts).
- Lightning strikes to a pipeline or to earth in the vicinity of a pipeline, can produce effects similar to those caused by ac fault currents.
- Permanent earthing control features may not safely mitigate induced voltages from lightning or from abnormal operating conditions of an overhead power transmission system. Duration of strike is 1 to 2 microseconds with a pause of about 50 microseconds as more charge is accumulated before resuming another strike in a slightly or significantly different direction.
- ***CP testing or work of similar nature should not be undertaken during a period of lightning storm activity or in conditions such as high winds, wet snow or freezing rain, when in the vicinity of power transmission systems. Some International guidance is work with 50 km of lightning storms be suspended***

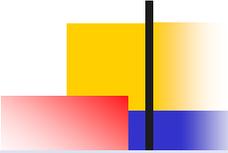
Lightning Density Map

- Some areas of UK there is a higher risk of lightning than in others.
- Thus, higher risk for personnel working on pipelines
- Lightning density map given in BS EN 62305-2



Lightning Arc Damage to Pipelines





What Caused This to Happen to An 80 Bar Gas Line?



The Investigation



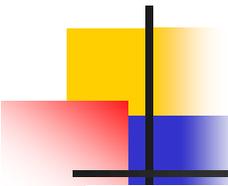
3LPE Coating Internal Epoxy Coating Perforation on Gas Pipeline by Lightning



Spark over voltage

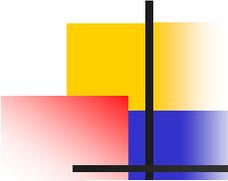
- The spark over voltage for this type of surge protection device is relatively high ≤ 2.5 kV
- IJs can only withstand 2kV so could be damaged even with surge protector fitted
- Lower spark over voltage arrester better surge protection





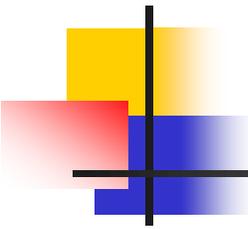
Safety in Construction Issues

Topic	Comment
Stringing out pipelines close to overhead HV powerlines	Induced voltages can be present on pipelines due to capacitive coupling, welding operations can be affected and personnel safety issues. Contractors need to ensure pipes are effectively earthed at least at two locations .Voltages up to 100V are not uncommon
Plant crossing of powerlines	If construction plant cross powerlines GS 6 notification in place but all ENA guidelines to be followed e.g. ENA TS-43-8 gives guidance on clearance distances for different voltage cables
Cutting of pipelines	If pipelines are cut then there could be an incendive spark risk on separating of pipelines either AC or DC current flow in cross country pipelines will exist and could be 10s of Amps of AC
AC voltages present across IJs	If an IJ is unintentionally short circuited this could create a spark risk if AC voltage exists across an IJ. Sometimes testing IJs can result in incendive ignition risks. Particular care required during pigging operations
Personnel working on pipelines close to powerlines	Need to be aware of electrical risks and also safe working distances. Correct PPE and test equipment complying with GS 38
Work on CP groundbeds	This is a risk not often thought of. However, CP groundbeds will act as earths for discharge of AC faults on powerlines. Current will discharge through TR units to the groundbed. Personnel working on a groundbed replacement could receive a fatal electrical shock risk. Need to disconnect groundbed cables at TR unit before work takes place on groundbed installation.



Safety in Construction Issues 1

Topic	Comment
Cranes and side booms	Rubber tyre vehicles should be fitted with earth chains when operating underneath or close to overhead power line
Static shock risk particularly on 3LPE systems	On 3LPE system Holiday detection of coating can leave static charge present personnel contacting coating pipe could receive shock not likely to be fatal due to current but could result in involuntary action and accident. Risk greater with 3LPE coatings than FBE.
AGI Touch Voltage tolerance	Use of crushed stone or similar high resistivity material to be used within AGI will increase touch voltage resistance for personnel
Overhead/buried power cables	Should ensure that all cables whether overhead or buried are located within working width and the nature of the voltage hazard is identified
Health of workers	Personnel with heart conditions who may be more susceptible to electric shock to avoid work on pipelines where hazardous touch voltages may be present
Welding	AC voltages present on pipeline can affect welding operations

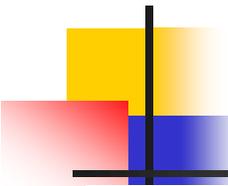


Holiday Detection of Pipeline Coating



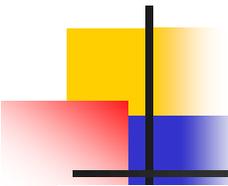
3 Layer Polyethylene





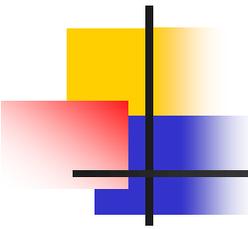
Safety in Operation Issues

Topic	Comment
Pipelines close to overhead HV powerlines	Induced voltages can be present on pipelines due to low frequency Inductive coupling. Voltages up to 100V could exist in some locations and personnel need to be aware of this risk
Transformer rectifiers	Transformer rectifiers ideally should have double wound isolating transformer to prevent AC mains voltage flowing to pipeline during fault. Also reduced level of AC ripple on high output current TR units. When working on TR it is effectively connected to pipeline so can form part of pipeline in terms of electrical hazard.
Short circuit of IJs/IFs	Not uncommon to have resistive connection across IJ/IF e.g cladding or metallic paint coating. During voltage surges these can burn out and provide incendive ignition risks
AC voltages present across IJs	If an IJ/IF is unintentionally short circuited this could create a spark risk if an AC voltage exists across an IJ i.e. each side of IJ. Coating of IJs/IFs prevents fortuitous short circuit e.g. dropping of tools across IF. Erecting scaffolding for pigging operations possible short circuit risk



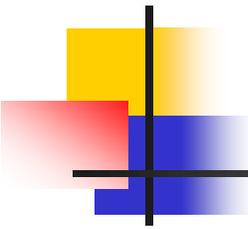
Safety in Operation Issues 1

Topic	Comment
Training	Need to be ensure operatives aware of electrical risks and also safe working practices
Lightning electrical storm activity	Need to limit work during these times as higher probability of shock. 3m touch potential separation limit for different earth systems e.g separation of fence from pipework by 3m partially associated with increased shock risk from lightning activity.
Where PCR's are installed	Limits ability to perform CIP and DCVG surveys but can also cause AC current to flow in earth cables and pipework. If disconnecting PCR cables. Earthing arrangement not strictly TN-S as AC current will flow in earthing cables.
Change of situation	If new power systems installed at substations or power stations then the Ground Potential Rise can change and Ground Potential Rise levels could change and affect touch potential risks on pipeline resulting in higher levels. Increase in fault current will increase ground potential risk. Induced voltage levels can also increase if power loading on powerlines are increased
Pigging operations	Effect of AC interference on pigging operations should be considered possible spark risk on erecting of scaffolding, inspection vehicle shorting IJ and AC affecting pig data



Safety in Operation Issues 2

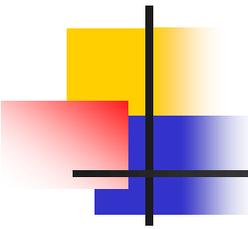
Topic	Comment
Electrification of Rail Lines	If rail lines are electrified how this affects a pipeline should be assessed especially if pipeline runs parallel with traction circuits. Special considerations should be undertaken e.g. location of pylons, spacing of CP test
PCRs, surge protection and earthing	Need to ensure electrical engineers review and accept use of decoupling devices and surge protection
Microwave transmission	Should not install microwave transmission towers in close proximity to AGIs guidance given in PD/CLC TR 50427 Assessment of inadvertent ignition of flammable atmospheres by radio-frequency radiation. Guide
Surge protection inspection	To comply with BS EN 60079-17 Explosive atmospheres Part 17: Electrical installations inspection and maintenance in case of surge protection devices it is visual annual and every 3 years detailed
Use of decoupling devices and over the line surveys	PCRs store energy and where decoupling devices are installed they can affect the ability to carry out over the line surveys e.g. CIPS and DCVG.



