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Assessment of Materials Used in Penstock in Small Hydro Power by TOPSIS Method

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Abstract

There are three kinds of energy resources: fossil fuels, renewable resources, and nuclear resources. An impulse or response turbine is used in a small hydropower (SHP) facility, which is mostly a "run-off-river" in nature. SHP technologies are being employed to generate power for rural electrification in both wealthy and undeveloped nations, and they have minimal maintenance costs and assist to slow down climatic change (but high capital costs). When compared to fossil and nuclear fuels, hydropower constitutes a considerable source of electrical energy today. Hydro resources are also widely available. In many countries, small, mini, and micro-hydro plants are crucial for rural electrification and have the fastest turnaround time for any renewable energy source. This allows them to quickly replace fossil fuels. Selecting the right material plays a crucial part in product design to satisfy all functional criteria. Design is the formulation of data or information, both quantitative and qualitative, where there is always some element of risk and uncertainty. A probabilistic or utilitarian strategy is best adapted to deal with risk and uncertainty. MCDM approach in this study, TOPSIS is utilized to choose the components of the tiny hydropower penstock. The analysis took into account four alternative materials, including polyvinyl chloride (PVC), high-density polyethene (HDPE), glass-reinforced polymer (GRP), and mild steel (MS), as well as five assessment attributes/criteria, including yield strength, life, thickness, material cost, and maintenance cost. polyvinyl chloride (PVC) ranked two, high-density polyethene (HDPE) has rank one, glass-reinforced polymer (GRP) has rank four and mild steel (MS) is having rank three. According to the findings of this investigation, the best materials for penstock in small hydropower are high-density polyethene (HDPE), polyvinyl chloride (PVC), followed by mild steel (MS), and glass-reinforced polymer (GRP).

Introduction

Fossil fuels, renewable energy sources, and nuclear energy are the three main types of energy resources. When compared to fossil and nuclear fuel, hydropower constitutes a considerable source of electrical energy today. Hydro resources are also widely available. It makes up one-fifth of the world's power and is sometimes the only home source of electrical generation [1]. Coal and petroleum are traditional sources of energy available in practically all nations, but their rapid depletion, high prices, and environmental concerns compel researchers to look for alternate clean and sustainable energy sources. Pollution problems are a challenge to the sustainability of people since access to clean air, water, and other natural resources is necessary for a thriving, developed civilization. Therefore, finding answers to environmental problems is essential for sustainable development. Respecting the laws of mass and energy balance is necessary for human sustainability [2]. Energy and development go hand in hand. Growing the production of energy based on fossil fuels has a huge negative impact on the environment, both locally and worldwide. Regulations on greenhouse gas emissions and rising electricity consumption are problems for the power sector. Finding efficient, widely applicable sustainable generating techniques is essential. There are just a few options for electricity generation that meet this condition, including solar, wind, and modest hydropower [3]. 19% of the world's electricity, large and small, from hydroelectricity, which still is "Renewable Energy" for electricity generation and is a very important source. Small Scale hydro is low in Rural in developed countries Electrification is very affordable and environmentally friendly One of the reliable energy solutions is Because it is primarily dam or water "Running down the river" without storage. [4]. Hydropower projects may provide a cheap source of energy and promote the growth of small businesses using a variety of modern technology. The sustainable and environmentally friendly source of power is the energy of moving water. One of the first sources of energy employed by humans, hydraulic power is used in manufacturing and irrigation. Multiple irrigations and drinking water proposals can benefit from installing modest hydro plants [5]. The cost of the project varies depending on the location and the penstock material used, the alignment, the design, and the implementation. Geographical and geological factors have a major role, but so do the manner of construction and the substance [6]. Because of this, it is important to carefully consider the material selection for penstock as well as related factors including surface roughness, design pressure, method of jointing, weight, simplicity of installation, availability, and maintenance [7]. Water is transported from the intake to the powerhouse using penstocks (pipes). They can be built above or below the ground, depending on the conditions and requirements of the location, the kind of ground, the materials used for the penstock, and the temperature [8]. A separate penstock for each turbine Unlike a hydro plant with a common one that provides multiples Separate penstocks from tunnels Branches out to units are hydraulic The link gives results. [9]. Because of their compatibility, availability, and approval, the most typically used materials for a penstock are mild steel, high-density polyethene (HOPE), and un-plasticized polyvinyl chloride (uPVC). In terms of friction losses, weight, corrosion, and cost, for example, uPVC outperforms mild steel and HPDE [10]. High-density polyethene, mostly Polyethylene as a high-density polymer is called, the monomer ethylene A thermoplastic polymer derived from is When used for HDPE pipes It is sometimes referred to as "Alcathene" or "Polythene". is called GRP (Glass Fiber Reinforced Plastic) is a polymer A composite of matrix and glass fibres is a compound object. High-strength steel Application Penstock manufacturing and assembly Technology, management etc. are equivalent It has greatly improved with economic gain. However, numerous misconceptions about the use of high-strength steel plates remained, which weakened their strength [11]. Four alternative materials such as polyvinyl chloride (PVC), high-density polyethene (HDPE), glass reinforced polymer (GRP) and mild steel (MS) and five assessment attributes/criteria such as yield strength, life, thickness, cost of material and maintenance cost have been considered in the analysis. Yield strength (YS) is an incredibly important characteristic in penstock design. Life (L): The useful existence of the substance up to which they serve under all environmental conditions. Thickness (T): The distance between the material's top and bottom surfaces. The quantity of material grows as the thickness increases. Cost (C): The cost of purchasing the material. Maintenance cost (MC): The expense incurred to keep it in proper functioning order before any major problem. [12].

