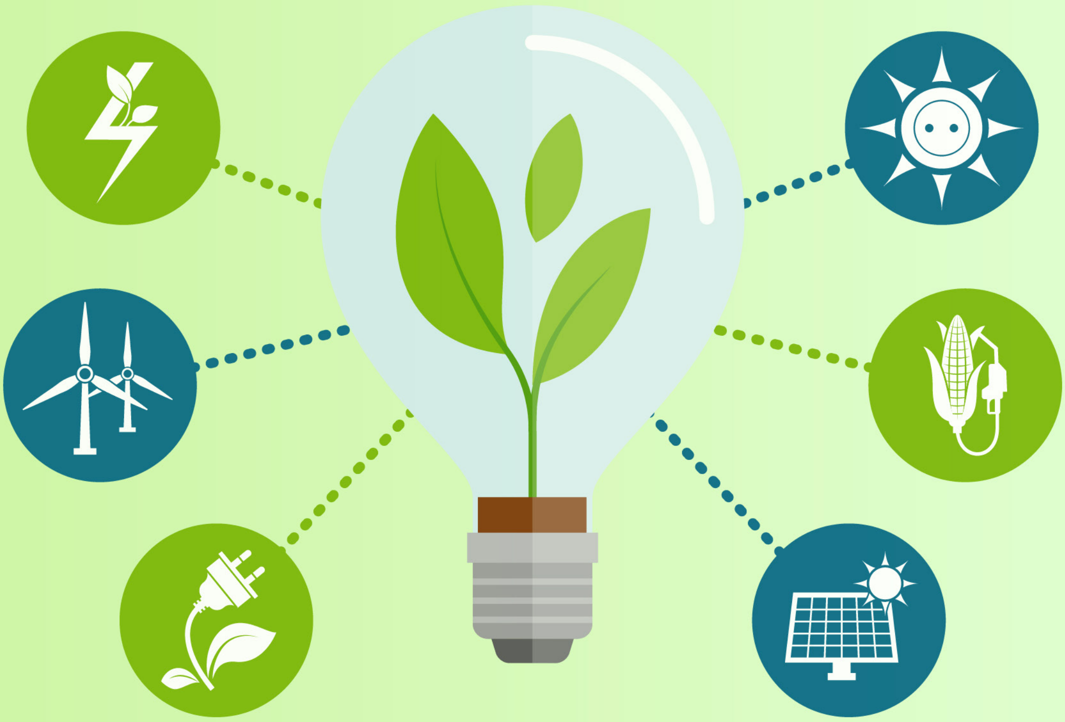
e-palli

AMERICAN JOURNAL OF ENERGY AND NATURAL RESOURCES (AJENR)

ISSN: 2835-9186 (ONLINE)

VOLUME 2 ISSUE 1 (2023)



PUBLISHED BY
E-PALLI PUBLISHERS, DELAWARE, USA

American Journal of Energy and Natural Resources (AJENR)
Volume 2 Issue 1, Year 2023
ISSN: 2835-9186 (Online)
DOI: https://doi.org/10.54536/ajenr.v2i1.1101
https://journals.e-palli.com/home/index.php/ajenr

Selection of a Suitable Material by a Multi-Criteria Decision Aid Method (Mcdm) for the Manufacture of the Buckets of a Micro Pelton Turbine

Haoua Laila Tidjani[1*], Matho Mekjele Raïssa[1], Joseph Kenfack[2], Oumarou Hamandjoda[2], Patrice Abiama Ele[1]

Article Information

Received: December 21, 2022
Accepted: January 04, 2023
Published: January 26, 2023

Keywords

Ahp, Micro Hydro Power Plant, Pelton Turbine, Topsis, Vikor

ABSTRACT

Micro hydro power plant remains a sustainable solution to meet the electrical needs of isolated populations when the potential is there. The discovery of new materials leads engineers to review the choice of material, in order to reduce the cost and facilitate the manufacture of hydromechanical components. In this study, to select the best choice of material for the manufacture of buckets of a micro Pelton turbine, we used multi-criteria decision support methods (MCDM) such as the Analytical Hierarchy Process (AHP), the order preference technique by similarity to the ideal solution (TOPSIS), the compromise solution (VIKOR). Based on of the literature review on the materials usable for the manufacture of hydraulic turbines, we were able to select five alternative materials such as mild steel ; aluminum alloy ; stainless steel ; high density polyethylene ; cast iron and seven very important material evaluation criteria for manufacturing such as machinability ; ultimate tensile strength ; the density ; hardness ; the cost ; maintenance cost and corrosion resistance. It appears from results via the AHP method that the coherence index of 0.0904 and the coherence ratio of 0.0669 are usable for the practice of material selection. Considering the performance scores for the five alternatives obtained via the TOPSIS and VIKOR techniques, it appears that high density polyethylene is the best material, followed by the aluminum alloy.

INTRODUCTION

Energy is the engine of global economic and social development. Climate change requires us to focus on reducing CO2 emissions and developing alternative energy production methods to overcome the current state of global energy shortages. The Africa Energy Outlook 2019 published by the International Energy Agency (IEA) indicates that in thirteen countries of Sub-Saharan Africa, more than three quarters of the population do not have access to electricity (Korkovelos A, 2018). It is estimated in the region that around 580 million people do not have access to electricity in 2019 (IEA., 2020) and early 730 million still depend on traditional fuels to meet basic household energy needs such as cooking, lighting, etc.(IEA.A., 2019).

Today, access to electricity, and reliable energy supply are key elements that support the economic development of a nation. This is why several studies in many countries show that micro hydro power stations are likely to respond, in various places, to the enormous demand for electricity, when the hydrological conditions are suitable.

In the existing literature, Cameroon has the second largest hydroelectric potential in Central Africa after the Democratic Republic of Congo.(Lui D, 2019), with a gross hydroelectric potential estimated at 23GW with nearly 115 TWh of technically exploitable potential (Engo, 2019). The magnitude of its potential in micro hydro power plant has led several researchers to carry out studies on the feasibility, design and installation of micro hydro power stations ((Elie Bertrand Kengne Sign BB, 2019),(Elie Bertrand Kengne, 2017),(Elie Bertrand Kengne Signe OH, 2017),(Fanyep Nana Antoine, 2020)), in order to propose this technology as a possible solution for increased rural electrification in Cameroon(Kenfack J, 2014)and attract decision makers to turn to the latter for electricity supply and development of remote areas.

Thus, several solutions have been proposed in the context of the development of technologies and the establishment of micro hydro power plants in the literature ((Chisomo Kasamba, 2015),(I. Loots, 2015),(Moradeyo K. Odunfa, 2019)), yet in the Cameroonian context the development of micro hydropower technology has taken a hit (TEKOUNEGNING, 2009) and slow to develop.

Although technologies of micro hydro power plants are identified in the literature in Africa, there is very little research and development of a methodology for the selection of material of a micro turbine using multi-criteria decision using materials from local origin yet we have a multitude, to be able to domesticate micro hydro power plant technologies in Saharan South Africa, especially in regions that have abundant untapped micro hydroelectric potential.

This study is therefore designed to simplify the selection of the best choice of materials among several by MCDM methods. Thus, a study on the micro hydro power station and the hydroelectric turbines in particular the Pelton turbine will be made, thereafter the literature review on the choice of material of turbines of the micro hydro power station and on the selections of materials by the MCDM methods will be made. . Since, the complex interrelationships between the variety of materials and their selection criteria often make the material selection process a difficult and time-consuming task. A systematic and efficient approach to material selection is necessary in order to select the best alternative for a product, hence the proposal of a combination model of MCDM that

[1] National Committee for Development of Technologies, Ministry of Scientific Research and Innovation, Yaoundé, Cameroon
[2] National Higher Polytechnic School, University of Yaoundé, Yaoundé, Cameroon
[*] Corresponding author's email: haoualaila@yahoo.fr

can exhaustively select the best alternative from a finite set of local material opportunities. Thus, the novelty of this study is the proposal of an MCDM methodology for the selection of the material, which is the combination of three MCDM (AHP, TOPSIS and VIKOR) innovative and applicable in our context, which could be adapted in other countries with local materials that can be used for the manufacture of micro turbines. Thus, the application of the methodology was done by using the Excel 2020 software.