NACE SP 0177 Topics

Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems

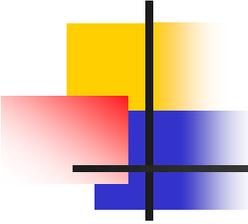
Topic	Comment
Power Arc Overhead Powerline to Pipeline	If the potential gradient in the earth is large enough to ionize the soil for a finite distance, a direct arc from the power system ground to the structure can occur within that distance and result in coating damage, arc burn, or puncture/failure of the structure.
Casings	Bare or poorly coated casings may be deliberately connected to a coated structure through a DC decoupling device to lower the impedance of the structure to earth during surge conditions and to avoid arcing between the structure and the casing.
Guidance on conductor size	Bonding cables and current carrying cables should be of sufficient conductors size to carry the likely fault current for duration of any fault.
Guidance on body resistances and permissible currents	The NACE standard provides guidance on safe current and body resistance levels . These values are lower than given in EN standards



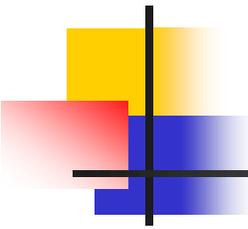
NACE SP 0177 Topics

Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems

Topic	Comment
Safe voltage levels	I/Js max voltage 2kV, 2 kV for tape wraps and coal tar enamels and 3 to 5 kV for fusion-bonded epoxy (FBE) and polyethylene coatings for a short duration
Attachment of grounding cable	The grounding cable shall first be attached to the grounding facilities and then securely attached to the affected structure. Removal shall be in reverse order. Properly insulated tools or electrical safety gloves shall also be used to minimize the shock hazards. THE END CONNECTED TO THE GROUND SHALL BE REMOVED LAST
Above ground connections	At all aboveground pipeline metallic appurtenances, devices used to keep the general public or livestock from coming into direct contact with the structure shall be examined for effectiveness. If the devices are found to be ineffective, they shall be replaced or repaired immediately
CP test lead connection	In making test connections for electrical measurements, all test leads, clips, and terminals must be properly insulated. Leads shall be connected to the test instruments before making connections to the structure. When each test is completed, the connections shall be removed from the structure before removing the lead connection from the instrument. All test



Clearance Distances



Work Underneath Powerlines

- Need to follow guidelines given in GS 6 for work underneath powerlines
- Erect warning tape and notify powerline operator of work underneath powerlines comply with ENA TS 43-8 guidelines
- The latter document gives guidance on clearances between plant and powerlines and also how far away safety barrier need to be erected from powerlines

ENA TS 43-8 Guidelines

Description of Clearance	Nominal System Voltage (kV) Minimum Clearance Distance m				
	<33	66	132	275	400
Line Conductor to any Point Not Over a Road	5.2	6.0	6.7	7.0	7.6
Line Conductor to Road	5.8	6.0	6.7	7.4	8.1
Line Conductor to Any Object on which a Person Cannot Stand	0.8	1.0	1.4	2.4	3.1

Clearance Distances ENA TS 43-8

Table 11.2 - Vertical Passing Clearances

Item No.	Nominal System Voltage		≤33 kV	66 kV	132 kV	275 kV	400 kV
11.2.1	Passing Clearance fixed height loads	m	0.8	1.0	1.4	2.4	3.1
11.2.2	Passing Clearance variable height loads	m	2.3	2.5	3.2	4.1	5.0

The above clearances shall be used to determine the maximum distance to the underside of barriers erected to prevent vehicles or plant from infringing these clearances whilst traversing the line. The height to the underside of the barrier shall be the minimum ground clearance of the line less the specified passing clearance in Table 11.2.

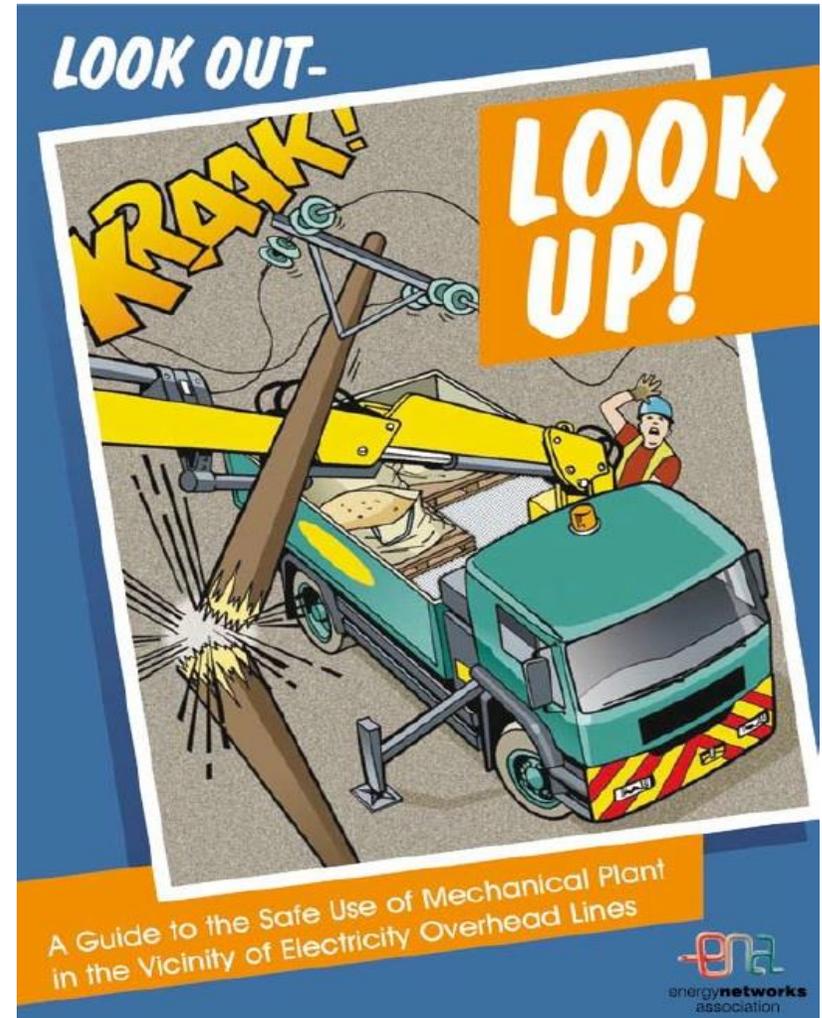
Table 11.1 - Horizontal Distances to Safety Barriers

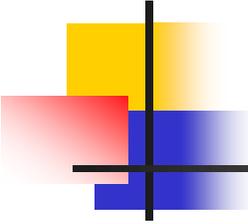
Voltage / Type	≤33 kV Wood Pole	66 kV Wood Pole	132 kV Wood Pole	132 kV Tower	275 kV Tower	400 kV Tower
Minimum horizontal distances to safety barriers.	6.0 m	6.0 m	6.0 m	9.0 m	12.0 m	14.0 m

Note: Site conditions will dictate whether this clearance is adequate and consideration shall be given to line parameters e.g. span length, maximum sag etc. when calculating an actual clearance.

