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Selection of Erosive Wear Rate Parameters of Pelton Turbine Buckets using PSI and TOPSIS Techniques

Robin Thakur, Sunil Kumar, Kamal Kashyap, Ashwani Kumar, Sorabh Aggarwal

Abstract: ***Hydro turbine machineries erosion due to silt is a complex issue for the effective practice of hydropower plants. Erosion caused by silt of the Pelton turbine buckets is a compound phenomenon that depends on size of silt particles*** (S_p)***, silt particles concentration*** (C_s)***, velocity of jet*** (V_j)***, and working time*** (t_w)***. This paper deals with the influence of silt erosion for various silt loaded factors and effective parameters. The preference selection index (PSI) and technique for order of preference by similarity to ideal solution (TOPSIS) approaches has been adopted to find optimal set of parameters which offers the highest performance for the Pelton turbine. Based up on the results obtained from both PSI and TOPSIS approaches it is found that optimal performance has been provided by A-1 alternate with geometric and flow parameters as*** $S_p = 90\ \mu$***,*** $C_s = 2000\ ppm$, $V_j = 27.309\ m/s$ ***and*** $t_w = 3\ hrs$ ***respectively.***

Keywords: ***Hydro energy, silt size, Pelton turbine, PSI, TOPSIS***

Nomenclature

b	Length of the weir crest (perpendicular to flow), (m)
b_e	Effective width, (m)
C_e	Coefficient of discharge
C_s	Concentration of silt particles, (ppm)
g	Acceleration due to gravity, m/s^2
h	Measured upstream head over the weir, (m)
h_e	Effective head, (m)
H	Net head, (m)
k_b	Width correction factor
k_h	Head correction factor
k_V	Velocity coefficient (= 0.98 as 2% losses are considered in the nozzle)
P	Pressure, (kPa)
Q	Discharge, (m^3/s)
S_p	Size of silt particles, microns (μ)
t_w	Working time, (hrs)
V	Jet velocity in (m/s)
V_j	Velocity of jet, (m/s)

Greek symbol

ρ	Density of water (kg/m^3)

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***** Correspondence Author

Robin Thakur*, School of Mechanical & Civil Engineering, Shoolini University, Solan, India. Email: robinthakur@shooliniuniversity.com

Sunil Kumar, School of Computer- Science & Electrical Engineering Shoolini University, Solan, India. -. Email: sunilthakur@shooliniuniversity.com

Kamal Kashyap, School of Mechanical & Civil Engineering, Shoolini University, Solan, India. Email: kamal.maximus23@gmail.com

Ashwani Sharma, School of Computer- Science & Electrical Engineering Shoolini University, Solan, India. -. Email: ashwanisharma@shooliniuniversity.com

Sorabh Aggarwal, School of Mechanical & Civil Engineering, Shoolini University, Solan, India. Email: sorabh.btech11@gmail.com

I. INTRODUCTION

Hydropower plants are the most progressive and established renewable energy technology and provides some level of power generation in more than 160 countries globally. Power generated from hydro has very slight environmental and social impact if we will compare it to other renewable energy resources by Singh and Singhal [1] and Robb [2]. Hydropower is the main renewable electrical energy source at universal level and contributes to sustainable progress. Hydropower is able to supply clean and reasonable energy in its most valuable form, electricity. Hydro turbine is suppose to be primary segment of a hydro control plant but regrettably, hydro turbines experience issues like sediment ersion which declines the proficiency over a time of their functioning life. Residue erosion occurence in hydro turbine is real issue ,as it effects the smooth functioning of hydropower plants by Bansal et al. [3] and Pundir and Kumar [4].

Several experimental and analytical investigations for the deteriorated efficiency and performance of the hydro turbines due to silt erosion have been suggested and discussed by various investigators. Woodcock and White [5] studied the basics of a Pelton turbine, single-wheel development and close running clearances absence makes it more appropriate for applications. Their outcomes showed that the Pelton turbines have been employed for a long time in high-head hydroelectric power plants and high water powered production.

Chattopadhyay [6] did observation of runners from different water samples of different rivers having high silt content and observe that the wear occurred is unusual in the runners of the turbine. Their conclusions are described against microstructure, hardness and work-hardening rate based on the various wear rates of the alloys. Mann [7] examined the matter of erosion in various hydel power locations situated in Himalayan area. Mann & Arya [8] stated the abrasion and silt erosion features of HVOF coatings and plasma nitriding beside with usually used steels in hydel turbines. Their outcomes show that the HVOF tungsten carbide on steel seems, by all accounts, to be an outstanding disintegration protection shield to battle with low and high-energy molecule impingement wear.

Desale, Gandhi, & Jain [9] analyzed the influence of erodent properties on slurry erosion. The investigation shows that with the reduction in the shape factor, there is a rise in wear and in the density. Bajracharya et al. [10] investigated that erosion of hydro turbine machineries is one of the complex trouble especially in monsoon season through silt in the Himalayan region. Chauhan et al. [11] observed that cavitation, material defects, fatigue and sand erosion are the major reasons for the damaging of hydro turbines in hilly terrain. Agar & Rasi [12] portrayed the development of the Pelton turbine, the test contraption and the estimation strategy. They concluded that the Pelton turbine and mechanical assembly show the standards of hydropower and are suitable for instruction in renewable power source.

Padhy & Saini [13] studied the erosive wear of hydro turbine machineries which mainly relies on various parameters, for example, size of buckets, rigidity and consideration of residue particles, jet velocity , properties of metal used as base material and the period of time a turbine works continuously. Thapa, Thapa, & Dahlhaug [14] concluded that, remarkable erosion is found on the needle rather than on the buckets which mainly occurs due to fine silt particles. [15] Numerical approach is established for a fast and actual simulation and investigation of the complex flow and energy conversion in Pelton turbines. Goyal et al. [16] did his all observations with the help of a high-speed erosion test rig developed by his own and used it for different tests based on slurry erosion , he give his observations based on speed, average particle size and slurry concentration.

