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Cathodic protection systems: approaches and open challenges

Sistemas de protección catódica: enfoques y desafíos abiertos

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ABSTRACT

Cathodic Protection System (CPS) is used on a variety of structures to prevent corrosion in ship hulls, pipelines, and underground storage tanks. Transmission pipelines extend over wide distances that may extend for hundreds of kilometers, the problem of corrosion exists in pipelines transporting liquids such as oil, petroleum or water, as well as in pipelines transporting gases. Corrosion leads to leakage into the surrounding environment, causing pollution. Artificial intelligence (AI) is used in risk management to determine the possibility of corrosion growth rates, considering all the determinants and factors that contribute to corrosion, including alternating currents, soil properties, environmental conditions, and geographical features. According to research, there are two ways to enhance the performance of cathodic protection systems: one is to design cathodic protection in unconventional ways based on different algorithms and methods that show superiority over the traditional method in determining the number and location of anodes, and the other is to continuously monitor the environmental conditions surrounding the structure to be protected, which includes soil and weather. A study will be conducted to determine the most effective factors in protecting the pipelines and other factors to determine the required energy in an efficient method.

Keywords: Cathodic protection, Pipelines, corrosion.

RESUMEN

El Sistema de Protección Catódica (CPS, por sus siglas en inglés) se utiliza en una variedad de estructuras para prevenir la corrosión en cascos de barcos, tuberías y tanques de almacenamiento subterráneos. Las tuberías de transmisión se extienden a lo largo de grandes distancias que pueden alcanzar cientos de kilómetros, y el problema de la corrosión existe en las tuberías que transportan líquidos como petróleo, agua o productos químicos, así como en las tuberías que transportan gases. La corrosión conduce a fugas en el entorno circundante, causando contaminación. La inteligencia artificial (IA) se utiliza en la gestión de riesgos para determinar la posibilidad de tasas de crecimiento de corrosión, teniendo en cuenta todos los factores y determinantes que contribuyen a la corrosión, incluyendo corrientes alternas, propiedades del suelo, condiciones ambientales y características geográficas. Según la investigación, existen dos formas de mejorar el rendimiento de los sistemas de protección catódica: una es diseñar la protección catódica de formas no convencionales basadas en algoritmos y métodos diferentes que demuestran superioridad sobre el método tradicional para determinar la cantidad y ubicación de ánodos, y la otra es monitorear continuamente las condiciones ambientales que rodean la estructura a proteger, lo que incluye el suelo y el clima. Se llevará a cabo un estudio para determinar los factores más efectivos en la protección de las tuberías y otros factores para determinar la energía requerida de manera eficiente.

Palabras claves: Protección Catódica, Tuberías, corrosión.

1. INTRODUCTION

Many oil-producing countries like Venezuela, Saudi Arabia, Canada, Iran and Iraq possess the largest proven crude oil reserves in the world, as Iraq has the fifth place among the countries producing crude oil, in these countries' pipelines are very important means of transporting oil and gases. This applies to the transport of crude, final products and natural gas (EIA, 2017; Task, 2017). The problem of metal corrosion is great from an economic point of view, as statistics indicate that approximately 5% of the income of industrialized countries is spent on preventing corrosion as well as maintaining and replacing lost and contaminated products as a result of corrosion reactions (Callister, 2017). All over the world, millions of kilometers of gas, oil pipelines, as well as other metallic structures including storage tanks are buried underground in the soil, suffering from corrosion problems which mainly affects the external surface of that metallic structure (Ferraris et al., 2012). Several methods have been made to get rid of this problem by using different types of techniques. There are two methods of eliminating buried metal corrosion sacrificial anode cathodic protection and impressed current cathodic protection (ICCP) (Classnotes, 1996; Garcés-Gómez et al., 2021; Mujezinović et al., 2012; Turkovic & Mujezinovic, 2017). ICCP is the most common method for eliminating corrosion of metallic structures buried in soils (Task, 2017). It works by suppressing the steel dissolution (anodic reaction) by passing an ionic current from an external anode through the electrolyte (sea water or soil) (Guyer et al., 2014; Hanif et al., 2019). This current promotes the oxygen reduction catholic and hydrogen evolution reaction on the steel surface (Al−faiz & Liqaa saadi mezher, 2014). ICCP systems are distributed on pipelines which are spaced over long distances. Data is typically collected from specialized sensors for the ICCP system to ensure continuity of monitoring of the status of these pipelines in real time. Relaying data from distributed protection systems by deploying sensors over large areas for monitoring center are ineffective and expensive due to its distance from other ICCP systems (Hapsari et al., 2020; Standard, 2019). Cost-effective ways are designed to connect distributed ICCP systems to a cloud server over the Internet and produce an online web page for costumer to get the required data. (Ee, 2015; Kanagaraj et al., 2015).

