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# *Efficiency Assignment of Hydropower Plants by a Hybrid MCDM Method*

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***Abstract***

*The ever-growing demand for luxury has increased the stress on conventional energy sources and encourages scientists and engineers to look for alternatives. Hydropower is by far the most inexpensive but reliable source of energy which is deemed to have the capacity to substitute for conventional energy sources. The worldwide contribution of hydropower plants (HPP) in supplying the demand for electricity is 1106 TWh. The problem with hydropower lies with the fact that its efficiency depends on multiple factors which are a function of climatic, hydraulic and socio-economic parameters. All these parameters again depend upon hydraulic loss imposed due to time in use, change in energy requirements, locational interference and quality of the machine installed. As there are multiple parameters having different levels of influence on the performance efficiency of HPP. Thus some factors are overrated and some others remain under rated which results in erroneous decision-making. The present study proposes a new hybrid model based on Decision-Making Trial and Evaluation Laboratory (DEMATEL) with ORESTE. The priorities are determined by hybrid method namely DEMATEL-ORESTE. According to the results, efficiency of generator is most significant for efficiency of HPP.*


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***Keywords:*** *Hydropower Plants, Hybrid MCDM Method, Decision-Making Trial and Evaluation Laboratory (DEMATEL), ORESTE*

## INTRODUCTION

Progress in renewable energy boosts energy protection, addresses environmental problems and climate trade, as well as contributing to other points of social development [1, 2]. There is the potential for renewable energy to represent more than one third of worldwide energy development [3]. Hydropower is the leading renewable source for electricity generation globally, supplying 76% of all renewable electricity. Total installed capacity in 2013 was 1000 GW. Hydropower produces 16.4% of the world's total electricity from all sources [4]. Among renewable resources, hydropower occupies a superior role in the renewable energy market and leads the way for reliable, renewable and clean energy [5].

The performance efficiency of HPP depends on various climatic, hydraulic and socio-economic parameters. According to the literature, the following parameters control the overall efficiency of HPP: efficiency of penstock, efficiency of turbine, efficiency of generator and labor efficiency. Although various studies have been conducted to propose a methodology to analyze HPP performance, answers to the following problems remain inconclusive:

i. It is not possible to analyze the performance using so many parameters. This is why it is necessary to identify the most important parameters (MIP).

ii. Any indicator/media which represents the performance of HPP must not be biased and must consider the input parameters as per their contribution to the plant O/P.

The present study attempts to find a solution to these problems, by adopting a new MCDM method which generates a decision for normal conditions, does not require human inferences and determines contributions based on the importance of the parameter in influencing the plant performance.


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## 2. METHODOLOGY:

In this study one hybrid MCDM technique namely DEMATEL-ORESTE,was usedfor finding MIP in the normal scenario for performance of HPP.

### *2.1. Decision-Making Trial and Evaluation Laboratory:*

One of the multiple criteria approaches proposed by Fontela and Gabus [6], known Decision-Making Trial and Evaluation Laboratory (DEMATEL) by which analyzing decisions only for criteria. DEMATEL) method [14, 15, 16] has been applied to illustrate the interrelations among criteria and to find the central criteria to represent the effectiveness of factors/aspects. In the current study, hence, utilize DEMATEL decision-making method to determine the importance weights of evaluation criteria.

Consider the number of criteria is n. Construct a direct-relation matrix by $B_1=[b^{(1)}_{ij}]_{n\times n}$, $B_2=[b^{(2)}_{ij}]_{n\times n}$, $B_3=[b^{(3)}_{ij}]_{n\times n}$, ....., $B_s=[b^{(s)}_{ij}]_{n\times n}$ such that $A= [a_{ij}]_{n\times n}$

Where, $a_{ij} = \{b^{(1)}_{ij}+ b^{(2)}_{ij}+ b^{(3)}_{ij}+.....+ b^{(s)}_{ij}\}/m$, $i, j = 1, 2, 3,....., n$ and $i \neq j$.

$a_{ii} = 0$, $i = j = 1, 2, 3,....., n$.

Also $B_1$, $B_2$, $B_3$, ....., $B_s$denote the s number of experts is asked to make pairwise comparisons in terms of influence between criteria by an evaluation scale showing in table 1.