LITERATURE REVIEW

Description of the micro hydropower plant

A micro hydro power plant is a power plant using hydropower to produce electricity on a small scale. The basic components of a micro hydropower plant can be broadly categorized into civil works and electromechanical equipment as shown in Figure.1, the river waters flow through the forebay reservoir and reach the turbine. The latter converts the hydraulic power received into mechanical energy. The presence of a forebay reservoir facilitates the water supply of the system (Valipour, 2015). Thus, the mechanical energy generated is sent to the electrical unit which includes the synchronous generator connected to a shaft to produce useful electrical energy to meet the needs of the rural community and subsequently the water is discharged to the river or stream without causing erosion (Mohammad., 2015). The civil works make up the power plant building which is a simple structure housing the generating unit, the tailrace is a simple water channel to transport water from the turbine and back to the flow that flows. Regarding the electromechanical components of the power plant we have the inlet valve, the turbine, the draft tube, the gates, the generator, the control and protection equipment and the substation for the transformation of power to the transmission line. The literature reveals that the turbine, the penstock and the alternator are the key and expensive elements in the process of generating electricity (Kusakana, 2014). Several researchers have directed their work to find solutions to design and manufacture this equipment using local materials available in their environment. This is the case of (Ebhota, 2017), which promotes the use of local materials for the manufacture of buckets for the Pelton turbine. Considering the wealth of Cameroon with regard to exploitable local materials such as steel; aluminum; plastic etc. We opted for the selection of materials for the local manufacture of a micro hydraulic turbine.

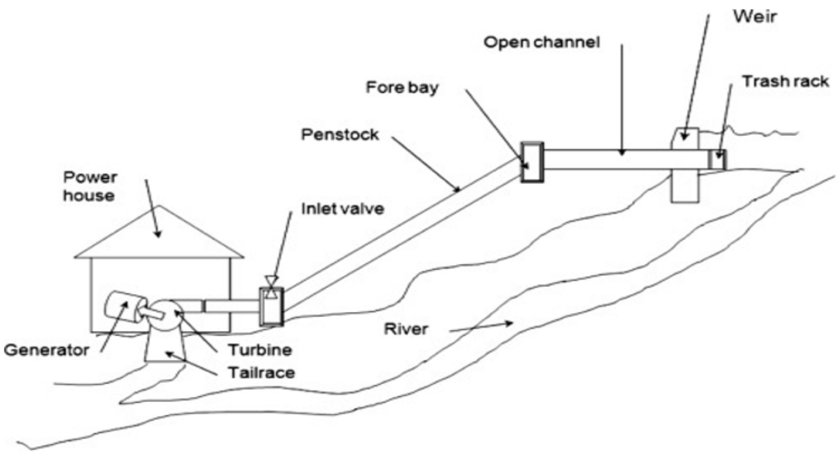


Figure 1: Description of a typical micro hydropower plant (Valipour, 2015).

Description of hydraulic turbines

A hydraulic turbine is a rotating machine that produces mechanical energy from moving water (river or tide) or potentially moving water (dam). It is the essential component of hydroelectric power stations intended to produce electricity from a flow of water. Turbines can be broadly classified into two groups; namely impulse and reaction turbines. Impulse turbines (e.g. Pelton and Cross-flow with many modifications) use impellers which are rotated by water thrown at them at high speed. In reaction turbines, a flow of water is used to generate an upward hydrodynamic force which in turn rotates the impeller blades. Generally, impeller wheel turbines are more suitable for high head applications and reaction wheel turbines are more suitable for low head hydroelectric installations, although there are exceptions. It is in this perspective that the work of (Mutiara AS, 2018) and (SJ Williamson, 2014) show that Pelton turbines have an advantage over other turbines in being the most suitable for low flow power generation and highly re-adapted for low head. They justify the choice of this turbine because of its ability to produce a proportionally efficient amount of electricity compared to the speed of the jet. Its advantage of using light, economical and locally available materials with an appreciable surface finishing capacity during manufacture and provisions of the mechanical and physical specifications necessary for an extended service life, possessing a natural capacity for resistance to corrosion (Deng, 2017). Hence our interest in this choice of turbine.

Description of the Pelton turbine

Pelton turbines work by directing one or more jets of water tangentially at a runner with split buckets, as shown in Figure 2. The jet of water causes a force on the buckets, causing the buckets to rotate, causing a torque on his tree

(Paish, 2002). After propelling the buckets, the water falls into the tailrace, ideally with almost zero remaining energy. This type of impeller is typically used for high head installations, but some manufacturers supply small impellers for low head applications. Buckets are usually bolted to the guide disc, but sometimes they are cast as a single unit. The inner surface of the cups should be as smooth as possible to facilitate jet splitting and therefore effective drive onto the impeller. Reason why we must use a material with good mechanical, chemical, economic properties for the manufacture of buckets of the Pelton turbine.

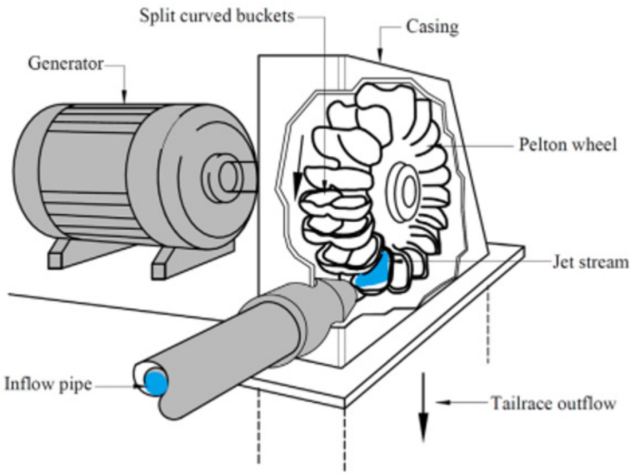


Figure 2 : Typical Pelton turbine (Paish, 2002) used with permission from IT Power Limited

Review of the choice of turbine material of the micro hydroelectric power station in the published literature

The material selection procedure is complex, and of a complexity that is only partially attributable to the variety of materials and processes. A choice of materials is, by nature, a multi-criteria choice. For the manufacture of a micro turbine we need easily machinable materials, durable, available, with a high resistance to corrosion, high resistance to wear, especially profitable to facilitate the latter. Some of these criteria are contradictory, it will be necessary to weight the relative importance of the various constraints. In a design procedure, the key word is compromised. It is for these reasons that researchers are conducting studies using different methods to investigate the choice of material for the design of hydroelectric turbines.

1. The method of selecting materials by determining performance using software.

(CH Achebé, 2020), for the choice of material, in its work uses ANSYS software to analyze materials, with a view to determining the degree of stress and deformation under the impact of hydraulic jets to determine its operation.

(Felix A. Isholaa, 2019), in their work for the design of a Pico hydroelectric power plant for additional energy storage uses AUTODESK INVENTOR software to determine the performance of materials to make the choice. It appears that the result shows that optimum wheel and bucket performance without an undesirable level of in-service failure was achieved by using the aluminum alloy.

(Williams S. Ebhota1, 2017), in their work uses SOLIDWORKS modeling and simulation software to determine material performance as measured by von Mises, displacement and deformation results in order to select the best material for bucket design and production. Pelton turbine.

(Reddy NNI, 2015), uses CATIA V5 design and modeling software, in order to choose the best material to design and optimize a Pelton turbine. It appears from this study that among the three bucket materials selected (steel, cast iron and fiberglass reinforced plastic matrix), the fiberglass reinforced plastic matrix has outstanding performance compared to cast iron.

(Gudukeya L, 2013), investigated the effects of materials, surface texture, and manufacturing methods on the efficiency of a hydropower project within an acceptable cost range. The study concluded that manufacturing more efficient and financially viable Pelton turbines for micro-hydropower system (MHS) is possible. In their project, more electricity was produced at a reduced cost per unit of kW improving its viability.

2. Selection method using the multi-criteria decision method (MCDM).

There is no systematic and efficient approach to selecting the best material ; therefore, engineers adopt a number of criteria for such selection. The following work presents some results of the use of MCDMs for the selection of materials.

