Technical Evaluation of Cathodic Protection of Subsea Structures

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Abstract: **This paper carried out the performance evaluation of cathodic protection in comparison with other corrosion prevention techniques based on factors like conductivity, maintenance requirement, cost, electrical continuity, and surface area of structure treated. In the course of the work, the comparative analysis of these techniques was carried out using a multi criteria analysis tool 'TOPSIS'. After going through all the stages in the TOPSIS assessment, the best corrosion prevention technology with respect to all the considered criteria, which comprised of: treatment time, effectiveness, energy consumption, durability, economics and maturity is reinforcing materials with a TOPSIS score of 0.7745. The second-best technology is cathodic protection with a TOPSIS score of 0.6729, followed by surface treatment and coating with a TOPSIS score of 0.5903. Inhibitors came fourth with a TOPSIS score of 0.5897 while the worst technology per the analysis in this study is electrochemical chloride removal with a TOPSIS score of 0.2355.**

***Keywords*: Cathodic protection; Corrosion; Subsea structures; TOPSIS.**

I. INTRODUCTION

The impact of corrosion is three directional, the three aspects being economic, safety, and environment (Dong *et al*., 2012). The impact of corrosion, and the prevention thereof, is felt economically, and affects the safety and environmental conservation of resources. Economically, it implies the loss of infrastructure by way of loss of materials used in tanks, process equipment, pipelines, platforms, bridges, and many other important structures (Bernhammer *et al*., 2016). The economic losses could be direct or indirect. The direct losses would include, for example, the cost of replacing the corroded structures, equipment, and the cost of painting, upkeep, and monitoring of cathodic protection as well as the associated labour cost. Another cost would be the use of expensive corrosion resistance materials (Chew *et al*., 2016). The indirect cost of corrosion is difficult to assess accurately as more complex aspects come into play. However, activities that can be counted as contributing to the indirect cost of corrosion might include the closing of plants and facilities for repair and maintenance needed because of corrosion damages and failures. These costs add up because shut down involves reduction in production, loss of product, costs for cleaning and repair of environmental damages, and wages paid for the duration of the nonproductive time (Jang *et al*., 2015). In a nutshell, it can be said that indirect losses are a chain of activities that will take place and have to be paid for even when production is not there to support those costs. The loss of structure materials to corrosion is not only an economic loss but it makes the structures weak and degrades their designed capabilities and reduces the structure's designed purpose (Herrmann *et al*., 2016). On the extreme end of this deterioration, such structures can become a safety hazard and the loss may lead to structure failures, some of which could even be catastrophic, leading to property damage and loss of lives (Gallego-Calderon & Natarajan, 2015).

The prevention of corrosion leads to the reduction of damage to the environment. The economic impact is possibly the prime motivator for the study of corrosion and the development of preventive measures by the industry. The use of corrosion protection systems is essential to reach the expected service life for which a structure was designed. Different protection systems can be used to delay and mitigate corrosion initiation and its related consequences such as safety, structural integrity and service life. A passive approach to corrosion protection involves depositing a barrier layer that prevents contact of a material with the corrosive environment. Active approaches reduce the corrosion rate when the protective barrier is already damaged and corrosive agents come into contact with the metal substrate. Cathodic protection is a proven method for preventing and protecting buried and submerged steel and reinforced concrete structures from corrosion. More recently, the method has been introduced to prevent and control corrosion in subsea structures. In this paper, the performance evaluation of cathodic protection in comparison with other corrosion prevention techniques was conducted using the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS).

II. METHODOLOGY

In this paper, the analysis, evaluation and comparison of the different corrosion prevention technologies is done using a multi-criteria analysis approach 'the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)'. The technologies compared here include: Cathodic Protection (CP), Re-alkalisation (RA), Electrochemical chloride removal (ECR), Inhibitors (INH), Surface treatment and coatings (STC) and Reinforcing materials (RM). These technologies are compared and evaluated based on six broad criteria: Treatment time, Effectiveness, Energy Consumption, Durability, Economics, and Maturity (Track record).