ENA Guidance

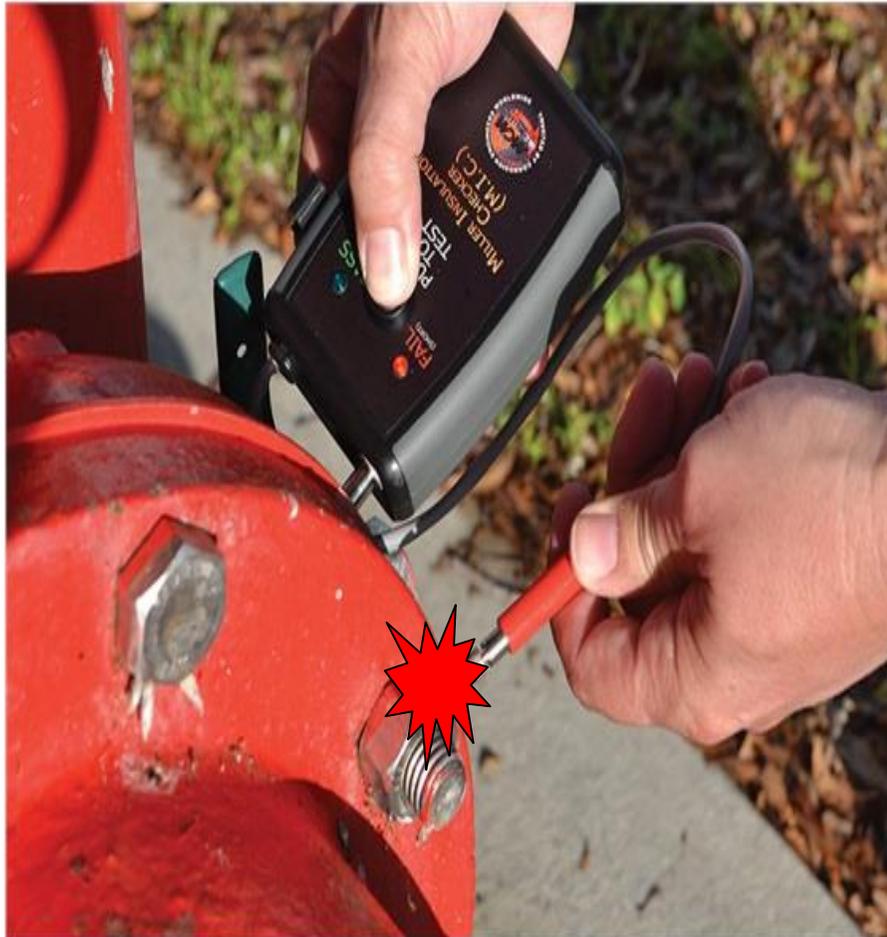
- ENA gives good guidance on measures to take for work near powerlines
- HSE document GS 6 statutory guidelines for work near overhead pylons





Testing IJs and IFs

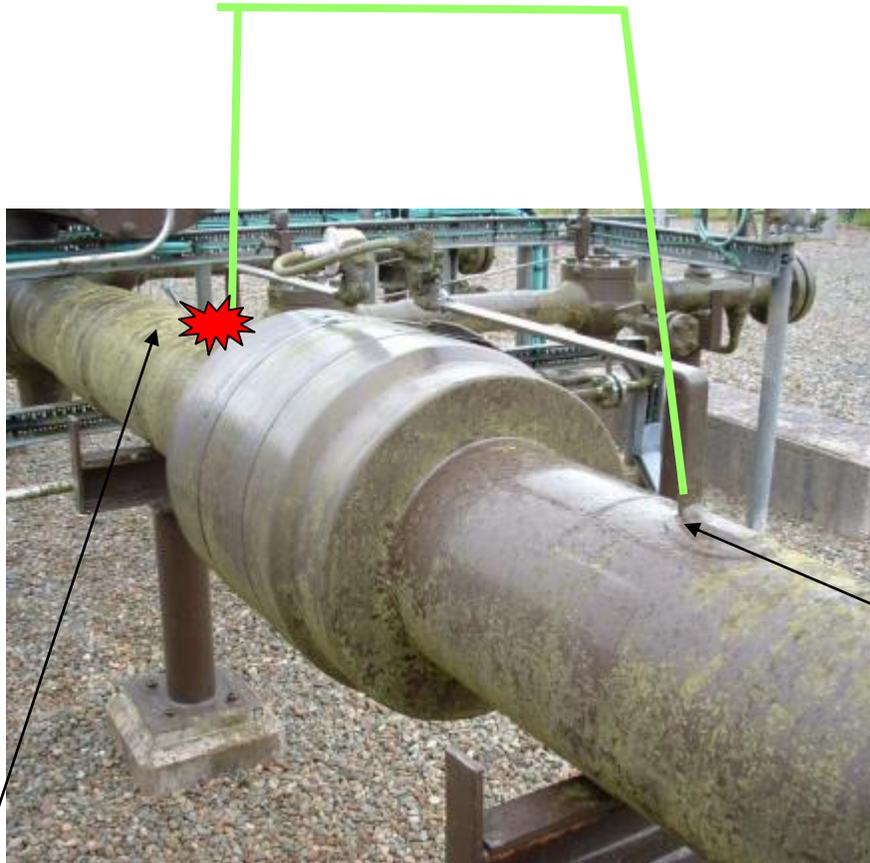
Flange Testers



- The internal resistance of these devices is only a few ohms
- If there is an AC voltage present across a flange then there may be a spark risk on testing
- We have seen this on testing a flange with sparks on making contact with probes
- Currents above a few mA flow and can create a spark dependent upon voltage

Short Circuit of IJ

Can get short circuit from pig scaffolding, testing with CP equipment and tools shorting flange I/F

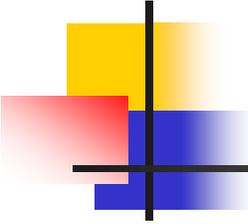


15V AC pipeline line of I/J

0V AV Dead side of I/F

IACS

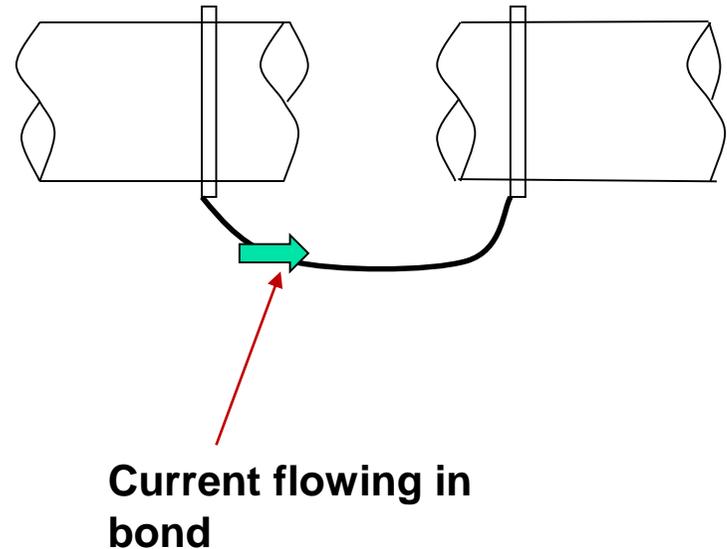
Corrosion Engineering Ltd.



