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Different Polarization Cells Based for Mitigating theAC Induced Voltages on the Metallic Pipeline

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Abstract : Natural gas metallic pipelines are frequently passed by high-voltage overhead transmission lines (HVOHTLs). Corrosion may occur due to the parallelism between HVOHTLs and pipelines, where electromagnetic fields couple between them. Furthermore, these fields cause an AC voltage to generate on the buried pipeline. This study presents two examinations that use two several AC mitigation units: a potassium hydroxide polarization cell (KOH-PC) and a Solid State Polarization Cell (SSPC) to mitigate induced AC voltage and enhance cathodic protection performance. The solid-state polarization cell will contribute more controllability than the conventional cell. This paper proposes the electrical modeling for both KOH-PC and SSPC, in addition to their optimal configuration. This paper also presents a comprehensive comparison of optimal KOH-PC and SSPC parameters to give an effective solution to the AC corrosion problem. Finally, the optimal design of the SSPC gives the best performance in preventing AC corrosion.

Keywords:AC Corrosion, Potassium Hydroxide Polarization Cells (KOH-PCs), Solid State Polarization Cell (SSPC), hill-climbing algorithm.

1. Introduction

Corrosion can occur if there is an intrusion effect among the pipeline and nearby power transmission lines. This ac corrosion can be detected in buried pipelines, making the covering material to deteriorate [1]. A plenitude of means characterize the pipeline-induced voltage formed by the interference force. These mechanisms are defined by the variety of coupling (capacitive, inductive, or conductive) among the pipeline and the power transmission line [2]. Induced AC voltage mitigation is an essential activity for minimizing induced voltage and limiting corrosion along the pipeline. The main objective of most AC mitigation is to depreciate the AC steady-state induced voltage to 15 V (RMS) according to the NACE standard [3]. The pipeline can be directly attached to a fitting grounding system to overcome AC-induced voltage, but this will deteriorate the DC voltage cathodic protection. Decouplers have a long proven record of adequately isolating cathodically protected constructions from other objects or grounding systems, as well as diminishing the consequences of direct links. Solid-state decouplers and polarization cells are the most popular models of decouplers employed for AC mitigation [4-5]. This paper introduces the numerical modeling of buried pipelines, transmission lines, two mitigation units; potassium hydroxide and solid-state polarization cells, and cathodic protection systems. AC mitigation arrangements serve a significant role in disseminating the induced voltage into the ground system, but it may depreciate the cathodic protection performance. Besides, the situation and amount of these units are significant in relieving the pipeline's voltage and diminishing the DC-CP voltage. Therefore, it is imperative to inject the mitigation units to decrease the induced AC voltage without negatively harming the cathodic protection. Accordingly, it suggests potassium hydroxide and solid-state polarization cells to mitigate the unfavorable induced AC voltage and diminishing the deterioration of the DC CP voltage.

In this study, different polarization cell models such as PC-25, PC-50, and SSPC are applied to mitigate the induced voltage. Additionally, this paper combines the optimization of the parameters for a specific unit. An optimized SSPC's parameters are presented and compared with an optimized KOH-PC. The acquired results exhibit the effectiveness and robustness of the hill-climbing optimization algorithm for optimizing the parameters of either potassium hydroxide or solid-state polarization cells. A contrastive analysis of the obtained results shows that the induced voltage is mitigated to the acceptable limit by employing two polarization cell types. Consequently, the selection of a fitting mitigation unit diminishes the impact of the interfering transmission line with the pipeline remarkably. Finally, the solid-state polarization cell presents the most advanced evolution in the field of AC induced voltage mitigation, where this cell has more controllability compared to conventional polarization cells.

The paper is organized as follows: Section 2 introduces the problem description Section 3 describes the hill-climbing algorithm. Further, section 4 shows the proposed model results and comparative performance evaluation for different models of two polarization cell types with optimized models. Finally, conclusions and possible future work are given in Section 5.

2. Problem Statement

The induced AC voltage along the pipeline can be calculated using a variety of techniques. The methodologies explained in [6-7] are used in this study, and a valid compromise between measurement and calculation results is achieved. The pipeline's electrical circuit is shown in Figure 1, which is developed based on the lossy transmission line approach.

