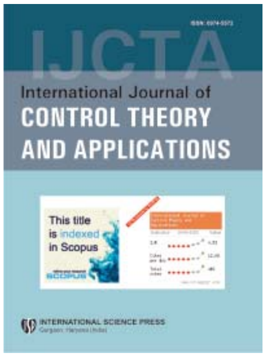

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Application of Decision Making for Optimal Condition Method to Analyze Operational Efficiency of Hydropower Plants

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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, Multi Criteria Decision Making (MCDM) was used to develop an indicator which can represent the performance status of the power plant. MCDM generally estimates priority values (p.v.) for normal conditions, but this study utilizes the method to determine the contribution of the parameters for optimal conditions only. Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH) and Analytical Network Process (ANP) were used to determine the constraints and Teaching–Learning-Based Optimization (TLBO) was utilized to find the p.v. at optimal condition.

Keywords: *Efficiency, HPP, MCDM, OT.*

1. 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 parameters like efficiency of penstock, efficiency of turbine, efficiency of generator, labor efficiency, amount of discharge, turbulence in water, difference in supply and demand energy, pressure difference between inlet and power house, pressure difference between power house and tailrace and distance from nearest grid etc. control the overall efficiency of HPP [9-16]. Although various studies have been conducted to propose a methodology to analyze HPP performance, answers to the following problems remain inconclusive:

1. 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).
2. 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.
3. Any analysis regarding performance must be conducted in view of the optimal scenario, not for the normal conditions.

The present study attempts to find a solution to these problems, by proposing a new MCDM method: Decision Making for Optimal Condition (DMO) which generates a decision for an optimal condition only. The indicator was made in such a way that it does not require human inferences and determines contributions based on the importance of the parameter in influencing the goal of the decision.

Multi Criteria Decision Making is widely applied for estimation of priority value for a specific decision objective and helps to select an optimal option from the available many. This type of methods uses objective equations to separate the better option from the multiple options available with the help of either a weightage value known as Priority Value (PV) or by ranking of the available alternatives.

The present investigation aims to use the advantages of MCDM method like Analytical Network Process(ANP) and Measuring Attractiveness by a Categorical Based Evaluation Technique(MACBETH) was used to identify the most important parameter for regulating the performance efficiency of HPP(Solution to Problem 1). The priorities of the parameters which is used as the alternative for the MCDM method is determined with the help of statistical control charts which identifies the most influential parameter as per their impact on the decision making output. In this aspect the charting methodology considers the real life dataset of the alternatives for a real life situation and rates the parameter as per their significance to the output. Interference from either experts or stakeholder or literatures is completely avoided. The resources (experts, stakeholders and literatures) are used only for initial selection of the related parameters for performance analysis of HPPs. (Solution to Problem 2).

The priority value or weightage of importance for all the considered alternatives are estimated based on their role to generate optimal performance efficiency for the power plant. In this aspect the PV of each of the parameter was treated as the design factor of an optimization problem where as the output function is selected as the objective function. The design parameters have constraints like the values will be within the minimum and maximum priority proposed by the ANP and MACBETH method. The Teaching Learning based Optimization (TLBO) algorithm was used as the programming technique to maximize the function which will be directly proportional to the performance efficiency of HPPs. The magnitude of the priority at the optimal condition of the output function is treated as the weightage of importance for the parameters at the optimal condition (Solution to Problem 3).The section 2 will describe about the methods selected for application in the present investigation.

2. METHODS ADOPTED

In this study two MCDM techniques, ANP and MACBETH, were used to determine the boundary of the search space for the priority of the parameters. Here a nature-based optimization technique, Teaching–Learning-Based Optimization (TLBO) was used to maximize the performance function of efficiency. The MCDM method ANP was selected for their features like comparing alternatives with respect to criteria and vice-versa. The impact of both criteria and alternatives on each other is considered before estimating the priority value of the alternatives. In the present study also as the decision making is required to be in both direction this method was considered for the determination of priority value. The MACBETH method is specialized in the identification of important based on its dissociation from the objective. The procedure of comparing the alternatives based on its inverse impact on the output will solve the problems of overlapping in interdependence of criteria and alternative.

