ASSESSMENT OF CORROSION ON BURIED METALLIC PIPELINE INDUCED BY AC INTERFERENCE BELOW HIGH TRANSMISSION LINE

BY

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A project paper submitted in fulfilment of the requirement for the degree of Master Science (Materials Engineering)

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ABSTRACT

The assessment of corrosion on buried metallic multi-product pipeline (MPP) induced by alternating current (AC) interference below high transmission lines was investigated. Power transmission lines or high voltage alternating current (HVAC) transmission lines generate inductive coupling on buried metallic pipeline or any metallic structures located near to it. This electromagnetic field created from HVAC's stray current is impressed onto the MPP and will introduce an AC corrosion at certain AC current density. The AC corrosion occurred on the pipeline surface at the location where the AC stray current is leaving the pipeline (coating defect) to return to its original path. The AC stray current will cause asset damage (AC corrosion) such as leak or burst and danger (electrocuted) to the personnel working on the pipeline route. The AC corrosion occur when adequate stray current from HVAC flow through soil and enter the pipeline at any nearest coating defect then leave the pipeline at another coating defect to return to its original path to complete the electrical circuit. The stray current favors to enter the metallic structures due to its low resistance property compared to soil (relatively high resistance). High voltage alternating current (HVAC) transmission line is usually shared the same right of way with buried metallic pipeline. Long term exposure of inductive coupling on buried metallic pipeline will cause AC corrosion at any coating defects on the pipeline. In the West Coast of Malay Peninsula, the AC induced corrosion is not well studied, and the preventive maintenance is not taken into consideration by some of the pipeline operators. The objective of this paper is to measure the parameters involved at the location of the buried metallic multi product pipeline (MPP) which is cross or parallel to the HVAC. From the parameters collected, the current density will be calculated and the pipeline sections which are in the risk of AC corrosion are determined. On the other hand, the cathodic protection (CP) system affected by stray current are further analyzed. This MPP is laid from Sg. Udang, Melaka to distribution terminal in Dengkil, Selangor with the estimated length of 130.0 km. Along the pipeline routing, only 16 locations of MPP sections are cross and parallel to the HVAC. The equipment used to conduct this corrosion assessment are multimeter, clampmeter, portable current interrupter, soil resistivity meter and portable $Cu/CuSO_4$ reference electrode. CP potential and AC output are measured using multimeter, clampmeter and $Cu/CuSO_4$ reference electrode. For soil resistivity, it is determined by using soil resistivity meter with the native soil sample at site. Magnetic field magnitude is determined by using Biot-Savart Law formula and current density is calculated using current density formula. Three (3) locations (TP 43, TP 102 and TP105) are found under risk of AC corrosion which is in the range of 20 A/m^2 to 100 A/m^2. As per standard industry practice such as NACE SP-0169 and PTS 30.10.73.10, AC corrosion is unpredictable for AC current density in between 20 A/m^2 to 100 A/m^2. These three (3) locations have the highest AC voltage output, the lowest soil resistivity value and the CP potential measured are under protected value. However, the effect of magnitude of magnetic field is literally no significant effect on the AC corrosion activity. In conclusion, AC voltage, soil resistivity and CP potential at the crossing and parallel section to the HVAC will affect the behaviour and severity of the AC corrosion on the metallic buried pipeline.

