Investigation on power aspects in impressed current cathodic protection system

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Abstract

Impressed current cathodic protection system is used for protecting the underground long distance pipelines from corrosion. In this cathodic protection (CP) system direct current is applied to the pipeline which is of sufficient magnitude so as to polarize all the anodic area. Transformer rectifier unit (TRU) /Cathodic protection power supply module (CPPSM) units acts as a source for the direct current (DC) power supply. The power supplied by the TRU/CPPSM unit will attenuate after a certain distance so the power is supplied from either ends of all sections of the pipeline. So there will be current overlap in all sections of the pipeline to ensure complete protection. The objective of this project is to detect the amount of current overlap in each section of the pipeline and to develop a simulation model for determining the current overlap in each section of pipeline. Calculations has been carried out for determining the amount of current overlap at present in three sections of the pipeline under observation and voltage values has been suggested for reducing current overlap in the selected section to minimum. A power saving of about 50KW of DC power will be then achieved for remaining life of pipeline.

Keywords: *Cathodic protection, Corrosion, Current overlap, impressed current, pipeline*

Introduction

Cathodic protection (CP) system is used to prevent corrosion by maintaining the buried pipelines in constant potential [1, 2]. It is one of the most unique methods used for corrosion control since corrosion can be completely eliminated with this method [4]. The principle of cathodic protection system can be implemented in two ways, as Sacrificial anode and impressed current system [7]. In this case we are considering impressed current CP system. Permanent Cathodic protection system has been installed in the PL1 for protecting the pipeline from corrosion. In this CP system, direct current is applied to the pipeline which is of sufficient magnitude so as to polarize all the anodic area [9]. TRU/CPPSM units acts as the source for the DC power supply. In this case, it is assumed that pipeline is having a perfect coating [3].TRU units are installed in the receiving Station and pumping station Terminal. There are six sectionalizing valve stations in the PL1 and CPPSM units are installed in these six SV stations. Corrosion hazards in the buried pipeline are evaluated on the basis of its potential measured with respect to a reference electrode [8]. Receiving station (RS) terminal of pipeline in which this case study was carried out is the receiving station for two product pipelines (Pipeline1 (PL1) and Pipeline 2 (PL2)) and it also pumps products to another Oil terminal through two pipelines. Permanent cathodic protection system has been installed in the PL1 (240km) for protecting the pipeline from corrosion. In this cathodic protection (CP) system direct current is applied to the pipeline which is of sufficient magnitude so as to polarize all the anodic area. Transformer rectifier unit (TRU) /Cathodic protection power supply module (CPPSM) units acts as a source for the direct current (DC) power supply.

The project is mainly concentrated on the pipeline section from receiving station (RS) to sectionalizing valve-4 (SV4), since RS terminal is in charge of this section (120km) of the PL1. The power supplied by the TRU/CPPSM unit will attenuate after a certain distance so the power is supplied from either ends of all sections of the pipeline (RS-SV6, SV6-SV5, SV5-SV4). So there will be current overlap in all sections of the pipeline to ensure complete protection. The objective of this project is to detect the amount of current overlap in each section of the pipeline and to develop a simulation model for determining the current overlap in each section of pipeline. Calculations has been carried out for determining the amount of current overlap at present in three sections and voltage values has been suggested for reducing current overlap in the section SV6-SV5 to minimum. The objective of this project is to detect the amount of current overlap in each section of the pipeline and a feasibility study on how to reduce the current overlap in the sections where there is more overlap. Since Longer distance of current overlap will affect the coating of pipeline and also the power can be saved by reducing the overlap. For this purpose a detailed study of the CP system and all maintenance reports including ON-OFF potential survey is carried out.

On-Off Potential Survey

This survey aims at determining the polarized potentials of the pipeline when switched on and off [5]. The pipeline is designed as per the NACE criteria that the pipe to soil potential measurements shall be between (-) 0.95V (OFF) min and (-) 1.18V (OFF) max (both OFF potential) with respect to copper/copper sulphate reference electrode/half-cell, the maximum remaining the same (-) 1.5V (ON) with respect to Cu-$CuSO_4$ reference electrode. The structure to electrolyte potential measured during switched ON condition of CP system is called ON potential (V_{ON}) and the potential measured immediately after switching OFF the CP system for a short duration (up to 3seconds) is called OFF potential (V_OFF). The ON-OFF potential survey is carried out to determine the pipe to soil potential (PSP) at all Test Stations (TLPs) along the length of the pipeline in field and boundary element method can be used for mathematical modelling of the potential along the entire length of pipeline. using theoretical calculations [10]. The readings of the ON-OFF potential survey conducted are used to draw a graph. From the graph it was evident that there is some current overlap since the PSP value at the midpoints between two stations are found to be more negative than – 0.95V. So calculations are carried out for determining the distance at which the current attenuates from each station.