***Table 1: Table showing evaluation scale for DEMATEL preferences [6]***

| Verbal judgments of preferences | Numerical rating |
|---|---|
| No influence | 0 |
| Low influence | 1 |
| Medium influence | 2 |
| High influence | 3 |
| High influence | 4 |


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For a fixed $\lambda > 0$ ∃ a normalized direct-relation matrix M such that $M = \lambda A$

Here taking $\lambda = \min \{(\max_i \sum_{j=1}^{n} a_{ij})^{-1}, (\max_j \sum_{i=1}^{n} a_{ij})^{-1}\}$

Since M is an×n matrix then $(I - M)^{-1}$ must be exist and it is also n×n matrix. Where I is an×n identity matrix. As M and $(I - M)^{-1}$ both are squire matrix and same order so $M(I - M)^{-1}$ must exist, called total-relation matrix and is denoted by $T=[t_{ij}]_{n\times n}$.

The sum of rows and the sum of columns of T are separately denoted as D and R.

$$D = \sum_{j=1}^{n} t_{ij}$$

$$R = \sum_{i=1}^{n} t_{ij}$$

The D + R value indicates the degree of importance that the corresponding criterion plays in the entire system. The factor having greater value of D + R has more inter relationships with other factors. On the other hand, criteria having positive values of D – R are on the cause group and dispatches effects to the other criteria. On the contrary, criteria having negative values of D – R are on the effect group and receive effects from the other criteria. Since the total-relation matrix T provides the information on how one criterion affects another, decision maker group should set up a threshold value in order to filter out some negligible relationships. This way enables the decision maker to choose only the relationships greater than the threshold value and to map the cause-effect relationship accordingly. The causal diagram can be acquired by mapping the dataset of the (D + R, D – R) where the horizontal axis D + R and the vertical axis D – R.

### *2.2 Multicriterion Analysis of Preferences by Means of Pairwise Actions and Criterion Comparisons method :*

One of the multiple criteria approaches proposed by Roubens[7], known ORESTE, by which analyzes decisions for alternatives. It is based on only takes into account the ranking of alternatives and criteria, it is suited to problems with ordinal data. The method does not require quantification of criteria weights and alternatives' performance values, only their ordinal rankings [13].In the current study, hence, we utilize a multi-criteria decision-making method to determine the importance weights of evaluation criteria, and ORESTE method


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to obtain the performance ratings of the feasible alternatives.

Each alternative $\alpha_j$is assigned a qualitative value, $v_{ij}$, relative to each $C_i$ representing the rank value of its performance relative to $C_i$. A qualitative value, $w_i$, is assigned to each $C_i$ representing the rank value of its importance relative to the other $C_i$. On the basis of these values, the distance, $\delta(0, v_{ij})$, between an arbitrary origin, 0, and $v_{ij}$ is defined such that for any two alternatives, $\alpha_e$and$\alpha_f$, and for each $C_i$

$\delta(0, v_{ie}) < \delta(0, v_{if})$iff $v_{ie} > v_{if}$

Distances are thus assigned to each Alternative relative to each criterion on the basis of which a rank, $\rho(v_{ij})$ is assigned to each of the mxn$v_{ij}$ with [15].

$0 < \rho(v_{ij}) \leq nm$

Where, for any two alternatives, ,$\alpha_e$ and $\alpha_f$, and for any two criteria, $C_e$and $C_f$,

$\rho(v_{ee}) \leq \rho(v_{ff})$iff$\delta(0, v_{ee}) < \delta(0, v_{ff})$

A concordance index, C(, $\alpha_e$,$\alpha_f$) is defined for each pair of alternatives , $\alpha_e$ and $\alpha_f$such that

$$C(, \alpha_e, \alpha_f) = \sum_{i:\delta(0,v_{ie})>\delta(0,v_{if})}(v_{ie} - v_{if})$$

The rank, $\rho(A_j)$, of an alternative $A_j$ is defined by

$$\rho(A_j) = \sum_{i=1}^{n} v_{ij}$$

Quantitative value, $\beta$and $\gamma$, are defined where $\beta$ represent the maximal level of and $\gamma$ represents the minimal level of incomparability between two alternatives (Bourguignon and Massort, 1994). A preference relation,< , is defined such that given any two alternatives, $\alpha_e$ and $\alpha_f$, , $\alpha_e < \alpha_f$ if and only if

$$\frac{R(\alpha_f) - R(\alpha_e)}{n^2(m-1)} \leq \beta$$

$$\frac{C(\alpha_e, \alpha_f)}{R(\alpha_f) - R(\alpha_e)} \leq \gamma_{ef}$$

## 3. RESULTS AND DISCUSSION:

In this study this new method is applied for finding the MIP for efficiency of HPP.