ICCP system that measures the potential voltage between pipelines or structured to be protected (cathode) and reference electrode (e.g., Cu/ CuSo4) to fix and keep the protection voltage (Bushman & Associates Inc., 2006), that measured by the reference electrode, on the value of (-0.9) V or within the range of (-0.85) V to (-1.6) V according to the NACE international organization (National Association of Corrosion Engineers) (Atshan Ȧ et al., 2017), a DC power supply (power station) is used to drive a required power as shown in Figure 1. A computer can predict outcomes by learning how to process data using machine learning. Additionally, ML continuously raises the accuracy of predictions while posing important questions about the learning process (How and Why). Robotics is the main focus of AI, which has spread to other fields including manufacturing, process automation, and sports analytics. Data analytics relies on probabilistic techniques and allows for decision-making in ambiguous situations. In order to produce precise predictions using machine learning approaches, predictive modeling involves creating a mathematical equation (Pushpa et al., 2017; Sen et al., 2021; Vázquez-Marrufo et al., 2022). The model construction process comprises data translation, data exploration, and data purification, performance estimation using known quantitative statistics, model evaluation, and model selection (Aliar et al., 2022). The crucial phase in evaluating a machine learning model is performance evaluation, which ultimately guides the adoption of the best performing model (Kareem & Jasim, 2022). The percentage of error between the real and expected values is useful in evaluating classification models, whereas root-mean square error (RMSE) and mean absolute error (MAE) are two recommended metrics for assessing the effectiveness of the linear regression model (Rossouw & Doorsamy, 2021).

Many machine learning algorithms are used as important and effective methods in studying corrosion phenomenon, such as artificial intelligence models (Abdulelah et al., 2021), self-organized map (SOM) model and radial basis function (RBF) neural network model. Artificial intelligence is used to determine the current density of steel reinforced concrete, the possibility of polarization, the current density, the corrosion rate, etc. Recently, Artificial Neural Network has adopted as a robust tool using in a lot of engineering applications (Desmira et al., 2022; Fadhil et al., 2020). In the subject of corrosion process prediction, the neural network has been widely utilized. The essential benefit of a neural network is its outstanding ability to capture nonlinear relationships between inputs and corrosion datasets. However, there are some problems in the application of neural networks such as poor robustness, the weak ability in global and it is simple to fall into the minimum value (Abdalkafor & Aliesawi, 2022). As a result, many techniques are used to optimize the ANN, including the genetic algorithm (GA), gravitational search algorithm (GSA), and particle swarm optimization (PSO) (Ma et al., 2020).