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ملخص البحث

أجرينا البحث على سبب التآكل في خطوط الأنابيب متعدد المنتجات المعدنية الواقعة تحت الأرض (MPP) الناجم عن تداخل التيار المتناوب (AC) أسفل خطوط النقل العالية ، يولد خطوط نقل الطاقة أو خطوط نقل التيار المتردد عالي الجهد (HVAC) اقترانًا استقرائيًا على خط الأنابيب المعدني المدفون أو أي هياكل معدنية تقع بالقرب منه ، هذا المجال الكهرومغناطيسي الذي أنشئ من تيار HVAC الشارد يتم عزله على MPP وسيؤدي إلى تآكل التيار المتردد عند كثافة تيار متردد معينة ،كما يحدث تآكل التيار المتردد على سطح خط الأنابيب في الموقع الذي يغادر فيه التيار المتردد الشارد خط الأنابيب (عيب في الطلاء) للعودة إلى مساره الأصلي ،كما يتسبب التيار المتردد الشارد في بعض المشاكل (تآكل التيار المتردد) مثل التسرب أو الانفجار أو خطورة على الموظفين (الصعق بالكهرباء) الذين يعملون على مسار خط الأنابيب ، أيضا يحدث تآكل التيار المتردد عندما يتدفق تيار شارد كافٍ من HVAC عبر التربة ويدخل خط الأنابيب عند أي عيب طلاء ثم يترك خط الأنابيب عند عيب طلاء آخر للعودة إلى مساره الأصلي لإكمال الدائرة الكهربائية ، كما يفضل التيار الضال دخول الهياكل المعدنية نظرًا لخاصية المقاومة المنخفضة مقارنة بالتربة (مقاومة عالية نسبيًا) ، كما يتم عادة مشاركة خط نقل التيار المتردد عالي الجهد (HVAC) بنفس الطريق مع خط الأنابيب المعدني المدفون ، كما يسبب التعرض الطويل الأمد للاقتران الاستقرائي على خط الأنابيب المعدني المدفون في تآكل التيار المتردد عند أي عيوب طلاء على خط الأنابيب ، وفي الساحل الغربي لشبه جزيرة الملايو ، لم تتم دراسة التآكل الناجم عن التيار المتردد جيدًا ولم يتم أخذ الصيانة الوقائية في الاعتبار من قبل بعض مشغلي خطوط الأنابيب. الهدف من هذا البحث هو قياس (البراميتر) المتضمنة في موقع خط الأنابيب المعدني متعدد المنتجات المدفون (MPP) المتقاطع أو الموازي مع HVAC، كما يتضح من (البراميتر) التي تم جمعها، سيتم حساب كثافة التيار وتحديد أقسام خطوط الأنابيب المعرضة لخطر تآكل التيار المتردد، من ناحية أخرى يتم تحليل نظام الحماية الكاثودية (CP) المتأثر بالتيار الشارد. تم وضع MPP هذا من Melaka ،Sg.Udang إلى محطة التوزيع في Dengkil، Selangor بطول يقدر بـ 130.0 كم ، على طول مسار خط الأنابيب ، هناك 16 موقعًا فقط من أقسام MPP متقاطعة ومتوازية مع HVAC ، المعدات المستخدمة لإجراء تقييم التآكل هي أجهزة القياس المتعددة ، مقياس المشبك ، قاطع التيار المحمول ، مقياس مقاومة التربة والقطب المرجعي المحمول Cu / CuSO4. ويتم قياس جهد CP ومخرجات التيار المتردد باستخدام مقياس متعدد و clampmeter وقطب مرجعي Cu / CuSO4 ، بالنسبة لمقاومة التربة، يتم تحديدها باستخدام مقياس مقاومة التربة مع عينة التربة الأصلية في الموقع، بالإضافة لذلك يتم تحديد حجم المجال المغناطيسي باستخدام صيغة قانون Biot-Savart ويتم حساب كثافة التيار باستخدام معادلة الكثافة الحالية، لذا نستطيع القول أنه تم العثور على ثلاثة (3) مواقع (TP 43 و TP 102 و TP105) تحت خطر تآكل التيار المتردد والذي يقع في نطاق 20 A/m^2 إلى 100 A/m^2 ، ووفقًا للممارسات الصناعية القياسية مثل NACE SP-0169 و PTS 30.10.73.10 ، لا يمكن التنبؤ بتآكل التيار المتردد بالنسبة لكثافة تيار التيار المتردد بين 20 أمبير/م^2 إلى 100 أمبير/م^2 ، هذه المواقع الثلاثة (3) لديها أعلى ناتج لجهد التيار المتردد ، وأدنى قيمة لمقاومة التربة وإمكانية CP المقاسة تحت القيمة المحمية ، ومع ذلك ، فإن تأثير حجم المجال المغناطيسي ليس له تأثير كبير على نشاط تآكل التيار المتردد. نستطيع القول في النهاية أنه سيؤثر جهد التيار المتردد ومقاومة التربة وإمكانية CP عند المقطع العرضي والقسم الموازي للتكييف على سلوك وشدة تآكل التيار المتردد على خط الأنابيب المعدني المدفون.

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APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a project paper for the degree of Master of Science (Materials Engineering).

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DECLARATION

I hereby declare that this project paper is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Muhamad Izwan Bin Zakaria

Signature .... Date 14/02/2022 ....

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ASSESSMENT OF CORROSION ON BURIED METALLIC PIPELINE INDUCED BY AC INTERFERENCE BELOW HIGH TRANSMISSION LINE

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Alhamdulillah, praise be to Allah for all his blessings to allow this “Assessment of Corrosion on Buried Metallic Pipeline Induced by AC Interference Below High Transmission Line” project to be successfully completed.

