Identification of Most Important Parameter for Efficiency Performance of Hydro Power Plant by Harmonic Mean Hierarchy Process (HMHP)

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Abstract: **The accuracy of any decision making model depends mainly on the performance in estimation of the priority of each factors in respect to the objective. Multi-criteria decision making (MCDM) offers a feasible option in this regard. The priority value which is determined by the MCDM can differentiate the factor based on their degree of importance with respect to the decision objective. But the problem different ranking results are very sensitive to the changes in attribute weights and difficult to understanding of scale would be a ranking order or a ratio scale by decision maker (DM). In this present study tries to overcome this two disadvantage of MCDM. For overcoming this weakness of MCDM, first time introduce a novel MCDM namely Harmonic Mean Hierarchy Process (HMHP). This new MCDM technique used to solve multi criteria decision making (MCDM) problem. These new methods first time apply for estimate the efficiency of HPP. According to the result selected Efficiency of turbine to be the most influential parameter for efficiency performance of HPP. Also this problem solve by some existing MCDM techniques for verifying the result, which is solved by HMHP.**

1. INTRODUCTION

Multiple criteria decision-making (MCDM) refers to making decisions in the presence of multiple conflicting criteria. It is widely applied in risk assessment [1], supply chain management [2], manufacturing environments [3], material selection [4], and weapons system evaluation [5]. For example, when a company wants to know most important parameter (MIP) of performance efficiency of Hydropower Plant (HPP), they must consider loss (L), quality of machine (QM), energy requirement (ER) and so on. These criteria are frequently in conflict with each other. It is a difficult work to choose the MIP from efficiency factors with increasing the efficiency of HPP. There are many MCDM problems that are more complicated than selecting the MIP of efficiency of HPP. The world's increasing complexity and uncertainty make the decision-making process even more challenging. So main objective of MCDM is to provide decision makers with a tool in order to enable them to advance in solving a multi-criteria decision problem, where several conflicting criteria are taken into account.

In decision making problem, a decision maker (DM) must choose the MIP that satisfies the determination criteria among a set of candidate solutions. Depending on the DM's previous experience, how to make trade-off between these conflicting alternatives and make a scientific decision largely. Recently, there are many MCDM methods that have been developed to solve this type of decision making problem. The most commonly used methodologies are the analytical hierarchy process (AHP) [6], Weighted-sum model (WSM)[], preference ranking organization method for enrichment evaluation (PROMETHEE) [19], elimination and choice translating reality (ELECTRE) [21-23], techniques for order preference by similarity to an ideal solution (TOPSIS) [20]. Different types of methods or models are used to solve different type of decision problem. AHP method decomposes the decision problem into a hierarchy system of sub-problems, each of which is analysed in terms of each criterion [7, 8]. WSM method is based on the assumption of additive utility [15]. PROMETHEE is one type of outranking method, and requires the concordance and discordance indices [16, 17]. ELECTRE is one type of outranking method, and each criterion associates a preference function [16, 18]. TOPSIS method is based on the notion that the best decision should be the closest to the ideal solution and farthest from the non-ideal solution [main paper].