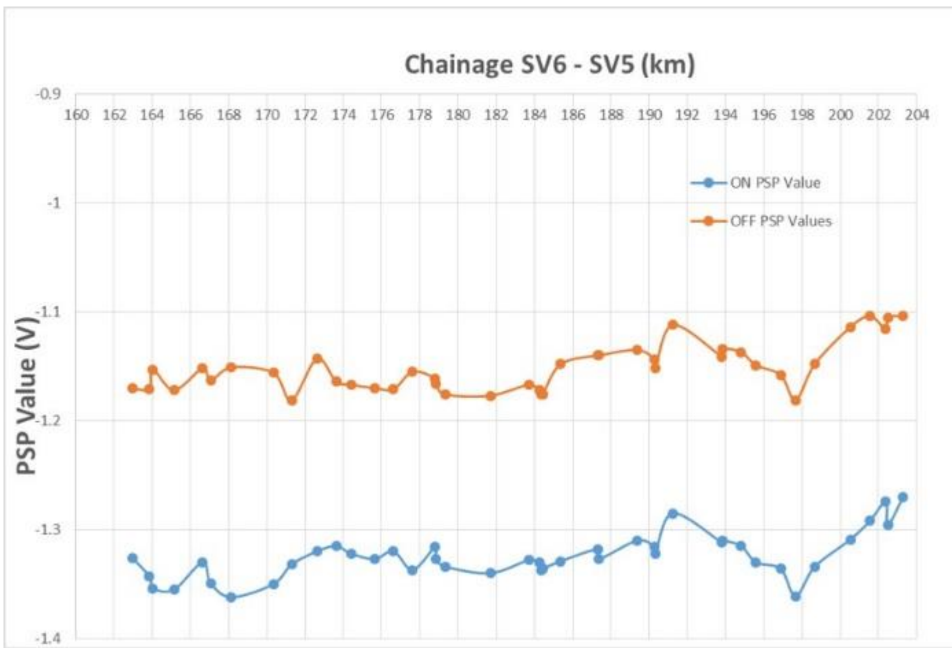

Fig no.1 On-Off potential survey graph

Attenuation Calculation

On an electrically long pipeline, attenuation is the term applied to the decrease in pipe-to-soil voltage shift produced by a cathodic protection system as the distance from the source of current (drain point) increases. On a pipeline, the incremental loss in pipe-to-soil potential shift is caused by the buildup of a voltage drop along the pipeline. This build up is caused by the flow of current back to the Source (rectifier) through the electric resistance of the pipe wall. The attenuation calculation for 18” pipeline is as below

- Cross Section Area of Pipe (A_{cross})

$$A_{cross} = \frac{\Pi}{4} \times (D^2 - (D - t)^2) \qquad (1)$$

- Linear Resistance of pipe (R_s):

$$R_s = \frac{\rho_s \times L_s}{A_{cross}} \qquad (2)$$

- Coating Leakage resistance of pipe (R_L)

$$R_L = \frac{R_p}{A_s} \qquad (3)$$

- Attenuation Constant (α):

$$\alpha = \sqrt{\frac{R_s}{R_L}} \qquad (4)$$

- Length of pipeline protected from drain point (L_p):

One side length of pipeline is protected from the drain point within the given criteria limit with above calculated attenuation constant for 18" pipeline with thickness 7.9mm. The length of pipeline protected but the CP system from RS, SV6, SV5 and SV4 are calculated by using this formula below and the readings are tabulated.

$$L_p = \frac{1}{\alpha} \times \cosh^{-1}\left(\frac{V_d}{V_x}\right) \qquad (5)$$

- Length of overlap (L_o)

$$L_o = (L_{p1} + L_{p2}) - L_{12} \qquad (6)$$

D = Diameter of pipeline (0.4570 Meter)
t = Thickness of pipeline (0.0079 Meter)
A_{cross} = Cross section area of pipeline (0.0057 Sq.)
ρ_s= Resistivity of Steel (1.2E −07 Ohm meter)
L_s= Length of pipeline unit section (1000 meter)
R_s= Linear Resistance of pipeline unit section (.021 Ohms)
R_p= Coating resistance of pipe (17000 Ohm meter) – Assumed
A_s= Surface area of unit pipe length (1436.33 Sq.)
R_L= Coating Leakage resistance of pipe unit section (11.83 Ohms)