Padhy & Saini [17] also reviewed various erosion models, case studies related to erosion of hydro turbine components and also investigated experimentally the erosive wear in the hydro turbine machineries. Williamson et al. [18] take 3.5 m to 1 m low head observations , the motion of a single jet Turgo turbine outside of its ordinary application area is investigated in which a regular head run accessible for remote groups. Cobb & Sharp [19] tested the working execution qualities of impulse turbines examined through the assembling of research center scale test installation. The outcomes stretch the significance of legitimate framework design and establishment and increment the learning base with respect to Turgo turbine execution that can prompt better reasonable usage in pico-hydro frameworks.

Khurana & Goel [20] analyzed experimentally erosive wear of hydro turbine segments and found that it is a critical phenomenon which mainly relies on various factors, like $size\ of\ silt\ particles\ (s)$, $silt\ concentration\ (c)$, $jet\ velocity\ (v)$, $hardness\ of\ silt\ particles\ (H)$, $properties\ of\ base\ materials, jet\ diameter\ (d)$, and $working\ hours\ (t)$. Platero et al. [21] discuss the novel procedure for Pelton turbine task without the use of water stream, as a methodology to give rapid power infusion on account of an unpredicted wind power diminish, or a wind generator trip. Židonis & Aggidis [22] uses commercially available CFD code fluent to accomplish an analysis of flow inside the bucket of a Pelton turbine and confirmed the results experimentally. Kumar & Bhingole, 2015[23] have applied a simulated flow on stationary flat plate and make it functional on Kaplan turbine.

Kumar & Singal [24] discuss that the hydraulic turbine is an imperative segment in hydro power plants and it has numerous issues which degrade its condition and proficiency and require appropriate operation and upkeep. Chávez et al. [25] examined the performance of a Pelton turbine runner comprises of 16 buckets on its periphery from a hydroelectric plant having two turbo generators with a minimal capacity of 2.33 MW each, located in Colombia. Židonis et al. [26] uses commercially available ANSYS CFX code to perform flow analysis inside stationary Pelton turbine bucket and confirmed the results experimentally. Židonis & Aggidis [27] make a numerical analysis presented by sorting the best arrangement of the radial and angular position for each bucket in which it is showed that lessening in the quantity of buckets.

Nguyen et al. [28] analyzed the particles formed by cavitation erosion and stated that many particles were quite uneven in shape. Gupta et al. [29] utilizing water and air as working fluid to examine the Pelton turbine to evaluate the productivity, blade loading, jet velocity and water appropriation over the bucket at various working segments of the turbine. Vessaz et al. [30] has optimizing the performance of a Pelton turbine runner relies on a parametric model of the bucket geometry, innovative optimization strategies and numerical simulations of massive particles. Egusquiza et al. [31] presented a process for the estimation of erosion characteristic of a hydro turbine runner under different situations. Morales B et al. [32] accomplished an experiment related to cavitation on a Pelton turbine. Kishor et al. [33] examined the impact of particle size and shape on hydraulic turbine components.

As Multiple Criteria Decision Making (MCDM) techniques are numerical methodologies for taking care of problems comprising a substantial number of options and execution assessment standards and have gotten open acknowledgment for application in different zones of science, building, administration and so on Maniya & Bhatt [34], Chauhan et al. [35], Vahdani et al. [36]. There are various MCDM techniques which are accessible in the writing to empower the inventors to assemble the superior option, in most of these techniques, the alternative rankings are influenced by the measure weight and are very strenuous to fathom and cloud to execute needful widespread mathematical complexity. It contains several strategies, specifically, grey relation analysis, preference ranking organization method for enrichment evaluations, elimination and choice translating reality, compromise ranking method, technique for order preference by similarity to ideal solutions and analytic hierarchy method which have been effectively used to take care of numerous decision-making issues Attri et al. [37], Mesran et al. [38] and Madić et al. [39].

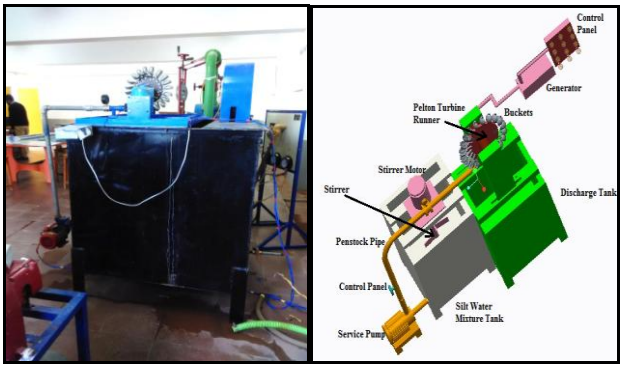
The PSI approach is more generalized to understand as compared to all MCDM techniques as it doesn't contain any comparative importance between the standards and the overall preference value which is attained by using the statistical concept. The superiority of PSI technique is that it is useful in estimation of ideal elective where there is conflict in choosing the relative significance between the foundations and contains less numerical computations by Lockwood [40] and Maniya & Bhatt [41].The methodology for order preference by similarity to an ideal solution (TOPSIS) technique is useful for decision makers to structure the problems to be sort out, conduct analyses, comparisons and ranking of the alternatives [42].

There are numerous investigators reports ([43], [44], [45]) presented in the literature that talk about TOPSIS approach in determining various engineering, management, energy and other technical concerns.

This study examines the suitability of PSI and TOPSIS techniques for calculating the best set of experimental factors which are especially responsible for erosive wear rate of Pelton turbine buckets. An experimental analysis has been conceded to fulfill this aim by finding the normalized erosive wear for Pelton turbine buckets made of different materials as a function of various sediment and operative factors. The projected technique is examined which decides the ideal outline parameters in order to achieve most extreme performance under desired working conditions.