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According to the literature survey the parameters efficiency of penstock (EP) [8], efficiency of turbine (ET) [9], efficiency of generator (EG) [9] and labour efficiency (LE) [10] 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 a group of expert was utilized. Table 2 showing the percentage of the each factor with respect to each criteria. In this study taking more than five expert's opinion for find the percentage.

***Table 2: showing the percentage of facto of efficiency with respect to criteria.***

| Percentage | EG | ET | LE | EP |
|---|---|---|---|---|
| L | 73.33% | 53.33% | 40.00% | 26.67% |
| QM | 46.67% | 33.33% | 20.00% | 60.00% |
| ER | 46.67% | 66.67% | 13.33% | 26.67% |
| LI | 40.00% | 53.33% | 33.33% | 26.67% |


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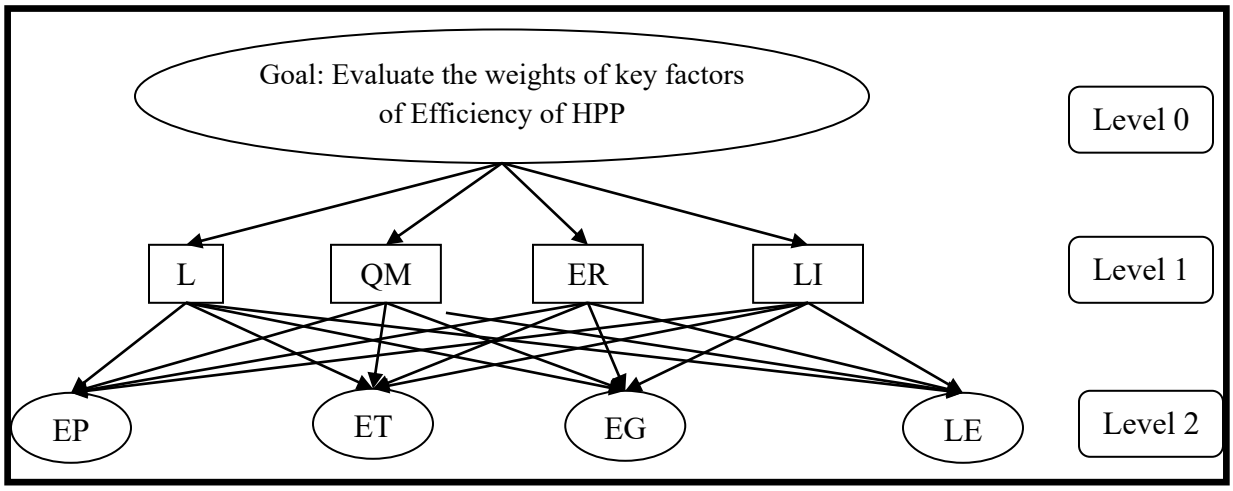



***Figure 1: figure showing typical hierarchy system for the decision problem.***

### *3.1. Results from DEMATEL MCDM Approach:*

Here the criteria L, QM, LE, LI is denoted by C1, C2, C3, C4 respectively.