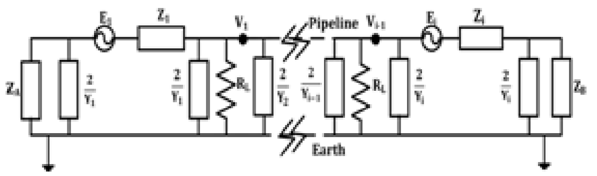


Fig 1: Equivalent circuit of multiple π-section pipeline

In the physical world, the power line – pipeline corridor is much more difficult. It regularly consists of parallelism, approaches, crossings as well as replacements. Besides, the non-uniform grounding parameters, such as the soil resistance, pipeline coating resistance, and corrosions, add even more complexity to the problem. To deal with these situations, subdivision is required. By splitting the pipeline into small sections, each section can be considered to have uniform grounding parameters. The length of each section will be limited to obtain a good evaluation of the profile of voltages and currents along the pipeline in all probable cases. Therefore, the pipeline is sub-divided into 77 sections, each section is represented as a π circuit with a length that does not exceed one kilometer. Moreover, the length of each section equals the tower span of the power line. The pipeline to ground voltage may be easily evaluated and measured at the end of each portion. Therefore, the description of the equivalent circuit for the pipeline is shown in Figure 1.

As shown in Eq.(1) [8], the AC voltage that develops at each π-section for the buried pipeline due to the magnetic field of the inductive coupling ranges from V_1 to V_{i-1}.

$$V_i = \frac{E_i}{\gamma}\left\{-\frac{Z_A}{Z_A+Z_C}e^{-\gamma x} + \frac{Z_B}{Z_A+Z_C}e^{-\gamma(L_p-x)}\right\} \quad (1)$$

Where E_i denotes the electromotive force (EMF) per unit length along the pipeline (V/km), $\gamma = \sqrt{ZY}$ denotes the pipeline propagation constant (km^{-1}), and $Z_C = \sqrt{Z/Y}$ denotes the lossy pipeline characteristic impedance (Ω). The circuit pipeline-impedance earth's and admittance per unit length (Ω/m) are Z and Y, respectively. The equivalent impedance of the left and right sides of a buried pipeline per unit length (Ω/m)is denoted by Z_A and Z_B, respectively. L_p is the length of a pipeline sub-section (m), and x is a variable distance along the buried pipeline's length (m). The descriptions and formulas for these parameters are introduced in [9]. Besides, the details of polarization cells'construction and parameters are introduced in [9-10]. Besides, the solid-state polarization cell is represented as a series resistor-capacitor, which blocks direct current while enabling alternating current to flow along the pipeline to the ground without weakening cathodic protection levels.

3. Proposed algorithm

Hill climbing is a numeric optimization algorithm that iteratively adjusts its solution by modifying one dimension at a moment. In each iteration, the algorithm attempts to adjust a single dimension of its current state and accepts that change if and only if it improves value space. This process is repeated until the maximum number of iterations has been completed until no further improvements can be found. Unlike most randomized optimization algorithms, hill climbing has proper intermediate states, allowing for proper visualization of the optimization process. Therefore, the parameters of polarization cells are optimized by using the hill-climbing algorithm to develop a polarization cell's construction for managing the best performance in mitigating the induced voltage without a negative impression on the DC voltage. The equivalent (Thevenin) impedance may calculate by dividing the AC voltage on the diffused alternating current throughout the cell as in Eq. (2).

$$Z_{th_{PC}} = \frac{V_{AC}}{I_{AC}} \qquad (2)$$

In hydroxide polarization cell, it is found that the main parameters that influence the Z_{th} are; the horizontal lengthL_H, the horizontal width W_H, the vertical part lengthL_V, the vertical part widthW_V, the length of the impressed part in the KOH solution x, the plate thickness T in addition to the number of plates N_P. Besides,the stainless-steel plate's thermal capacity (C_{th}) is an important constraint that should be considered into account, especially in the fault condition. Each plate takes a current portion from the total discharged current. Maybe the heat generated from the plate-current enough to exceed the thermal capacity of the plate, and it might reach the melting point. Otherwise, in a solid-state polarization cell, the main parameters that influence the Z_{th} areresistance and capacitance. Both types of polarization cells have been built using MATLAB/Simulink, initial values for all these parameters, an AC voltage source has been applied to this model, and the flowing current is measured. This impedance is determined based on Eq. (1), where all these parameters are selected in a globalization mode during the optimization process. Mainly, the objective function is to maximize the discharged current from the pipeline to the soil. So, this impedance, Z_{th}, should be minimized as in Eq. (3) to maximize the discharged current. These parameters have lower and upper limits should be satisfied as follows;