II. INVESTIGATION METHODOLOGY

In this investigation an attempt has been made to do a parametric optimization of erosive wear rate of Pelton turbine buckets for which a related schematic of test setup as appeared in Fig.1. All the operating parameters and sediment parameters were introduced with a specific end objective to reproduce real working state of a Pelton turbine. The examination wear problem areas were recognized inside the Pelton buckets. The runner of Pelton turbine having diameter of pitch circle is $145\ mm$, diameter of nozzle $12\ mm$ and buckets quantity having 20 in number has been utilized for the test examine. The weight of each bucket was estimated one by one, and it was around 115g. Fig.2 represents the schematic and photographic view of Pelton runner and buckets.



(a) (b)

Figure 1. Photographic view of experimental set-up

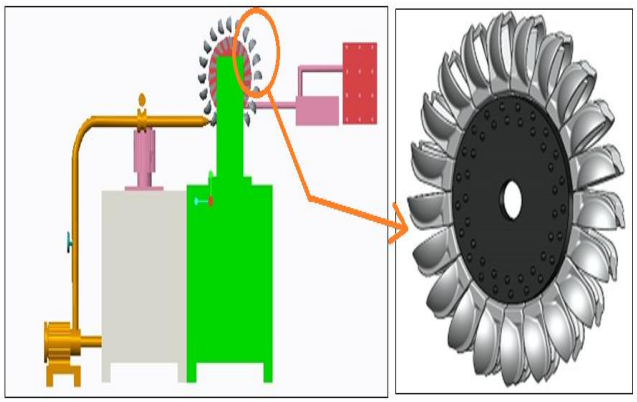


Figure 2. Pelton runner and buckets

The sediment water composite having different concentrations, required amount of silt with chosen, water sample was made by mixing different parameters and is placed in the tank. The rotating stirrer was at a speed of 60 rpm with the assistance of an electric-motor of 1.0 HP limit through a gear box to make turbulence all through the volume of water and sediment composite in the tank. So as to research the impact of residue parameters on erosive wear sediment loaded water was provided to the turbine worked under a given head.

The buckets were disassembled from the runner after every 3 hours of experimental trial, washed with cleanser, cleaned with fresh water and dabbed with tissue paper. At that point these buckets were washed with acetone and indorsed to dry in oven for a time interval of 2 hours at constant 60° C temperature. The weight reduction of the buckets was assessed after at regular intervals of run. One keep running of investigation comprised of three hours and after each one hour the sediment slurry was worn-out away totally and subsequent to cleaning the tank appropriately, fresh residue slurry was set up for the next 60 minutes.

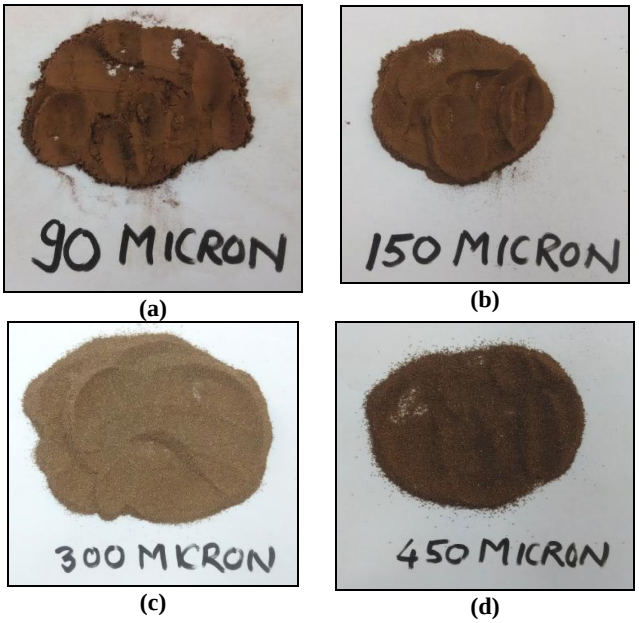
Three sets of experiments were accompanied for jet velocity and four sets for silt size. A discussion also has been made in this study for the effect of efficiency loss of Pelton turbine due to change of bucket shape as a result of alteration of Pelton buckets.

III. SELECTION OF PARAMETERS AND GOVERNING EQUATIONS

In this investigation concentration of silt, size of silt, velocity of jet and hours of working were looked into parameters. For this, sediment specimen was accumulated from Chamera Lake, Chamba (Himachal Pradesh, India) as shown in Fig.3 in which 20000 ppm silt concentration during monsoon season and the typical quartz substance was realized to be around 80% and the samples of silt of various sizes are shown in Fig. 4.

Figure 3. Photographic view of Chamera dam

Deposit was dehydrated in the day light for 3-4 days and sieves of various sizes were used to strain the sand before mixing with water. The component of trial which has been contemplated contains four estimations of S_p, four estimations of C_s, four estimations of V_j and four estimations of t_w separately. The range of various parameters is portrayed in Table1.



(a) (b) (c) (d)

Figure 4. Silt samples of various sizes of Chamera dam

Table 1 Range of experimental parameters

Sr. No.	Symbols	Parameters	Range
1	S_p	Size of silt particles, μ	90 μ – 600 μ
2	C_s	Concentration of silt particles, ppm	2000 ppm – 10000 ppm
3	V_j	Velocity of jet, m/s	27.309 m/s - 27.352 m/s
4	t_w	Working time, hrs	3-15 hrs

Governing Equations

Considering the range of parameters discussed above, experimentations were carried out for various combinations of parameters and data was collected. The data were collected for all the values concentration of silt, size of silt, angle of nozzle and velocity of jet for a time interval of two hours of turbine operation. Sample calculations for one set of readings were given in Appendix A1.