(Thakker A, 2008), presented a novel approach to developing a strategy for turbine blade material selection. The results were found consistent by finite element analysis and sensitivity analysis, which further validated the material selection approach developed. This approach has proven useful in selecting the correct hardware components for rotating parts/machines.

(Rao RV, 2008), proposed a decision-making framework model for material selection using the combined methods MADM with TOPSIS and AHP to assess the rank of the material in the selection index. MSI evaluated the rank order to select the best material for a given engineering application.

(Chatterjee, 2009), have proposed a compromise ranking and over-ranking method for the material selection problem. Here, ELECTRE I is used to obtain a partial ranking and ELECTRE II is used to calculate the final ranking of the alternatives.
(Mansor, 2013), described the application of the Analytical Hierarchy Process (AHP) to evaluate the appropriate natural fiber polymer composite for the design of a passenger vehicle mid-lever brake component.
(Anojkumar L, 2014), developed hybrid MCDM method by combining four MCDM methods namely FAHP-TOPSIS, FAHP-VIKOR, FAHP-ELECTRE and FAHP -PROMTHEE to solve the difficulty of selecting pipe materials in sugar industry to choose the best one pipe material. This method can also be applied to other sugar industry problems and other decision-making problems. TherebyIhe comparative results show that the application of VIKOR provides valuable support for decision-making problems in material selection. (Ohunakin, 2018), used five multi-criteria methods to investigate a suitable siting site for solar power plants for power generation. The result shows that the MCDM method used was valid for the study since solar energy is one of the most cost-effective renewable energies for sustainability.
By comparing the methods of selection of materials by the determination of the performances using the software and that of selection by the multicriteria decision method (MCDM), we note that that of determinations of the performances are limited only on the aspect of the physical, mechanical properties. While MCDM methods take into account several aspects such as environmental, economic and sometimes even social. View that the research work on the choice of materials of the buckets of the micro Pelton turbine by the MCDM method is non-existent ; we requested the latter because it allows us to base ourselves on several criteria in order to choose the best choice among several alternatives. Thus, the novelty of this study is the proposal of a methodology, consisting of the combination of AHP, TOPSIS and VIKOR to select the best material for the bucket of a micro Pelton turbine in the Cameroonian context.

METHODS

Analytical Hierarchy Process

The Analytical Hierarchy Process (AHP), developed by (Saaty, 1980), explains how to determine the relative importance of a set of activities in a multi-criteria decision problem. The process allows for the integration of judgments on intangible qualitative criteria alongside tangible quantitative criteria (Badri, 2001). The AHP method is based on three principles : first, the structure of the model ; second, a comparative judgment of alternatives and criteria ; third, the summary of priorities. In the literature, AHP has been widely used to solve many complex decision-making problems ((Chan, 2007);(Dagdeviren, 2008) (Kahraman, 2004);(Kulak, 2005)). In AHP, pairwise multiple comparisons are based on a standardized comparison scale of nine levels. The coherence study calculates the coherence ratio (RC), the coherence index (CI) while adopting the R. I of Satty (1990). Thus Tables 2 and 3 shows the relative ranking scale and the R.I values to generate the pairwise comparison matrix.

Table1: Satty Relative Ranking Scale (2008)

Definition	The intensity of materiality
Equal importance	1
Moderate importance	3
High importance	5
Very strong importance	7
Extreme importance	9
Intermediate values	2, 4, 6, 8

Table 2: Random inconsistency indices for n=10

Not	1	2	3	4	5	6	7	8	9	10
IR	0.00	0.00	0.58	0.9	1.12	1.24	1.35	1.41	1.46	1.49

Thus for the calculations of the criterion weights, AHP recommends the use of the following equations

M
$$\begin{array}{cc} & \begin{array}{cccc} C_1 & C_2 & - & C_n \end{array} \\ \begin{array}{c} A_1 \\ A_2 \\ A_3 \\ - \\ A_M \end{array} & \begin{bmatrix} x_{11} & x_{12} & - & x_{1n} \\ x_{21} & x_{22} & - & x_{2n} \\ x_{31} & x_{32} & - & x_{3n} \\ - & - & - & - \\ x_{m1} & x_{m2} & - & x_{mn} \end{bmatrix} \end{array}$$
Where i=1, 2, 3,…, m and j=1, 2, 3,…,n 8

D
$$a_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \qquad 2$$

$$w_{ij} = \frac{\sum_{j=1}^{n} b_{ij}}{n} \qquad 3$$

Assuming that all i and j = 1 ; 2 ; 3……; n, the equation below gives the correlation between the weights of the vectors, w, and the pairwise comparison matrix b output.
A_W=λ_max W 4
If the pairwise comparisons are perfectly consistent, matrix A has rank 1 and. In this case ; the weights can be obtained by normalizing one of the rows or columns of Aλ_max=n(Wang, 2007).
If
$$\lambda_{max} = \frac{\sum_{j=1}^{n} w_{ij}}{n}$$
It should be noted that the quality of the AHP output is strictly related to the consistency of the pairwise

comparison judgments. Consistency is defined by the relationship between the entries of R : The CI coherence index is :$a_{ij} \times a_{jk} = a_{ik}$

$$CI=(\lambda_{max}-n)/(n-1) \quad 6$$

The final consistency ratio (CR), the use of which allows someone to conclude whether the ratings are sufficiently consistent, is calculated as the ratio of the CI and the random index (RI), as shown.

$$CR=CI/RI \quad 7$$

The number 0.1 is the accepted upper limit for CR. If the final consistency rate exceeds this value, the evaluation procedure should be repeated to improve the consistency. The consistency measure can be used to assess the consistency of the decision makers as well as the consistency of the overall hierarchy (Wang, 2007).

Order Preference Technique by Similarity to Ideal Solution

TOPSIS (Order preference technique by similarity to the ideal solution) is an MCDM method which takes the decision matrix as input and produces a ranking of the candidates as output, but it is limited by a phenomenon of ranking anomaly which can alter the quality of the selection. This technique was developed by (Hwang CL, 1981), the alternative is selected based on the shortest Euclidean distance of the ideal solution. In an ideal solution, all attribute value solutions correspond to the highest attribute values and the negative ideal solutions are the lowest attribute values in the database. Therefore, the TOPSIS method chooses the solution which is close to the positive ideal solution and far for the negative ideal solution (Khorshidi R, 2013) n. If, an MCDM problem contains an alternative solution (A_1, A_2, A_3,…,Am) and m Criteria (C_1, C_2, C_3,…, Cn) all the alternatives are evaluated by m Criteria. In the decision matrix, the assigned values are denoted by X (xij). Let W= (w_1, w_2, w_3,….,wm) is the satisfying vector criterion. Therefore, create a decision matrix for ranking. $n \times m \; \sum_{j=1}^{m} wj = 1$

The formation of the matrix can be expressed as follows :

$$\begin{bmatrix} & C_1 & C_2 & - & C_n \\ A_1 & x_{11} & x_{12} & - & x_{1n} \\ A_2 & x_{21} & x_{22} & - & x_{2n} \\ A_3 & x_{31} & x_{32} & - & x_{3n} \\ - & - & - & - & - \\ A_M & x_{m1} & x_{m2} & - & x_{mn} \end{bmatrix} \text{Where } i=1, 2, 3,..., m \text{ and } j=1, 2, 3,...,n \quad 8$$

The TOPSIS technique can be as follows :

Step 1: Analyze the normalized decision matrix and the value where rij is calculated as

$$r_{ij} = {X_{ij}} \Big/ {\sqrt{\sum_{j=1}^{i=m} x_{ij}^2}} \quad \text{Where } i=1, 2, 3,..., m \text{ and } j=1, 2, 3, ..., n$$

Step 2: Similar to the AHP method, analyze the weighted normalized decision matrix and the value which is expressed asv_{ij}

$v_{ij}=w_i r_{ij}$ Where i=1, 2, 3,…, m and j=1, 2, 3, …n

Step 3: Find out the positive (best) ideal (V+) and the negative (worst) ideal solutions (V-) as shown in the following equation:

$$v^+ = \left\{\left(\sum_i^{max} {v_{ij}}/_{jej}\right), \left(\sum_i^{min} {v_{ij}}/_{jej'}\right) \, i = 1,2,3, \, ,m\right\}, v^+ = \{v_1^+, v_2^+, v_3^+, v_4^+, v_5^+\} \quad 10$$

$$v^- = \left\{\left(\sum_i^{min} {v_{ij}}/_{jej}\right), \left(\sum_i^{max} {v_{ij}}/_{jej'}\right) \, / \, i = 1,2,3, \, ,m\right\}, v^- = \{v_1^-, v_2^-, v_3^-, v_4^-, v_5^-\} \quad 11$$

Where j = (j=1, 2, …, n) / j is the ideal criterion and j' = (j=1, 2, …, n) / j is the non-ideal criterion.