$$f_{min} = Z_{th_{PC}} \qquad (3)$$

For KOH-PC model

Subjected to

$$L_H^{min} \le L_H \le L_H^{max}$$

$$W_H^{min} \le W_H \le W_H^{max}$$

$$L_V^{min} \le L_V \le L_V^{max}$$

$$W_V^{min} \le W_V \le W_V^{max}$$

$$0 \le x \le x_{max}$$

$$T_{min} \le T \le T_{max}$$

$$N_P^{min} \le N_P \le N_P^{max}$$

$$C_{th}^{min} \le C_{th} \le C_{th}^{max}$$

For SS-PC model

Subjected to

$$R_{min} \le R \le R_{max}$$

$$C_{min} \le C \le C_{max}$$

4. Results and discussion

In this section, the induced voltage has been examined in numerous polarization cell forms. There are two KOH-PCs types: the first has 25 plates and the second has 50 plates. Hydroxide polarization cells require periodic fluid level maintenance, and if they fail while in use, they can be dangerous. As a result, a solid-state polarization cell is recommended as an alternative system to prevent the deleterious impacts of hydroxide polarization cells. Furthermore, the hill-climbing algorithm is used to optimize the parameters of KOH-PCs and SS-PCs to promote the polarization cell's formation for the best performance in relieving the induced voltage without a negative impression on the DC voltage. The investigated pipeline is considered as the continuation of the earlier work [9-10]. Fayoum Gas Company owns the studied pipeline. As is distinguished, this line 72-kilometer long, as illustrated in Figure 2, runs adjacent to three overhead high-voltage transmission lines. Two of the three transmission lines have a 500 kV voltage, with only one three-phase power circuit and two earth wires carried on the tower. The tower consists of two three-phase power circuits and one earth wire, with a 220 kV voltage. Figure 3 (a) depicts the El-Kurimate-Cairo and Samaloute-Cairo transmission lines, while Figure 3 (b) depicts the Dimo-6th of October transmission line.

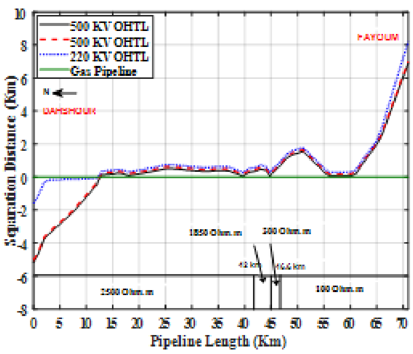
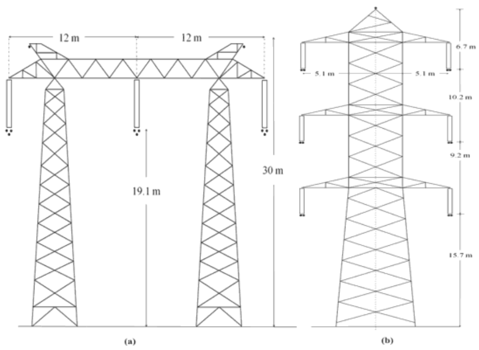


Fig 2: Pipeline-transmission line configuration for Fayoum Gas Co.