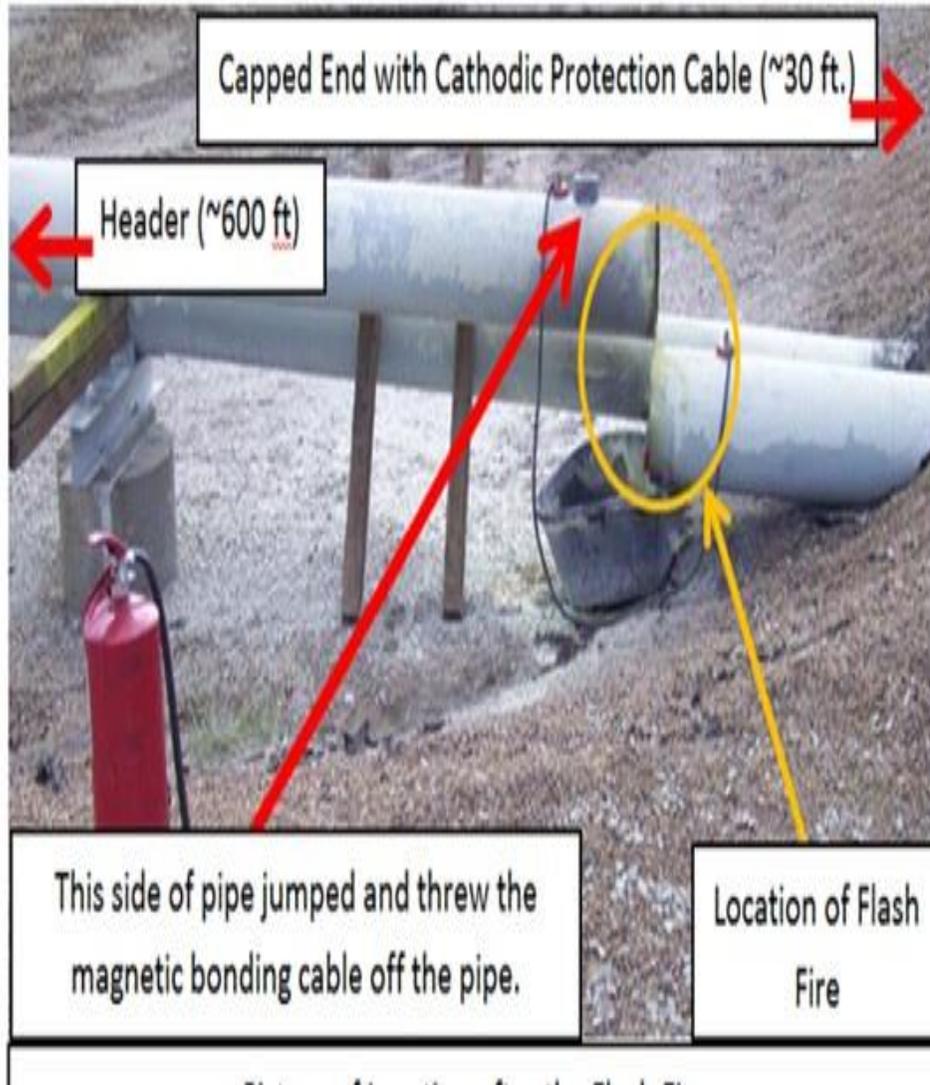
Current Flow in Pipelines

Disconnection of Piping

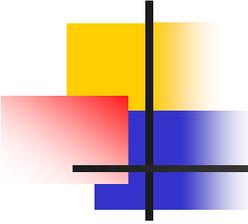
- Cathodically protected and in some cases non cathodically protected pipes will have AC/DC current flowing in the pipe wall. If the pipes are mechanically disconnected, the current flow will be disrupted which could cause sparking.
- An alternative path should therefore be provided for the current when disconnecting any pipework by installing an electrical continuity bond across the intended break. The continuity bond should be left in place until the pipe is reconnected.
- In addition it is some times advisable to temporarily switch off any transformer-rectifiers affecting the section of pipe being worked on at least 24 hours in advance.



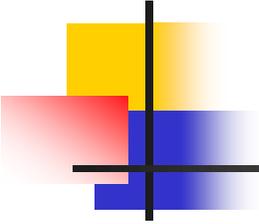
Cause of Incident



- It was later determined the rectifier protecting the piping was on and not locked out at the time of the incident. A cathodic protection cable was found attached to the piping being removed.
- Workers did not recognize the cable attached to the pipe as a potential energy source and did not take action to isolate out all sources of energy.
- Bonding cable design was inadequate to provide continuous bond during a pipe jump. Workers did not consider the potential for pipe movement to defeat the magnetic strength of the bonding cable.
- Flammable product in dead leg was not adequately drained to prevent fire potential.



PCRs and Surge Protection



Use of PCRs Across IJs

- Not all operators use these devices
- For operators that don't have PCRs there is a possible AC spark risk across IJ. There can be a different AC voltage each side of IJ and if the IJ was short circuited there may be a spark/incendive ignition risk
- Those operators that do have PCRs fitted can have appreciable AC current flow through any PCR. Thus, there is a possible spark risk on disconnection of AGI pipework or PCR cables. There will be AC current flow in the AGI earthing so disconnection of earth cables could result in spark risk. AGI earth is also not strictly a TT or TN-S earthing system now.

PCR Across Flanges or IJ

- The term PCR stands for Polarization Cell Replacement. A PCR is a solid-state device designed to simultaneously provide DC decoupling and AC continuity / grounding when used with cathodically protected structures, such as pipelines
- PCRs have very high AC fault current and lightning surge current ratings.
- Low impedance about 0.05 Ohms and allow AC currents up to 40A to flow to earth but block low level DC voltages typically + 2V to -2V.
- PCRs ensure effective AC coupling across flanges/IJs but there safety issues to consider:
 - Spark hazard on disconnection of cables
 - Quite easy to short terminals as Zone 2 PCR terminals do not have a protective covers
 - There will be AC current flowing in pipework AGI side of I/IJ could be spark hazard on disconnection.
 - Will cause AC current to flow in AGI earth
 - If AGI fence connected to AGI earth then any voltage fault on pipeline will be transferred to the fence