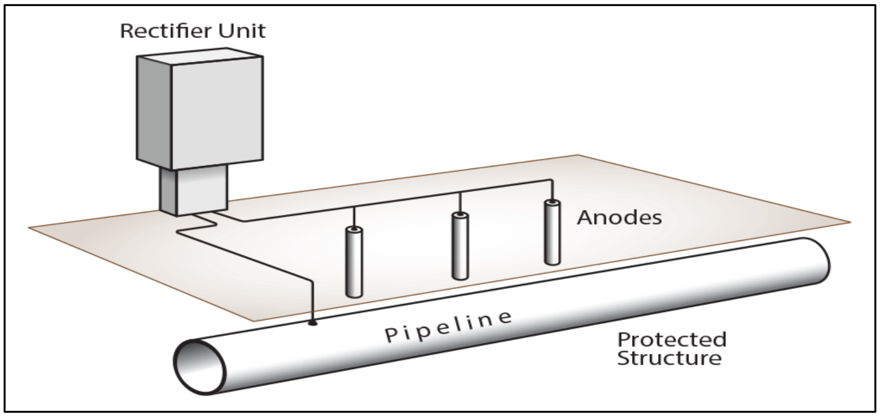

Figure 1. Impressed current cathodic protection (ICCP) system

2. LITERATURE REVIEW

Corrosion avoidance and control is a complicated process that is influenced by several external variables (Frankenthal, 2002). Cathodic protection is the most dependable, efficient, and cost-effective way of corrosion protection (Gurrappa, 2005). A neural network is now widely used in a variety of technical and industrial applications. It is capable of predicting and preventing corrosion, environmental impacts, and operational conditions (Dayhoff, 1990; Rumelhart et al., 1986). Steel structures and buried pipelines in subway systems are exposed to the effects of stray currents, causing electrochemical corrosion. The density of stray currents determines the speed and degree of corrosion.

In 2019, Wang, Wei Li and Xin presented a study to determine the stray corrosion current density and chloride ion interact, integrating neural network algorithms with electrochemical experiments. A neural network model for quantum particle swarm optimization (QPSO-NN) created for this study was used to forecast the corrosion current density during the stray current corrosion process. The artificial neural network's changing biases and weights was optimized using the QPSO method (ANN). The suggested QPSO-NN model outperforms the backpropagation neural network (BPNN) and particle swarm optimization neural network models in terms of accuracy (PSO-NN). The QPSO-NN model's accuracy distribution is more stable than those of the BPNN and PSO-NN models (Wang et al., 2019).

In 2014, Sai Shankar, K. P. Pranav, Kiran Raj focuses on the utilization of the revolutionary approach of Impressed Current Cathodic Protection to prevent corrosion in iron pipelines. Solar energy is used to power this procedure rather of a traditional AC power source. Corrosion is a common concern in underground metal pipelines that transport gases or liquids such as crude, petroleum production, or water across long distances. Corrosion of these metal pipelines results in the leakage of inner gases or liquids into the surrounding environment. Consequently, corrosion in these metal pipelines pollutes the environment in addition to the financial losses resulting from the replacement of these pipelines. This research explains how solar energy can be applied to address an extensive industrial problem. This approach is also a small, long-lasting and cost-effective option. The suggested method is experimentally examined and effectively tested over a period of time in order to get and verify the model's performance and efficiency in real time (B et al., 2014).

In 2018, gas metering infrastructures of wM-Bus at 169 MHz have been suggested as the foundation for a distributed monitoring system by Francesco, Domenico and Giuseppe. The objective is to create a cost-effective system that can control and monitor pipeline potential at a center location. The focus of the research was on ICCP systems in networks of gas distribution, which confront the same measurement issues as transportation networks. The intricacy of the network makes it more challenging to forecast how potential different among network branches in distribution networks, even though it is simpler to track potential over the pipeline in transport networks. Based on the use of a cathodic protection meter, a remotely monitored and controlled system was suggested to monitor the potential in an appropriate test point: It must determine whether the pipeline is polarized and transmit the information it has learned. In order to decrease power consumption through cathodic protection, this potential information is sent to a center location that must be close to the power source and is equipped to change the controller parameters in response to the data it receives (Abate et al., 2018).

In 2018, Sibiya, Kusakana, and Numbi proposed a system for ICCP that was driven by renewable energy. In order to prevent corrosion to the portion of the unprotected pipeline due to deteriorated coating and stray currents, additional corrosion prevention measures, such as auxiliary anodes, ICCP, and Mitigation of alternating Current, are typically installed in buried pipelines. The pipeline load profile that needs to be safeguarded serves as a clear demonstration of the studies to determine the sufficient power required to modify the potential level of the underground pipeline. From there, a hybrid system is built and simulated (Sibiya et al., 2018).