Step 4: Using the Euclidean distance, find the separation measurements. It is calculated from the positive and negative ideal, the ideal solutions as follows :

$$s_i^+ = \sqrt{\sum_{j=1}^{n}\left(v_{ij} - v_j^+\right)^2} \quad \text{Where } i = 1, 2, 3,..., m$$

$$s_i^- = \sqrt{\sum_{j=1}^{n}\left(v_{ij} - v_j^-\right)^2} \quad \text{Where } i = 1, 2, 3,..., m \quad 13$$

Step 5: Determine the relative proximity of the ideal solution and the alternative Aij can be defined as

$$R_i = \frac{s_i^-}{s_i^+ + s_i^-}, S_i^+ \geq 0, S_i^- \geq 0, \; et \; R_i \in [0,1].$$

Step 6: Based on Ri values, rank the alternatives in descending order and select an alternative that has the maximum Ri value.

Vikor

The VIKOR method was developed by Opricovic (1998) to solve MCDM problems with contradictory and non-commensurable criteria. The method focuses on selecting and ranking from a set of alternatives and a compromise solution is obtained with the initial weights of a problem with conflicting criteria (Anojkumar L, 2014). Since the TOPSIS methodology does not take into account the relative distances of the positive and negative ideal solution. The limitations can be overcome through the VIKOR methodology. This method focuses on ranking and selecting among a set of alternatives, and determines the compromise solution obtained with the initial weights for a problem with conflicting criteria. Assuming that each alternative is calculated according to each criterion function, the trade-off ranking is performed by comparing the proximity measure to the ideal alternative. The different alternatives are denoted A1, A2. . . Am. For alternative Aj, the rating of the ith aspect is denoted by fij, ie fij is the value of the ith criterion function for the alternative aj; n is the number of criteria.

$$L_{pj} = \left\{\sum_{i=1}^{n}\left[w_i\left(f_i^* - f_{ij}\right)/\left(f_i^* - f_i^-\right)\right]^p\right\}^{1/p} \; 1 \leq p \leq \infty, \; j = 1,2,\ldots,j$$

In the VIKOR method L1,j (as Sj) and L1,j (as Rj) are used to formulate a ranking measure. The results are obtained in minj Sj est with the maximum utility of the group (rule of the "majority"), and the response obtained by min Rj is with a minimum of individual regret of the "opponent". VIKOR's Compromise Ranking Algorithm includes the following steps

Step 1: The purpose of performance matrix normalization is to unify the unity of matrix entries. The determination of the normalized values of the alternatives Xij is the numerical score of the alternative j on criterion i. The corresponding normalized value fij is defined as follows.

$$r_{ij} = X_{ij} \Big/ \sqrt{\sum_{i=1}^{i=m} x_{ij}^2} \quad \textit{Where } i=1, 2, 3, \ldots, m \textit{ and } j=1, 2, 3, \ldots, n$$

Step 2: Determine the best Fi and the worst Fi from the criteria functions, i =1, 2, 3, . . .,m

$f_i^*=\max_j f_{ij}, f_i^-=\min_j f_{ij}$

Step 3: The utility measure and the regret measure for each maintenance alternative are given as by:

$$S_j = \sum_{i=1}^{n} w_i \left(f_i^* - f_{ij}\right)/\left(f_i^* - f_i^-\right) \qquad 17$$

$$R_j = max_i \left[\left(f_i^* - f_{ij}\right)/\left(f_i^* - f_i^-\right)\right] \qquad 18$$

Where Sj and Rj represent the usefulness measure and the regret measure respectively and wj is the weight, jth the criterion.

Step 4: Calculate the VIKOR index.

$$Q_j = \vartheta \frac{(S_j - S^*)}{(S^- - S^*)} + (1-\vartheta) \frac{(R_j - R^*)}{(R^- - R^*)} \qquad 19$$

Where S*= minj Sj, S- = maxj Sj, R*= minj Rj, R- = maxj Rj group"), here $\vartheta=0{,}5$

Step 5 : Rank the order of preference

The alternative with the lowest VIKOR value is determined to be the best value. Propose as a compromise solution the alternative A', which is ranked the best by the measure Q (Minimum) if the following two conditions are met :

METHODOLOGY

The proposed methodology is the combination of three MADM comprising three basic steps : (1) Identification of the criteria to be used in the model, (2) Calculation of the AHP, (3) Ranking of the alternatives using TOPSIS and VIKOR. The schematic diagram of the proposed methodology for material selection is shown in Figure 3. In the first step, material alternatives and evaluation criteria were identified and a decision hierarchy was framed. The AHP model was structured such that the objective was at the first level of the hierarchy ; the criteria at the second level and the alternative materials at the third level.

The decision-making hierarchy was approved by the decision-making team at the end of the first stage. After approval from the decision hierarchy, the criteria used in material selection were weighted using the AHP in the second step. In the second phase, in order to determine the weights of the criteria, pairwise comparison matrices were formed.

Experts from the decision-making team perform ratings using the Satty scale to determine the values of items in pairwise comparison matrices. The geometric mean of the values obtained from the evaluations was calculated. Consensus iwa reached on a final pairwise comparison matrix that was formed. Based on this final comparison matrix, the criteria weights were calculated. These weights were approved by a decision-making team towards the completion of this phase. The ranks of the materials were determined using the VIKOR, TOPSIS methods, in the third step.

Material Selection Criteria

In this article, the evaluation criteria and materials are identified for the selection of the optimal material through the literature ((smith, 2005),(Prado, 2010),(Pravin, 2007),(Wesley, 2012)) and industry experts. After the evaluation criteria are identified, alternative materials are studied and the decision-making team determines five possible alternatives and the seven influencing criteria for the evaluation process. The identified evaluation criteria are described as follows :

(1) Machinability of the material (M) : ability of a material to be easily cut or worked ; does not cause excessive tool wear

(2) Ultimate Tensile Strength (UTS) : It helps to provide a good indication of a material's toughness and it is the material's ability to withstand external forces well.

(3) The density of the material (D) : the value of the density is very important because the density influences

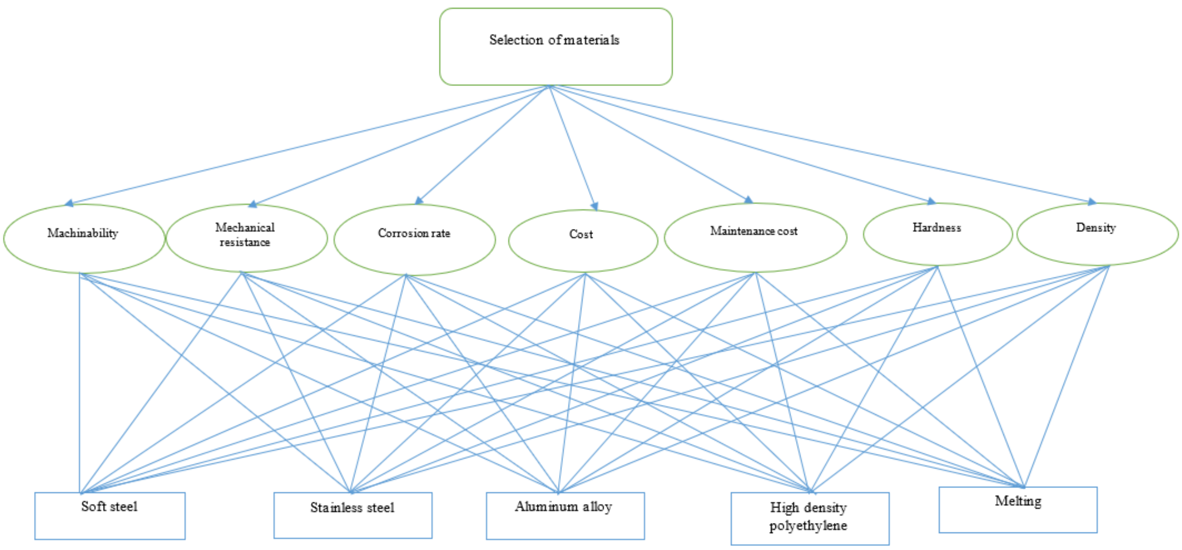


Figure 2 : The decision-making hierarchy by the AHP.

the weight/strength ratio.