Methodology

Hwang and Yoon's TOPSIS ("Technique for Order of Preference by Similarity to Ideal Solution") approach Chatty's After Analytical Hierarchy Process (AHP). The second is more widely used and is a popular MCDM method. This is because it is basic and straightforward to use, and it can be used in situations with a huge number of criteria and options [13]. Vector normalization of the TOPSIS calculation steps, Calculating the weighted normal result matrix, positive ideal (PIS) solution Finding the negative optimal solution (NIS), and Finding the separation or distance of each resulting array by Boil to normalize. BIS and Change from NIS, Rank by finding the code, each How close the substitution is to the bis Find out that there is, finally optional Sorts the array [14]. Numerous practical applications of TOPSIS exist, including firm performance comparison, financial ratio performance within a certain industry, and monetary investment in modern manufacturing systems, among others. There are certain restrictions, though. The performance ratings and weights of the criterion are provided as precise values in the TOPSIS procedure [15]. Up until now, efforts to enhance the original TOPSIS approach have mostly focused on increasing the weight in order to increase the R value's sensitivity. Additionally, the R-value formula has been improved, for example with the "Miqiezhi" approach [16]. The TOPSIS approach does, however, have certain downsides. The fact that TOPSIS can result in the phenomena known as the rank reversal is one of the issues it raises. When an alternative is added to the selection problem or when removed, this event Changes the order of preference for alternatives. When an alternative is added to the process or when removed, it sometimes is The total rank is known inversely, and the order of preferences is completely reversed When changing and before that is better The considered alternative now turns out to be worse. In many cases, such an event may be unacceptable [17].

Step 1: The decision matrix X, which displays how various options perform in relation to certain criteria, is created.

$$x_{ij} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & x\cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \tag{1}$$

Step 2: Weights for the criteria are expressed as

$$w_j = [w_1 \cdots w_n], \tag{2}$$

where ,$\sum_{j=1}^{n}(w_1 \cdots w_n) = 1$

Step 3: The matrix x_{ij}'s normalized values are computed as

$$n_{ij} = \frac{x_{ij}}{\sqrt[2]{\sum_{i=1}^{m} x_{ij}^2}} \tag{3}$$

Weighted normalized matrix N_{ij} is calculated by the following formula

$$N_{ij} = w_j \times n_{ij} \tag{4}$$

Step 4: We'll start by determining the ideal best and ideal worst values: Here, we must determine whether the influence is "+" or "-." If a column has a "+" impact, the ideal best value for that column is its highest value; if it has a "-" impact, the ideal worst value is its lowest value.