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LIST OF ABBREVIATIONS

HVAC	High voltage alternating current
AC	Alternating current
DC	Direct current
CP	Cathodic protection
SACP	Sacrificial anode cathodic protection
ICCP	Impressed current cathodic protection
MPP	Multi-product pipeline
NACE	National Association of Corrosion Engineer
PTS	Petronas Technical Standard
DNV	Det Norske Veritas
API	American Petroleum Institute
ASTM	American Society for Testing and Materials
ASME	American Society of Mechanical Engineers
TNB	Tenaga Nasional Berhad
GDP	Gross domestic product
SCC	Stress corrosion cracking
TRU	Transformer rectifier unit
CI	Current interrupter
CBF	Coating breakdown factor
TP	Test post
$Cu/CuSO_4$	Copper/copper sulphate
SHE	Standard hydrogen electrode
Ag/AgCl	Silver/silver chloride

SCE	Saturated hydrogen electrode
PSI	Pound-force per square inch
Zn	Zinc
MMO	Mixed metal oxide
3LPE	3 Layer polyethylene
FBE	Fusion bonded epoxy
SRB	Sulphate-reducing bacteria
IR	Current x Resistance
GPS	Global positioning system
ROW	Right of way

LIST OF SYMBOLS

V	Voltage/Potential
I	Current
r	Resistance
B	Electromagnetic field magnitude
J	Current density
μ_0	Permeability of free space
f_c	Final coating
I_{ac}	AC current density
V_{ac}	AC voltage/potential
V_{dc}	DC voltage/potential
ρ	Soil resistivity
d	Diameter
T	Tesla

CHAPTER ONE

INTRODUCTION

1.1 OVERVIEW

Metallic materials are commonly used to build up structures that can withstand high pressure, mechanical stress, load and deformation such as bridge, railway track and pipeline. Compare to non-metallic materials, metallic materials are good in physical properties (high strength, malleable, high density etc.) thus suitable to be used for many constructions related structures. For example, transportation pipelines (in water, oil and gas industries) carrying products such as petroleum, water and chemical shall have physical properties to withstand high pressure, physical damage and erosion. Transportation pipeline used carbon steel as the materials due to its abundant, relatively cheap, good mechanical properties, excellent weldability and corrosion resistance which can be enhanced by installing coating, chemical inhibition and CP system (Ali N. Moosavi, 2017). However, metallic materials are prone to be corroded in a certain condition that will affect their performance. Metallic corrosion brings a high impact to the industry which causes structure failure, retarded production, financial loss and danger to the surrounding environment and working personnel. A study was done to unveil the direct cost (of maintenance and repair works) associated with metallic corrosion in United State of America (USA) by National Association of Corrosion Engineer (NACE) from 1999 to 2001. Estimated direct cost of corrosion in the USA is 276 billion USD ($) which is approximately 3.1% of the nation’s gross domestic product (GDP) (Koch, G. H., 2002). Corrosion is treats as one of the major problem in most of the industries especially for oil, gas, petrochemical and water industry. There are many types of corrosion associated with pipeline and the type of corrosion is depending on the surrounding environment, pipeline material and product. External and internal corrosion can occur to the pipeline and corrosion assessment and monitoring shall be done to minimize the effect. New pipelines are well coated and act as a 1st protection layer to corrosion and mechanical damage and CP system as a 2nd protection to corrosion (I. Thompson et al., 2015, Kim.D.K. et al., 2006). However, for under protected CP system and degraded coatings, it will lead to a multiple type of external corrosion such as stress corrosion cracking (SCC), localized corrosion, microbiological corrosion and intergranullar corrosion. (A. Benmoussat et al., 2001). Due to rapid industries development of oil and gas, energy, power generation and transportation, some of the buried pipeline might run across or parallel with HVAC and railway track or sometimes cross in development areas (S. Nikolakakos et al., 1998, K. Zakowski et al, 1999). There will be a potential risk if the pipeline is located near to the DC and AC power sources; where these power sources might introduce a stray current effect. AC stray current is a common threat to the pipeline as the pipeline usually shares the right of way (ROW) with power transmission lines or HVAC. AC corrosion (resulted from AC interference) is one of the threats to the buried metallic pipeline which cause from nearest HVAC structures. This is due to swift development of energy infrastructure of both buried metallic pipeline and HVAC which caused the AC interference (Junker Olesen A. 2018). The HVAC transmission line will create induction in the form of AC stray current to enter and leave the pipeline structure (H. Hogna et al., 2012, J. Zhao et al., 2007, T. Zhang et al, 2012, Q. Ding et al., 2013). Adequate AC current density on pipeline will cause severe AC corrosion and lead to the metal loss, worst case is pipeline's leak or burst. There is no exact distance for the pipeline to be safe from the stray current produce by HVAC as the current flow into the soil is depending on other parameters such as electromagnetic field magnitude, soil resistivity and composition, coating breakdown factor (CBF) of the pipeline and AC current density. In general, the farthest the distance of buried pipeline with HVAC will minimized the effect of AC interference. AC corrosion is a serious issue which it can occur even the buried pipeline is well protected by CP system (N. Kioupis et al, 2003). AC corrosion due to AC stray current is an interesting topic of research because the AC corrosion is unpredictable and some of the pipeline operator is unaware of the stray current effect to their pipeline and the cases for AC interference are varies. As a result of this assessment, an AC mitigation can be applied at affected locations to reduce the effect of AC interference, thus will stop the AC corrosion on the pipeline. This corrosion assessment will investigate on a 16 inches' diameter multi-product pipeline (MPP) made from a API 5L X52 carbon steel with a total length of 130.0 km and transporting multi petroleum products such as Jet-A1 fuel, diesel and petrol from refinery to distribution center. This MPP is cathodically protected by using impressed current cathodic protection (ICCP) system as a main CP protection and sacrificial anode cathodic protection (SACP) system as a secondary CP system. There are four (4) numbers of CP stations are installed along the pipeline route which consists of transformer rectifier unit (TRU) to provide direct current (DC) power source and anode groundbed. Additional SACP system is usually installed at certain locations such as near to road/railway crossing, river crossing, under bridge, near to foreign CP protected pipeline and under protected locations to provide an additional CP current.