Fige 3: The towers for the overhead high voltage transmission lines

Table 1 shows the statistics for power lines and towers' structures. To begin, the pipeline in the study has a 16-inch inner diameter (0.4064 m). The pipeline is painted by three coats of High-Density Polyethylene (HDPE), which has a coating resistance of 10^6 Ω/m^2, a relative permittivity of 5, and a thickness of 4 mm. It is buried at a depth of 1.5 m with soil resistivity ranges from 2500 to 100 Ω.m along the pipeline path. The three transmission lines are El-Kurimate-Cairo, Samaloute-Cairo, and Dimo-6th October HVOHTLs. El-Kurimate-Cairo transmission line has a length of 124 km with a rated capacity of 575 MVA at 500 kV operating voltage. There are two earth lines and a single three-phase circuit on this line. Each phase comprises three sub-conductors. Samaloute-Cairo is the second line, which has 1000 MVA and a length of 209 kilometers at a 500 kV operating voltage. The Samaloute-Cairo tower is very similar in layout to the El-Kurimate-Cairo transmission line. The last line is the Dimo-6th of October transmission line, which has a voltage of 220 kV and a length of 90 kilometers. This line has two circuits and one earth line. The rated power of each phase is 158 MVA, and each phase has two sub-conductors. The transmission line, polarization cell models and cathodic protection system are electrically modeled. The entire equivalent electrical circuit is examined in the MATLAB/Simulink platform to evaluate both the induced voltage formed on the pipeline by interfering TLs and the cathodic protection performance along the pipeline. The circuit parameters are computed with MATLAB code, and the obtained results are managed with Simulink software.

Table 1: Power line technical details

Parameter	Value	
Rated Power in MVA	575	158
Line to line voltage in kV	500	220
Transmission lines length in km	124	90
No. of tower circuits	1	2
No of the phase conductors	3	2
Conductor diameter in mm	30.6	27
The conductors separation in cm	47	30
Towers span in meter	400	360
The vertical height of first conductor in meter	19.1	15.7
No of ground wires	2	1
The ground wire height in meter	30	41.8
The ground wire diameter in mm	11.2	13.6

Figure 4 demonstrates the determined and measured induced AC voltage along the pipeline at normal operating conditions based on the pipeline design as shown in Figure 1. It is observed that the induced voltage approaches a maximum rate at some locations due to the minimum separation distance between the pipeline and transmission line. The induced voltage increases with decreasing the separation interlude between the pipeline and the transmission line. The pipeline's lowest separation distance points are 12.75,18, 39.7, 44.8, and 58 km from the start of the pipeline, where the induced voltage levels are 20.43, 17, 43.12, 49.79, and 35.93 volts, respectively. Corrosion of pipelines becomes more familiar as a result of the high induced voltage. Therefore, the induced voltage must be decreased to a secure voltage level (15 V) to limit AC corrosion. AC corrosion can decrease if polarization cells place along the pipeline at the smallest separation distance between the transmission line and the pipeline. Also, it can be recognized that there are an extraordinary consistency between the estimated voltage and the measured voltage at the field locality.

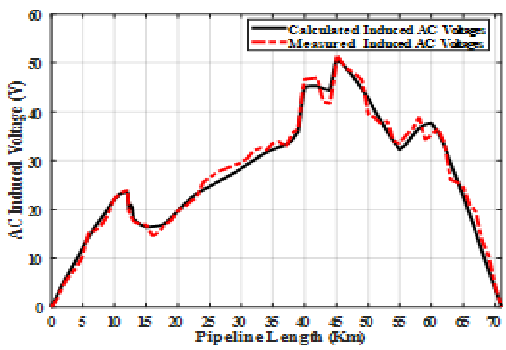


Figure 4: Comparison between measured and calculated induced voltage along the pipeline.

However, there are insignificant deviations between them due to the complexities of accurately assessing transmission line operating parameters and the pipeline's surrounding conditions. There are two impressed current cathodic protection stations on this pipeline. The first is located at the start of the pipeline, while the second is installed at the end. Cathodic protection is also calculated using negative DC voltage in millivolts (mV). As a result, the CP values are highest at the start and end of the pipeline, then gradually fall to the lowest value in the middle of the pipeline. As shown in Figure 5, the CP potential varies between -1.5 and -1.445 V_{DC}, with a value of about -1.5 V_{DC} at the pipeline line terminals and a value of -1.445 V_{DC} in the pipeline center. Furthermore, the pipeline's minimum DC voltage occurs in the middle due to its largest distance from the central ICCP stations. The approved effective cathodic protection potential for steel pipelines buried in the soil differs from -0.85 V to -1.5 V_{DC}. As a result of these conditions, the pipeline is effectively protected from AC corrosion.

The main factor in preventing metal corrosion is the minimization of induced AC voltage along the pipeline. Besides, the coating of the contamination regions is identified as a powerful method as long as the incorporation between the coating and impressed current system to decrease staff susceptibility to electrical dangers and achieves sufficient cathodic protection for the pipeline. As the utilized voltage increases through the polarization cell, evaporation adulterates the KOH solution within the cell. An open circuit will occur if this solution blisters. As a result of the open circuit, the plates may erode. As a result, a solid-state polarization cell is submitted as an efficient solution to these problems. Diversified KOH-PC configurations, such as PC-25, PC-50, and SS-PC, can be utilized to mitigate induced AC voltages along gas pipelines in normal operating conditions.