(4) Hardness (H) : Ability of a material to resist pressure

(5) Cost (C) : it symbolizes the value of the money that was used to buy the material.

(6) Maintenance cost (MC) : this represents the cost incurred to keep the material in good working order before any major defect.

(7) Corrosion Resistance (CR) : This is a natural process that seeks to reduce the bond energy in metals. It has a major role to improve the service life of the material.

The alternatives considered are the alternative materials : mild steel (MS) ; aluminum alloy (AA) ; stainless steel (SS) ; high density polyethylene (HDPE) and cast iron (E).

The decision-making hierarchy by the AHP and. Schematic flowchart of the methodology developed for an optimal selection of materials.

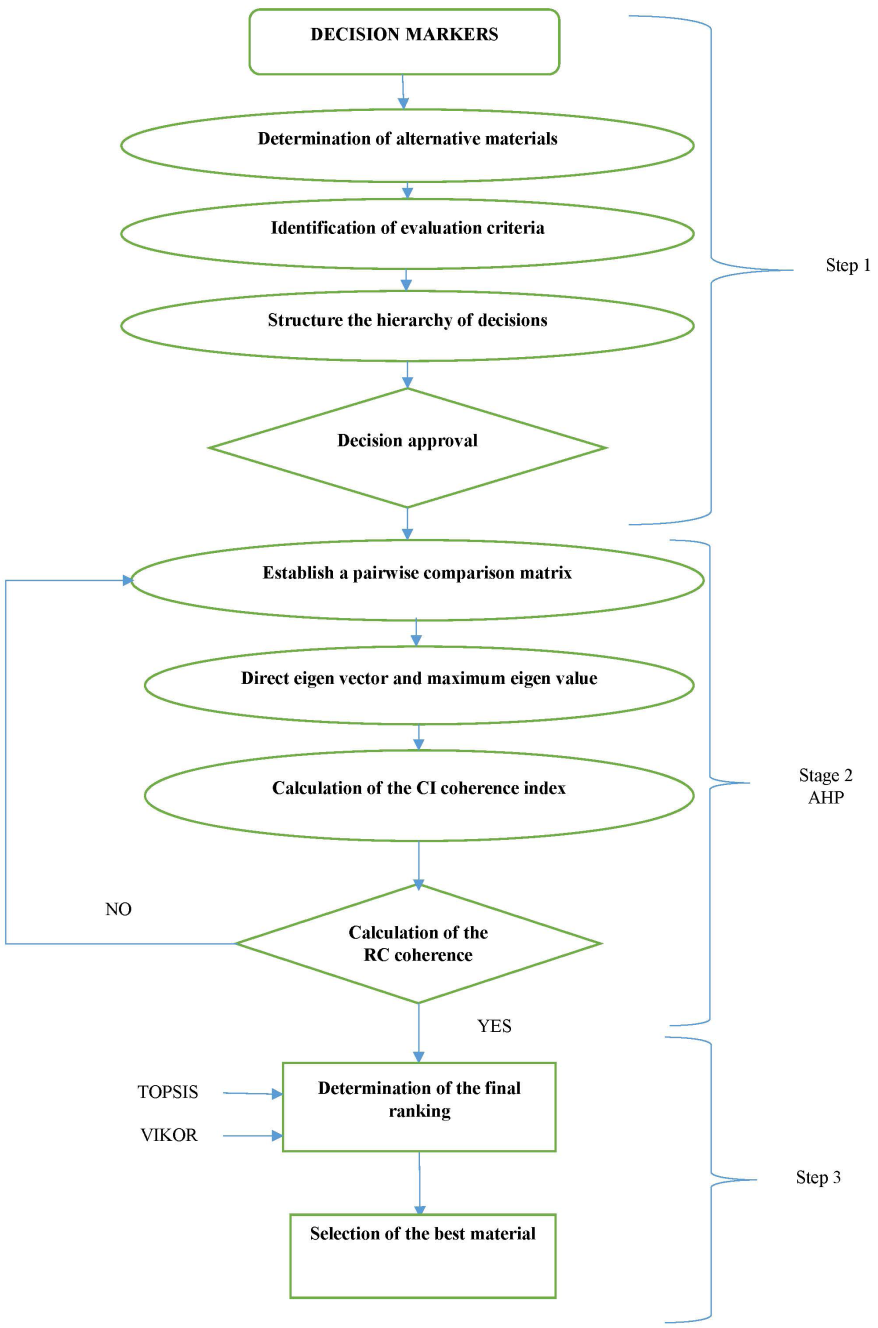


Figure 3 : Schematic flow chart of developed methodology for optimal material selection

RESULTS AND DISCUSSION

For the determination of the suitable material for making the buckets of the micro Pelton turbine, we defined the pairwise comparison matrix and scored the criteria according to the relative scale of extreme importance to equal importance in Table 3. Normalized pairwise model, the total pairwise model, is used to divide each interest ; we obtain Table 4, and equation (2) is used for the average weight of the pairwise matrix, as shown in Table 4.

After feedback of questions we sent to material science experts, engineers and power plant manufacturers we got the decision matrix below.

The details of the survey carried out, of the questionnaire given in appendix A.

Table 3: The pairwise comparison matrix developed using the AHP method for the seven (7) criteria.

	Machinability	**Corrosion resistance**	**Density (kg/cm3)**	**Tensile strength Rm (Mpa)**	**Hardness**	**Cost (€ / kilo)**	**Maintenance cost**
M	1.0000	7.0000	3.0000	4.0000	3.0000	4.0000	2.0000
UTS	0.1429	1.0000	0.3333	0.5000	0.3333	0.2000	0.5000
D	0.3333	3.0000	1.0000	3.0000	3.0000	2.0000	5.0000
RC	0.2500	2.0000	0.3333	1.0000	0.3333	0.3333	0.5000
H	0.3333	3.0000	0.3333	3.0000	1.0000	3.0000	3.0000
RC	0.2500	5.0000	0.5000	3.0000	0.3333	1.0000	2.0000
CM	0.5000	2.0000	0.2000	2.0000	0.3333	0.5000	1.0000
TOTAL	2.8095	23.0000	5.7000	16.5000	8.3333	11.0333	14.0000

We used equation (2) for matrix normalization.

Table 4: Normalization of the expanded pairwise comparison matrix.

Criteres	**M**	**Uts**	**D**	**Cr**	**H**	**Cr**	**Cm**
M	0,32777357	0,27694945	0,64489173	0,22911482	0,46952812	0,48537338	0,16513379
UTS	0,0468	0,0396	0,0717	0,0286	0,0522	0,0243	0,0413
D	0,1093	0,1187	0,2150	0,1718	0,4695	0,0589	0,4128
CR	0,0819	0,07912842	0,0717	0,0573	0,0522	0,0404	0,0413
H	0,1093	0,11869262	0,0717	0,1718	0,1565	0,3640	0,2477
CR	0,0819	0,19782104	0,1075	0,1718	0,0522	0,1213	0,1651
CM	0,1639	0,07912842	0,0430	0,1146	0,0522	0,0607	0,0826
TOTAL	0,9209	0,9100	1,2253	0,9451	1,3042	1,1550	1,1559

To determine the consistency analysis of the pairwise comparison matrix, equations (3), (5), and (6) are used. Thus Table 5 presents the result obtained with the AHP method.

Table 5: The result obtained by the AHP method.