Table 1-1: Multi-product pipeline (MPP) details

Pipeline Type	Multi-product pipeline (MPP)
Pipeline Material	Carbon steel (API 5L X52)
Dimension	Length = 130.0 km, Diameter = 16 inches
Coating Type	Epoxy coating
CP System	ICCP and SACP system
Total CP Station	Four (4) locations
Total Test Post (TP) Numbers	158 numbers
Total Locations Near to HVAC	16 locations

1.2 PROBLEM STATEMENT AND ITS SIGNIFICANCE

A well coated buried metallic pipeline with a good cathodic protection system will protect the structure from corrosion externally. However, during the transportation and installation phase and long service time, the integrity of coating layer on pipeline surface is not 100% guaranteed to sustain from damage or disbondment. As per nominal industry standards, the coating breakdown factor (CBF) shall be considered 1-2% initial, with 1% annual increase; hence, for a 10 years' life design, the CBF value would be 11% or 12% (J. Bascos et al., 2015). The CP system is designed base on the current requirement from the assumption of coating breakdown of the pipeline, total surface area and current density. This CP system will protect the pipeline from corrosion at coating defect areas. However, if the coating defect is increased by time the CP current required will also increase. A long transportation pipeline usually will be installed by ICCP system as a main system; while SACP system is to provide an additional protection to the pipeline and some of them are used to mitigate the stray current (act as a grounding system). There are two (2) types of stray current which are generating from

AC and DC sources. The DC stray current commonly come from other nearby metallic buried structures that have their own CP system, either the current is going out or going into the pipeline. Another type of stray current is from AC sources such as HVAC or railway. In this corrosion assessment, it is to investigate the effect of AC interference on buried pipeline section located near to the HVAC along the pipeline ROW which is approximately 130.0 km in length. All the sections of the pipeline which is parallel or perpendicular to the HVAC are further investigated to identify the AC corrosion risk on the pipeline. Out of 158 test posts (TP), 16 locations are identified and have been further analyzed for this corrosion assessment project. In brief, this 130.0 km MPP has been operated for more than 20 years and being well-maintained to make sure it is in a good condition for service. Monitoring facilities such as TP is installed along the MPP to monitor the CP potential and other parameters during maintenance work. For this assessment, the nearby HVAC carries a total of 275.0 kV of AC current as per Tenaga Nasional Berhad (TNB) specification. This HVAC will create an AC interference to the MPP nearby as the AC voltage will be impressed (induction) into the soil and enter the pipeline. As a result of AC interference, AC corrosion might take place if the stray current enters the pipeline through soil at any coating defects and travel along the pipeline surface and leave the pipeline to re-enter the soil and complete the electrical circuit (Richard W. Bonds et al., 2017). The corrosion occurs at the area which the stray current is leaving the pipeline surface through coating defect and the amount of metal loss is directly proportional to the amount of current discharged (A. W. Peabody, 2001). If the pipeline is 100% guaranteed to be insulation coated, there will be no risk to the pipeline as the AC stray current is stopped from entering the pipeline. The problem will come when the pipeline is already in service for a quite sometimes; this MPP is being operated for more than 20 years which is the coating system is assumed not in a good condition and the coating defect percentage is unpredictable. Hence, if the MPP's coating at the HVAC location is in a bad condition, it will allow the AC stray current to enter the pipeline and the process will cause AC corrosion to the pipeline structure. This corrosion assessment will provide data on the risk of AC interference and predict the corrosion activities on the MPP that located near to the HVAC.