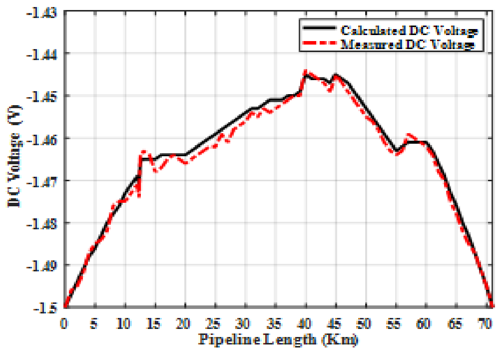


Fig 5:CP DC voltage distribution along the pipeline without mitigation.

The un-mitigated transmission line produces the highest induced voltage on the buried pipeline. Therefore, it converges on the mitigation system's influence on induced AC and DC voltage. Figure 6 illustrates the mitigated induced voltage along the pipeline in the case of using the PC-25, PC-50, and SS-PC at normal operating conditions. The mitigation positions are decided based on the induced voltage conditions. As a result, polarization cells are established at 12.75, 18, 39.7, 44.8, and 58 kilometers from the pipeline's start, where the induced voltage has a maximum rate. After connecting KOH-PCs and SS-PCs, the maximum value of induced AC voltage along the pipeline does not surpass 15 V (RMS). The highest induced voltage is 14.32 V, 14.5 V, and 12.98 V when using the PC-25, PC-50, and SS-PC, respectively. Furthermore, from this figure, it can be noted that SS-PC gives the best execution in mitigating the induced voltage.

Figure 7 shows the impact of several polarization cells on the CP voltage distribution along the pipeline. When compared to traditional cells, solid-state polarization cells have a less negative influence on cathodic protection and do not provide a reduction in DC voltage, as illustrated in Figure 7. However, after the polarization cells are located on the pipeline, the DC voltage is imperceptibly shifted. However, the DC Voltage drop in the PC-25 is lower than that in the PC-50. The PC-50 offers an easier joint that diffuses current into the soil efficiently. As designated in Figure 7, the lowest DC voltage is occurred in the centre of the pipeline, with -0.767 V, -1.375 V, and -1.421 V for PC-50, PC-25, and SS-PC, respectively. The PC-50 cell has the most crucial CP performance because the DC CP voltage being near the minimum authorized DC voltage boundary (-0.85 V_{DC}). Consequently, the increased plate number in polarization cells prompts supplementary electrical paths to the soil. On the other hand, the PC-25 reduces the CP voltage from -1.445 V to -1.375 V, while the PC-50 decreases the DC voltage from -1.445 V to -0.767 V. It is observed that the decrease in DC voltage in the case of PC-25 is smaller than that in the case of PC-50.

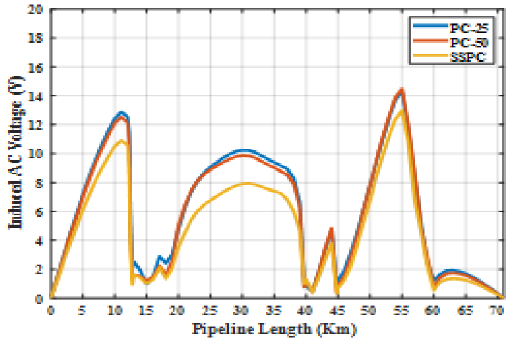


Fig 6: Mitigated induced voltage with different models of KOH and SSPC

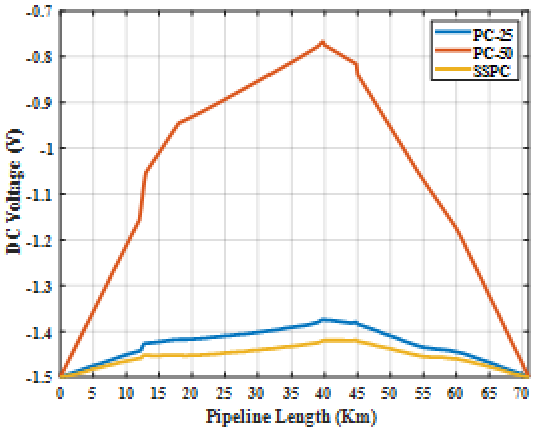


Fig 7: DC voltage with different models of KOH and SSPC.