Calculation of silt concentration:

Size of the tank:

Length of the Tank: 65 cm

Width of the tank:52cm

Height of the tank:80cm water level)

Sand concentration: 10,000ppm

(i) Volume of water in the tank

$= 68 \times 53 \times 81\ cc = 270.400\ cc = 270\ L$

(ii) $10{,}000\ ppm = 10{,}000\ mg\ in\ one\ litre$

$10{,}000\ ppm\ in\ 270\ L = 10x270\ gm\ = 2.7\ kg$ of silt

Determination of Jet Velocity:

The jet velocity was calculated from the reading of pressure transducer observed during the experimentation as follows;

Pressure head $P = \rho g H$

$$Or \quad H = \frac{P}{\rho g} \qquad (1)$$

$$V = k_v\sqrt{2gH} \qquad (2)$$

Measurement of Blade Mass Loss

(i) Bucket mass loss = Mass of bucket before experiment – Mass of bucket after experiment

The bucket mass loss was normalized with the bucket mass before the respective experimental run.

(ii) Normalized bucket mass loss

= Bucket mass loss /Mass of bucket before experiment run

Discharge calculation:

The formula used for calculating the discharge is as given below (Bansal, 2008)

$$Q = \frac{2}{3}C_e b_e \sqrt{2gh_e} \qquad (3)$$

The effective width and head are defined by the following equations;

$$b_e = b + k_b \qquad (4)$$

$$h_e = h + k_h \qquad (5)$$

Preference Selection Index (PSI) approach

This approach designed by Maniya and Bhatt [46] which supports the decision maker to select the suitable alternate. In current study, the ranking of different substitutes has been executed for optimization of operational parameters and a optimum set of geometric factors has been obtained by using PSI approach. The methodology adopted in this study involves two steps and is determined as follow [34], [40] and [41]:

Step 1: Determination of alternatives and criterions

In this step alternatives and their variant criterions used for evaluating performance of specific MCDM are identified.

Step 2: Ranking of different alternatives by using PSI approach

This PSI approach of alternatives ranking involves different phases in order to calculate the perfect set of experimental results by using number of equations as shown below. The PSI approach involves seven different phases to determine the ranking of alternatives.

Phase I: Decision matrix

Decision matrix is designed once different criterions and alternatives are identified. Here A represents alternatives and C signifies criterions. Decision matrix having an order $A \times C$ is given as:

$$M_{A\times C} = \begin{matrix} A_1 \\ A_2 \\ M \\ A_a \end{matrix}\begin{bmatrix} D_{11} & D_{12} & K & D_{1C} \\ D_{21} & D_{22} & K & D_{2C} \\ M & M & K & M \\ D_{A1} & D_{A2} & K & D_{AC} \end{bmatrix} \qquad (8)$$

Phase II: Normalized decision matrix

In order to make simple comparison of criterions, the decision matrix data has been normalized with a series of [0, 1]. The normalized data of each value in decision matrix is determined as:

$$\begin{cases} X_{ij} = \dfrac{X_{ij}}{X_j^{max}}, & for\ larger\ the\ better\ condition \\ X_{ij} = \dfrac{X_j^{min}}{X_{ij}}, & for\ smaller\ the\ better\ condition \end{cases} \qquad (9)$$

Phase III: Computation of mean results:

In this part the data of decision matrix is computed by multiplying the mean values of normalized decision matrix with the ration of number of alternatives as:

$$\Delta_j = \frac{1}{A}\sum_{i=1}^{a} X_{ij} \quad (10)$$

Phase IV: Calculation of preference deviation (ϑ_j) :

The value of ϑ_j for each criterion is determined by subtracting the column wise decision matrix from mean results of normalized decision matrix and after the square root of these values their mean values are obtained as follow:

$$\vartheta_j = \sum_{i=1}^{A}\left[X_{ij} - \Delta_j\right]^2 \quad (11)$$

Phase V: Calculation of deviation in preference difference(ϕ_j) :

The value of ϕ_j are determined from following relation:

$$\phi_j = 1 - \frac{\vartheta_j}{A-1} \quad (12)$$

Phase VI: Determination of whole preference selection values (ψ_j) :

The value of ψ_j are determined from following relation:

$$\theta_j = \frac{\phi_j}{\sum_{j=1}^{C}\phi_j} \quad (13)$$

Moreover, the entire preference selection value of all criterions is 1 and is given as $\sum_{j=1}^{C}\phi_j = 1$

Phase VII: Calculation of preference selection index values

The preference selection index (χ_i) values for each alternative are obtained as follow:

$$\chi_i = \sum_{j=1}^{C}\left(X_{ij} \times \theta_j\right) \quad (14)$$

At the end of the calculations of χ_i, each alternative is ranked and an alternative with a highest value of χ_i is ranked as 1.

Technique for order preference by similarity to an ideal solution (TOPSIS) approach

TOPSIS is a popular multi criteria decision making method and multipurpose approach involving a unassuming mathematical model [43], [44] and [45].

Step 1: To create evaluation matrix containing m alternatives and n criteria, given by x_{ij} , as specified below

$$\begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \quad (15)$$

Step 2: To normalized above evaluation matrix to form the matrix $R = (r_{ij})_{mxn}$ using the normalization method

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad (16)$$

Where $i = 1, 2, \ldots, m$ *and* $j = 1, 2, \ldots . n$ The matrix would be given as

$$\begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \quad (17)$$

Step 3: To assign a weight factor for each criterion. This weight factor is to be determined objectively by the sum of all weight factors and is equal to 1.

