Effect of Increasing Energy Demand on the Corrosion Rate of Buried Pipelines in the Vicinity of High Voltage Overhead Transmission Lines

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***Abstract*— There are continuous cases of pipelines sharing corridor with high voltage overhead transmission lines (HVTLs) both in rural and urban areas due to economic reasons, increasing energy demand, environmental factors and land use regulations. There is induction of voltage on the pipes due to inductive, capacitive and resistive coupling between the pipelines and the HVTLs, which accelerate corrosion of pipes. In this work, we present the effect of increase in energy demand on the corrosion rate of buried steel pipelines in the vicinity of HVTLs. The corrosion penetration rate of a buried pipeline with variations in the line current of a nearby overhead single circuit transmission line of vertical geometry was computed using existing relations from literature. The results obtained showed that increase in line current increases the corrosion rate of the pipeline. It can therefore be inferred from the results that a pipeline sharing corridor with transmission lines in urban cities and industrial areas where the energy demand is high will experience greater corrosion than those in rural areas where load demand is less, assuming the same condition of soil resistivity and its composition. Also, AC corrosion mitigation system and cathodic protection criteria need to be reviewed from time to time to meet the trend in energy demand.**

Keywords*— Alternating current density; Buried pipeline; Corrosion rate; Energy demand; High voltage transmission line; Induced voltage; Right of way.

I. Introduction

The demand for energy and water consumption has increased drastically in the past few years. There is continuing tendency of installing metallic pipelines in the right of way (ROW) of high voltage transmission lines, thereby raising concern of alternating current interference from these lines on the pipelines. Long term interference from power lines causes accelerated corrosion of the pipelines as a result of the time varying magnetic field produced by the transmission line currents, which is coupled to the metallic pipeline [1-5]. This induces voltage on the pipe which may pose danger to working personnel working on the exposed part of the pipeline [1, 2, 6-8]. Moreover, the pipeline coating materials may be destroyed. This induced voltage on the pipe causes current circulation between the pipeline and the surrounding soil [9], thereby leading to accelerated corrosion at the precise point where the current leaves the pipe to the surrounding soil [10-13]. When current flows out of the pipe, that point becomes anodic and oxidation reaction occurs resulting in the dissolution of metals as given by equation (1) [11, 12, 14, 15].

$$Fe \rightarrow Fe^{2+} + 2e^{-} \quad (1)$$

The amount of current leaving the pipeline is directly translated into metal loss which is visible over time [11, 12]. Similarly, reduction of oxygen results at the precise point where the stray current enters the pipe, making that point cathodic in nature. The cathodic reaction occurring at that point is given by equation (2) [11, 12].

$$O_2 + 2H_2O + 4e^{-} \rightarrow 4OH^{-} \quad (2)$$

Research works have been conducted to explain the mechanism by which AC affects the corrosion process of pipelines [16-22]. AC affects the value of the cathodic protection criteria of -850mV copper/copper sulphate electrode on the pipe as stipulated by the European Standard EN12954 [22], thereby shifting it from the designed value [20, 24]. Zhiguang, Chaoki, Jixu and Yu (2013) pointed out that the best way to assess the corrosion due to AC interference is to determine the change in current density through a coating defect on the pipe [13]. Moreover, authors in [16, 20-22, 25] have determine AC current density as a valuable parameter in determining the corrosion rate due to AC interference. The corrosion rate of pipeline defined in [26] is the depth of penetration in millimeter per year (mm/yr or μm/yr). The corrosion penetration rate of metal (*CPR*) due to AC interference, according to Faraday's law is given by equation (3) [26, 27]

$$CPR = \frac{M \times J_{ac}}{F \times \lambda} \quad (3)$$

where M, is the atomic mass of the metal, J_{ac} is the AC current density, λ is the density of the metal and F is the Faraday's constant given by (96485 C/g). To evaluate the corrosion penetration rate in mm/yr, equation (3) is expressed as

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$$CPR = 3.27 \times 10^{-3} \frac{M \times J_{ac}}{\lambda} \quad (4)$$

where M is in g, J_{ac} is in μA/cm^2 and λ is in g/cm^3.