All these methods there are four main disadvantages that need to be discussed. First, different users will obtain different results when using the same method. Different DMs often have different backgrounds, expertise and experience. The preferred information associated with DMs on the evaluation criteria varies from person to person. Meanwhile, different relative criteria weights have a significant effect on the selection of the most appropriate alternatives. The ranking results are very sensitive to the changes in attribute weights. The presence of different attribute weights may result in different ranking orders [9]. The decision made by a single expert may not be conclusive. In most of these cases, different groups of DMs are involved in the selection process. Each group has different criteria and perspectives to make the decision more reliable [10]. Second, different techniques may yield different results when applied to the same problem [11]. Different approaches are proposed from various schools of thinking. There are no better or worse techniques, only techniques that fit better to a certain situation. It is not easy to say which MCDM approach is more reasonable and reliable for a given decision-making problem, as the selection of MCDM methods itself is a complicated MCDM process [12]. Many DMs apply several MCDM approaches to the same problem, compare their results, and then make the final decision. This approach is difficult to comprehend and complex to implement because it requires extensive technical knowledge in MCDM fields. A combination of different MCDM evaluation techniques to construct a hybrid model may be the correct choice in solving this problem. Third, the evaluation process of the existing MCDM approaches is complicated. For a proper and effective evaluation, DMs require a large amount of data for analysis and many factors for consideration. The DM should be an expert or, at least, very familiar with the selection problem. It is difficult for a general DM who does not have a strong background in mathematics to effectively complete the evaluation process. On the other hand, when the selected alternatives have changed, e.g., a new alternative is added to the MCDM problem, the entire mathematical calculation process must be repeated. This is impracticable and ineffective for DMs. Thus, a simple, logical and systematic approach to solving MCDM problems is required. An MCDM model constructed by experienced experts may be useful and effective for decision-making. Fourth major weakness of MCDM method is identifying whether the DM's understanding of this scale would be a ranking order or a ratio scale [13].

In this study, a novel MCDM model namely Harmonic Mean Hierarchy Process (HMHP) inspired by existing MCDM techniques basically AHP. Three most impotent part use in this new MCDM techniques, these steps are (1) determination of rank of parameters, in this step, the rank of the parameters are at first determined as per the importance of the variables in expansion of the objective function. Here objective function is contracted by product of the sum of each beneficiary factor with its weightge divided by product of the sum of each non-beneficiary factor with its weightge. In this regard, statistical methods like t-test, x-bar, µ-chart etc. are utilized. So it is cleared that in our method, there is no need for an expert to assign exact numerical values to the comparison judgments. (2) Pair-wise comparison, one of the major disadvantages of MCDM understands of this scale would be a ranking order or a ratio scale by DM's. Consider the equation 2 and 3 for overcoming this weakness of MCDM. In equation 2 and 3 does not require any scale or ratio, only require rank of each parameter. (3) Selection of priority, in AHP pair-wise comparisons matrices are aggregated using geometric mean (GM) [14], but one of the disadvantages of GM is that 'it is difficult to calculate particularly when the items are very large or when there is a frequency distribution'. So the pair-wise comparisons matrices are aggregated using harmonic mean (HM) because it is the most suitable average when it is desired to give greater weight to smaller observations and less weight to the larger ones. It is clear that the lowest normalized value of HM of a factor is most important factor.

The remainder of this paper is organized as follows. In Section 2, brief description of HMHP. A case study of MIP factor of efficiency of HPP selection problem is proposed in Section 3 to explain the detailed application process of the proposed method. Conclusions are presented in the last section.

2. METHODOLOGY

The HMHP method is basically based onone method namely HM and two important steps namely determination of rank of parameters as well as construct a pair-wise comparison matrix. In HMHP pair-wise comparisons matrices are aggregated using HM. The step, determination of rank of parameters is used to find the rank of each parameter by statistical methods. Also the step pair-wise comparison matrix is used to find the comparison between two attributes by the equations 2 and 3. The proposed HMHPis sequentially presented in the following subsection.

(I) Structuring the decision problem:

Consider that the new MCDM technique has (m + n) input factors as $\{c_1, c_2, c_3,......, c_m\}$and $\{a_1, a_2, a_3,......, an\}$. Here $\{c_1, c_2, c_3,......, c_m\}$and $\{a_1, a_2, a_3,......, a_n\}$ are set of criteria and alternative respectively. The main aim of a MCDM method is to find the most important alternatives. For this structuring the decision problem is the most important because it is obvious that the process of structuring a decision making solution (DMS) appears to many as the most valuable and existing part of the whole MCDM methodology [11]. Moreover, the different MCDM methods are based on the decision maker (DM) performs articulation and actually new psycho-cognitive findings reveal that modelling and structuring processes affect the performance articulations: "one of the most perplexing aspects of human decision making behaviour under risk is the sensitivity of preferences to seemingly minor changes in the way a problem is presented"[12]. In this section involve two necessary steps for MCDM techniques, namely (a) selection alternatives and (b) selection of criteria. Using this new MCDM method find the most important parameter (MIP) with respect to that criteria.

a. Selection of alternatives: In MCDM techniques, DMs'collect of all those factors (alternatives), which are inversely and directly proportional to decision problem.Some time DMfacing some problem for collecting alternative with relative data of that factor. Most of the time DM depends on various surveys.