A weighted matrix is to be created to form a matrix where

$$a_{ij} = w_j r_{ij} = w_j \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad (18)$$

Where $i = 1, 2, \ldots, m$ *and* $j = 1, 2, \ldots . n$ and synthesis weight W_j for the j[th] attribute is:

$$W_j = \frac{\alpha_j \times \beta_j}{\sum_{j=1}^{n} \alpha_j \times \beta_j} \quad j = 1, 2, \ldots \ldots, n \quad (19)$$

The matrix would be given as

$$\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix} \quad (20)$$

Step 4: Determine the positive ideal solution (A_j^+) and the negative ideal solution (A_j^-) for each criterion. The coordinates for (A_j^+) of positive ideal solution $A^+ = (A_j^+, A_2^+ \ldots \ldots A_n^+$ are chosen using the formula

$$A_j^+ = \begin{cases} \max a_{ij} \; for \; j = 1, \ldots . k \\ \min a_{ij} \; for \; j = k+1, \ldots . n \end{cases} \quad (21)$$

The coordinates for (A_j^-) of positive ideal solution $A^- = (A_j^-, A_2^- \ldots \ldots A_n^-$ are chosen using the formula

$$A_j^+ = \begin{cases} \text{MIN}\, a_{ij} \; for \; j = 1, \ldots . k \\ \text{MAX}\, a_{ij} \; for \; j = k+1, \ldots . n \end{cases} \quad (22)$$

Step 5: Calculate the distance between the target alternative i and the positive ideal solution S^+ is given by

$$S^+ = \sqrt{\sum_{j=1}^{n}\left(a_{ij} - A_j^+\right)^2} \quad (23)$$

Similarly, calculate the distance between the target alternative i and the negative ideal solution S^- is given by

$$S^- = \sqrt{\sum_{j=1}^{n}\left(a_{ij} - A_j^-\right)^2} \quad (24)$$

Step 6: Calculate the relative distance of the points from the ideal solution using the formula

$$S = \frac{S^-}{S^+ + S^-} \quad (25)$$

Step 7: Rank the S in the descending order with the highest valued criteria/option/alternative being an ideal one.

IV. RESULTS AND DISCUSSION

To find erosive wear rate on Pelton turbine, experimentation has been performed among blends of exploratory factors as portrayed in Table 2. After the examination of every elective which is parametric arrangement of erosive wear rate on Pelton turbine, the outcomes have been noted and ascertained for Normalized wear (W) and loss of efficiency. Table.2 describes Normalized wear (W) and efficiency loss reactions accomplished for all alternatives combinations. The surface conditions of turbine bucket after the examination are appeared in Fig.5. The consequences of Table 2 have been introduced in Figures 6 & 7 in order to watch the slant of Normalized wear (W) and efficiency loss contrast simultaneously. It has been discovered that where the efficiency loss is enhanced, in the meantime the estimation of Normalized wear (W) has additionally moved forward.

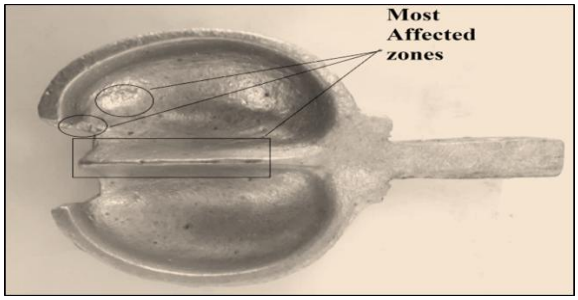


Figure 5. Condition of the bucket after experimentation

Table 2 Experimental results details

Sr. No.	Silt Concentration (ppm)	Silt size (µ)	Time period (hrs)	Jet velocity (m/s)	Weight loss (gms)	Efficiency (%age)	Normalized Wear (gms)
1.	2000	90	3	27.309	0.47848	67.206	0.0002443
2.	2000	150	6	27.323	0.61904	64.962	0.0005868
3.	2000	300	9	27.333	0.78442	62.464	0.0010541
4.	2000	450	12	27.344	0.91294	59.845	0.0016697
5.	2000	600	15	27.352	1.11234	59.556	0.0012513
6.	4000	90	6	27.333	1.21216	66.829	0.0010982
7.	4000	150	9	27.344	1.30502	64.492	0.0018151
8.	4000	300	12	27.352	1.43002	61.917	0.0026284
9.	4000	450	15	27.309	1.41798	59.347	0.0027669
10.	4000	600	3	27.323	1.58879	59.065	0.0023480
11.	6000	90	9	27.352	2.10780	66.130	0.0028371
12.	6000	150	12	27.309	2.26072	63.657	0.0040621
13.	6000	300	15	27.323	2.24214	61.142	0.0041528
14.	6000	450	3	27.333	2.08978	58.720	0.0031113
15.	6000	600	6	27.344	2.27034	58.404	0.0026830
16.	8000	90	12	27.323	2.75412	65.096	0.0040469
17.	8000	150	15	27.333	2.76602	62.646	0.0048589
18.	8000	300	3	27.344	2.20660	60.766	0.0011646
19.	8000	450	6	27.352	2.38800	57.932	0.0020784
20.	8000	600	9	27.309	2.71968	57.503	0.0051067
21.	10000	90	12	27.344	3.41301	64.686	0.0061570
22.	10000	150	3	27.352	3.43504	61.756	0.0070269
23.	10000	300	6	27.309	3.13406	59.879	0.0038560
24.	10000	450	9	27.323	3.34410	56.843	0.0047169
25.	10000	600	15	27.333	3.74979	56.813	0.0079370