Steps involved in analysis with TOPSIS

Step 1 – Standardize the decision matrix

This step changes the attributes from dimensional to dimensionless attributes, thereby allowing comparisons across the criteria. For standardizing to be achieved, each column of the decision matrix is divided by the root of sum of square of respective row.

Step 2 – Develop weighted standardized decision matrix. This is achieved by multiplying the assigned criteria weight to each rating in the standardized decision matrix

Step 3 – Compute ideal solution and negative ideal solution. The ideal solution is a set of maximum ratings for each criterion. Similarly, a set of minimum scores for each attribute is the negative ideal solution.

Step 4 – Compute the separation from ideal solution S_i*. This is the square root of the sum of the difference between the ideal solution and the corresponding ratings across the rows of the weighted standardized decision matrix.

Step 5 – Compute the separation from negative ideal solution Si'. This is the square root of the sum of the difference between the negative ideal solution and the corresponding ratings across the rows of the weighted standardized decision matrix.

Step 6 – Compute the relative closeness to ideal solution (Beg and Rashid, 2014; Greene *et al*., 2011). This is done using the formula:

$$C_i^* = \frac{S_i'}{(S_i^* + S_i')} \quad (1)$$

The option with value closest to 1 and farthest from 0 is the best option. The algorithm for these steps above is provided in Figure 2.

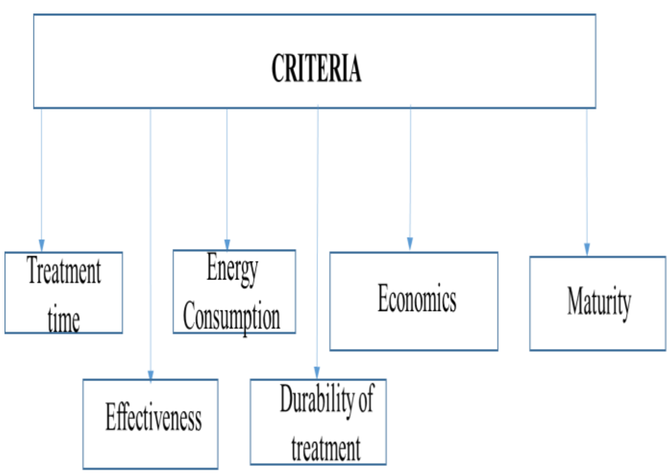

Figure 1: TOPSIS Criteria for the Study

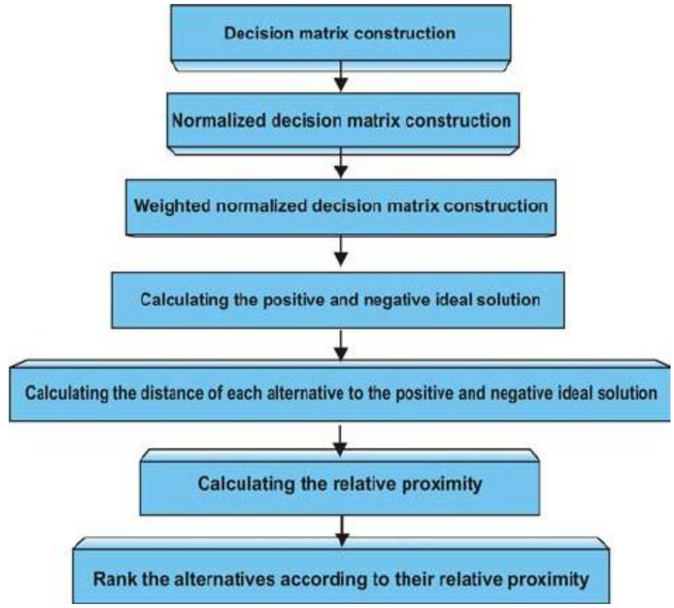

Figure 2: TOPSIS Algorithm

III. RESULTS AND DISCUSSION

Table 1: The assigned weights to the criteria using a rating scale (1 implies very significant, 0 implies not significant).