The answer matrices corresponding to the intelligible maps are as follows:

$$B(1) = \begin{bmatrix} 0 & 2 & 3 & 4 \\ 1 & 0 & 4 & 3 \\ 2 & 1 & 0 & 2 \\ 3 & 2 & 1 & 0 \end{bmatrix},$$

$$B(2) = \begin{bmatrix} 0 & 3 & 4 & 4 \\ 1 & 0 & 3 & 4 \\ 2 & 2 & 0 & 2 \\ 3 & 3 & 2 & 0 \end{bmatrix},$$

$$B(3) = \begin{bmatrix} 0 & 4 & 2 & 3 \\ 3 & 0 & 4 & 1 \\ 3 & 2 & 0 & 4 \\ 4 & 3 & 2 & 0 \end{bmatrix},$$

$$B(4) = \begin{bmatrix} 0 & 4 & 2 & 4 \\ 2 & 0 & 4 & 4 \\ 4 & 3 & 0 & 3 \\ 2 & 2 & 4 & 0 \end{bmatrix},$$

$$B(5) = \begin{bmatrix} 0 & 4 & 2 & 4 \\ 2 & 0 & 4 & 4 \\ 4 & 3 & 0 & 3 \\ 2 & 2 & 4 & 0 \end{bmatrix}$$

The direct-relation matrix:

$$A = \begin{bmatrix} 0 & 3.2 & 3 & 3.6 \\ 2.4 & 0 & 3.6 & 3.2 \\ 2.8 & 2 & 0 & 2.4 \\ 3.2 & 2.6 & 2.6 & 0 \end{bmatrix}$$


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Normalizing the direct-relation matrix: M = λ A

$$= \begin{bmatrix} 0 & 0.3265 & 0.3061 & 0.3673 \\ 0.2449 & 0 & 0.3673 & 0.3265 \\ 0.2857 & 0.2041 & 0 & 0.2449 \\ 0.3265 & 0.2653 & 0.2653 & 0 \end{bmatrix}$$

$\lambda = 0.1086956$

The total-relation matrix:

$T = M(I - M)^{-1}$

$$= \begin{bmatrix} -0.2244 & 0.2782 & 0.1897 & 0.3125 \\ 0.1075 & -0.1717 & 0.3278 & 0.2628 \\ 0.2534 & 0.1131 & -0.1600 & 0.1540 \\ 0.3040 & 0.1900 & 0.1588 & -0.2126 \end{bmatrix}$$

The dispatcher group and receiver group:

***Table 3: Showing the value of D, R, D+R and D – R***

| Criteria | D | R | D + R | D – R |
|---|---|---|---|---|
| QM | 0.440577 | 0.556002 | 0.996579 | -0.11542 |
| ER | 0.409585 | 0.526389 | 0.935974 | -0.1168 |
| LI | 0.516352 | 0.360589 | 0.876941 | 0.155763 |
| L | 0.516735 | 0.440271 | 0.957006 | 0.076464 |

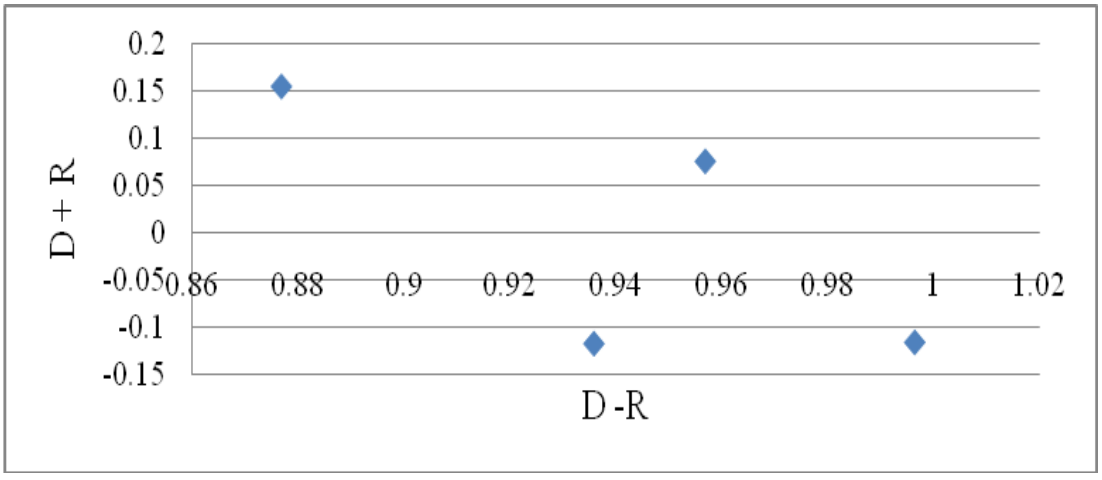



***Figure2: figure showing overall DEMATEL prominence–causal graphs.***


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It is clear that QM is the most important criteria from ER, LI, L.