R_s= Linear Resistance of pipeline unit section (11.83 Ohms)
α= Attenuation constant (0.0421)
V_d= Max change in potential at drain point (Volts) ie ($PSP_{natural}$ – PSP_{max_off})
V_x= Min change in potential at remote point (Volts) i.e. ($PSP_{natural}$ – PSP_{min_off})
L_p= Length of pipeline protected (km) – one side
L_{p1} & L_{p2} = Length of pipeline protected from station 1 and 2
L_{12} = Length of pipeline section between two stations 1 & 2

From the data obtained from above calculations the length of pipeline protected on either side of the stations by the TRU/CPPSM units are obtained and schematic diagram (fig no.1) is drawn and the length of the overlap in different sections are calculated. Length of overlap can be reduced by reducing the PSP value at drain point of the corresponding stations. The PSP value at RS cannot be altered since it also protects the PL2 which is out of the scope of this project. The PSP value at SV4 also cannot be altered since it involves the protection of the section in the direction of SV3, which is not under RS terminal. So the PSP values at SV5 and SV6 can only be altered and current overlap in the section between SV5 and SV6 can be minimized.

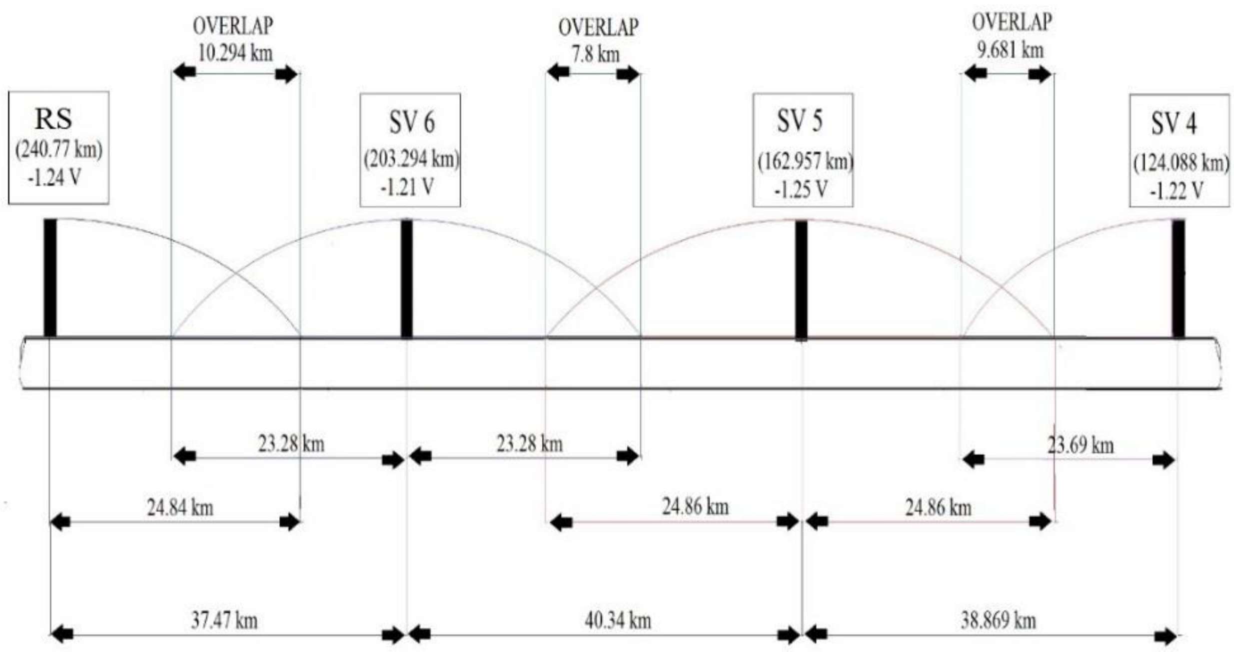

Fig no.2 Schematic Diagram for CP system current overlap with present operation values

By back calculations, it can be found that the current overlap in the section can be minimized to 1km, which can be obtained if the length of pipeline protected by SV6 is reduced to 19.5 km and the length of pipeline protected by SV5 is reduced to 21.86 km. The required PSP values can be obtained by doing back calculations in the equation for finding the length of pipeline protected by substituting the desired length of pipeline to be protected by corresponding stations as mentioned above. Based on the new length of pipeline protected from stations and PSP values schematic diagram (fig no.2) is drawn and the reduction in length of overlap is found out. It is found that the pipeline section between SV6 and SV5 will be having minimum overlap and there is also reduction in the overlap in other sections. A MATLAB simulation model has been developed for carrying out the calculations for determining the current overlap in each section, as shown in figure 3.