ICCP cathodic protection technique is used to face soil-side corrosion in aboveground storage tanks (ASTs). Special regulations have been imposed by the US Department of Transportation for the use of cathodic protection for above-ground storage tanks. A new bottom is applied in which the anodes are placed inside a layer of sand between the old and new tank bottom. Galvanic anode cathodic protections are used with small diameter tanks, while the impressed current protection systems are used with large diameter tanks due to high current demand. Vapor corrosion inhibitors (VCIs) are used conjunctions with cathodic protection to prevent corrosion. The output of the cathodic protection circuit is determined by the potential changes between anode and structure to be protected (cathode), circuit resistance and supplying voltage. The inherent potential (anode and cathode) of metal surfaces tends to change when VCIs are exposed to them, changing the driving voltage. Due to their high ionic strength, VCIs are particularly conductive, and when they are injected beneath ASTs, they have a tendency to reduce the sand bed resistivity, modifying the resistance of the CP circuit. Depending on the compatibility of the anodes with VCIs, significantly the presence of VCI affects the fluctuation of the output current of the cathodic protection. The authors presented a study on the effect of VCIs on sacrificial anodes and the effect of the VCI-saturated electrolyte on the depletion speed of sacrifices, as well as the long-term performance of the cathodic protection system in the presence of VCIs in 2019 (Math & Shukla, 2019).

The value of the output current and the position of the sacrificial anodes are the primary variables determining the distribution of the protection potential on the pipeline. a mathematical model and numerical simulation methods of pipeline cathodic protection are suggested by Qizhi Zhang and Lin Li to study pipeline cathodic protection potential and its distribution rule of this potential in 2020. The optimum output current value as well as the optimum anode position are found to improve the performance of the cathodic protection system for the pipeline. The authors used the simulated annealing approach to find the optimal value of the variables (the value of the output current and the position of the sacrificial anodes). The results demonstrate that the approach has a specific reference value for cathodic protection design and reveal the potential of the actual protection for the pipeline (Zhang et al., 2020).

In 2020, H. M. Oghli and M. Akhbari presented a new distributed approach for designing a pipelines cathodic protection system that may be extended and used to other constructions. The suggested model differs from the standard technique in that it uses real measured soil resistance throughout the building rather than a fixed mean value. Analytical studies and computer-based simulations have proved the efficiency of the proposed model. when an oscillation of soil resistance is high, the proposed technique outperforms standard lumped models significantly. As a result, the protection quality is improved when the developed method is used in the design of a pipeline CP system. A 20 km length pipeline with a cathodic protection system and soil data collected is used to construct and investigate the performance of a real-world scenario using the distributed equivalent circuit model. To determine the projected CP system's performance, the results are compared to those of the traditional model (Oghli et al., 2020).

In the field of control of the impressed cathodic protection system, Ali M. Jasim established in 2020 a monitoring and control system with a cathodic protection system for a section of the buried oil pipeline in south Iraq, where the cathodic protection drives an impressed current between the electrolyte (soil) and the metal of the pipeline to make it a cathode and thus protect it from corrosion. A DC-to-DC converter is used to supply a variable DC voltage. The Wi-Fi Microcontroller (Wi-Fi MC) controls the output voltage of the buck converter with a PID controller. The user can view a display in the field or utilize the Internet of Things (IoT) to remotely monitor the cathodic protection readings (Jasim, 2020).

in 2020, M. A. Bawa and M. H. Ibrahim investigated the potential of different locally made anodes, as four anodes were made of different materials. The corrosion cells were made by using harsh soil saturated with sodium chloride solution, and then cathodic protection was done by burying a group of pipelines with four anodes to create different corrosion cells, each of which was provided with a DC source current to monitor the performance and depletion period of the anode, As well as monitoring the complete electrochemical behavior and corrosion protection for both anodes and pipelines voltage between the soil and the pipelines was periodically measured based on the reference cell, as well as measuring the pH and temperatures in the simulated corrosion cells. In comparison to the Cupper based and Aluminum based Anodes, the Anode made of Lead material displayed good protection quality, displaying only 10.22 percent depletion after twenty-one days of testing. Based on the findings, it was determined that a locally produced Pb-based anode could be a promising option for use in an ICCP system in harsh conditions (Bawa et al., 2020).