Criteria	**Weight**	**λ_max**	**CI**	**CR**
M	0.32777357	7.54269427	0.09044904	0.06699929
UTS	0.03956421			
L	0.21496391			
D	0.0572787			
VS	0.15650937			
RC	0.12134335			
CM	0.08256689			

After determining the weight of the criteria with the AHP, we will apply the TOPSIS technique to rank the selected alternatives. Thus Table 6 shows the vector matrix.

Table 6: Vector matrix of chosen materials

Materials/ Alternatives		**Properties**					
	Machinability	**Corrosion resistance**	**Density (kg/cm3)**	**Tensile strength (Mpa)**	**Hardness**	**Cost (€/kilo)**	**Maintenance cost**
Soft steel	3	1	7.85	400	5	1.25	4
Stainless steel	4	4	7.7	720	4	1.5	3
HDPE high density polyethylene	5	5	0.965	6	2	1.67	2
Melting	3	2	7.2	350	4	0.9	4
Aluminum alloy	4	5	2.7	80	4	2.48	2

Subsequently, we will use equation (8). And equation (9) to determine the best ideal and the worst ideal for the four alternatives. Hence the Euclidean distance from

Subsequently, we will use equation (8). And equation (9) to determine the best ideal and the worst ideal for the four alternatives. Hence the Euclidean distance from best

ideal (V+), worst ideal (V-), using equations (13), (14), and (15) to analyze the performance score for the final ranking of the alternatives. Tables 7, 8, 9, and 10 give the results respectively. S_1^+ S_1^-

Table 7 : The standardized decision matrix with criteria and alternatives.

Criteria / Alternatives	**Machinability**	**Corrosion resistance**	**Density**	**Tensile strength**	**Hardness**	**Cost (price)**	**Maintenance cost**
Soft steel	0.043478261	0.01408451	0.06171324	0.000617536	0.0877193	0.09434461	0.10810811
Stainless steel	0.057971014	0.05633803	0.06053401	0.001111564	0.07017544	0.11321353	0.08108108
HDPE	0.072463768	0.07042254	0.0075864	9.26303E-06	0.03508772	0.12604439	0.05405405
Melting	0.043478261	0.02816901	0.05660323	0.000540344	0.07017544	0.06792812	0.10810811
Aluminum alloy	0.057971014	0.07042254	0.02122621	0.000123507	0.07017544	0.1871797	0.05405405

Table 8 : The weighted normalized decision matrix with criteria and alternatives

Criteria / Alternatives	**Machinability**	**Corrosion resistance**	**Density**	**Tensile strength**	**Hardness**	**Cost (price)**	**Maintenance cost**
Soft steel	0.014251025	0.00055724	0.01326612	3.53716E-05	0.01372889	0.01144809	0.00892615
Stainless steel	0.019001366	0.00222897	0.01301263	6.36689E-05	0.01098311	0.01373771	0.00669461
HDPE	0.023751708	0.00278621	0.0016308	5.30575E-07	0.00549156	0.01529465	0.00446308
Melting	0.014251025	0.00111448	0.01216765	3.09502E-05	0.01098311	0.00824262	0.00892615
Aluminum alloy	0.019001366	0.00278621	0.00456287	7.07433E-06	0.01098311	0.02271301	0.00446308
Weight	0.327773567	0.03956421	0.21496391	0.057278704	0.15650937	0.12134335	0.08256689

Table 9 : The calculation of the best ideal value and the worst ideal value

V+	0.023751708	0.00278621	0.0016308	6.36689E-05	0.00549156	0.02271301	0.00892615
V-	0.014251025	0.00055724	0.01326612	5.30575E-07	0.01372889	0.00824262	0.00446308

Table 10: The Euclidean distance () best ideal () worst ideal and the performance score used for rankingS_1^+ S_1^-

Alternatives	S_i^+	S_i^-	**Pi**	**Rank**
Soft steel	0.020624374	0.00549502	0.21038089	4
Stainless steel	0.016374223	0.00825492	0.33516871	3
HDPE	0.008657663	0.01866003	0.68307485	1
Melting	0.021062601	0.00538297	0.20354916	5
Aluminum alloy	0.009013445	0.01789447	0.66502624	2

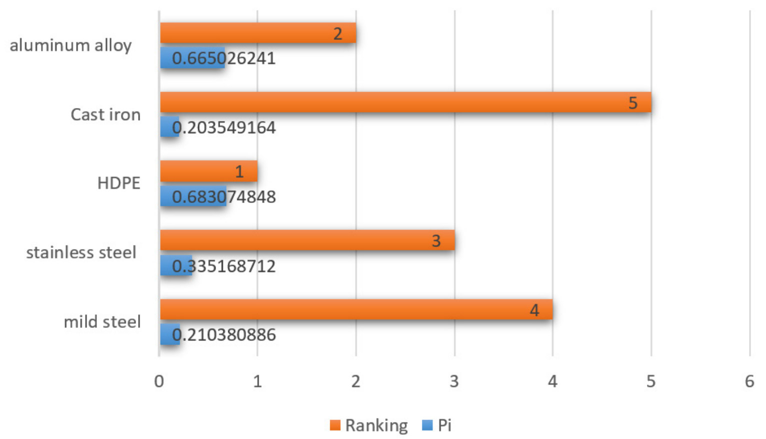


Figure 4: Classification diagram TOPSIS method

In the selection of a suitable material for the manufacture of a Pelton turbine bucket by the TOPSIS method, High Density Polyethylene (HDPE) has the best performance value of 0.68, followed by aluminum alloy of 0.66; stainless steel 0.33; mild steel 0.21 and cast iron 0.20. Analysis of the results shows High Density Polyethylene (HDPE) is the appropriate material to manufacture the bucket of the micro Pelton turbine.

After using the TOPSIS method, we move on to the VIKOR method to also propose a classification of the alternatives selected for the manufacture of the micro turbine buckets. The normalized decision matrix is calculated in the same way as the TOPSIS methodology, the resulting normalized decision matrix is shown in Table 11.

Table 11: The standardized decision matrix

Criteria	Machinability	Corrosion resistance	Density	Tensile strength	Hardness	Cost (price)	Maintenance cost
Soft steel	0.04347826	0.01408451	0.06171324	0.00061754	0.0877193	0.09434461	0.10810811
Stainless steel	0.05797101	0.05633803	0.06053401	0.00111156	0.07017544	0.11321353	0.08108108
HDPE	0.07246377	0.07042254	0.0075864	9,263E-06	0.03508772	0.12604439	0.05405405
Melting	0.04347826	0.02816901	0.05660323	0.00054034	0.07017544	0.06792812	0.10810811
Aluminum alloy	0.05797101	0.07042254	0.02122621	0.00012351	0.07017544	0.1871797	0.05405405

The best and worst values for each criterion are calculated using Equation 17 and the resulting values are tabulated in Table 12.

Table 12: The best and the worst values of each criterion

X+	Best	5.0000	5.0000	7.8500	720.0000	5.0000	2.4800	4.0000
X-	worth	3.0000	1.0000	0.9650	6.0000	2.0000	0.9000	2.0000

The utility measure and regret measure values are calculated using equations (18) and (19). Finally, the value of the VIKOR index is calculated using equation (20). Based on the value of the VIKOR index, the rankings are assigned to the materials and the results obtained are all the results are in Table 13.

Table 13: Result of the classification by the VIKOR method

Criteria	Machi -nability	Corrosion resistance	Density	Tensile strength	Hard-ness	Cost (price)	Mainte-nance cost	Si	Ri	Qi	rank
Soft steel	0.81230841	0.04931595	0.24316639	0.05775999	0.25627266	0.18321735	0.16067071	1.76271144	0.81230841	0.52072945	4
Stain lesssteel	0.80993323	0.04889802	0.2432032	0.05775999	0.25718791	0.18176822	0.16178648	1.76053706	0.80993323	0.26275352	3
HDPE	0.80755806	0.04875871	0.24485634	0.05775999	0.25901843	0.18078282	0.16290225	1.7616366	0.80755806	0.01678676	1
Melting	0.81230841	0.04917664	0.37101953	0.05775999	0.25718791	0.18524612	0.16067071	1.89336931	0.81230841	1	5
Aluminum alloy	0.80993323	0.04875871	0.24443048	0.05775999	0.25718791	0.17608765	0.16290225	1.75706022	0.80993323	0.25	2
							S*,R*	1.75706022	0.80755806		
							S-,R-	1.89336931	0.81230841		

In the selection of a suitable material for the manufacture of Pelton turbine buckets by the VIKOR method, High Density Polyethylene (HDPE) has the smallest VIKOR index of 0.016; followed by 0.25 aluminum alloy ; stainless steel ; mild steel and 0.26 cast iron ; of 0.52 and 1. Analysis of the results shows high density polyethylene (HDPE) is the appropriate material to manufacture the bucket of the micro Pelton turbine.