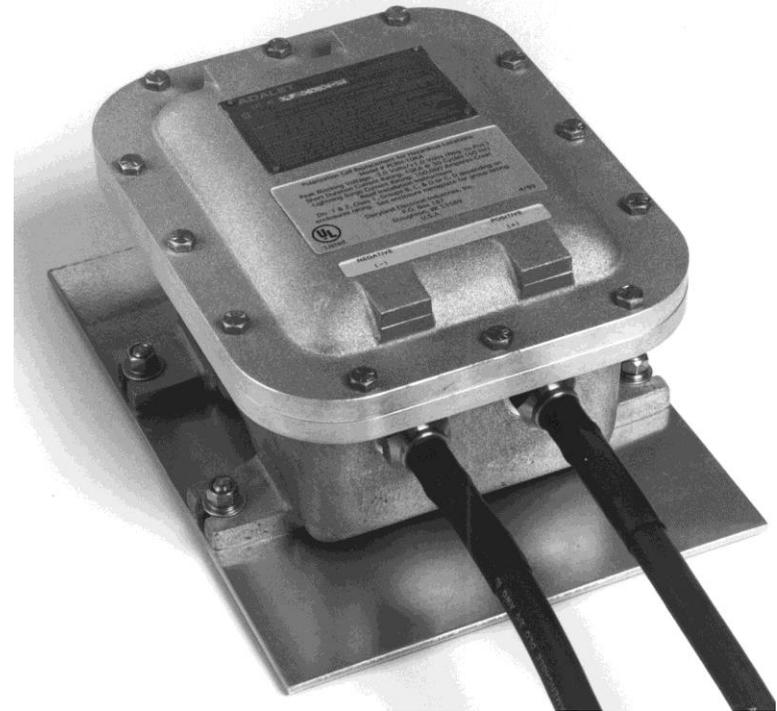


PCRs for Zone 2 Area Easy to Short Circuit

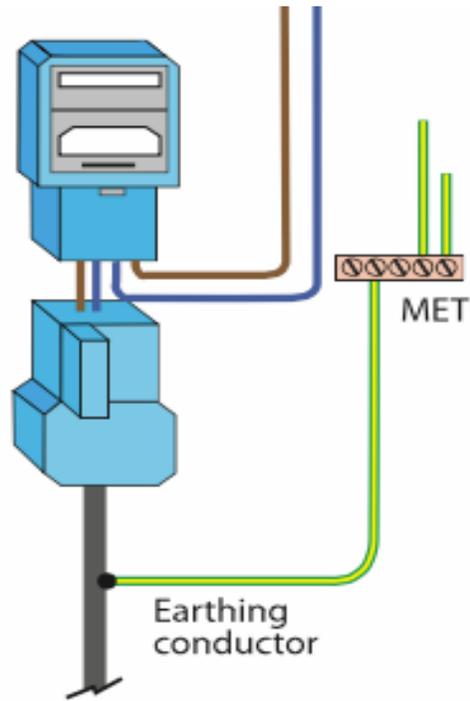
**Zone 2 Certified Device-
Spark risk easy to short
circuit terminals**



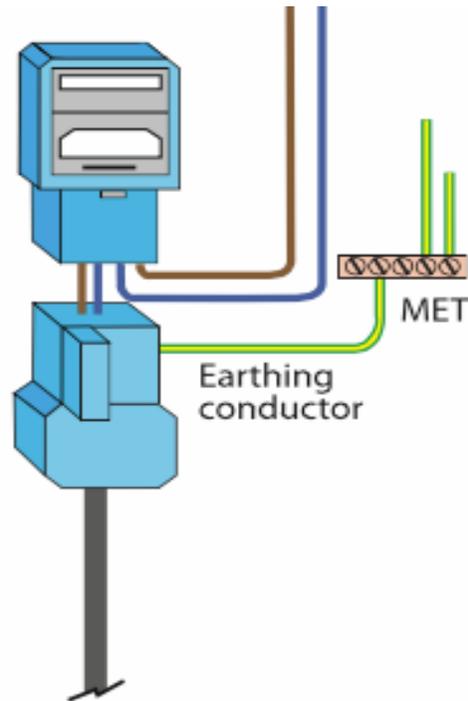
**Zone 1 Certified Device
Terminals within EExd
enclosure**