The European specification EN15280 [25] published a value of AC current density as a threshold value for AC corrosion damage to occur on a pipe. More recently, a threshold value of AC current density that can cause corrosion damage to the pipeline have been agreed upon among authors [16, 22, 24]. Moreover, there are research works that reveal that alternating voltage is also a parameter of concern as it contributes to corrosion process of pipelines, although this depends on the resistivity of the soil in which the pipeline is laid. Research in [25] concluded that to reduce corrosion likelihood of pipeline in the presence of AC interference, the pipe-soil voltage measured at some selected points along the length of the pipe should at any time not exceed 10 V where the soil resistivity is greater than 25 Ωm, and 4 V where the soil resistivity is less than 25 Ωm.

Human population is increasing every year, and with advancement in technology, and improving standard of living, more industries are being established especially in urban cities, requiring increase in energy demand. This then necessitates increase in energy supply thereby forcing Electric Power Generation Companies to continually make effort to increase their generated output. As energy demand increases, there is attendant increase in load demand which translates to increase in steady state load current along the power lines. The increase in the transmission line currents creates increasing magnetic fields around the power lines which continually interferes with the pipelines causing accelerated corrosion. Therefore, the objective of this work is to investigate (through modelling and evaluation) the effects of increasing energy demand on the corrosion rate of pipelines, using one of the Rand Water sites in South Africa as a case study. We opined that increasing energy demand translates to continuous long term increase in load currents of the transmission lines, and therefore is used as the variable in the model.

II. MATERIALS AND METHOD

This work is focused on the interference from a single circuit transmission line in vertical geometry on a buried steel water pipeline, in a Rand Water site at Alberton, South Africa. The load current on the transmission line was varied to investigate its effect on the corrosion rate of buried pipelines.

A. The Model

The model of the pipeline and transmission line is shown in Fig. 1. The steel pipeline, buried at 1 m beneath the soil, is exposed to interference from a single circuit three phase transmission line for a length of 3 km.

Current flowing through an energized conductor in Fig. 1, produces a time varying magnetic field which couples to the metallic pipe, inducing voltage on it according to Faraday's law. For the calculation of this induced voltage on the pipe due to the magnetic field created by the transmission line current, the concept of mutual impedances between the pipeline, phase conductor and the earth wire conductor as presented by Carson [28] was used.

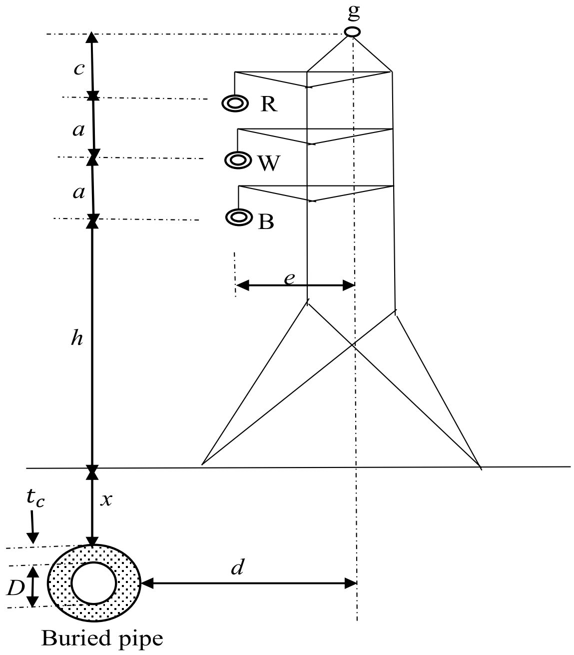

Fig. 1. Model of a single circuit three phase transmission line and a buried pipeline (not to scale).

From Fig. 1, the longitudinal induced electromotive force (emf) E_p (in V/km), on the pipe is given by

$$E_p = 3 I_L Z_{cf} \quad (5)$$

where I_L is the transmission line current and Z_{cf} is the coupling impedance (in Ω/km) given by equation (6) [4-6, 28]

$$Z_{cf} = Z_{pcp} - \frac{Z_{pcg} Z_{gp}}{Z_g} \quad (6)$$

In equation (6), Z_{pcp} is the mutual impedance between the phase conductors and the pipeline, Z_{pcg} is the mutual impedance between the phase conductors and the overhead ground wire, Z_{gp} is the mutual impedance between the ground wire and the pipeline while Z_g is the self-impedance of the ground wire.