Let B $= \{a_1^b, a_2^b, \dots\dots\dots, a_r^b\}$ and

$N_B = \{a_r^{nb}, a_{r+1}^{nb}, \dots\dots\dots, a_n^{nb}\}$ be the set of beneficial and

non- beneficial factors respectively

Therefore

$B \cup N_B = \{a_1^b, a_2^b, \ldots\ldots\ldots\ldots, a_r^b\} \cup \{a_r^{nb}, a_{r+1}^{nb}, \ldots\ldots\ldots\ldots, a_n^{nb}\}$

$= \{a_1, a_2, a_3, \ldots\ldots, a_n\}$

a. Selection of criteria: In MCDM techniques MIP was selected with respect to (w. r. t.) criteria. So all selected factors are depends on each criteria. Some factors are directly or inversely impacted by each criteria. That is

   If $C = \{c_1, c_2, c_3, \ldots\ldots, c_m\}$ be the set of criteria then $a_i = f_i(c_1, c_2, c_3, \ldots\ldots, c_m)$ where $i = 1,2,\ldots\ldots\ldots,n$.

   Basically which criteria are selected those are impacted by decision problem.

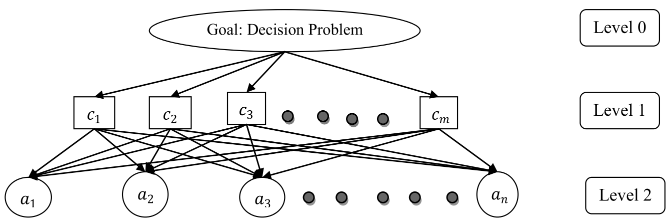

Fig 1: Figure showing the structuring the decision problem

(ii) Determination of rank of parameters:

In the MCDM method, the rank of the parameters is at first determined as per the importance of the variables in expansion of the objective function. In this regard, statistical methods are utilized.

If r (p.v. of the beneficiary parameter) and n (p.v. of the non-beneficiary parameter) are the weights of importance then the objective equation is used to find the rank of each parameter.

$$I = \frac{\sum rB_r}{\sum nNB_n} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eqn. 1}$$

Where r = random (0, 1) and n = random (0, 1)

First consider sample size krandomly for all alternatives with respect to each criteria. Then apply statistical methods on nk data set for each criteria. After applying statistical methods find the index vale by the equation 1. If the criteria is beneficiary then choose that value of alternative in which index value is maximum. If the criteria is non-beneficiary then choose that value of alternative in which index value is minimum.

(iii) Construct a pair-wise comparison matrix:

The pair-wise comparison is constructed among all criteria in the dimensions of the hierarchy system based on the DMs' preferences as following matrix A,

$$\begin{array}{c|c} \text{Factor} & a_1 \quad a_2 \quad a_3 \ldots\ldots\ldots a_n \\ \hline A = & \begin{array}{c} a_1 \\ a_2 \\ \cdots \\ a_n \end{array} \begin{bmatrix} 1 & a_{12} & a_{13} & \cdots & a_{1n} \\ a_{21} & 1 & a_{23} & & a_{2n} \\ & \vdots & & \ddots & \vdots \\ a_{n1} & a_{n2} & a_{n3} & \cdots & 1 \end{bmatrix} \end{array}$$

In this matrix all entries of pair-wise comparison of factor a_i with factor a_j is denoted by a_{ij} and is defined by

$$a_{ij} = \text{Factors } a_i \text{ importance then factors } a_j = \begin{cases} b_j^{\,b_i}, \ if\ b_j^{\,b_i} > b_i^{\,b_j} \\ b_i^{\,b_j}, \ otherwise \end{cases} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{Eqn. 2}$$

$$a_{ij} = \text{Factors } a_i \text{ less importance then factors } a_j = \begin{cases} b_j^{\,b_i}, \ if\ b_j^{\,b_i} < b_i^{\,b_j} \\ b_i^{\,b_j}, \ otherwise \end{cases} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{Eqn. 3}$$