S/No	CRITERIA	WEIGHT
1	Treatment Time	0.7
2	Effectiveness	0.9
3	Energy Consumption	0.7
4	Durability	0.9
5	Economics	0.9
6	Maturity	0.7

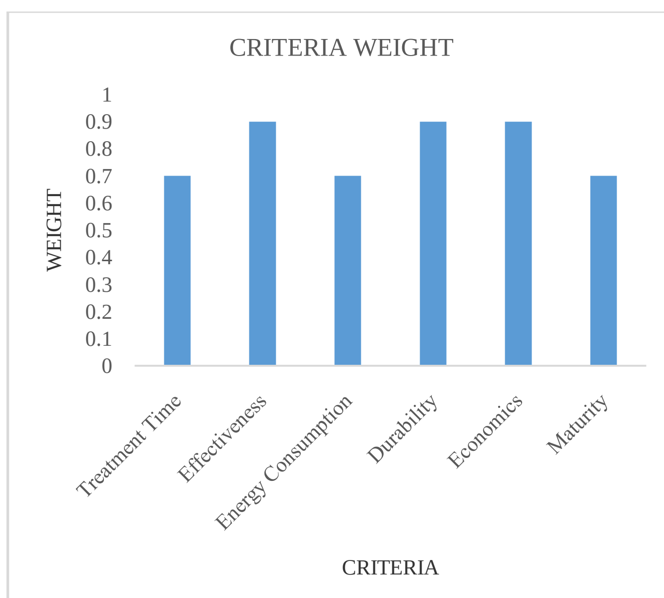

Figure 3: The assigned criteria weights

Table 2: xij = Weight of alternative i with respect to criterion j

CRITERIA	**CP**	**RA**	**ECR**	**INH**	**STC**	**RM**	**Rating Scale**
Treatment time	6	8	8	8	6	7	(1-10) 1 means very poor, 10 means very excellent
Effectiveness	8	7	7	8	8	9	
Energy Consumption	8	6	5	7	8	8	
Durability	8	6	6	7	7	9	
Economics	7	6	5	7	7	6	
Maturity	8	6	6	7	8	8	

Table 3: Computation of $(\Sigma x_{ij}^2)^{\frac{1}{2}}$

CRITERIA	CP	RA	ECR	INH	STC	RM	$(\Sigma x_{ij}^2)^{\frac{1}{2}}$
Treatment time	6	8	8	8	6	7	17.69181
Effectiveness	8	7	7	8	8	9	19.26136
Energy Consumption	8	6	5	7	8	8	17.37815
Durability	8	6	6	7	7	9	17.74824
Economics	7	6	5	7	7	6	15.6205
Maturity	8	6	6	7	8	8	17.69181

Table 4: The normalized decision matrix $rij = x_{ij}/(\Sigma x_{ij}^2)^{\frac{1}{2}}$

CRITERIA	CP	RA	ECR	INH	STC	RM
Treatment time	0.3391	0.4522	0.4522	0.4522	0.3391	0.3957
Effectiveness	0.4153	0.3634	0.3634	0.4153	0.4153	0.4673
Energy Consumption	0.4603	0.3453	0.2877	0.4028	0.4603	0.4603
Durability	0.4507	0.3381	0.3381	0.3944	0.3944	0.5071
Economics	0.4481	0.3841	0.3201	0.4481	0.4481	0.3841
Maturity	0.4522	0.3391	0.3391	0.3957	0.4522	0.4522

Table 5: The weighted normalized decision matrix $v_{ij} = w_j r_{ij}$

CRITERIA	**CP**	**RA**	**ECR**	**INH**	**STC**	**RM**
Treatment time	0.2374	0.3165	0.3165	0.3165	0.2374	0.2770
Effectiveness	0.3738	0.3271	0.3271	0.3738	0.3738	0.4205
Energy Consumption	0.3222	0.2417	0.2014	0.2820	0.3222	0.3222
Durability	0.4057	0.3043	0.3043	0.3550	0.3550	0.4564
Economics	0.4033	0.3457	0.2881	0.4033	0.4033	0.3457
Maturity	0.3165	0.2374	0.2374	0.2770	0.3165	0.3165