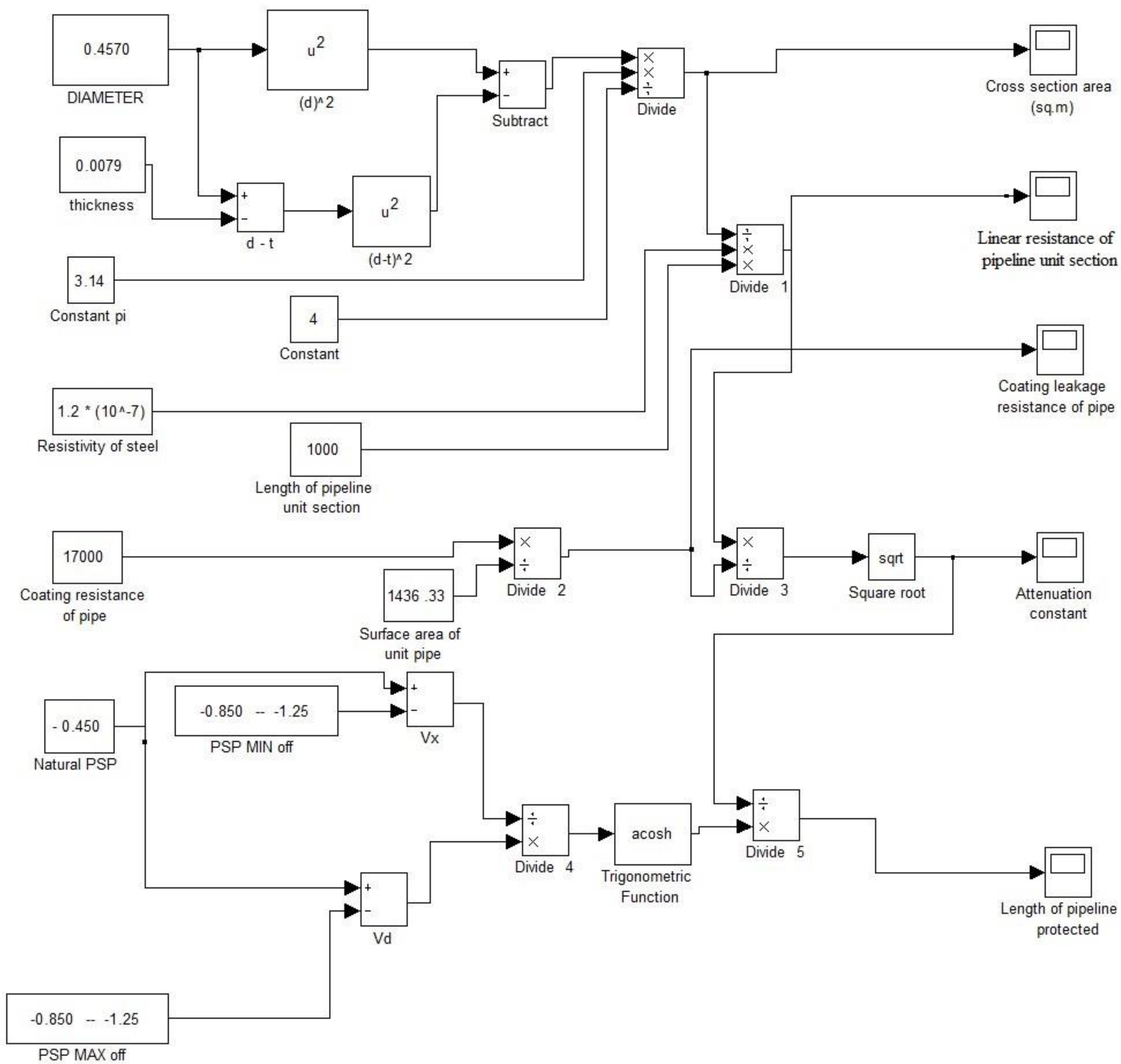

Fig no.3: Simulation model for determining the length of pipeline protected

Results and Discussion

From the calculations above it is found that the length of overlap can be reduced and the power can be saved by reducing the PSP value of the drain point to the values obtained by theoretical calculations. (ie -1.128 V at SV6 and -1.177 V at SV5). CPPSM unit will work in two modes of operation and method to set the required PSP values in both modes of operation are explained below.