Z_{pcp} is expressed in equation (7) [4, 6, 28] as

$$Z_{pcp} = \frac{\mu_0 \omega}{8} + j \frac{\mu_0 \omega}{2\pi} \ln\left(\frac{\delta_e}{D_{pcp}}\right) \quad (7)$$

where μ_0 is the permeability of free space, ω is the angular frequency (in rad), D_{pcp} is the geometric mean distance (GMD) between the phase conductors and the pipeline (in m); and δ_e is the depth of earth return conductor (in m) which equals to the earth's skin depth given by

$$\delta_e = \sqrt{\frac{\rho_{soil}}{\mu \pi f}} \quad (8)$$

In equation (8), ρ_{soil} is the soil resistivity (in Ωm), f is the operating frequency of the line (in Hz) and $\mu = \mu_0 \mu_r$ is the permeability of the medium with μ_r being the relative permeability of the soil. Typical values of relative permeability of various soils and rocks ranges from 1.00001 to

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1.136 except rocks in iron-mining areas [29]. Other mutual impedances were also calculated using same approach in equation (7), with each having different GMDs. The self-impedance of the ground wire Z_g, is given by equation (9) [4]

$$Z_g = R_g + \frac{\mu_0 \omega}{8} + j\frac{\mu_0 \omega}{2\pi}\left[\frac{1}{4} + \ln\left(\frac{\delta_e}{R_{GM}}\right)\right] \quad (9)$$

where R_g and R_{GM}, are the earth wire ac resistance and its geometric mean radius respectively. Therefore, for a pipe with exposure length of L (in km), the induced voltage on the pipe is given by

$$V_p = E_p \times L \quad (10)$$

A pipeline coated with thickness t_c, having a defect size of D (in mm) on its surface, where corrosion occurs; the AC current density J_{ac}, corresponding to the coating defect on the pipe is given by equation (11) [24]

$$J_{ac} = \frac{8V_p}{\pi \rho_{soil}\left(8t_c + D\right)} \quad (11)$$

Therefore for a steel pipeline with atomic mass M and density λ, the corrosion penetration rate due to AC interference, according to Faraday's law is given by equation (3) [26, 27].

For this study, the transmission line has a ground clearance (h) from the lowest conductor of 12 m with conductor vertical separation (a) of 4 m. The pipeline distance measured from the centre of the transmission lines (d) is 30 m. The density of the steel pipeline is 7.86 g/cm^3 [30, 31]. The soil is assumed to be homogenous with resistivity of 100 Ωm and is assumed to be magnetically transparent. Other parameters used for the study are given in Table 1.

TABLE 1: PIPE PARAMETERS

S/N	Parameter	Value
1	Pipe Material	Steel
2	Pipe material atomic mass	56 g
3	Pipe radius	600 mm
4	Coating thickness	1 mm
5	Burial depth	1 m
6	Pipe exposure length	3 km

III. RESULTS AND DISCUSSIONS

The corrosion penetration rate on a steel pipeline has been calculated using electrochemical relations from Faraday, and Carson's mutual impedance relations of determining induced voltage on a pipe from HVTLs. Fig. 2 shows the variation of the AC current density and corrosion penetration rate with transmission line current for different soil resistivities. Fig. 2(a) shows the AC current density variations with line current while Fig. 2(b) depicts the variation of corrosion penetration rate with line current. It can be observed from the figure that the corrosion rate of the pipe and the current density increases with the line current. These values are higher in soil with low resistivity than soil with higher resistivity. It can be seen that