Table 6: Computation and results of the relative closeness to the ideal solution $C_i^* = S_i^{'}/(S_i^* + S_i^{'})$

	CP	**RA**	**ECR**	**INH**	**STC**	**RM**
Si*	0.1049	0.2189	0.2569	0.1251	0.1368	0.0699
Si'	0.2159	0.1058	0.0791	0.1798	0.1972	0.2400
Si*+Si'	0.3208	0.3248	0.3360	0.3049	0.3340	0.3099
Si'/(Si*+Si')	**0.6729**	**0.3259**	**0.2355**	**0.5897**	**0.5903**	**0.7745**

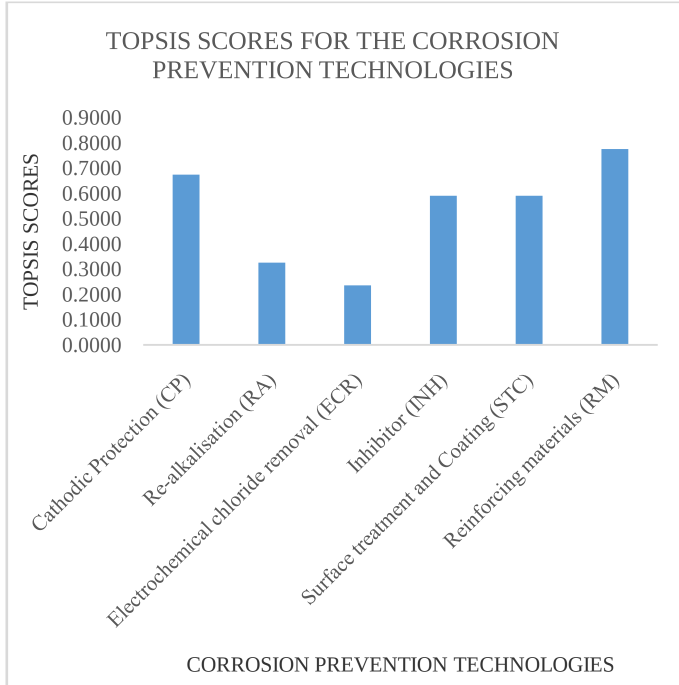

Figure 4: TOPSIS final scores for the corrosion prevention technologies

IV. DISCUSSIONS

By utilizing TOPSIS in this paper; m = 6 alternatives and n = 6 broad attributes/criteria, which are all shown in Table 1. These weighting has been largely influenced by the outcome of literature review and the input of a corrosion engineer. xij is the score of option i having attribute j (Table 2). J is a set of benefit attributes: low treatment time, high effectiveness, low energy consumption, high durability, low cost (economics), and high track record (very mature). The significance of each criterion to the theme of the study has been translated to weighting and provided in Table 2.

The data were gotten through interview of experts in the industry. With the data in Tables 1 and 2, TOPSIS implementation was done as below:

The normalized decision matrix $rij = x_{ij}/(\Sigma x_{ij}^2)^{\frac{1}{2}}$ is provided in Table 3. The weighted normalized decision matrix $v_{ij} = w_j r_{ij}$ is computed by multiplying each column of the normalized decision matrix by its associated weight.

A set of maximum values for individual criterion, referred to as the ideal solution $A^* = \{v_1^* \dots v_n^*\}$ is computed in step 3. Also, a set of minimum values for individual criterion, referred to as the Negative ideal solution $A' = \{v_1' \dots v_n'\}$ is computed in step 3.