Manual mode (AVCC)

In this mode, O/P voltage set potentiometer is used to increase the DC output gradually. Reference voltmeter will display three external reference voltages. The reference voltmeter selector switch has to be kept in the lowest reference position and also it must be ensured that the lowest voltage is being displayed. The DC output current is increased and it can be observed that reference potential is increasing in the protective direction. The DC output current is increased until the reference potential becomes equal to the required value (i.e. -1.128 V at SV6 and -1.177 V at SV5). Note the DC output voltage, DC output current and the selected reference voltage.

Auto reference mode

Auto reference mode setting can be done only after ensuring that the structure is sufficiently polarized and also the changes in the DC output current is making the reference electrode signal to respond. The reference voltmeter selector switch has to be kept in auto select position. Reference voltage set potentiometer will be then turned slowly in clockwise direction till the reference voltmeter shows the desired protective potential (i.e. -1.128 V at SV6 and -1.177 V at SV5).Locknut of the potentiometer is tightened lightly and also it must be checked.

Table No 1 Reduction in overlap and % power savings (Present and Proposed values)

Present Operation Values				
Station Name	**BRS**	**SV-6**	**SV-5**	**SV-4**
DC O/P Voltage	2.2 V	1.4 V	1.3 V	1.2 V
DC O/P Current	1.8 A	0.4 A	0.5 A	0.6 A

O/P Power	3.96 W	0.56 W	0.65 W	0.72 W
PSP value at drain Point (V)	–1.24 V	–1.21 V	–1.25 V	–1.22 V
Length Of Pipeline protected	24.48 km	23.28 km	24.86 km	23.69 km
Section Name	**BRS-SV6**	**SV6-SV5**	**SV5-SV4**	–
Length of section (km)	37.47 km	40.34 km	38.869 km	–
Length of overlap in section(km)	10.294 km	7.8 km	9.681 km	–
Proposed Operation Values				
Station Name	BRS	SV-6	SV-5	SV-4
DC O/P Voltage	2.2 V	1.305 V	1.162 V	1.2 V
DC O/P Current	1.8 A	0.3728 A	0.447 A	0.6 A
O/P Power	3.96 W	0.487 W	0.519 W	0.72 W
PSP value at drain Point (V)	–1.24 V	–1.128 V	–1.177	–1.22 V
Length Of Pipeline protected	24.48 km	19.5 km	21.86 km	23.69 km
% power savings	–	13.125 %	20.15 %	–
Power saved per year	–	700 W	1138 W	–
Power saved for remaining life of pipeline (28 years)	–	19600 W	31886 W	–
Section Name	**BRS-SV6**	**SV6-SV5**	**SV5-SV4**	–
Length of section (km)	37.47 km	40.34 km	38.869 km	–
Length of overlap in section(km)	6.514 km	1.02 km	6.681 km	–
Reduction in length of overlap achieved(km)	3.78 km	6.78 km	3 km	–