Where b_i and b_j are rank of factors a_i and a_j respectively. Here rank of a_i decided by statical method. Where

$b_k \in N \ (k = 1, 2, \ldots\ldots, n)$

Table 1: table showing rank of each factors with the help of survey

Factor	a_1	a_2	a_3	....	a_n
Rank	b_1	b_2	b_3	....	b_n

When pair-wise comparison is completed, then find

$$A^2 = AA = \begin{bmatrix} a'_{11} & a'_{12} & a'_{13} & \cdots & a'_{1n} \\ a'_{21} & a'_{22} & a'_{23} & & a'_{2n} \\ & \vdots & & \ddots & \vdots \\ a'_{n1} & a'_{n2} & a'_{n3} & \cdots & a'_{nn} \end{bmatrix}$$

(iv) Aggregate DMs' preferences:

The pair-wise comparisons matrices are aggregated using harmonic mean (HM). After finding A^2 then find the harmonic mean (HM) of element of each respective rowand is denoted by h_{i1}^*. That is

$$h_{i1}^* = \frac{n}{\sum_{j=1}^{n} \frac{1}{a'_{ij}}} (i = 1, 2, 3, \ldots, n)$$

Construct a column matrix $H^{(2)} = [h_{i1}^{*}]$ by all the elements of $\{h_{i1}^{*}: i = 1, 2, 3, \ldots, n\}$

(v) Normalized Matrix:

Find the sum of each h_{i1} i.e., $\sum_{i=1}^{n} h_{i1}^{*} = s^{*}$, then find normalized of each element of $H^{(2)}$by dividing each elements of $H^{(2)}$by s^{*} and is denoted by w_{i1}. That is

$$w_{i1}^{(2)} = \frac{h_{i1}}{s^{*}}$$

Construct a weights column matrix $W^{(2)} = [w_{i1}^{(2)}]$ by all the elements of $\{w_{i1}^{(2)}: i = 1, 2, 3, \ldots, n\}$

Now find A^3

$$A^3 = A^2 A = \begin{bmatrix} a_{11}^{//} & a_{12}^{//} & a_{13}^{//} & \cdots & a_{1n}^{//} \\ a_{21}^{//} & a_{22}^{//} & a_{23}^{//} & & a_{2n}^{//} \\ & \vdots & & \ddots & \vdots \\ a_{n1}^{//} & a_{n2}^{//} & a_{n3}^{//} & \cdots & a_{nn}^{//} \end{bmatrix}$$

After finding A^3 then find the harmonic mean (HM) of each element of each respective row and is denoted by

$$H^{(3)} = [h_{i1}^{**}], \text{ where } h_{i1}^{**} = \frac{n}{\sum_{j=1}^{n} \frac{1}{a_{ij}^{//}}} (i = 1, 2, 3, \ldots, n)$$

Find the sum of each h_{ij} i.e., $\sum_{i=1}^{n} h_{i1}^{**} = s^{**}$, then find the normalized of each element of $H^{(3)}$by dividing each

elements of $H^{(3)}$ by s^{**} and this normalized matrix is denote by $W^{(3)} = [w_{i1}^{(3)}]$, $w_{i1}^{(3)} = \frac{h_{i1}}{s^{**}} (i = 1, 2, 3, \ldots, n)$

(vi) Selection of priority matrix:

Find the sum of each h_{i1} i.e., $\sum_{i=1}^{n} h_{i1}^{*} = s^{*}$, then find

Using above two steps find $W^{(r+1)}$and $W^{(r)}$. Here stop this process if given $\epsilon > 0 \exists$ a natural number r such that

$$\left|w_{i1}^{(r+1)} - w_{i1}^{(r)}\right| < \epsilon; (\forall i = 1, 2, 3, \ldots, n)$$

That is after finding of $W^{(r+1)}$and $W^{(r)}$, calculate the difference between absolute value of each element of each corresponding element of each row is small. Theneach elements of $([1]_{n\times1} - W^{(r)})$................................ Eqn. 3 taken as weights of importance of each factors.