The separation from the ideal alternative, $S_i^* = \left[\Sigma\left(v_j^* - v_{ij}\right)^2\right]^{\frac{1}{2}}$ is calculated. And the separation from the negative ideal solution, $S_i' = \left[\Sigma\left(v_j' - v_{ij}\right)^2\right]^{\frac{1}{2}}$ is likewise calculated. In the last steps, the relative closeness to the ideal solution $C_i^* = S_i'/(S_i^* + S_i')$ is estimated and the outcomes are as provided in Table 6.

The decision matrix for the alternative scores is provided in Table 2.

Applying TOPSIS in the analysis resulted to:

Step 1(a): Standardization of the decision matrix was done.

This stage transforms the scores to dimensionless scores by dividing individual column of the decision matrix by root of sum of square of respective rows. The outcome of this is provided in Table 4:

Step 1 (b): $\left(\Sigma x_{ij}^2\right)^{\frac{1}{2}}$ was first computed to get r_{ij} that is the standardized decision matrix provided in Table 4.

Step 2: The weighted standardized decision matrix was developed by multiplying the criteria weight (Table 1) with each rating in Table 4. The weighted standardized decision matrix is presented in Table 5:

Step 3: The ideal alternative and negative ideal alternative were determined.

A set of maximum values for individual criterion is the ideal alternative while a set of minimum values for individual criterion is the negative ideal alternative.

Ideal alternative A*: {0.3165, 0.4205, 0.3222, 0.4564, 0.4033, 0.3165}

Negative ideal alternative A’: {0.2374, 0.3271, 0.2014, 0.3043, 0.2881, 0.2374}

Step 4 (a): The separation S_i^* from ideal solution (A*) was determined.

$S_i^* = \left[\Sigma\left(v_j^* - v_{ij}\right)^2\right]^{\frac{1}{2}}$ for each column.

$\boldsymbol{S_i^* = \left[\Sigma\left(v_j^* - v_{ij}\right)^2\right]^{\frac{1}{2}}}$ **= {0.1049, 0.2189, 0.2569, 0.1251, 0.1368, 0.0699}**

Step 4 (b): The separation from negative ideal solution (A') was found and $S_i' = \left[\Sigma\left(v_j' - v_{ij}\right)^2\right]^{\frac{1}{2}}$ for each column as shown below.

$\boldsymbol{S_i' = \left[\Sigma\left(v_j' - v_{ij}\right)^2\right]^{\frac{1}{2}}}$ **= {0.2159, 0.1058, 0.0791, 0.1798, 0.1972, 0.2400}**

Step 5: The relative closeness to the ideal solution $C_i^* = S_i'/(S_i^* + S_i')$ was computed.

The matrix of the closeness to the ideal solution is provided in the Table 6.

After going through all the stages in the TOPSIS assessment, the best corrosion prevention technology with respect to all the considered criteria, which comprised of: treatment time, effectiveness, energy consumption, durability, economics and maturity is Reinforcing materials with a TOPSIS score of 0.7745, which plain steel is one of them. The second-best technology is Cathodic protection with a TOPSIS score of 0.6729, followed by surface treatment and coating with a TOPSIS score of 0.5903. Inhibitors came fourth with a TOPSIS score of 0.5897 while the worst technology per the analysis in this study is Electrochemical chloride removal with a TOPSIS score of 0.2355 (Figure 4).

From Table 1, it is evident that the top priority was placed on criteria like effectiveness, durability, and economics.

V. CONCLUSION

This paper conducted a comparative analysis of the corrosion prevention techniques using a multi-criteria analysis tool ‘TOPSIS’ and the analysis was based on factors/criteria like treatment time, effectiveness, energy consumption, durability, economics and maturity. After going through all the stages in the TOPSIS analysis, the best corrosion prevention technology with respect to all the considered criteria, which comprised of: treatment time, effectiveness, energy consumption, durability, economics and maturity was reinforcing materials, which plain steel is one of them. The second-best technology was Cathodic protection, followed by surface treatment and coating. Inhibitors took fourth while the worst technology per the analysis in this study was electrochemical chloride removal. In the analysis, the top priority was placed on criteria like effectiveness, durability, and economics.

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