1.3 SIGNIFICANT OF STUDY

In the West Coast of Malay Peninsula, the AC induced corrosion is not well studied and the preventive maintenance is not taken into consideration by some of the pipeline operators. The effect of AC interference to the nearby metallic structures is unpredictable and varies depend on location and parameters. The worst case impact of AC interference is high voltage that will electrocuted any personnel working nearby and lead to the AC corrosion to the metallic structure such as buried metallic pipeline. This assessment will focus on AC interference effect on buried pipeline in the West Coast of Malay Peninsula. A corrosion assessment study on AC interference is very important to the pipeline operator since it will provide the data of the pipeline section to be mitigate from the AC interference effect. On the other hand, mitigation of AC interference will provide a true data from the CP system potential as the CP system is now not affected by foreign current. Hence, operator can re-adjust their CP system in order to make sure the pipeline is in optimum protection level.

1.4 OBJECTIVES

The objectives of this research are:

1) To measure the AC voltage and current output, soil resistivity, cathodic protection potential and magnetic field magnitude of the MPP pipeline located near to the HVAC transmission lines.
2) To calculate the AC current density on the MPP and identify the affected location towards AC corrosion attack.
3) To study the effect of AC stray current on the cathodic protection system.

1.5 SCOPE OF THE PROJECT

The main scope of this project is to identify affected pipeline section from AC interference and to study the effect of AC interference to the cathodic protection system at 16 locations along the 130.0 km length of MPP in the West Coast of Malay Peninsula. The measurement of cathodic protection potential, AC voltage and current output, soil resistivity, electromagnetic field magnitude and AC current density are recorded and tabulated. The data is collected at 16 locations which are located near to the HVAC source. Soil samples are taken at each location for laboratory testing (soil resistivity measurement). The collected data will be calculated and analyzed to categorize the corrosion risk and its effect to the cathodic protection system.

1.6 ORGANIZATIONAL OF REPORT

This project paper is organized into five (5) chapters. Elaboration on each chapter is described as follow:

1) CHAPTER ONE: An overview of this project paper is explained briefly on the CP system and AC interference effect on buried metallic pipeline

(in this case is MPP). The issue is then elaborated further in the problem statement and is emphasized on the significant to tackle this issue. In the research methodology, the steps taken to conduct the project are explained in detail. Scope of the project is also included to brief on the area will be covered in this study.

2) CHAPTER TWO: This chapter is focus on literature review in the technical and field aspects of corrosion assessment. The technical review is narrow in depth on the AC interference, AC corrosion, CP system, electromagnetic field, soil resistivity and current density. This chapter also emphasizes the mechanism of AC interference which leads to AC corrosion and creates a disturbance on CP system of the MPP.
3) CHAPTER THREE: This chapter will focus on the research methodology on how it been done through several step and guidelines. The details on equipment and instrument setup, CP monitoring, field measurement, electromagnetic field and soil resistivity testing.
4) CHAPTER FOUR: This is the chapter which discusses the result from the project that required field testing and analyzing. The data collected are discussed and compared to the technical standard. Explanation on the outcome is explained to prove the effect of AC interference on MPP.
5) CHAPTER FIVE: This chapter will explain and summaries the entire chapter in this project paper with the conclusion and recommendation as a further work guideline.