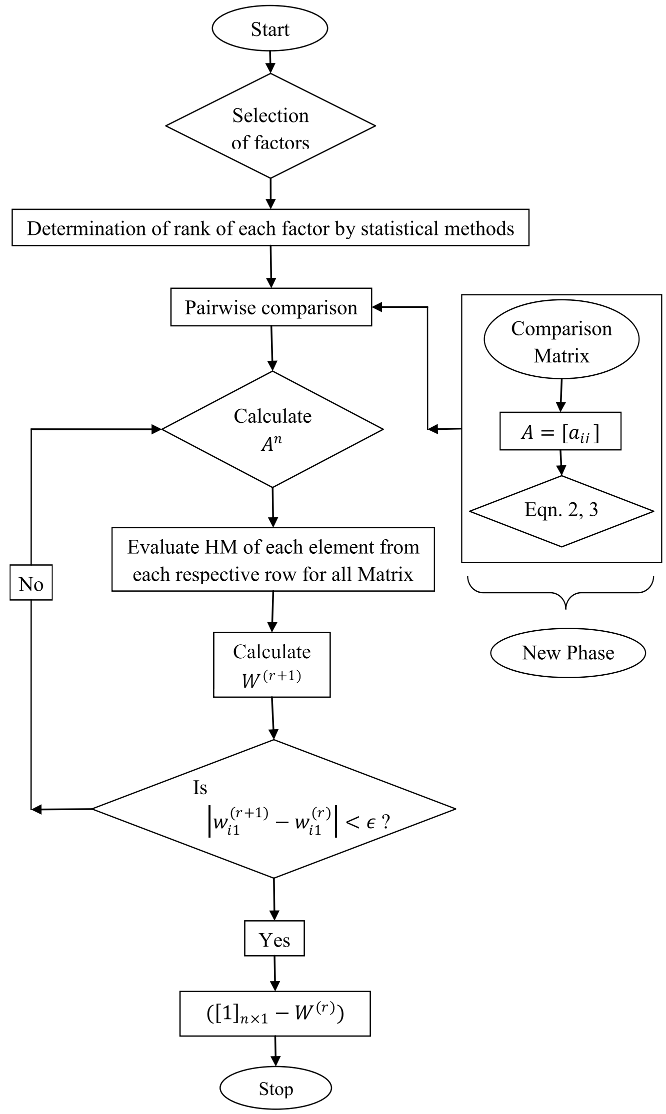

Fig. 2 Figure showing a schematic of the proposed methodology

3. APPLICATION OF THE MCDM

In this study this new method is applied for finding the MIP (most important parameters) for efficiency of HPP.

According to the literature survey the parameters efficiency of penstock (EP) [13], efficiency of turbine (ET) [14], efficiency of generator (EG) [14] and labour efficiency (LE) [15] control the overall efficiency of HPP (Hydro Power Plant). Again in a study conducted by loss (L), quality of machine (QM), energy requirement (ER) and locational interference (LI) by the important factors which can change the efficiency factors of a HPP.

Here {L, QM, LE, LI} and {EP, ET, EG, LE} taken as a set of criteria and alternative.

In the MCDM method the rank of the parameters were at first determined as per the importance of the parameter in the objective. In this regard statistical method like t-test was utilized. Table 1 showing the rank of the each factor with respect to each criteria and table 2 showing the rank of criteria by t-test.

Table 1: showing the rank of facto of efficiency with respect to criteria.

Rank	EP	ET	EG	LE
L	4	2	1	3
QM	1	3	2	4
ER	3	1	2	4
LI	4	1	2	3

Table 2: showing the rank of criteria

Criteria	rank of criteria
L	4
QM	1
ER	2
LI	3

After the ranking was completed the parameters were compared with each other with respect to the study objective based on the criteria given the table 3.