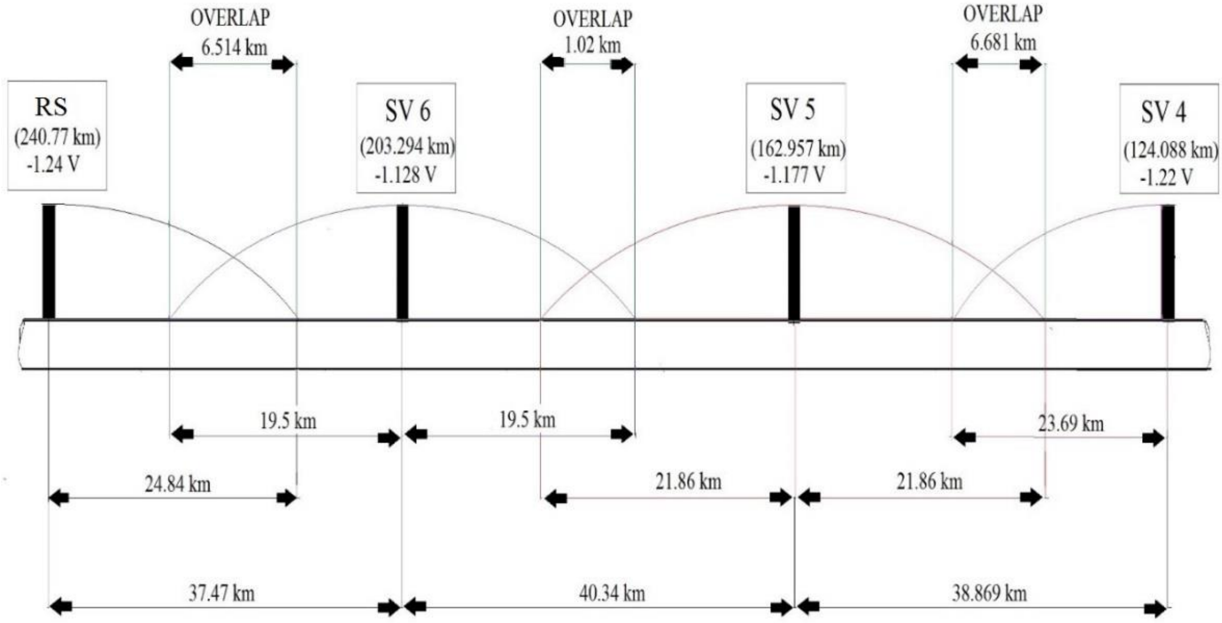

Fig no.4: Schematic Diagram for CP system current overlap with proposed operation values

Conclusion

Current overlap in the cathodic protection system of the PL1 from receiving station to SV4 (120 km) has been calculated and a method has been proposed to reduce the current overlap by adjusting the Point Source potential in the CPPSM units at SV6 and SV5. Current overlap in the section will lead to overprotection of pipeline and will affect the pipeline coating in the area of overlap. The current overlap in the pipeline section between SV6 and SV5 can be reduced to minimum by adjusting the PSP values as proposed in this project. The current savings that can be achieved by reducing the PSP value at SV5 will be around 700 watts per year and at SV6 will be around 1138 watts per year. The remaining life of the pipeline is 28 years and the current savings of about 51 kilo watts can be achieved if the proposed values are put into operation. This is the power savings achieved by minimizing the current overlap in a single section of the pipeline and there are 7 similar sections in the pipeline. Minimizing the current overlap in each of those sections would result in higher power savings.

References

[1] Osella, Ana, and Alicia Favetto. "Effects of soil resistivity on currents induced on pipelines." Journal of applied geophysics 44.4 (2000): 303-312.

[2] Metwally, I. A., et al. "Factors affecting cathodic-protection interference." Engineering analysis with boundary elements 31.6 (2007): 485-493.

[3] Abdel-Gawad, Nagat MK, Adel Z. El Dein, and Mohamed Magdy. "Mitigation of induced voltages and AC corrosion effects on buried gas pipeline near to OHTL under normal and fault conditions." Electric Power Systems Research 127 (2015): 297-306.

[4] Al Habobi, Naseer A., and Shahad F. Abed. "Simulation of Cathodic Protection System Using Matlab."

[5] Onyechi, Pius, Obuka, Nnaemeka, Agbo, Cornelius and Igwegbe, Chinenye, Monitoring and evaluation of Cathodic protection performance for oil and Gas pipelines: A Nigeria situation, Department of Industrial and Production Engineering, Nnamdi Azikiwe University, Awka, Nigeria.

[6] Xu, L. Y., X. Su, and Y. F. Cheng. "Effect of alternating current on cathodic protection on pipelines." Corrosion Science 66 (2013): 263-268.

[7] Safuadi, M., et al. "Optimization of cathodic protection system design for pipe-lines structure with ribbon sacrificial anode using BEM and GA." Key Engineering Materials. Vol. 462. Trans Tech Publications, 2011.

[8] Allahkaram, Saeed Reza, et al. "Investigation on corrosion rate and a novel corrosion criterion for gas pipelines affected by dynamic stray current." Journal of Natural Gas Science and Engineering 26 (2015): 453-460.

[9] Hameed, Khalid W., Aprael S. Yaro, and Anees A. Khadom. "Mathematical model for cathodic protection in a steel-saline water system." Journal of Taibah University for Science 10.1 (2016): 64-69.

[10] Xing, Pengxiang, et al. "Potential Calculation on the Oil-Gas Pipeline with Geosynthetic Clay Liners Based on BEM." Journal of Power and Energy Engineering 2.04 (2014): 594.