CHAPTER TWO

LITERATURE REVIEW

2.1 OVERVIEW

This multi-product pipeline (MPP) is made from API 5L X52 carbon steel grade. This standard grade indicates minimum yield strength of 520000 PSI and minimum ultimate tensile strength of 66000 PSI. The API 5L X52 pipe is come in seamless and welded which is suitable for transportation system in the oil and gas industries. This MPP is being operated more than 20 years transporting multi petroleum products and almost to its end of design life. During service, threat or risk will affect the pipeline sustainability due to different factors such as natural disaster, corrosion and human error (Muhammad Rizwan et al., 2020). A study was done in Europe to record the pipeline failure factors as per Figure 2-1.

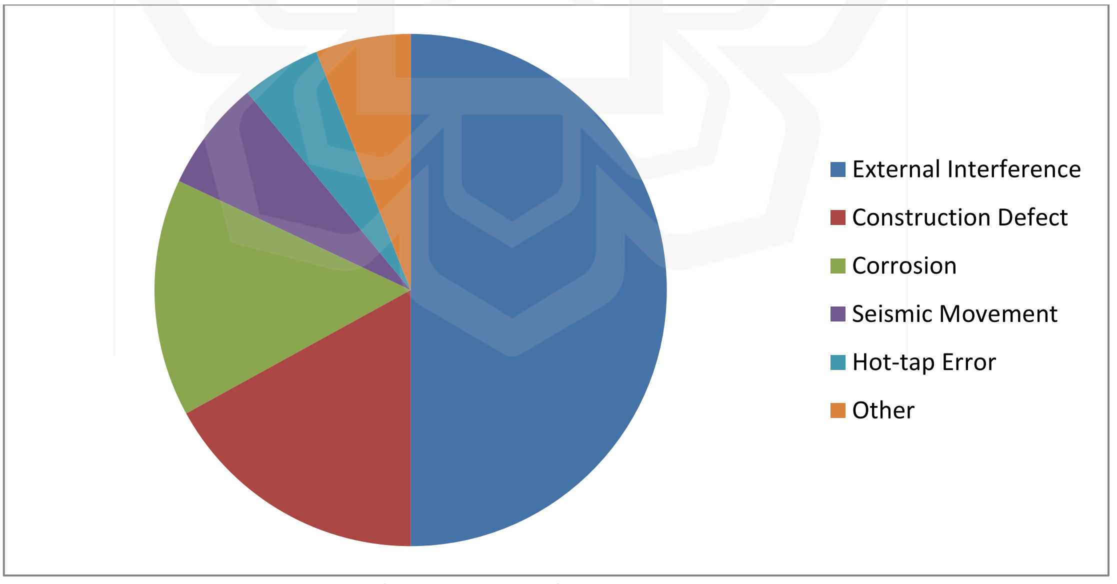

Figure 2-1: Distribution of the causes of accidents on European pipelines during period 1970/2001 (5th Report of the European Gas Pipeline Incident Data Group, 2002)

The pie chart explained factors that affecting the pipeline sustainability and external interference represent 50% of the pipeline failure; which include pipeline is under load actions (compaction and foundation reaction), cyclic loads (traffic loads and service pressure), impact loads, surrounding environment and construction processes (Safety, Reliability and Risks Associated with Water, Oil and Gas Pipeline, 2007). Corrosion (internal and external) represents 15% of the pipeline failure factor. The life cycle of the pipeline is determining by the corrosion activity (Xu. D. et al., 2013) due to the degradation of metal loss that will end up with failure (Ebadzadsahrei. S. et al., 2019; Walker. J., 2010; Kishawya. H.A. et al., 2010). Corrosion attack is due to many factors and AC corrosion is one of the corrosion types that might occur if the buried pipeline is located near to the AC power sources such as HVAC.

HVAC can generate inductive coupling to the nearest metallic structures such as buried metallic pipeline. This inductive coupling or induction is created by the electromagnetic field produced around the cable carrying electric current. Some fraction of this AC stray current will be impressed on the metallic pipeline underneath or nearby (Richard W. Bonds et al., 2017). This AC stray current produce from HVAC transmission line is dangerous and hazard to the personnel and pipeline. At certain value of AC current density, it will create AC corrosion at any coating defects on the pipeline surface.

Although the pipeline is cathodically protected by minimum protection criteria which is the “OFF” potential is more negative than -850 mV with reference to copper/copper sulphate ($Cu/CuSO_4$) reference electrode or 100 mV shift polarization, AC interference still can have occurred at coating defects and rate of corrosion can accelerate (Kioupis, N. et al., 2013). The only way to eliminate the AC stray current effect is by the mitigation method installed at the affected location; where the stray