In 2021, A set of studies has been reviewed by Vadim Kramar and Anna Rodkina to provide a description of new scientific facts, where procedures were presented to carry out experimental investigations of the electrochemical properties of ships and structures of some floating facilities. experimental investigations were done under cathodic polarization in a test seawater solution. This procedure makes use of a test facility designed for the purpose of obtaining the results of laboratory tests on the electrochemical properties of such hull structures. A method of protecting ship and floating facility hull structures from local corrosion mechanical damages using cathodic polarization at the potential of the uncharged s has been developed, along with neural network-based techniques for predicting the protection potential of ships and floating facilities from local corrosion mechanical damages and an algorithm for determining the protective potential for ship and floating facility hull structures (Kramar et al., 2021).

In 2015, Aimee Byrne and Niall Holmes discussed some of the modern techniques in cathodic protection through renewable energy systems for reinforced concrete, where the incompatibility between providing energy from renewable sources and the energy required for cleaner production was addressed by evaluating current requirements and some innovative concepts. Regarding the cathodic protection of reinforced concrete, there are several assumptions. On the other hand, cathodic protection for such structures is hailed as the most robust and dependable corrosion-control alternative. Increasingly, cathodic protection should and should depend on renewable energy sources. To make this more effective, the power requirements need to be detected and specified adequately. The results of this review study show that more research is required to determine whether intermittent sources can provide adequate protection, whether reinforced structures may be cathodic ally protected using renewable energy, and whether other unusual power sources can be used in ICCP (Byrne et al., 2015).

F. Varela1 and Y. evaluate patented and previously published devices to manage the ICCP output current of systems in 2019. The study is organized chronologically, illustrating how advances in electronics have allowed for increasingly complicated and convenient systems. Because typical closed-loop ICCP control systems have drawbacks, researchers are focusing on solutions that aim to mitigate the impacts of IR dips and reduce the requirement for unstable permanent reference electrodes. The article also includes techniques

for corrosion rates detection under CP and their potential use as feedback for ICCP system control (Varela & Tan, 2019).
A new technology that Muhammad Saddam Khan and Faizullah Khan Kakar presented in 2018, is used in this research study to prevent corrosion of buried metal structures in general and oil and gas pipelines in particular impressed-current cathodic protection system requires an electrical current from a continuous external power source. Three essential DC power sources Solar cells System, Thermoelectric Generator, and Transformer Rectifier are adopted for this task and projected throughout time in an ICCP for high transmission subterranean gas pipeline in Pakistan's Baluchistan area. The efficiency of selected power sources is then evaluated and contrasted in terms of climatic impacts, versatility effects, power output intensity, operational constraints, and initial, operating, and maintenance expenses. The most efficient DC power source for ICCP of subterranean gas pipelines was discovered to be the Solar System. When you choose an effective corrosion prevention system, It is clear that there is a smooth flow of oil and gas products through these pipelines, which could otherwise result in significant monetary and unintentional losses if they corrode (Khan et al., 2018).
In 2017, Adnan Mujezinovi and Irfan Turkovi provide an overview of the methodologies used to determine the cathodic protection system parameters. A mathematical model based on the boundary element approach for the computation of the cathodic protection system parameters is also described in greater detail due to its frequent application. The parameters of a simple geometry cathodic protection system were calculated using the presented mathematical model. Through the polarizing properties, the electrochemical processes that occur on the electrode surfaces are taken into consideration in the provided mathematical model. A geometrically simple example of the cathode protection system with sacrificial anodes is used to demonstrate the applicability of the proposed mathematical model (Mujezinovic & Turkovic, 2017).
In 2020, Ueli M. Angs evaluates the suitability of CP as an efficient solution to address the issues associated to infrastructure corrosion after conducting a rigorous examination in science and engineering. As these two key applications of CP methods have many parallels, this study focuses on the CP system of ron-based alloys embedded porous media. First, various opposing theories are explored together with the scientific understanding of CP. According to the authors, there is extensive evidence in the literature that (time-dependent) chemical processes, rather than polarization into the immunity domain, are often responsible for attaining of iron and steel corrosion protection. Corrosion protection is maintained even when cathodic protection current is temporarily lost, which is a significant and well-documented technological advantage of these chemical reactions. The relationship between corrosion prevention current density and fluctuations in the electrolyte's chemical composition at the metal surface is complicated. The influencing factors are due to the elements such as the microstructure of the medium as well as the presence of reactive phases, in addition to that, the movement of water and the presence of microorganisms (Angst, 2019).
Xu Rongrong, Wang Beifu, and Nie Lihong investigated the numerical model of CP system and its use in the deterioration of undersea pipeline coating in 2017. Utilizing the Laplace equation and the necessary boundary conditions for the destruction of the submarine pipeline coating, build a numerical model that is appropriate for the degradation of the undersea pipeline coating under cathodic protection. The cathodic protection potential distribution of the undersea pipeline can be calculated using various values of the apparent resistivity of the coating in the boundary condition. Computer software can calculate the numerical model using the three-dimensional finite element approach. After that, examine the numerical model's applicability in underwater pipeline corrosion and damage rate (Xu et al., 2017).
(Javadi et al., 2014) present a photovoltaic power system for intelligent cathodic protection of underground pipes. The system's structure is as follows: The solar cell array transforms sunlight into electricity and serves as a voltage source. Using a buck converter, the high DC voltage generated by the module should be reduced to supply an acceptable voltage for the batteries. The Buck - Boost converter and battery are connected to the buck converter's output, and the Buck - Boost converter feeds the pipeline and anode-bed circuits in the end. Because the power produced by the module is highly dependent on the point of operation, the converter should have a mechanism to track the maximum power point (MPPT). A new controller has been built to extract the greatest amount of power from the solar array, resulting in a significant increase in the system's overall efficiency. Furthermore, a new circuit model for subterranean pipelines is given, which can be