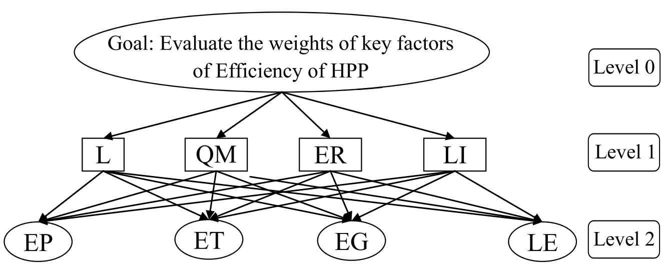

Fig. 2 figure showing typical hierarchy system for the decision problem

Table 3a: showing the pairwise comparison between criteria and p.v.

	L	QM	ER	LI	p.v.
L	1	1^4	2^4	4^3	0.392343
QM	4^1	1	2^1	3^1	0.041194
ER	4^2	1^2	1	3^2	0.134169
LI	3^4	1^3	2^3	1	0.432293

Table 3b: showing the pairwise comparison of alternatives with respect to loss and p.v.

L	EP	ET	EG	LE	p.v.
EP	1	4^2	1^4	4^3	0.392343
ET	2^4	1	1^2	3^2	0.134169
EG	4^1	2^1	1	3^1	0.041194
LE	3^4	2^3	1^3	1	0.432293

Table 3c: showing the pairwise comparison of alternatives with respect to quality of machine and p.v.

QM	EP	ET	EG	LE	p.v.
EP	1	3^1	2^1	4^1	0.041194
ET	1^3	1	2^3	3^4	0.432293
EG	1^2	3^2	1	4^2	0.134169
LE	1^4	4^3	2^4	1	0.392343

Table 3d: showing the pairwise comparison of alternatives with respect to energy requirement and p.v.

ER	EP	ET	EG	LE	p.v.
EP	1	1^3	2^3	3^4	0.432293
ET	3^1	1	2^1	4^1	0.041194
EG	3^2	1^2	1	4^2	0.134169
LE	4^3	1^4	2^4	1	0.392343

Table 3e: showing the pairwise comparison of alternatives with respect to locational interference and p.v.

LI	EP	ET	EG	LE	p.v.
EP	1	1^4	2^4	4^3	0.392343
ET	4^1	1	2^1	3^1	0.041194
EG	4^2	1^2	1	3^2	0.134169
LE	3^4	1^3	2^3	1	0.432293

$$\begin{pmatrix} 0.399468 & 0.041794 & 0.38994 & 0.398885 \\ 0.136544 & 0.385656 & 0.031955 & 0.026105 \\ 0.02436 & 0.133426 & 0.134583 & 0.136042 \\ 0.439628 & 0.439124 & 0.443523 & 0.438967 \end{pmatrix} \begin{pmatrix} 0.399468 \\ 0.136544 \\ 0.02436 \\ 0.439628 \end{pmatrix} = \begin{pmatrix} 0.383237 \\ 0.093783 \\ 0.097691 \\ 0.425287 \end{pmatrix}$$

Using Eqn. 1 it was found that

$$\begin{bmatrix} 1 \\ \\ 1 \\ 1 \end{bmatrix} \begin{pmatrix} 0.383237 \\ 1-0.093783 \\ 0.097691 \\ 0.425287 \end{pmatrix} = \begin{pmatrix} 0.616763 \\ 0.906217 \\ 0.902309 \\ 0.574713 \end{pmatrix}$$

Using new MCDM technique it was found that labour efficiency is the most important parameter for efficiency of HPP. Table 4 represent the weights of importance of each alternative.

Table -4: Showing the weights of importance of each alternative using new MCDM technique.