Step 5: Now we need to calculate the difference between each response from the ideal best,

$$S_i^+ = \sqrt{\sum_{j=1}^{n}(N_{ij} - A_j^+)^2} \qquad \text{For } i \in [1, m] \text{ and } j \in [1, n] \tag{5}$$

Step 6: Now we need to calculate the difference between each response from the ideal worst,

$$S_i^- = \sqrt{\sum_{j=1}^{n}(N_{ij} - A_j^-)^2} \qquad \text{For } i \in [1, m] \text{ and } j \in [1, n] \tag{6}$$

Step 7: Now we need to calculate the Closeness coefficient of i_{th} alternative

$$CC_i = \frac{S_i^-}{S_i^+ + S_i^-} \qquad \text{Where } 0 \le CC_i \le 1, i \in [1, m] \tag{7}$$

Now rank according to the Closeness coefficient, i.e. higher the score, better the rank
Four alternative materials such as polyvinyl chloride (PVC), high-density polyethene (HDPE), glass reinforced polymer (GRP) and mild steel (MS) and five assessment attributes/criteria such as yield strength, life, thickness, cost of material and maintenance cost have been considered in the analysis. **Yield strength:** Depending on the yield strength, a material Can be rigid or flexible. Anything from elastic to plastic This is the moment of change. Based on requirements, Suitable materials for construction yield strength helps in selection [18]. **Life:** Concrete dams and embankments with good design, construction, maintenance, and monitoring can easily last 100 years. After 30 to 50 years, hydro-mechanical components like gates and their motors need to be changed. Penstocks have a lifespan of 40 to 60 years. **Thickness:** Due to the risk of bursting, the pipe wall should be sturdy enough to resist the maximum water pressure, making the penstock's pressure rating crucial. The head determines the pressure of the water in the penstock; the higher the head, the higher the pressure. [20]. **Cost of material:** Oftentimes, the penstock—which might account for up to 40% of the project's overall cost—is the most expensive component [21]. **Maintenance cost:** During usage, the penstock should be given rust prevention treatment. Every two to three months, grease or oil should be added to the penstock hoist, bearing, nut, and screw, and the surface of the penstock should be cleaned of rust and sprayed with anti-rust paint. To make sure that the water-stop joint surface of the penstock and the penstock frame is smooth when opening and closing, the bearing section should be filled with butter during major maintenance [22].

Analysis and Results

TABLE 1. Quantitative values of the material selection attribute.

Materials	YS(Mpa)	L(year)	T(mm)	C($/m)	MC($/m/year)
PVC	26	12	40	863.59	17.26
HDPE	34	25	46	1239.61	37.19
GRP	138	40	8	470.42	7.05
MS	252	50	9	630.65	37.84

Table 1 shows the data for the decision matrix. The analysis took into account four alternative materials, including polyvinyl chloride (PVC), high-density polyethene (HDPE), glass-reinforced polymer (GRP), and mild steel (MS), as well as five assessment attributes/criteria, including yield strength, life, thickness, material cost, and maintenance cost.

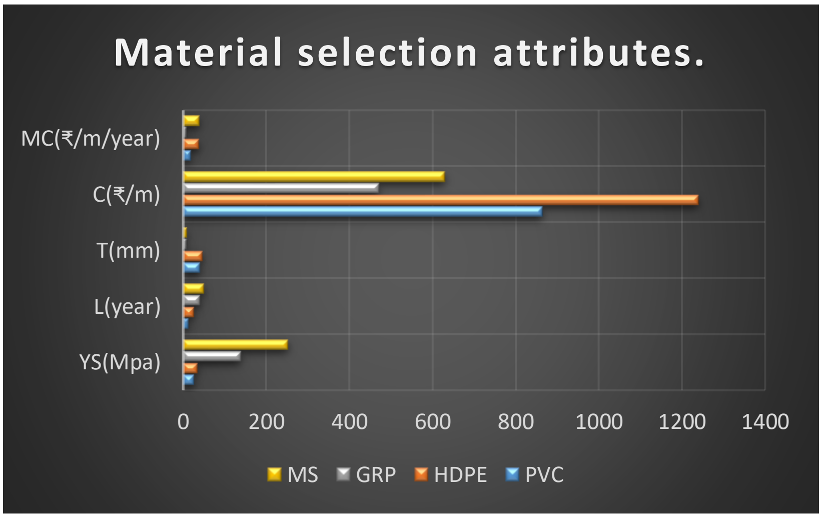

FIGURE 1. Quantitative values of the material selection attribute.

The graphical representation of the selected data is shown in Figure 1. The analysis took into account four alternative materials, including polyvinyl chloride (PVC), high-density polyethene (HDPE), glass-reinforced polymer (GRP), and mild steel (MS), as well as five assessment attributes/criteria, including yield strength, life, thickness, material cost, and maintenance cost.