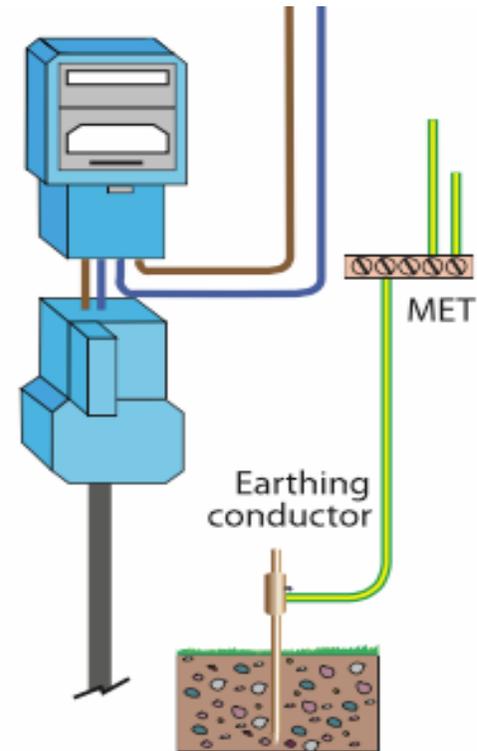
Earthing Connections



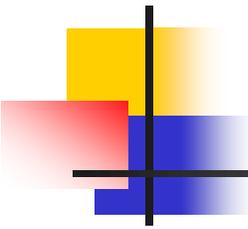
TN-S System



TN-C-S System



TT System



TT and TN-S With PCR

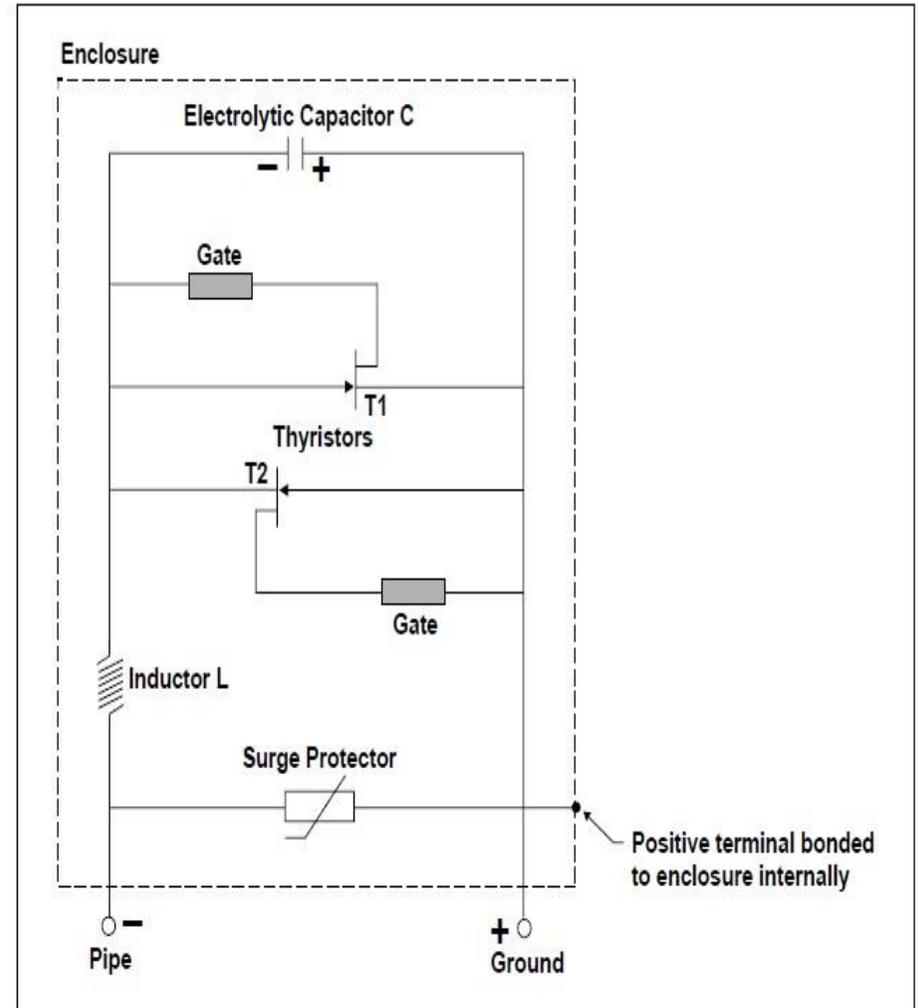
- Earthing systems in hazardous areas are either a TT or TN-S system. Terra is Latin for Earth and the TN –S means earth and neutral are separate. TT means the protective earth connection for the consumer is provided by a local earth electrode, and there is another independently installed at the generator. There is no 'earth wire' between the two
- These system are installed in hazardous areas for safety reasons as when other electrical earthing systems e.g Protective Multiple Earthing (PME) are employed disconnection of earth cables or earthed structure can result in a spark risk because of neutral current flow in earth cables.
- When PCR connected across IJ/IF then AC current flowing in pipeline can flow through AGI earth system. This current level can be quite substantial sometimes up to 40A and result in spark risk on disconnection of PCR cables, earth cables or pipework in a similar manner to that with a PME system. Electrical engineers need to be aware of this risk as CP designers do not often have sufficient understanding of the nature of different earthing systems

Surge Protection Issues

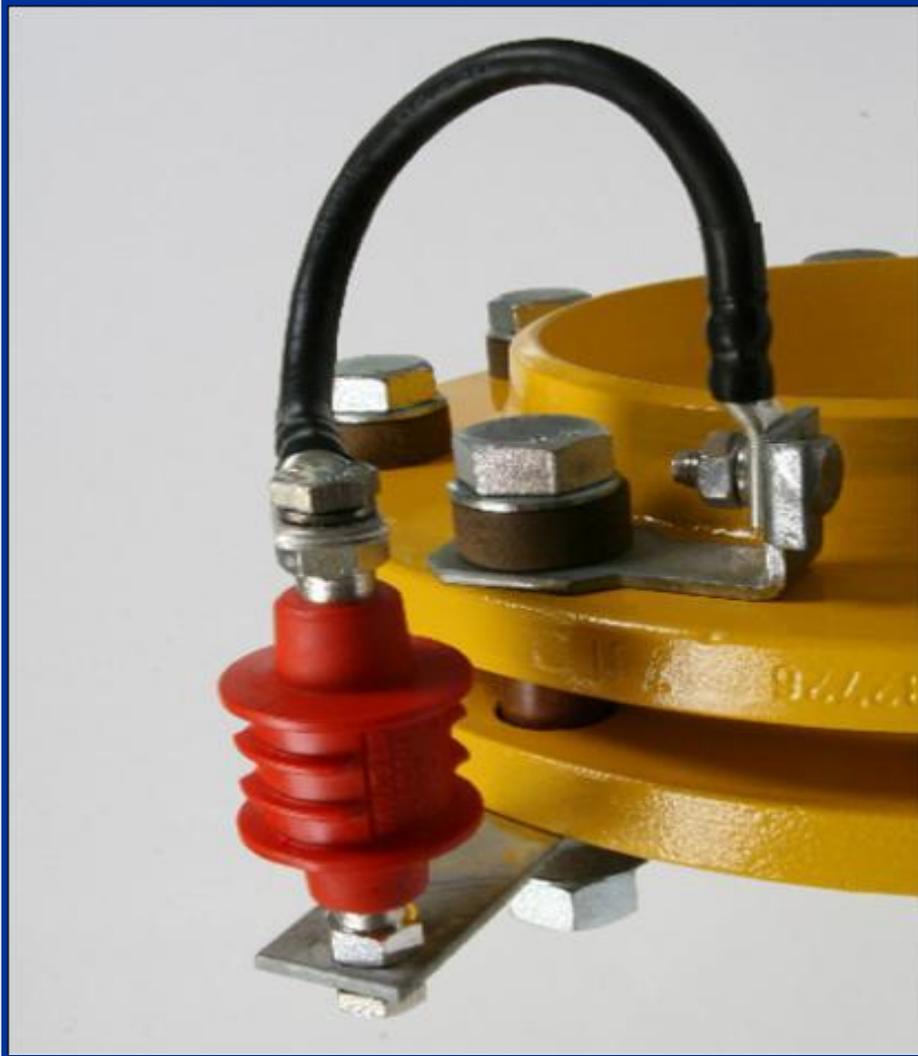
Topic	Advantage	Disadvantage
Protection of IJ from damage max voltage limit for IJs is 2000V	Surge protection helps protect IJ from overvoltage. Failed IJs very difficult and expensive to repair	Fault current discharged to AGI earth if AGI earth low resistance this could cause voltage rise above safe limits and damage sensitive equipment
AC coupling	PCR is used this will ensure pipeline and AGI pipework electrically connected in AC terms. Thus, no AC touch or spark risk across IJ. If spark gap device then no AC coupling	AC current induced on pipeline will also flow through AGI pipework and earth if PCR installed. If fence is bonded to AGI earth then fault on pipeline will be transferred to fence
IFs protected by surge arrestors	If PCR and surge protection device correctly rated can prevent spark across IF under fault conditions	Need to ensure correct Ex rating for arrestor some are only EExn certified so only Zone 2 use. Surge arrestors and PCRs can be easily short circuited and give spark risk

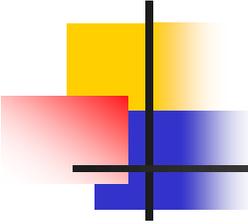
PCRs in Earthing Circuits

- Some operators put PCRs in earthing circuits to DC electrically isolate earths from pipeline but allow AC current to flow to earth
- Other operators do not permit the use of PCRs for this application as BS 7671 does not permit switching devices in earthing circuits
- Always seek approval of discipline electrical engineer before installation of surge protection