	EP	ET	EG	LE
weights	0.616763	0.906217	0.902309	0.574713

Table – 5: showing Ranking results of the selected problem

Alternatives	Ranking results						
	Proposed method	AHP	WSM	Promethee	Electre-I	Electre-II	Topsis
EP	3	3	3	3	2	2	3
ET	1	1	1	1	1	1	2
EG	2	2	2	2	1	1	1
LE	4	4	4	4	2	2	4

The index of Efficiency of HPP = $I_{efficiency}$ = 0.616763× EP + 0.906217 × ET + 0.902309 × EG +0.574713 ×LE .....Eqn. 4

With the help of proposed model, $I_{efficiency}$ is found for HPP of Gomti HPP, Kopli,Loktak and Umium Umtru northeast in India which are predicted showing in Fig. 4. Table 6 showing the inputs data of four different HPP in normalized form for estimation of the $I_{efficiency}$.

Table 6: Table showing the Inputs data of HPP

	EP	ET	EG	LE
Gomti	0.253247	0.305556	0.257732	0.204082
Kopli	0.194805	0.25	0.309278	0.204082
Loktak	0.275974	0.222222	0.216495	0.306122
Umium Umtru	0.275974	0.222222	0.216495	0.285714

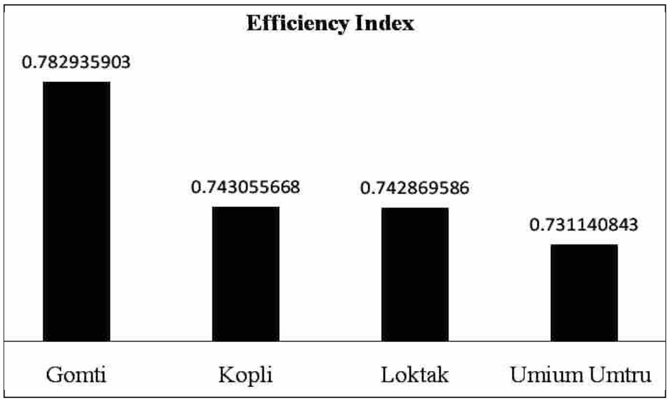

Fig 4: Efficiency Index Value

The new method identified that the most important parameter (MIP) of performance of HPP is Efficiency of turbine, which concords with what is also recommended by the studies such as those by the studies like Cordova [24] and Iemsomboon [25].Detailed comparative results are tabulated in table 5. It is clear that most of the method gives ET is the impotent for efficiency increasing of HPP. Also some methods give EG also important factor. From the Fig. 4 it is clear that index value of Gomti HPP is greater than remaining three hydro power stations. It is logical because efficiency of turbine of Gomti HPP is greater than other hydro power plants.

4. CONCLUSION

The present investigation is an attempt to find p.v. of decision variables. The aim was to replace the weakness of MCDM techniques which gives p.v. at a common of regular scenario. Accordingly a rule was made by equation 1, 2 as well as HM to estimate the efficiency of HPP at normal scenario. The result selected Efficiency of turbine to be the most influential parameter for efficiency performance of HPP. The main advantage of this method is 'it handles both qualitative and quantitative criteria'. The drawback of this MCDM method is it determines this weight of importance for common scenarios which includes both optimal and non optimal cases. Although there are many scopes of improvement in this method among which constriction of the feasible domain of the design variables is the most important and may be achieved by hybridizing with MCDM techniques.

REFERENCE

[1] Y.M. Wang, J. Liu, T.M.S. Elhag, An integrated AHP-DEA methodology for bridge risk assessment, Comput. Ind. Eng. 54 (2008) 513–525.

[2] C.T. Chen, C.T. Lin, S.F. Huang, A fuzzy approach for supplier evaluation and selection in supply chain management, Int. J. Prod. Econ. 102 (2006) 289–301.

[3] R.V. Rao, B.K. Patel, Decision making in the manufacturing environment using an improved PROMETHEE method, Int. J. Prod. Res. 48 (2010) 4665– 4682.

[4] P. Chatterjee, V.M. Athawale, S. Chakraborty, Selection of materials using compromise ranking and outranking methods, Mater. Des. 30 (2009) 4043– 4053.