Finally, from these figures, the PC-25 has a salubrious influence on AC voltage discharge performance while pulling a minimum amount of direct current. It is also noted that the discharging of direct current into the soil will progressively increase if the KOH-PC plates' number increases. As a result, in the case of using PC-50, the DC voltage is the most significant compared to PC-25. As a result, both AC and DC voltages must coordinate using SS-PCs. The SS-PC diminishes the CP voltage from -1.445 V to -1.421 V. As a result, the decrease in the DC voltage in the case of the SS PC is quite small compared to the other polarization cell designs. For several numbers of SS-PC, Figure 8 displays the estimated AC induced voltage on the pipeline at each peak point along the pipeline. After installing one SS-PC, two SS-PC in series, and two SS-PC in parallel, the highest value of induced AC voltage along the pipeline does not exceed 15 V (RMS). Using one SS-PC, two SS-PCs in series, and two SS-PCs in parallel, the highest induced voltage is 12.98 V, 14.319 V, and 13.89 V, respectively, at point 54 km. Furthermore, as seen in Figure 8, the mitigated induced voltage in the case of using one SS-PC is lower than that in the other SS-PC scenarios. These figures show how solid-state polarization cells can minimize the cruelty of induced voltage on the pipeline produced by the transmission lines. Consequently, the solid-state polarization cell proposes an efficient solution in shielding the pipeline from AC corrosion. As shown in Figure 8, the induced voltage is marginally varied in all-solid-state polarization cell forms.

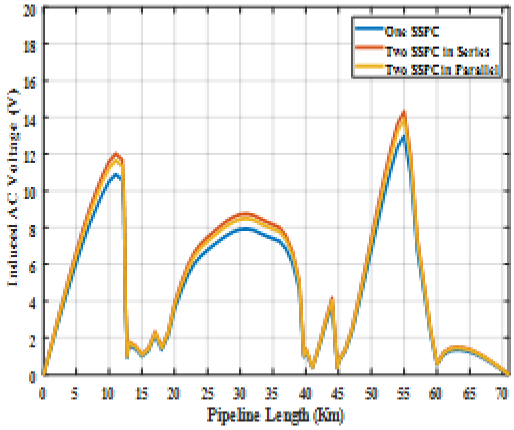


Fig 8: Mitigated induced AC voltage with different connections of SSPC.

Figure 9 depicts the influence of various numbers of solid-state polarization cells on the CP voltage distribution along the pipeline. As illustrated in Figure 9, the one solid-state polarization cell configuration has a less negative impact on cathodic protection compared to the other solid-state polarization cell configurations, The DC voltage at the middle pipeline for one SSPC, two SSPC in series, and two SSPC in parallel is -1.421 V, -1.392 V, and 1.410 V, respectively. The one SS-PC provides the best CP performance due to the smallest reduction in DC voltage. When two SS-PC are connected in series, the CP voltage is decreased from -1.445 V to -1.392 V, and while two SS-PC are connected in parallel, the DC voltage is reduced from -1.445 V to -1.410 V. According to these results, the decrease in DC voltage in one SS-PC is less compared to the other SSPCs' forms. As a result, the SS-PC number is determined by the number of joints required to disseminate induced voltage and improve CP performance. Finally, it is observed that one SS-PC performs well in accomplishing two aims: the first object is to minimize induced voltage, and the second aim is to reduce DC voltage deterioration phenomena. The quantity of direct current discharged to the earth is also lowered when only one SS-PC is applied. Figure 10(a) shows the mitigated induced voltage along the pipeline under normal operating conditions using the improved KOH-PC and optimized SS-PC. After installing numerous types of PCs, it was noticed that the optimized SS-PC gives the lowest induced voltage. Figure 10 (b) depicts the influence of several optimized polarization cell types on the DC CP voltage distribution along the pipeline. The optimized SSPC has the best DC distribution, which results in a DC voltage shift in the negative direction, as illustrated in Figure 10(b). The optimized SS-PC has a less negative influence on cathodic protection compared to optimized KOH-PC. Therefore, the optimized SSPC causes a lower DC voltage reduction. In the middle of the pipeline (at 39.7 km), the DC voltage for SS-PCs and optimized SS-PCs rises from -1.421 V to -1.432 V. Furthermore, optimized PC and optimized SS-PC have DC voltages of -1.389 V and -1.432 V, respectively.