utilized to simulate cathodic protection systems. The worst-case scenarios were explored in simulation to increase the system's lifetime and make the planned system viable in a variety of climates.

By using high-potential magnesium anodes, (Mansouri et al., 2021) present a pseudo-transient numerical method in 2021 for analyzing the effectiveness of sacrificial cathodic protection systems for the corrosion prevention of buried steel assets. Finite-element simulations are applied to model the three-dimensional distributions of potential and current density on the surface of the buried steel structure and in the soil environment. Actual measurements are contrasted with predictions for anode depletion rate and anode deformation pattern. In the analyzed example, it was found that the surface area of the sacrificial anode decreased by 65 percent after 30 years, which leads to a significant decrease in the level of protection. The suggested technique is also capable of capturing the interactions between various anodes inside the anode bed, which lead to a range of anode depletion rates. The impact of CP current leak on external or auxiliary structures (such grounding systems) is also investigated in this paper. Corrosion engineers can use the study's findings to enhance their work.

3. SUMMARY

It is required to use extremely precise and accurate methods for the computation of cathodic protection system parameters when designing and evaluating the effectiveness of modern cathodic protection systems. The study provides a summary of the techniques and methods that have been proposed in the literature to improve the cathodic protection system. Table 1 shows research focus in cathodic protection.

Table 1. the Research focus in cathodic protection

Purpose of research	Proposed technique or Methods	Results	Refs
Corrosion predication (ICCP)	A quantum particle swarm optimization-neural network (QPSO-NN) model developed in this study. Review study.	Predication of current density for the corrosion in the process of stray current corrosion illustrating how advances in electronics have allowed for increasingly complicated and convenient ICCP systems.	(Varela & Tan, 2019; Wang et al., 2019)
Power consumption reduction (ICCP)	Review study. Three primary DC power sources are chosen for this purpose T/R, Thermoelectric Generator, and Solar System. Design a controller circuit with solar cell for power source	Solar energy is used to power this procedure rather of a traditional AC power source. Solar System was discovered to be the most efficient DC power source for ICCP of subsurface gas pipelines. A new controller was created to get the most power out of the solar array,	(B et al., 2014; Javadi et al., 2014; Khan et al., 2018)
ICCP monitoring	a distributed monitoring system based on existing wM-Bus at 169 MHz infrastructures for gas metering. Design an electronic circuit uses a PID controller to manage the buck converter's output voltage.	develop a low-cost system that can monitor and manage pipeline potential. ICCP can be monitored the wirelessly via the Internet of Things (IoT) or on a display screen in the field	(Abate et al., 2018; Jasim, 2020)
Measurement of required power (ICCP)	Review study	Study estimated the amount of power required to change the potential level of the buried pipeline	(Sibiya et al., 2018)
Corrosion protection for aboveground tanks (SACP)	vapor corrosion inhibitors (VCIs) are employed in conjunction with CP systems	Investigated are the effects of VCIs on galvanic anodes, their ability to operate in an electrolyte saturated with VCIs, and the long-term performance of	(Math & Shukla, 2019)