### *3.2. Results from ORESTE- MCDM Approach:*

Here the alternatives EG, ET, LE, EP are denoted by A1, A2, A3, A4 respectively.

The first step is the ranks (into Basson ranks) of the actions for the criteria in ORESTE method. The ranking of the actions for the criteria are shown in the Table 4.

***Table 4: showing the ranks of the actions for the criteria***

| | $C_1$ | $C_2$ | $C_3$ | $C_4$ |
|---|---|---|---|---|
| $A_1$ | 1 | 3 | 2.5 | 1 |
| $A_2$ | 2.5 | 1 | 4 | 3 |
| $A_3$ | 2.5 | 3 | 1 | 4 |
| $A_4$ | 4 | 3 | 2.5 | 2 |

Then a first aggregation of the two-dimensional alternatives-criteria data is performed by computing for each couple alternative-criteria as “distance” score to and ideal position occupied by the best alternative for the most important criterion. This score is the mean value of the Besson-rank r_(c_j )of criterion c_j, and of the Besson-rankr_(c_j ) (a)of the alternative ain criterion c_j. In this application, Alpha threshold: 0.1, Beta threshold: 0.05 and Gamma threshold: 0.75 have been included. Then all these “distance” scores are converted into Besson-ranks in order to keep the method fully ordinal (Incomparability relations matrix). We call these Besson-ranks global ranks ρ_(c_j ) (a)which are upper-bounded by the value mkwith mthe number of alternatives (here 4) and kthe number of criteria (here 4). All of this application results are shown in table 5 and table 6 (R matrix).

***Table 5: Showing the Distance skores***

| | $C_1$ | $C_2$ | $C_3$ | $C_4$ |
|---|---|---|---|---|
| $A_1$ | 1 | 2.596 | 2.773 | 3.191 |
| $A_2$ | 2.026 | 1.651 | 3.570 | 3.570 |
| $A_3$ | 2.026 | 2.596 | 2.410 | 4.000 |
| $A_4$ | 3.191 | 2.596 | 2.773 | 3.302 |

***Table 6: showing the Incomparability relations matrix (R matrix) – continued***

| | $C_1$ | $C_2$ | $C_3$ | $C_4$ |
|---|---|---|---|---|
| $A_1$ | 1 | 7 | 9.5 | 11.5 |


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| | | | | |
|---|---|---|---|---|
| $A_2$ | 3.5 | 2 | 14.5 | 14.5 |
| $A_3$ | 3.5 | 7 | 5 | 16 |
| $A_4$ | 11.5 | 7 | 9.5 | 13 |

Then, we compute the "mean" rank for each alternative which is actually only the numerator of the mean of all the global ranks the alternative. Finally the alternatives are ranked in increasing order of the mean ranks. The ranking of the alternatives are represented in table 7.

***Table 7: Ranking of alternatives***

| Ranking | Alternative | Sum |
|---|---|---|
| 1. | $A_1$ | 29 |
| 2. | $A_3$ | 31.5 |
| 3. | $A_2$ | 34.5 |
| 4. | $A_4$ | 41 |

The new method identified that the most important parameter (MIP) of performance of HPP is Efficiency of generator, which concords with what is also recommended by the studies such as those Cordova [11] and Iemsomboon [12].

## CONCLUSION

The present investigation has attempted to identify the most important parameters which can maximize the performance of the HPP with the help of hybrid MCDM methods. In this way, the method can also analyze the financial feasibility of the new HPP. In this regard, one hybrid MCDM technique was applied after the ten most important parameters were identified with the help of a Literature Review survey. According to the results, EG was found to be the most important parameter. A sensitivity analysis was also conducted with the p.v. of all the parameters for validation. In this paper the four parameters can be taken as sub-criteria, and the five parameters can be taken as alternatives. The DEMATEL and ORESTE techniques are working as an aggregation method.

The study results show that in normal conditions EG will be the most important parameter to regulate the performance of the HPP. In feature the method can also be utilized to find the financial suitability of projects where the maximum value of the profit function can yield the most financially suitable HPP projects.

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