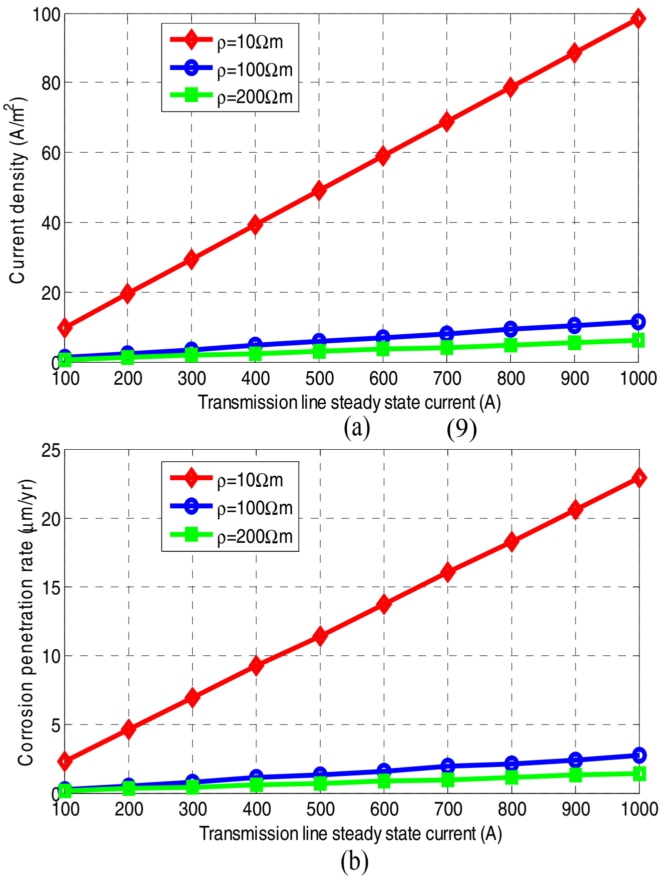

Fig. 2. Variation of the (a) AC current density and (b) Corrosion penetration rate with transmission line current for different soil resistivity.

the results presented in Fig. 2(a) and Fig. 2(b) follow similar pattern judging from relations (11) and (4), in which the AC current density is a linear function of the corrosion penetration rate. Moreover, the soil resistivity is known to be affected by seasonal variations. Therefore considering the result presented in Fig. 2(b) for this case study, it can be observed that soil resistivity variations from 10 Ωm to 100 Ωm for a particular value of line current will give a wide reduction in the corrosion penetration rate compare to the one with variations from 100 Ωm to 200 Ωm. Though part of the way of mitigating these effect as put in place by Rand Water is to add soil samples around the pipeline to maintain a homogenous resistivity throughout the entire length of the pipe. Also, utilizing relations (4) and (11), and from Fig. 2, the correlation between the corrosion penetration rate and the line current can be derived. Hence for this site, one can study the variations in the line current using its historical data to evaluate and predict corrosion penetration rate on the pipeline installed in that site.

Moreover, the soil composition is also a major concern that contributes to the corrosiveness of underground metallic pipelines. Soil with aggressive chemicals and element such as sulphur and chlorine and hydroxyl ions are more corrosive to the pipeline. Also, other soil parameters that aid corrosion process of buried pipelines include soil moisture content, soil pH, organic content and the resistivity of the soil. As reported in [32-35], soil with high moisture content, high organic content and high composition of aggressive element tends to be more corrosive to underground pipeline. These factors

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contribute to the overall soil resistivity which can lead to higher corrosion penetration rate on the pipeline in the presence of AC interference.

The variation of the AC current density and corrosion penetration rate with transmission line current for varying sizes of the pipe's coating defect and a soil resistivity of 100 Ωm is shown in Fig. 3. It can be observed from the figure that the smaller the size of defect, the higher the corrosion penetration rate. Thus the corrosion rate is high in 2 mm defect than 5 mm and 10 mm defects.