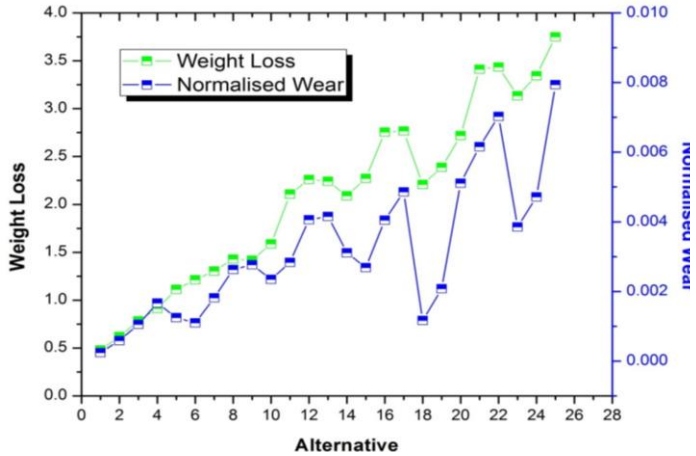


Figure 6. Difference of experimental results with alternatives

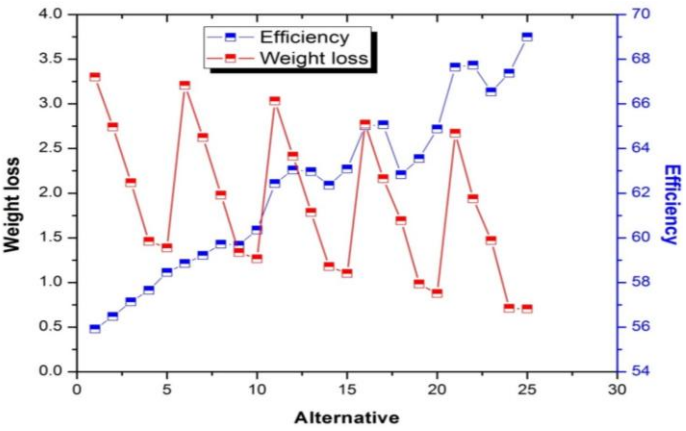


Figure 7. Difference of experimental results with alternatives

Numerical calculation for optimization of results

PSI technique

The criterion obtained from experimental investigation of erosive wear rate parameters in Pelton turbine bucket has been analyzed respectively. The different stages of simulation process are depicted below:

Elementary decision matrix:

The number of experimental runs is calculated as alternatives A-1 to A-25 and the criterion such as Weight loss, Efficiency, Normalized Wear are measured as C-1, C-2 and C-3 respectively for performance measurement of erosive wear rate parameters in Pelton turbine bucket. A resulting elementary decision matrix ($M_{A\times C}$) has been designed where A represents the number of alternatives and C represents the number of criterions. The resulting column wise decision matrix is depicted as below:

$$M_{A\times C} = \begin{matrix} A_1 \\ A_2 \\ A_3 \\ A_4 \\ A_5 \\ \text{M} \\ A_{25} \end{matrix} \begin{bmatrix} 0.47848(C_{11}) & 67.206(C_{12}) & 0.0002443(C_{13}) \\ 0.61904(C_{21}) & 64.962(C_{22}) & 0.0005868(C_{23}) \\ 0.78442(C_{31}) & 62.464(C_{32}) & 0.0010541(C_{33}) \\ 0.91294(C_{41}) & 59.845(C_{42}) & 0.0016697(C_{43}) \\ 1.11234(C_{51}) & 59.556(C_{52}) & 0.0012513(C_{53}) \\ \text{M} \quad & \text{M} \quad & \text{M} \quad \\ 3.74979(C_{A1}) & 56.813(C_{A2}) & 0.0079370(C_{AC}) \end{bmatrix} \quad (26)$$

After the calculation and design of decision matrix, the maximum criterion represented as $(X_j)_{max}$ and minimum criterion represented as $(X_j)_{min}$ has been determined by using Eq. (9):

$(X_j)_{max} = {}^{max}_{i}X_{ij} = [3.74979 \quad 67.206 \quad 0.007937]$

$(X_j)_{min} = {}^{min}_{i}X_{ij} = [0.47848 \quad 56.813 \quad 0.0002443$

Calculation of column-wise normalized decision matrix:

After the identification of highest and lowest values of criterions the normalized values of whole data in decision matrix are determined by employing Eq. (10) and the results of normalized values are shown in Table 3.

Table 3 Normalized Decision Matrix

Normalized Decision Matrix			
Alternative	**C-1**	**C-2**	**C-3**
A-1	1	1	1
A-2	0.772939	0.96661	0.416326
A-3	0.609979	0.929441	0.231762
A-4	0.524109	0.890471	0.146314
A-5	0.430156	0.886171	0.195237
A-6	0.394733	0.99439	0.222455
A-7	0.366646	0.959617	0.134593
A-8	0.334597	0.921302	0.092946
A-9	0.337438	0.883061	0.088294
A-10	0.30116	0.878865	0.104046
A-11	0.227004	0.98399	0.086109
A-12	0.211649	0.947192	0.060141
A-13	0.213403	0.90977	0.058828
A-14	0.228962	0.873732	0.07852
A-15	0.210753	0.86903	0.091055
A-16	0.173732	0.968604	0.060367
A-17	0.172985	0.932149	0.050279
A-18	0.21684	0.904175	0.209772
A-19	0.200369	0.862006	0.117542
A-20	0.175932	0.855623	0.047839
A-21	0.140193	0.962503	0.039678
A-22	0.139294	0.918906	0.034766
A-23	0.152671	0.890977	0.063356
A-24	0.143082	0.845802	0.051792
A-25	0.127602	0.845356	0.03078

Calculation of column-wise data:

The standardized values of normalized decision matrix have been determined by Eq. (10)

$\Delta_{C-1} = 0.04 \times 7.806229 = 0.312249$

$\Delta_{C-2} = 0.04 \times 22.87974 = 0.91519$

$\Delta_{C-3} = 0.04 \times 3.712798 = 0.148512$

Calculation of preference deviation data:

The preference deviation data (ϑ_j) for each criterion is determined with the help of Eq. (11)

ϑ_{C-1} = **1.114559**

ϑ_{C-2} = **0.053934**

ϑ_{C-3} = **0.93569**

Calculation of deviation in preference difference values:

The deviation in preference difference values (o_j) is calculated for every response by using Eq. (12):

$\phi_{C-1} = 1 - \frac{1.114559}{24} = 0.95356$

$\phi_{C-2} = 1 - \frac{0.053934}{24} = 0.997753$

$\phi_{C-3} = 1 - \frac{0.93569}{24} = 0.961013$

Calculation of whole preference selection values (θ_j):

The values of θ_j are determined with the help of equation (13):

$\theta_{C-1} = \frac{0.95356}{2.912326} = 0.327422$

$\theta_{C-2} = \frac{0.997753}{2.912326} = 0.342597$

$\theta_{C-3} = \frac{0.961013}{2.912326} = 0.329981$

Table 4 Optimization results of Preference deviation data, Preference difference values and Whole preference selection values

Criterions	**Preference deviation data (ϑ_C)**	**Preference difference values (ϕ_C)**	**Whole preference selection values (θ_C)**
Criterions - 1	**1.114559**	0.95356	0.327422
Criterions - 2	**0.053934**	0.997753	0.342597
Criterions - 3	**0.93569**	0.961013	0.329981

Calculation of preference selection index (χ_i) data

The PSI (χ_i) results for whole alternatives are determined by employing equation (14). The alternative having highest value of χ_i is selected as optimum set of geometric parameters.