TABLE 2. Normalized Data

2.3272	0.4957	5.5081	2567.4122	1.0254
3.9796	2.1516	7.2844	5289.8990	4.7604
65.5599	5.5081	0.2203	761.8180	0.1713
218.6157	8.6064	0.2788	1369.1476	4.9285

Table 2 above shows the normalized matrix of Performance Ratings of Materials Used in Penstock of Small Hydro Power. This matrix was produced using equation three.

TABLE 3. Weight

0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2

Table 3 Weights for the criteria are expressed as equally distributed among the evaluation parameters as shown the table 3.

TABLE 4. Weighted normalized decision matrix

0.4654	0.0991	1.1016	513.4824	0.2051
0.7959	0.4303	1.4569	1057.9798	0.9521
13.1120	1.1016	0.0441	152.3636	0.0343
43.7231	1.7213	0.0558	273.8295	0.9857

Table 4 shows the weighted normalized matrix of the decision matrix and it is calculated by table 2 and table 3 using equation 4.

TABLE 5. Positive Matrix

43.7231	1.7213	1.4569	1057.9798	0.9857
43.7231	1.7213	1.4569	1057.9798	0.9857
43.7231	1.7213	1.4569	1057.9798	0.9857
43.7231	1.7213	1.4569	1057.9798	0.9857

Table 5 shows the positive matrix calculated by using table 4. The ideal best for a column is the maximum value of that column in table 4.

TABLE 6. Negative matrix

0.4654	0.0991	0.0441	152.3636	0.0343
0.4654	0.0991	0.0441	152.3636	0.0343
0.4654	0.0991	0.0441	152.3636	0.0343
0.4654	0.0991	0.0441	152.3636	0.0343

Table 6 shows the negative matrix calculated by using table 4. The Ideal best for a column is the minimum value in that column in table 4.

TABLE 7. SI Plus and Si negative

Materials	SI Plus	Si Negative
PVC	546.216	361.1204
HDPE	42.94664	905.6179
GRP	906.1352	12.68622
MS	784.1515	128.9525

Table 7 shows the Si plus and Si negative values. difference of each response from the ideal best (S_i^+) is calculated using equation 5 and the difference of each response from the ideal worst (S_i^-) is calculated using equation 6.

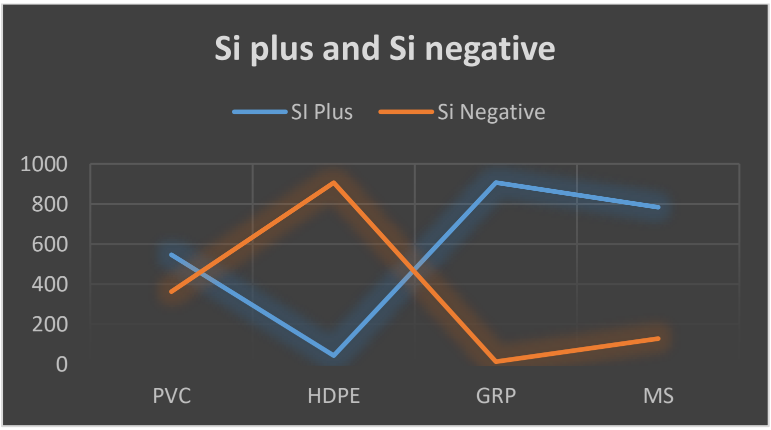

FIGURE 2. SI Plus and Si negative

Figure 2 illustrates the graphical representation of the Si plus and Si negative values. difference of each response from the ideal best (S_i^+) is calculated using equation 5 and the difference of each response from the ideal worst (S_i^-) is calculated using equation 6.

TABLE 8. Closeness coefficient

Materials	Ci
PVC	0.398001
HDPE	0.954725
GRP	0.013807
MS	0.141224

The proximity coefficient values of the alternatives are displayed in Table 8. Equation 7 is employed in the calculation. Here, the values for polyvinyl chloride (PVC), high-density polyethene (HDPE), glass reinforced polymer (GRP), and mild steel (MS) are 0.3981, 0.954725, 0.013807, and 0.141224, respectively.