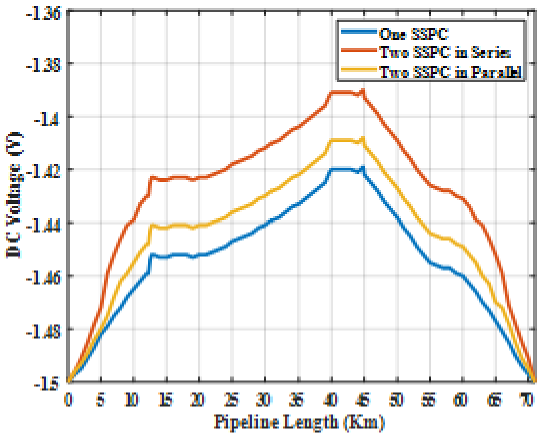
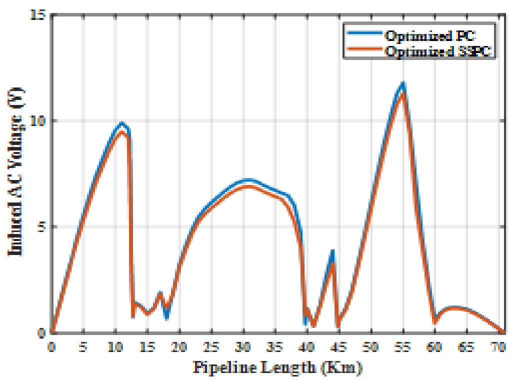
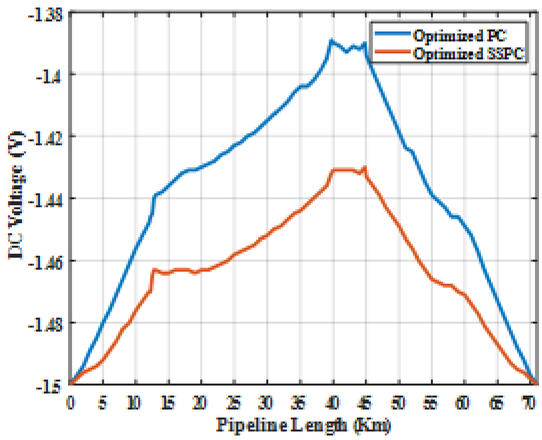


Fig 9: DC voltage with different connections of SSPC.

According to the results of this study, implementing the optimized SS-PC greatly intensifies cathodic protection performance. Furthermore, the optimized SS-PC is superior to that of the optimized KOH-PC in terms of meeting two requirements. Furthermore, as compared to the optimized polarization cell, the optimized SS-PC gives the best performance in mitigating the induced voltage while reducing DC voltage reasonably. As a result, when comparing the optimized SS-PC to other optimized KOH-PCs, the optimized SS-PC provides a significant enhancement in overall CP performance. Moreover, the AC intrusion predicament with the mitigation unit will eliminate, and overall cathodic protection performance along the pipeline will improve. Finally, the optimized potassium hydroxide and solid-state polarization cells exhibit that the optimized SS-PC performance provides two goals compared to the hydroxide and solid-state polarization cells. These goals involve the reduction of the induced voltage and the advancement of the DC CP performance.



(a)



(b)

Fig 10: (a) Mitigated induced AC voltage with optimization of KOH-PC and SSPC, (b) DC voltage with optimization of KOH-PC and SSPC's parameters