It is found that χ_i of alternative A-1 is maximum (0.9999) followed by A-2 (0. 0.721567) among all alternative.
The alternative A-25 depicts the minimum value of PSI having preference index value equal to 0.721567. The above examinations show that the alternative A-1 has an optimal set of geometric parameters i.e. silt concentration = 2,000 silt size = 90, time period = 3 hrs. and jet velocity = 27.309 which shows the best performance. The responses achieved in the form of rank after computations are shown in Table 5.

Table 5 PSI (χ_i) and rank of the alternatives

Alternative	Preference index (χ_i)	Rank
A-1	0.9999	1
A-2	0.721567	2
A-3	0.594592	3
A-4	0.524938	5
A-5	0.508844	6
A-6	0.543302	4
A-7	0.493207	7
A-8	0.455848	8
A-9	0.442142	10
A-10	0.434024	12
A-11	0.439843	11
A-12	0.413643	13
A-13	0.400963	14
A-14	0.400206	16
A-15	0.396769	18
A-16	0.408639	15
A-17	0.392577	19
A-18	0.449968	9
A-19	0.399701	17
A-20	0.366519	23
A-21	0.388743	20
A-22	0.371891	22
A-23	0.376134	21
A-24	0.353703	24
A-25	0.34155	25

TOPSIS Technique

Determination of weight for different criteria

The subjective weight (α_j) calculated using pairwise comparisons are given in Table 6. After the determination of α_j, the objective weight (β_j) is determined by using entropy method. From the values of α_j and β_j the value of synthesis weight (W_j) for each attributes is calculated by using Eq. (19) are given in Table 7.

Table 6: The pair wise comparison matrix for different criteria's

	C-1	C-2	C-3
C-1	0.22	0.22	0.25
C-2	0.67	0.65	0.63
C-3	0.11	0.13	0.13

Table 7: The criteria weights subjective(α_j), objective(β_j), and synthesis weight (ω_j)

	C-1	C-2	C-3
α_j	0.230	0.648	0.122
β_j	0.329	0.392	0.279
w_j	0.208	0.698	0.094

Calculation of Normalized and Weighted Normalized Decision Matrix

In application of TOPSIS method the decision matrix of criteria given in Eq. (26) is normalized using Eq. (16). The each column of this normalized matrix is multiplied by corresponding synthesis weight (w_j) to find weighted normalized matrix given in Table 8.

Table 8: Normalized and weighted normalized matrix

	Normalized Decision Matrix			Weighted Normalized Decision Matrix		
Alternative	C-1	C-2	C-3	C-1	C-2	C-3
A-1	0.0088	0.1523	0.0012	0.0088	0.1523	0.0012
A-2	0.0113	0.1473	0.0029	0.0113	0.1473	0.0029
A-3	0.0144	0.1416	0.0052	0.0144	0.1416	0.0052
A-4	0.0167	0.1357	0.0083	0.0167	0.1357	0.0083
A-5	0.0204	0.1350	0.0062	0.0204	0.1350	0.0062
A-6	0.0222	0.1515	0.0054	0.0222	0.1515	0.0054
A-7	0.0239	0.1462	0.0090	0.0239	0.1462	0.0090
A-8	0.0262	0.1404	0.0130	0.0262	0.1404	0.0130
A-9	0.0260	0.1345	0.0137	0.0260	0.1345	0.0137
A-10	0.0291	0.1339	0.0116	0.0291	0.1339	0.0116
A-11	0.0386	0.1499	0.0140	0.0386	0.1499	0.0140
A-12	0.0414	0.1443	0.0201	0.0414	0.1443	0.0201
A-13	0.0411	0.1386	0.0205	0.0411	0.1386	0.0205
A-14	0.0383	0.1331	0.0154	0.0383	0.1331	0.0154
A-15	0.0416	0.1324	0.0133	0.0416	0.1324	0.0133
A-16	0.0505	0.1476	0.0200	0.0505	0.1476	0.0200
A-17	0.0507	0.1420	0.0240	0.0507	0.1420	0.0240
A-18	0.0404	0.1377	0.0058	0.0404	0.1377	0.0058
A-19	0.0438	0.1313	0.0103	0.0438	0.1313	0.0103
A-20	0.0498	0.1303	0.0253	0.0498	0.1303	0.0253
A-21	0.0625	0.1466	0.0305	0.0625	0.1466	0.0305
A-22	0.0629	0.1400	0.0348	0.0629	0.1400	0.0348
A-23	0.0574	0.1357	0.0191	0.0574	0.1357	0.0191
A-24	0.0613	0.1288	0.0233	0.0613	0.1288	0.0233
A-25	0.0687	0.1288	0.0393	0.0687	0.1288	0.0393

Determination of the positive ideal solution (A_j^+) and the negative ideal solution (A_j^-)

The value of positive ideal solutions (A_j^+) and negative ideal solutions (A_j^-) of each criteria determined from weighted normalized matrix using Eqs. (21) and (22) are given in Table 9.

Table 9: Positive ideal solutions (A_j^+) and negative ideal solutions (A_j^-) each criteria.