Although in this study High Density Polyethylene (HDPE) is the appropriate material to manufacture the bucket of the micro Pelton turbine in our study because of its excellent machinability; good corrosion resistance

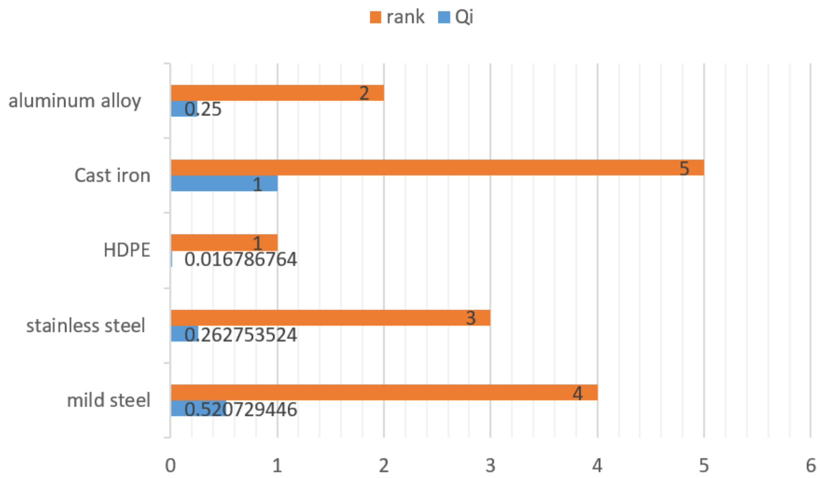


Figure 5 : Classification diagram VIKOR method

low maintenance cost. It will be advantageous to choose the aluminum alloy which comes in second position in the classification also because of the very good physical and chemical properties and above all a good resistance to ultimate traction compared to HDPE. Thus, this result agrees with that (Felix A. Isholaa, 2019) who in his work measured the performance of materials to determine stress, strain and von Mises displacement ; and the result shows that optimum wheel and bucket performance without an undesirable level of in-service failure was achieved by using the aluminum alloy. We can further justify our choice by the results obtained by (Asodariya, 2018), during their work; The authors performed a performance analysis on the speed ratio, weldability and running of the aluminum alloy. The result confirmed that the aluminum alloy has good functional speed.

CONCLUSION

Micro hydroelectricity is a very important solution in the production of electricity for isolated populations. In the selection of materials of hydromechanical components of hydropower plants, the choice of the best material is the major problem because of its impact on installation, operation and maintenance costs. The study proposed a material selection methodology for the fabrication of buckets of the micro Pelton turbine using AHP, TOPSIS and VIKOR in MCDM. The result of the rankings of the five alternatives, i.e. aluminum alloy, stainless steel, cast iron, Since we have made a review study on the materials studied for the choice of the material, we recommend the aluminum alloy which is second in the classification because of its excellent physical and chemical properties, especially its good resistance to ultimate traction and also its availability in our environment. Thus, the application of this methodology may have an impact on the rate of rural electrification, since it concerns the choice of local materials for the manufacture of micro hydroelectric turbines. The purpose of which is to facilitate the implementation of micro hydroelectric power plant technologies for isolated populations.

Acronyms

MCDM multiple criteria decision making
IEA International Energy Agency
AHP analytical hierarchy process
TOPSIS technique for order preference by similarity to ideal solution
VIKOR aims kriterijumska optimizacija kompromisno resenje
ELECTRE elimination and choice translating reality
PROMETHEE preference ranking organization method for enrichment of evaluations
FAHP fussy analytic hierarchy process
MPa mega Pascal
HDPE high density polyethylene.

Appendix A

In the material selection process, the assignment of attributes and weightings plays an important role. The AHP methodology requires a pairwise comparison of criteria to determine their relative weights. In order to determine the attributes and assign their weights, the following questionnaire was designed for the survey.
Questionnaire concerning the investigation of the selection of bucket materials for a micro Pelton turbine for hydroelectric power stations.
Thus, please read the following questions and give values on the pairwise comparison matrix below. These questions are designed to assess various attributes in pairs based on your experience. Values are given on a scale of 1 to 9.

Compared to machinability (M)

1. How important is Machinability (M) by Ultimate Tensile Strength (UTS)?
2. How important is machinability (M) versus hardness (H)?
3. How important is machinability (M) to density (D)?
4. How important is machinability (M) to cost (C)?
5. How important is machinability (M) to corrosion resistance (CR)?

6. How important is machinability (M) to maintenance cost (MC)?

Compared to the Ultimate Tensile Strength (UTS) criterion.

1. How important is Ultimate Tensile Strength (UTS) to Hardness (H)?
2. How important is ultimate tensile strength (UTS) versus density (D)?
3. How important is ultimate tensile strength (UTS) to cost (C)?
4. How important is Ultimate Tensile Strength (UTS) versus Corrosion Resistance (CR)?
5. How important is Ultimate Tensile Strength (UTS) to Maintenance Cost (MC)?

Compared to the hardness criterion (H)

1. How important is hardness (H) to density (D)?
2. How important is hardness (H) to cost (C)?
3. How important is hardness (H) to corrosion resistance (CR)?
4. How important is hardness (H) to maintenance cost (MC)?

Compared to the density criterion (D).

1. How important is density (D) versus cost (C)?
2. How important is density (D) to corrosion resistance (CR)?
3. How important is density (D) versus maintenance cost (MC)?

Compared to the cost criterion (C)

1. How important is cost (C) versus corrosion resistance (CR)?
2. How important is cost (C) compared to maintenance cost (MC)?

Compared to the maintenance cost criterion (MC).

1. How important is the maintenance cost (MC) compared to the corrosion resistance (MC)?

REFERENCES

Anojkumar L, IM (2014). Comparative analysis of MCDM methods for pipe material selection in sugar industry. *Expert Systems with Applications, 41,* 2964–80.

Asodariya, HP (2018). Application of multi-criteria decision-making method to select and validate the material of a flywheel design. Mater. Today: *Proceedings, 5,* 17147–17155.

Association., IH (2019). International Hydropower Association. Hydropower Status Report - sector trends and insights. London, UK.

Aydin, N. Y., Kentel, E., & Duzgun, H. S. (2013). GIS-based site selection methodology for hybrid renewable energy systems: A case study from western Turkey. *Energy conversion and management, 70,* 90-106. https://doi.org/10.1016/j.enconman.2013.02

Babu, KR (2006). The material selection for typical wind turbine blades using a MADM approach & analysis of blades. Proceedings of 18th International Conference on Multiple Criteria Decision Making (MCDM 2006), Chania, Greece, 19–23.

Badri, MA (2001). A combined AHP–GP model for quality control systems. *International Journal of Production Economics, 72,* 27–40.

CH Achebe, OO (2020). Design and implementation of a crossflow turbine for Pico hydropower electricity generation. *Helyon, 6.*

Chan, FT (2007). Global supplier development considering risk factors using fuzzy extended AHP-based approach. *OMEGA, 35,* 417–431.

Chatterjee P, AV (2009). Selection of materials using compromised ranking and outranking methods. *Mater Des, 30,* 4043–53.

Chen Y, LD (2016). Capturing the rains: a comparative study of Chinese involvement in Cameroon's hydropower sector. Washington, D.C.

Chisomo Kasamba, PM (2015). Analysis of Flow Estimation Methods for Small Hydropower Schemes in Bua River. *Energy and Power Engineering, 7,* 55-62.

Cicek K, CM (2010). Multiple attribute decision-making solution to material selection problem based on modified fuzzy axiomatic design-model selection interface algorithm. . *Mater Des 31,* 2129–33.