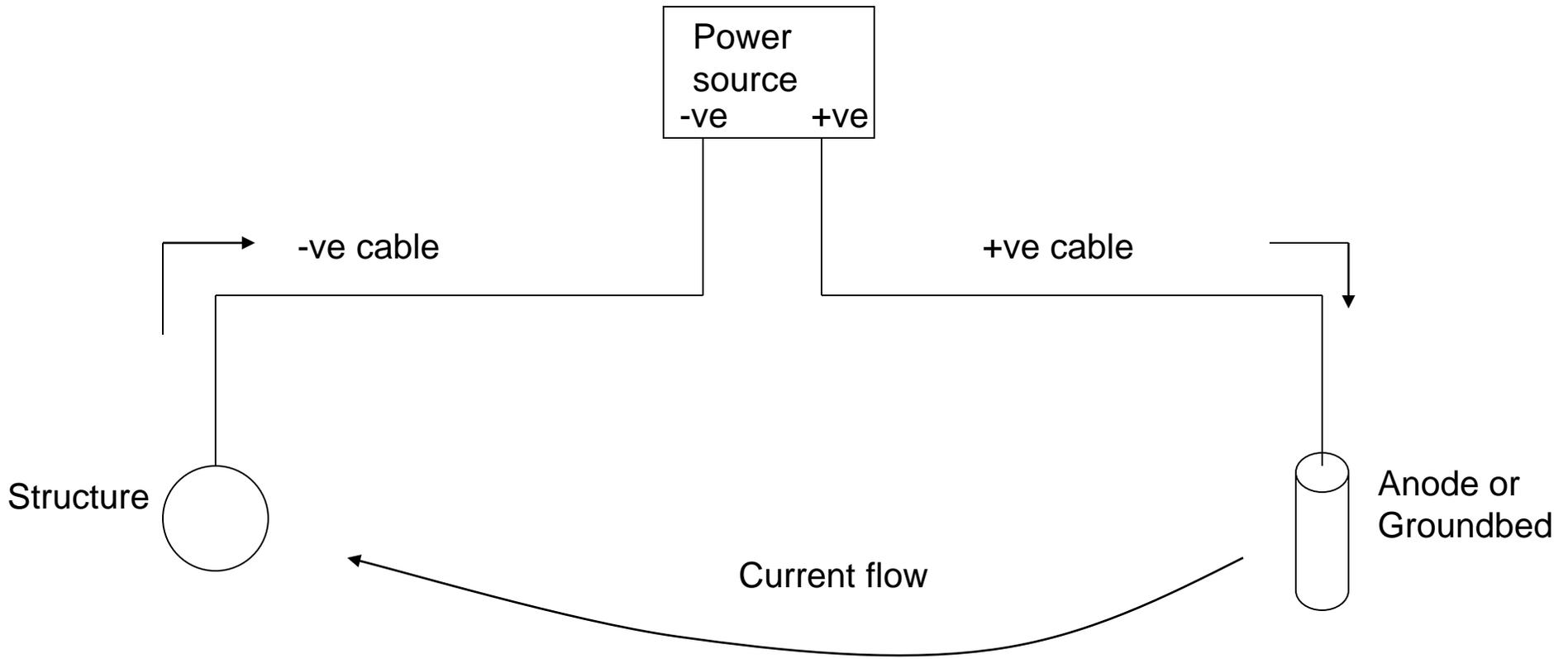
Arrestor on left Zone 1 one on right only Zone 2

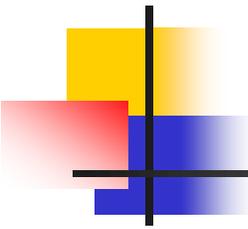




Groundbed Installation

Basic Features of an Impressed Current CP System





Work on Groundbed or TR

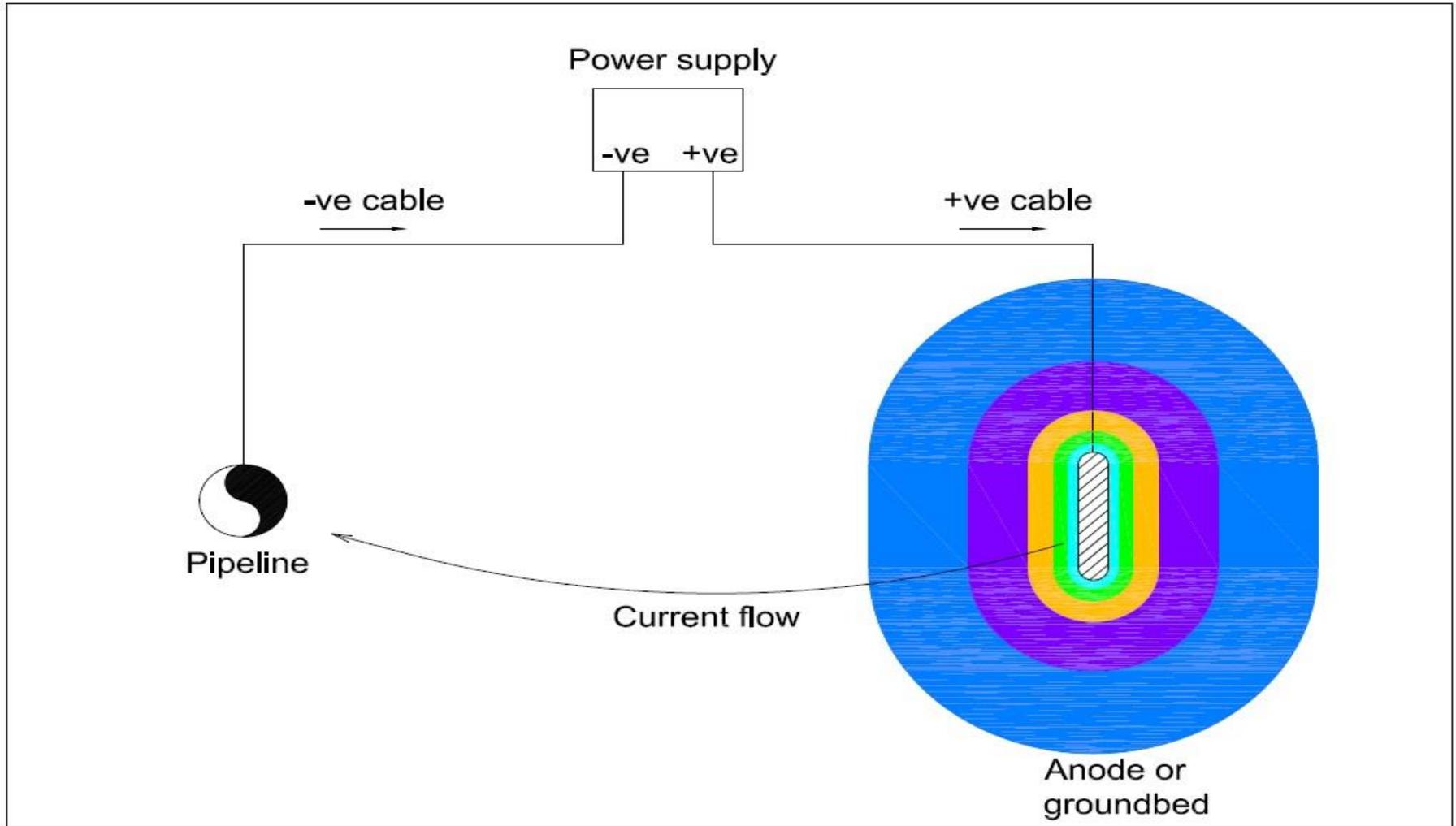
- Groundbeds typical resistance values 2 to 10 ohms will act as a good earth to discharge fault current off pipelines.
- The ground potential may rise at a groundbed and close to it during fault conditions as the current may flow through the CP TR unit to the groundbed or a surge diverter on the TR will discharge the current to earth .
- If personnel were working on a groundbed installation they could be exposed to a possibly fatal shock risk. It would be totally unexpected as it would be nowhere near a HV source.
- Disconnect groundbed cable at TR unit or pipe connection to TR to mitigate the risk when constructing or replacing groundbeds. It is simple but effective !
- Similar steps apply when installing earths associated with AC mitigation systems connect earth to pipeline only at the last minute after earth has been installed.