	PDA-1	PDA-2	PDA-3
A_j^+	0.0088	0.1523	0.0012
A_j^-	0.0687	0.1288	0.0393

Determination of relative distance and ranking of the alternatives

After finding A_j^+ and A_j^- the target distances of each alternative S_i^+ and S_i^+ calculated for all alternatives using Eqs. (23) and (24) are given in Table 10. Finally, the relative distance of the points from the ideal solution (S) of all alternatives is calculated using Eq. (25) and results are given in Table 10. In the end after whole calculation the ranking of alternatives done to get optimal set of operating parameters presented in in Table 10.

Table 10: Target distances, relative distance and ranking of the alternatives

Alternative	S+	S-	S	Rank
A-1	0.000	0.075	0.999	1
A-2	0.006	0.070	0.923	2
A-3	0.013	0.065	0.837	3
A-4	0.020	0.061	0.755	6
A-5	0.021	0.059	0.733	7
A-6	0.014	0.062	0.814	4
A-7	0.018	0.057	0.759	5
A-8	0.024	0.051	0.680	8
A-9	0.028	0.050	0.644	9
A-10	0.029	0.049	0.624	10
A-11	0.033	0.045	0.578	11
A-12	0.039	0.037	0.488	14
A-13	0.040	0.035	0.465	17
A-14	0.038	0.039	0.506	13
A-15	0.040	0.038	0.484	15
A-16	0.046	0.032	0.414	18
A-17	0.049	0.027	0.357	19
A-18	0.035	0.045	0.560	12
A-19	0.042	0.038	0.479	16
A-20	0.052	0.024	0.310	20
A-21	0.061	0.021	0.253	22
A-22	0.065	0.013	0.171	24
A-23	0.054	0.024	0.308	21
A-24	0.062	0.018	0.222	23
A-25	0.075	0.000	0.001	25

It has been found that alternative A-1 has maximum relative distance (0.999) from all the alternatives and is followed by A-2 (0. 0.923) alternative. The alternative A-25 depicts the minimum value of relative distance equal to 0.721567. The above inspections show that the alternative A-1 has an optimal set of geometric parameters i.e. silt concentration = 2,000 silt size = 90, time period = 3 hrs and jet velocity = 27.309 which shows the best performance. Figure 8 shows the rankings of all alternatives derived using PSI and TOPSIS methods.

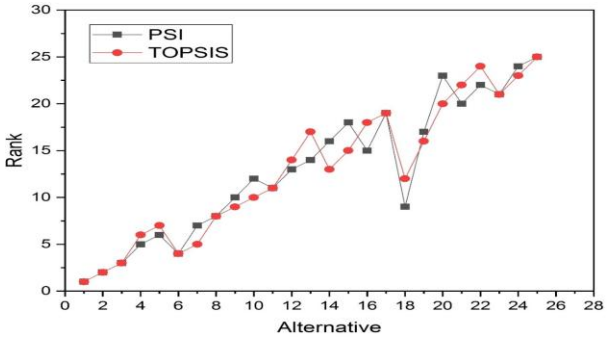


Figure 8. Comparisons of ranking obtained with the PSI and TOPSIS methods

Conclusion

In this study, PSI and TOPSIS approaches has been carried out to investigate the effects of wear rate on silt size and silt concentration in a Pelton turbine buckets. The PSI technique calculates the preference variance values and deviation in preference variance values of all the performance approximation criterions towards whole performance. The PSI technique ranked the whole alternatives by giving a significant solution which is nearest to real value and faraway from the least values. The experimental results exhibit variant capabilities for each alternative investigated, thus the PSI technique was employed to give an optimal set of alternatives on which structure will provided maximum performance with minimum energy inputs. Based up on the results obtained from both PSI and TOPSIS approaches it is found that optimal performance has been provided by A-1 alternative with geometric and flow parameters as $S_p = 90\ \mu$, $C_s = 2000\ ppm$, $V_j = 27.309\ m/s$ and $t_w = 3\ hrs$ respectively.

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AUTHORS PROFILE

Robin Thakur, He is currently working as an associate professor in Shoolini University, Solan. His qualifications includes B.Tech (Mechanical Engineering), M.Tech (Manufacturing Technology & Automation) & PhD (Mechanical Engineering). He has specialization in Hydro Turbines, Thermal Engineering & Mechanics. He has published several papers in reputed international journals and attended so many conferences. He has 13 years of Teaching & Industrial Experience. He also filed 7 patents in his field and 2 of them are granted by government of India.

Sunil Kumar is working as Assistant Professor, Shoolini University, Solan, India. He received M. Tech. degree in engineering education from Panjab University Chandigarh and pursuing PhD from Uttarakhand Technical University, Dehradun, India. He has published more than 15 research papers in international and national level. Currently working on heat transfer, fluid flow characteristics and properties of different Nanofluids in heat exchangers. Research work is based on numerical and experimental studies in developing new heat transfer fluids as well as heat transfer enhancement techniques for saving energy.

Ashwani Kumar, He is currently working as an Assistant Professor in ECE Deptt. in Shoolini Unversity, Solan (H.P). He has submitted PhD in University of Petroleum & Energy Studies, Dehradun (U.K) in Computer Sciences. He has also served Green Hills Engineering College as an assistant professor for 4 years and as a Quality and testing Engineer in Cenzer Industries Pvt. Ltd. He has published several papers in reputed international journals and attended so many conferences. His area of research is optical fiber communication, Basic Electronics & Digital Signal Processing. He has also filed several patents on his work.

Kamal Kashyap is a Ph.D. scholar at Shoolini University. He has published various papers in national and international journals. His area of interest is Hydro turbines, Eco friendly energy and Energy generation from traditional technologies.

Sorabh Aggarwal is working as Assistant Professor, Shoolini University, Solan, India. He Received M. Tech degree in Mechanical Engineering from NIT Kurukshetra. He has total of 6 Years of teaching experience, He has filed 25 patents in the field of Mechanical Engineering and 5 of them have been granted.