Dagdeviren, M. &. (2008). Developing a fuzzy analytic hierarchy process (AHP) model for behavior-based safety management. . *Information Science,* 1717–1733.

Deng, DZ (2017). Ultra-low-head hydroelectric technology: A review. *Renew. sustain. Energy Rev., 78,* 23–30.

Ebhota, WS (2017). Smart Design and Development of a Small Hydropower System and Exploitation of Locally Source of Material for Pelton Turbine Bucket Production. *Iran. J.Sci. Technology. Trans. Mech. Eng, 9.*

Elie Bertrand Kengne Signe, BB (2019). Performance in Feasibility Studies of Micro Hydro Power Plants New Software Development and Application Cases in Cameroon. *Energy Procedia 157*, 1391–1403.

Elie Bertrand Kengne Signe, OH (2017). Technical and Economic Feasibility Studies of a Micro Hydropower Plant in Cameroon for a Sustainable Development. *Journal of Power and Energy Engineering, 5,* 64-73.

Elie Bertrand Kengne, OH (2017). Methodology of Feasibility Studies of Micro-Hydro power plants in Cameroon: Case of the Micro-hydro of KEMKEN. *Energy Procedia, 119,* 17-28.

ENEO., C. (2019). Step by Step, Eneo is transforming electricity services towards modernizing electricity distribution 2018 Annual Report. Douala.

Engo, J. (2019). Barriers related to the deployment of renewable energies in Cameroon and ways to strengthen policies. *Resour Environ Econ, 1,* 29-38.

Fanyep Nana Antoine, GT (2020). Sustainable Development around Small Scale Mining Areas by the Development of Micro Hydro Power: Application Cases in Cameroon. *Journal of Power and Energy*

Engineering,, 8, 36-48.

Felix A. Isholaa, *. J. (2019). Simulation for Material Selection for a Pico Pelton Turbine's Wheel and Buckets. *Procedia Manufacturing 35,* 1172–1177.

Gudukeya L, MI (2013). Efficiency improvement of Pelton wheel and crossflow turbines in micro-hydro power plants: case study. *Int JEng Computing Sci 2,* 416–432.

Hwang CL, YK (1981). Multiple attribute decision making, methods and applications. Springer-Varlag.

HYDRO., A. (nd). Hydropower in central Africa. HydroNews Africa.

I. Loots, M. v. (2015). A review of low head hydropower technologies and applications in a South African context. *Renewable and Sustainable Energy Reviews, 50,* 1254–1268.

IEA. (2020). World. Energy Outlook 2020. Paris, France.

IEA., A. (2019). Energy Outlook 2019 world energy. Paris: Outlook special report.

Ilangkumaran, M. &. (2010). Integrated hazard and operability study using fuzzy linguistics approach in petrochemical industry. *International Journal of Quality & Reliability Management, 27,* 541–557.

Islam, A. K. M. K., Bhuyan, S., & Chowdhury, F. A. (2013). Advanced composite pelton wheel design and study its performance for pico/micro hydro power plant application. *Int. J. Eng. Innov. Technol, 2*(11), 126-132.

Kahraman, CB (2004). Measuring flexibility of computer integrated manufacturing systems using fuzzy cash flow analysis. *Information Sciences, 168*, 77–94.

Kenfack J, BO (2014). Addressing the current remote area electrification problems with solar and microhydro systems in Central Africa. Renew Energy. doi: https://doi.org/10.1016/j.renene.2013.11.044

Korkovelos A, MD (2018). A geospatial assessment of small-scale hydropower potential in sub-saharan. *Energy, 11,* 1-21.

Kusakana, K. (2014). A survey of innovative technologies increasing the viability of micro-hydropower as a cost effective rural electrification option in South Africa. *Renewable and Sustainable Energy Reviews, 37,* 370–379.

Him D, LH (2019). World small hydropower development report 2019 - Africa. . UNIDO & ICSHP; 2019.

Mahmoodzadeh, SS (2007). Project selection by using Fuzzy AHP and TOPSIS technique. International *Journal of Humanities and Social Sciences, , 1*(3), 135–140.

Mansor, MR (2013). Hybrid natural and glass fibers reinforced polymer composites material selection using analytical hierarchy process for automotive brake lever design. *Materials & Design, 51,* 484–492.

Mas'ud AA, VW-S. (2015). An assessment of renewable energy readiness in Africa: case study of Cameroon and Nigeria. *Renew Sustain Energy Rev, 51,* 775-784.

Mbiu RN, MS (2015). Performance of aluminum A356 alloy based buckets towards bending forces on Pelton turbine. In: *Sustainable research and innovation (SRI),* 134–138.

Mohammad., V. (2015). Future of agricultural water management in Africa. *Arch Agron Soil Sci*, 907-27.

Mohammed YS, MM (2013). Status of renewable energy consumption. *Renew Sustain Energy Rev, 27*, 453-63.

Moradeyo K. Odunfa, TC (2019). Development of a Small Hydropower Plant: Case of Ikere Gorge Dam, Oyo State, Nigeria. *Journal of Power and Energy Engineering, 7,* 31-45.

Mutiara AS, ,. M. (2018). Recent innovations and trends in in-conduit hydropower technologies and their applications in water distribution systems. *Journal of Environmental Management,* 416–428.

Ohunakin, OS (2018). A comparative study of selected multi-criteria decision-making methodologies for location selection of very large concentrated solar power plants in Nigeria. . *Afr. J.Sci. Technology. Innov. Dev. 10*(5), 551–567.

Opricovic, S. &. (2004). Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS. *European Journal of Operational Research, 156*(2), 445–455.

Paish, O. (2002). Small hydro power: technology and current status. *Renew Sustain Energy Rev, 6*(6), 537–56.

Prado, RV (2010). Abrasive wear effect of sugarcane juice on sugarcane rolls. *Wear, 270,* 83–87.

Pravin, GR (2007). Role of stainless steel to combat corrosion in the Indian sugar industry. *International Sugar Journal, 109*(1303), 449–453.

Ravi Kumar n, SS (2015). Penstock material selection in small hydropower plants using MADM methods. *Renewable and Sustainable Energy Reviews, 52*, 240-255.

Reddy NNI, SP (2015). Design and static analysis of Pelton turbine bucket. I*nt J Sci Technol Manag, 4,* 19–25.

SJ Williamson, BH (2014). "Low head pico hydro turbine selection using a multi-criteria analysis. *Renew. Energy, 61,* 43–50.

Saaty, TL (1980). The analytic hierarchy process. New York: McGraw-Hill.

San Cristobal, JR (2011). Multi-criteria decision-making in the selection of a renewable energy project in spain: *The Vikor method. Renewable Energy, 36,* 498–502.

Smith, P. (2005). Piping materials selections and applications. Elsevier.

Tekounegning, Ho (2009). Constraints Of Micro Hydroelectric Power Plants In The West Region Of Cameroon. *Global Journal Of Engineering Research, 8*(1&2), 27-33.

Thakker A, JJ (2008). A novel approach to materials selection strategy case study: wave energy extraction impulse turbine blade. *Mater Des, 29,* 1973–80.

Urban Nzotcha*, JK (2019). Integrated multi-criteria decision making methodology for pumped hydroenergy storage plant site selection from a sustainable development perspective with an application. *Renewable and Sustainable Energy Reviews, 112*, 930–947.

Valipour, MG (2015). Surface irrigation simulation models. a review. *Int J Hydrol Sci Technol, 5*(1), 51-70.

Wang, JJ (2007). Using a hybrid multi-criteria decision aid method for information systems outsourcing. C*omputers and Operations Research,* 3691–3700.

Weber H, P. (2003). FF Simulation models of the hydro power plants in Macedonia and Yugoslavia. . In: Proceedings of the power tech. 2003.

Wesley, S.B. (2012). Corrosion behavior of ferritic steel, ustenitic steel and low carbon steel grades in sugarcane juice. *Journal of Materials & Metallurgical Engineering, 2*(1), 9–22.

Williams S. Ebhota1, FL (2017). Smart Design and Development of a Small Hydropower System and Exploitation of Locally Sourced Material for Pelton Turbine Bucket Production. *Iran J Sci Technol Trans Mech Eng., 80.*