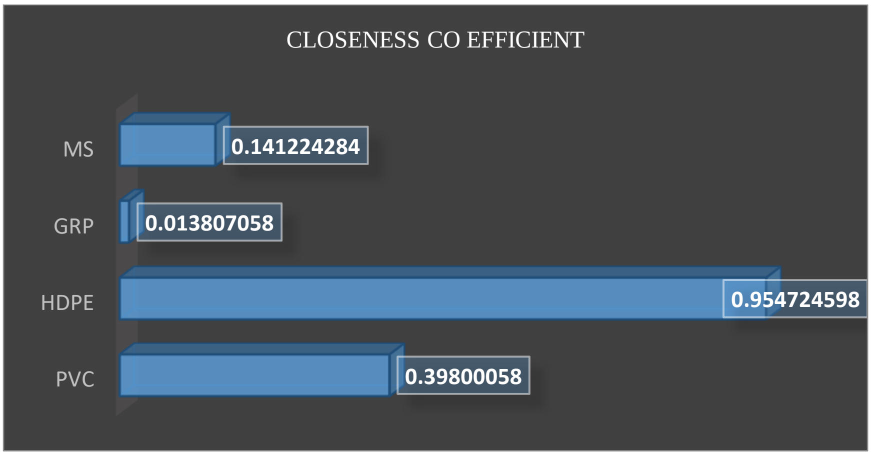

FIGURE 3. Closeness Coefficient(Ci)

Figure 3 illustrates the graphical representation of Ci. It is calculated by using equation 7. Here polyvinyl chloride (PVC) has a value of 0.398001, high-density polyethene (HDPE) has a value of 0.954725, glass reinforced polymer (GRP) has a value of 0.013807 and mild steel (MS) has a value of 0.141224.

TABLE 9. Rank

Materials	Rank
PVC	2
HDPE	1
GRP	4
MS	3

Table 9 shows the rank of materials for penstock used in small hydropower. Here rank is calculated using the closeness coefficient using table 8. Here polyvinyl chloride (PVC) ranked two, high-density polyethene (HDPE) has rank one, glass reinforced polymer (GRP) has rank four and mild steel (MS) is having rank three.

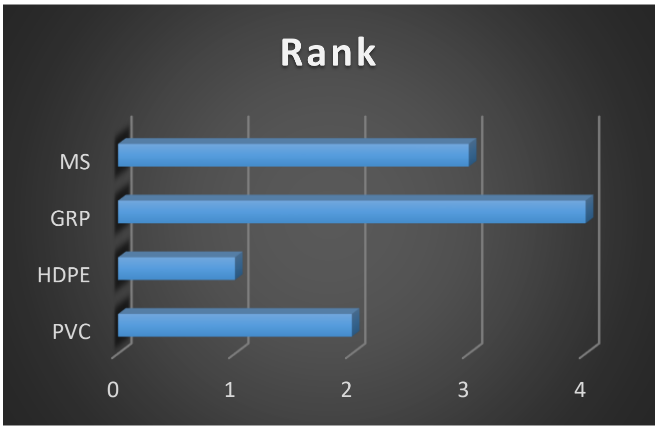

FIGURE 4. Rank

Figure 4 illustrates the graphical representation of the rank of materials for penstock used in small hydropower. Here rank is calculated using the closeness coefficient using table 8. Here polyvinyl chloride (PVC) ranked two, high-density polyethene (HDPE) has rank one, glass reinforced polymer (GRP) ranked four and mild steel (MS) is having rank three.

Conclusion

Fossil fuel-based energy generation is linked to issues including pollution, GHG emissions, and environmental risks. As a result, energy production from renewable sources must be expanded to promote sustainable growth. With 19% of the world's electricity coming from hydropower, large and small, it is still by far the most significant source of "renewable energy" for the production of electrical power. Small hydro is a clean and practical source of energy among all renewable ones. Small hydropower is one of the most valuable sources of rural electricity today that can enhance people's quality of life. Numerous irrigation and drinking water proposals can benefit from installing modest hydropower systems. SHP is an appropriate remedy for all the problems with major hydropower projects. Utilizing water, a limited natural resource that is the best option for achieving self-sufficiency, small hydropower plants enable decentralized, affordable energy generation. This analysis yielded the best outcome. Penstock materials for small hydropower plants include high-density polyethene (HDPE), and polyvinyl chloride (PVC), followed by mild steel (MS), and glass reinforced polymer (GRP).

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