		galvanic CP systems in the presence of VCIs.	
CP optimization	a mathematical model of pipeline cathodic protection and numerical simulation methods (ICCP). The distributed equivalent circuit model is used to design and study the performance of ICCP. four anodes made from various materials tested in ICCP system. propose a pseudo-transient numerical method for analyzing the efficiency of SACP	The optimal buried position of the anode and the optimal output current value of the anode. Analytical study and computer-based simulations have proved the efficiency of the proposed model When the fluctuation of soil resistance. the Anode made of Lead material displayed good protection quality, displaying only 10.22 percent depletion after twenty-one days of testing. Anode depletion rate and anode deformation pattern are predicted and compared to actual observations.	(Bawa et al., 2020; Mansouri et al., 2021; Oghli et al., 2020; Zhang et al., 2020)
hull structures of ships (SACP)	recommend a procedure for carrying out experimental studies of the electrochemical properties of ship hull structures under cathodic polarization in a test seawater solution.	a method of protecting ship and floating facility hull structures from local corrosion mechanical damages using cathodic polarization at the potential of the uncharged s has been suggested	(Kramar et al., 2021)
Power requirement (ICCP)	Review study	Examined is the possibility of reconciling the disparity between energy supplied by renewable sources (intermittent current) and energy needed for CP (constant current).	(Byrne et al., 2015)
ICCP parameters calculation	Provide a mathematical model, the parameters of a simple geometric cathodic protection system were computed.	give an overview of the approaches utilized to determine the parameters of ICCP	(Mujezinovic & Turkovic, 2017)
Corrosion prevention (ICCP)	CP of iron-based alloys embedded in porous media, including soil or concrete, is the focus of a review research.	Corrosion protection current density and alterations in the electrolyte's chemical composition at the metal surface have a complex interaction Due to the (microstructure, presence of reactive phases)	(Angst, 2019)
Corrosion rate measurement (ICCP)	construct a numerical model suitable for the damage of the undersea pipeline coating under cathodic protection.	examine the numerical model's applicability in underwater pipeline corrosion and damage rate	(Xu et al., 2017)

4. CONCLUSIONS AND FUTURE WORK SUGGESTIONS

Corrosion in underground transmission pipelines for oil and gas has numerous direct and indirect technical and economic consequences. Cathodic protection systems, which are carried out via current ICCP system, are currently the most essential technique of dealing with corrosion. As a result, proper cathodic protection system design and implementation can significantly reduce corrosion-related damages. The exact determination of the protective current necessary for structural protection is a prerequisite of a suitable design in the first phase. It was discovered that employing the soil resistance spread along the structure rather than the average value increases the design precision as well as the protection quality. Furthermore, the number of anodes, the anode laying position, and the value of anode output current are all parameters that influence the pipeline potential distribution. The objective function is determined based on the auxiliary anode's embedding position and output current value, and the optimal solution is found using intelligent approach. Examples show that using an intelligent approach to optimizing anode parameters can improve distribution of protection potentials and reduce power consumption.

The methodology focused on the majority of studies that dealt with challenges associated with the two cathodic protection systems (sacrificial anode and impressed current cathodic protection), as well as the methods and strategies utilized to address these problems. The results showed the most influential factors in the treatment and enhancement of cathodic protection for the second, more common approach, ICCP. It was additionally found that using neural networks could improve the performance of cathodic protection systems and minimize the power consumption utilized in supplying the current density of the secondary anodes, allowing for the use of renewable energy such as solar cells.

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