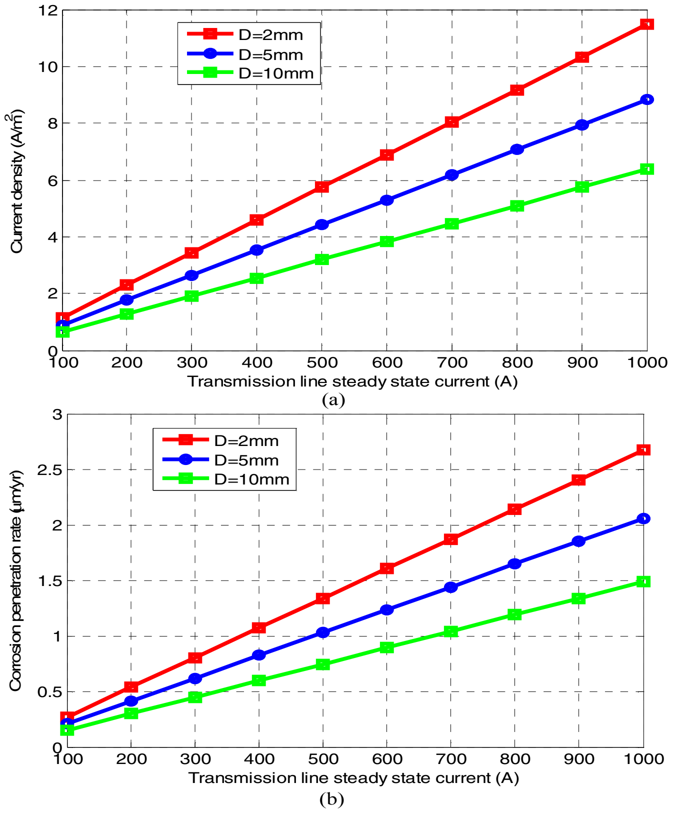

Fig. 3. Variation of the (a) AC current density and (b) Corrosion penetration rate with transmission line current for different sizes of coating defect.

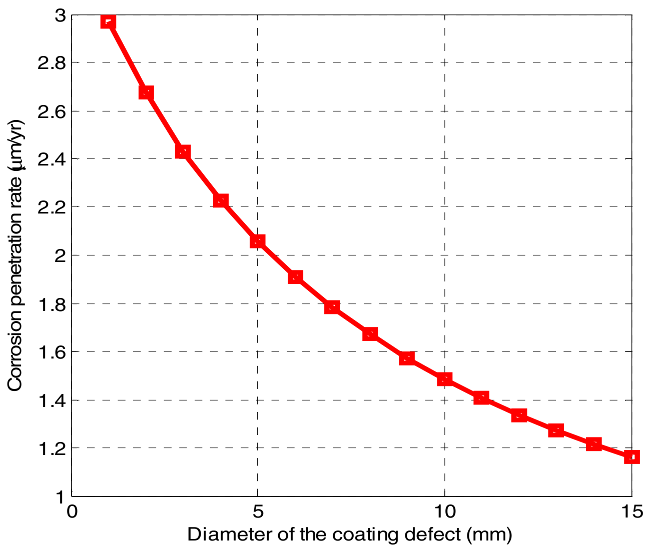

Fig. 4. Variation of the corrosion penetration rate with coating defect sizes at a given line current.

Fig. 4 shows the variation in the corrosion penetration rate of the pipe with different sizes of coating defect for a line current of 1000 A. It can be observed from the figure that the corrosion penetration rate reduces with increasing size of coating defect. Considering the variation of the corrosion penetration rate with marginal variations in the defect sizes, there is a large reduction in corrosion rate for a marginal change in defect size from 1 mm to 2 mm (smaller defects). However, for marginal variations of 10 mm to 11 mm, the corrosion rate shows little reduction in value. This shows that the smaller the size of the defect (at earlier stage of defect), the higher the tendency of increased corrosion. Hence more attention should be given to pipeline having smaller defect sizes than those with relatively wide sizes.

IV. CONCLUSION

The effect of increase in the energy demand on the corrosion rate of a buried pipeline nearby an overhead single circuit transmission line of vertical geometry has been determined through computations, and results presented. The corrosion rate on the pipe increases as the demand for energy increases (through increase in transmission line currents). This effect is more pronounced on pipeline installed in soil with low resistivity and smaller coating defect sizes. Therefore, as the demand for energy increases with time, AC corrosion mitigation system and CP criteria need to be reviewed from time to time to meet the trend in energy demand. This will drastically reduce the corrosion rate on pipeline in the right of way of these transmission lines, and ensures that the corrosion mitigation system/CP system remain effective over the operational life of the pipelines. Also, coating defects at earlier stages should be given appropriate attention against corrosion.

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