[5] M. Dagdeviren, S. Yavuz, N. Kilinc, Weapon selection using the AHP and TOPSIS methods under fuzzy environment, Expert. Syst. Appl. 36 (2009) 8143–8151.

[6] T.L. Saaty, The analytical hierarchy process, McGraw-Hill, New York, 1980.

[7] Mendoza, G.A., Sprouse, W., 1989. Forest planning and decision making under fuzzy environments: an overview and illustration. For. Sci. 35, 481e502.

[8] Phua, M.H., Minowa, M., 2005. A GIS-based multi-criteria decision making approach to forest conservation planning at a landscape scale: a case study in the Kinabalu Area, Sabah, Malaysia. Landsc. Urban Plan. 71, 207e222.

[9] M. Yurdakul, Y.T. Ic, Application of correlation test to criteria selection for multi criteria decision making (MCDM) models, Int. J. Adv. Manuf. Tech 40 (2009) 403–412.

[10] S.D. Pohekar, M. Ramachandran, Application of multi-criteria decision making to sustainable energy planning - A review, Renew. Sust. Energ. Rev 8 (2004) 365–381.

[11] S.H. Zanakis, A. Solomon, N. Wishart, S. Dublish, Multi-attribute decision making: A simulation comparison of select methods, Eur. J. Oper. Res. 107 (1998) 507–529.

[12] X. Sun, Y. Li, An intelligent multi-criteria decision support system for systems design, in: 10th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference, Fort Worth, Texas, American Institute of Aeronautics and Astronautics, 2010, pp. 1–11.

[13] Ozcan, T., Elebi, N., & Esnaf, A. (2011). Comparative analysis of multi-criteria decision making methodologies and implementation of a warehouse location selection problem. *Expert Systems with Applications*, 38(8), 9773–9779.

[14] Buckley, J. J. (1985). Fuzzy hierarchical analysis. *Fuzzy Sets and Systems*, 17(3), 233–247.

[15] Martins, A.G., Coelho, D., Antunes, H., Clímaco, J., 1996. A multiple objective linear programming approach to power generation planning with demand-side management (DSM). Int. Trans. Oper.l Res. 3, 305–317.

[16] Kangas, A., Kangas, J., Pyk€al€ainen, J., 2001. Outranking methods as tools in strategic natural resources planning. Silva Fenn. 35, 215–227.

[17] Schmoldt, D.L., Kangas, J., Mendoza, G.A., Pesonen, M., 2001. The Analytic Hierarchy Process in Natural Resource and Environmental Decision Making. Springer, Dordrecht.

[18] Laukkanen, S., Kangas, A., Kangas, J., 2002. Applying voting theory in natural resource management: a case of multiple-criteria group decision support. J. Environ. Manag. 64, 127–137.

[19] Brans, J.P., & Vincke, Ph. A. (1985). preference ranking organisation method: (The PROMETHEE method for multiple criteria decision-making). *Management Science*, 31(6), 647–656.

[20] C.L. Hwang, K. Yoon, Multiple attribute decision making: Methods and applications, Springer, New York, 1981.

[21] Belton, V., & Stewart T.J. (2002) Multiple criteria decision analysis: An integrated approach. *Dordrecht: Kluwer Academic Publishing*.

[22] Roy, B., & Mousseau, V. (1996) A theoretical framework for analysing the notion of relative importance of criteria. *Journal of Multi-Criteria Decision Analysis*, 5, 145–149.

[23] Vincke, P. (1992) Multicriteria decision-aid. *Bruxelles, Belgium: Wiley*.

[24] Cordova, M. M., Finardi, E. C., Ribas, F. A. C., Matos, V. L.,& Scuzziato, M. R. (2014).Performance evaluation and energy production optimization in thereal-time operation of hydropower plants. *Electric Power Systems Research*, 116, 201–207.

[25] Iemsomboon, P., Pati, T., &Bhumkittipich, K. (2013). Performance Study of Micro Hydro Turbine and PV for Electricity Generator, Case Study: Bunnasopit School, Nan Province, Thailand. *Energy Procedia*, 34, 235 – 242.

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