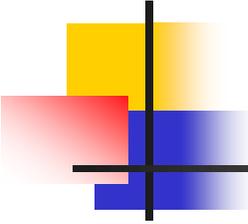
Groundbed Construction

- Groundbed act as earths on pipelines and current can discharge to earth at groundbeds during fault conditions
- Anyone working on groundbed at time of fault would be exposed to the risk.
- There would be a touch potential and step potential risk
- Workers could be exposed to the risk for the entire period of groundbed construction
- Risk would only be present if DC positive cable connected to TR unit at time works take place.
- Precaution is to disconnected either DC positive or DC negative connection from TR unit before any work on groundbed takes place

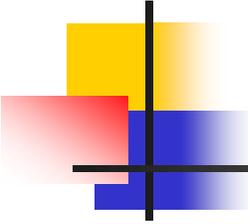


Voltage Rise Near Groundbed



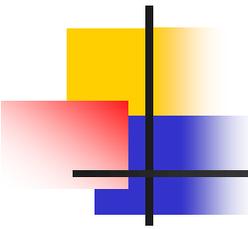


Training



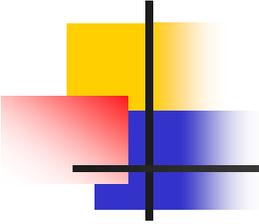
Training and Awareness

- My experience is that in general there is not the awareness that there should be within the pipeline industry on electrical safety risks associated with work on pipelines.
- Pipelines are still routed close to powerlines and pylons by designers
- A lot of technicians would not know what a touch potential was?
- Pipeline design codes e.g TD 1 and BS PD 8010 give limited guidance on electrical safety risks and concentrate more on AC corrosion risk
- New substations installed close to pipelines without assessment of touch potential risks
- Designers, planners all need to be aware of electrical interference risks and the risk should be identified in both Construction and Design Risk Registers
- BS EN 50443 recommends that *the voltage to earth of the pipeline and the voltage difference on the insulating joints shall be evaluated in normal operation and in fault conditions*



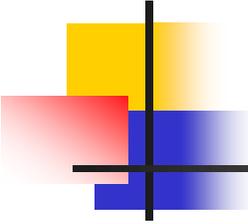
Training and Awareness-Cont

- Pipeline operators need to ensure that all personnel who could come in contact with a pipeline are aware of the possible electrical safety risks and dangers.
- There have not been any known incidents of fatal electrical shocks as HV powerline faults are a rare event say once every 10 years.
- BS EN 50522 states typical probability of an earth fault occurring, which results in a significant earth potential at a transmission substation, is 0.2 per annum; i.e. one significant earth fault every five years on average.
- If personnel experience electrical shocks when working on a pipeline they should be advised to report this
- Lightning strikes are a more frequent occurrence
- About 80% of powerline faults are related to spurious trips caused by lightning or bird strikes.



Mitigation measures

- Wear insulated footwear and do not kneel on ground when taking CP readings.
- Treat test post studs as possibly live
- Carry out pre-work risk assessments
- Use insulating gloves where possible and knee pads.
- Use fused test leads complying with HSE guidance note GS 38 on test equipment.
- Check the surrounding environment before carrying out testing to ensure that in the event of shock any slip or fall would not cause damage.
- Limit time making contact with CP posts

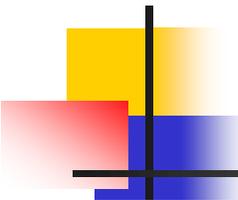


Powerline Operators

- Powerline operators increase load on powerlines without advising pipeline operators. This is because at present they believe they have no requirement to do so.
- Cable operators often do not consider the effects that overhead powerlines will have on buried utilities.
- There needs to be greater awareness in the power generation industry especially at the planning stage of the effects of AC interference on utilities.
- There is a general lack of awareness in the power generation industry of the effects of AC interference on buried utilities

Summary of Issues

Topic	Advantage
Touch potential	Is there sufficient separation between pylon /substation and pipeline to ensure touch potential within safe limits ? Have risk touch potential locations along existing pipelines been identified. Need clarity on permissible voltages and they should be as low as possible
Training	Have operatives been given training in awareness of AC interference risks ? Also designers need to be given guidance on risks as well as pipeline design standards give limited information at present in terms of electrical safety
UKOPA GPG	We will try and identify a lot issues raised in this presentation in the guide in relation to AC interference
Awareness	Need to be aware of fact that there issues associated with installation of microwave towers close to AGIs and overhead pipeline crossings of electrified railways. If railways electrified then this can affect overhead pipe crossings or result in AC interference on pipelines that are routed parallel to rail lines. If powerlines being up rated this can affect AC voltages levels on existing pipelines

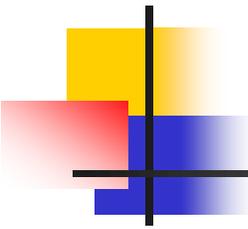


What the Pipeline Industry needs to Consider

Topic	Advantage
Power cable operators	If there are new developments e.g power stations, substations for offshore wind to be installed. The effects on buried services from increased loads on power cables needs to be considered at an early stage. At present power cable operators do not advise pipeline operators of any new developments
Touch voltage limits	There should be clarity as to acceptable touch voltage limits for pipelines. These values should also take into account access by not electrically instructed personnel, the general public and operation and control of pipeline CP systems
Assessment of High Risk Locations	Operators should identify high risk locations in terms of electrical shock risk to personnel
Standards	Pipeline design standards need to address not only AC corrosion risk but electrical safety risk from AC interference

Relevant Standards for AC Interference On Pipelines

Document	Title
AS/NZS 4853	Electrical hazards on metallic pipelines
BS EN 15280:2013	Evaluation of a.c. corrosion likelihood of buried pipelines applicable to cathodically protected pipelines
BS EN 50122-1:2011+A4:2017	Railway applications. Fixed installations. Electrical safety, earthing and the return circuit. Protective provisions against electric shock
BS EN 50443:2011	Effects of electromagnetic interference on pipelines caused by high voltage a.c. electric traction systems and/or high voltage a.c. power supply systems
BS EN 50522	Earthing of power installations exceeding 1 kV a.c.
BS EN 61010-1:2010	Safety requirements for electrical equipment for measurement, control, and laboratory use. General requirements
BS EN ISO 15589-1:2015	Petroleum, petrochemical and natural gas industries. Cathodic protection of pipeline systems. On-land pipelines
BS EN ISO 18086:2017	Corrosion of metals and alloys. Determination of AC corrosion. Protection criteria
ENA TS 41-24	Substation Earthing
ENA TS-43-8 Issue 3 -	Overhead Line Clearances
GS 6	Avoiding danger from overhead power lines
PD IEC/TR 60479-1	Effects of current on human beings and livestock- General Aspects
NACE SP0177-2014	Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems



THE END

Questions ?



IACS

Corrosion Engineering Ltd.