Tables 2 and 3 show induced voltage and DC voltage calculations using several types of polarization cells during normal operating conditions. In terms of induced voltage mitigation, all proposed polarization cell models produce reasonable results, as shown in Table 2. Table 2 shows the mitigated induced voltage in the case of the optimized SS-PCs is lower than that in the case of using various KOH-PCs models. Furthermore, the optimized SS-PC has a less negative influence on cathodic protection performance compared to PC-50, PC-25, and optimized KOH-PC. Table 3 shows the significant reduction in the required DC voltage in both optimized KOH-PC and optimized SS-PC. After analyzing the AC and DC voltages' results, it can be observed that the optimized KOH-PC and SS-PC successfully reduce induced voltage while having a less negative influence on cathodic protection performance. To sum up, the improved SS-PC strongly diminishes induced voltage in all the studied cases compared to the optimized KOH-PC. Also, in a comparison of the different PCs models, the optimized SSPC provides highly qualified in compensating the DC voltage interruptions. Finally, the acquired results demonstrate the ability of the optimized SSPC in mitigating the induced voltage. Moreover, the optimized SSPC can be very valuable in eradicating the negative impact on cathodic protection from mitigation systems. The hill-climbing algorithm has been proved to be an efficacious optimization technique to manage pipeline corrosion. As consequence, the hill-climbing algorithm increases the efficiency of the different polarization cell models.

5. Conclusions and extensions

This paper discusses the AC corrosion problem that may originate from the interference among the transmission lines and the buried pipeline. The main danger of AC corrosion is the disruption of the pipeline's coating. In previous analyses, the modeling of the KOH-PC model is introduced, as well as the electrical models of pipelines and cathodic protection systems. Various polarization cell types, such as the PC-25 and PC-50, have also been designed to guarantee the efficacy of deciding the plate's numbers on both induced AC and DC voltages. This paper introduces the hill-climbing algorithm to optimize the polarization cells parameters to control the induced voltage, which may deteriorate the pipeline. This aim is achieved by selecting a suitable number of polarization cell plates that can provide the optimal DC voltage distribution. Recently, a solid-state polarization cell is used due to the dilution of KOH solution in the hydroxide polarization cell. Different KOH-PC models with solid-state polarization cells are implemented to mitigate the induced voltage and improve the DC CP voltage. The obtained results reveal the effectiveness of the optimized SS-PC compared with the various KOH-PC types. Also, it is found that the optimized SS-PC is a more dependable mitigation technique and has capable of compensating the DC CP voltage disturbance. The obtained results reveal the effectiveness of the optimized SS-PC compared with the various KOH-PC types. Also, it is found that the optimized SS-PC is a better mitigation technique and has capable of compensating the DC CP voltage disturbance. Besides, it is observed that the polarization cell's parameters act a meaningful function in minimizing the induced voltage along the pipeline. Therefore, it is vital to improve the polarization cell performance using an optimized metaheuristic to utilize for optimizing the KOH's parameters in future work. Moreover, new topologies of the optimization algorithms will develop to be utilized

for preventing AC corrosion. Additionally, a wireless system will be developed to exploit the induced voltage in charging the batteries that can be used as an alternative for cathodic protection voltage.

Table. 2: Comparisons for the highest AC induced voltage points under normal operating conditions.

Point (Km)		12.75	18.00	39.70	44.80	58.00
W/O PC	Calculated	20.43 V	17 V	43.12 V	49.79 V	36.69 V
	Measured	18.2 V	16.8 V	44.5 V	48.4 V	38.9 V
PC-25	Calculated	1.353 V	1.582 V	0.81 V	0.803 V	5.293 V
	Measured	1.368 V	1.352 V	0.823 V	0.812 V	5.352 V
PC-50	Calculated	0.611 V	0.6992 V	0.379 V	0.353 V	5.029 V
	Measured	0.810 V	1.012 V	1.231 V	0.821 V	5.68 V
Optimized-PC	Calculated	0.755 V	0.682 V	0.432 V	0.325 V	4.391 V
Optimized-SSPC	Calculated	0.809 V	1.174 V	0.844 V	0.310 V	3.942 V

Table 3: Comparisons for the DC voltage points under normal operating conditions

Point (Km)	12.75	18.00	39.70	44.80	58.00
W/O PC	-1.465 V	-1.464 V	-1.446 V	-1.445 V	-1.461 V
PC-25	-1.427 V	-1.418 V	-1.374 V	-1.381 V	-1.441 V
PC-50	-1.073 V	-0.945 V	-0.767 V	-0.816 V	-1.133 V
Optimized-PC	-1.440 V	-1.431 V	-1.389 V	-1.394 V	-1.445 V
Optimized-SSPC	-1.463 V	-1.458 V	-1.432 V	-1.431 V	-1.467 V

6 References

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