The reason for the selection of TLBO as an optimization technique is its initiation with random values as well as the time taken to find convergence is also lesser compared to other methods like Particle Swarm Optimization or Genetic Alogorith [29] etc.

2.1. Analytical Network Process

Analytical Network Process (ANP) was first proposed by Thomas Saaty in 1996 [17]. The main advantage of ANP is that it can transform qualitative values into numerical values for comparative analysis [18]. It is difficult to provide a correct network structure, even for experts, and different structures lead to different results [19]. As ANP handles both quantitative and qualitative alternatives with respect to criteria and it can define the network structure it was chosen as one of the appropriate MCDM method for this study. ANP has been applied to the evaluation of performance indicators of reverse logistics in the footwear industry [20], wastewater treatment alternatives [21] and supplier selection [22].

2.2. Measuring Attractiveness by a Categorical Based Evaluation Technique

Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH) was first proposed by Bana and Vansnick in 1997 [23]. MACBETH is an MCDM approach which has the advantage of taking into account the decision makers' subjective judgments about different alternatives with respect to several evaluation criteria and translating those attributes into relevant quantitative scores [24]. One of the drawbacks of this method is related to linear programming (LP); it is well known that several optimal solutions (*i.e*. rankings) can be obtained with the LP method. These different ranks can be confusing for the decision maker (DM). As MACBETH handles subjective judgments about different alternatives with respect to criteria, it was applied in the current study. MACBETH has been used to determine the utility of governments to parties in coalition formation [25], for health value measurement [26], and for on-board hydrogen storage technologies [27].

2.3. Teaching–Learning Based Optimization

One of the most popular meta-heuristic optimization algorithms and parameter-free optimization techniques is Teaching–Learning-Based Optimization (TLBO). Rao et al. first proposed TLBO in 2011. It is based on the natural phenomenon of teaching and learning [28, 29]. TLBO is popular for its quick convergence time in cases of lower dimensional problems. But TLBO has two parameters in common with other heuristic optimizations, namely population size and stopping criteria. Although the convergence rate is one of the major disadvantages with TLBO, and it has been found that in cases of higher dimension problems [30], the convergence rate is largest. TLBO is a parameter-free technique and its effectiveness is not affected by algorithm parameters, such as those in GA, PSO and ACO [29]. Again, as the present problem is not a higher dimensional problem, TLBO can be used with the present decision-making objective due to its quick convergence.

3. DETAILED METHODOLOGY

The methodology employed to achieve the present objective can be divided into three steps and figure 1 showing a schematic of the proposed methodology:

1. Application of MCDM methods to determine the p.v. of the selected parameters.
2. Application of optimization technique (O.T.) to find the p.v. at optimal condition
3. Sensitivity analysis, scenario analysis, case study and data collection to evaluate and validate the model.

3.1. Application of MCDM

The application of the selected MCDM method follows a basic methodology of criteria and alternative selection and use of the aggregation method which depend on the type of method applied. In the next sections the method followed in selection of criteria, alternative and the way aggregation method was used is described.

1. **Selection of criteria:** In this investigation, criteria were selected from some statistical methods for finding the rank of parameters and showing in table 1.

Table 1
Table Showing the Description of the Statistical Process Control Charts

Name of criteria	*Description*	*B/ NB*
Two-sample *t*-test	A confidence interval is calculated and a hypothesis test of the difference between two means is done. Applied to test if a new process of treatment is superior of current process or treatment.	B
x-bar	*x*-bar can be used to find whether measurement process has gone out of statistical control or not.	B
μ-chart	The μ-Chart is a procedure show way of providing a denotational semantics to State charts and where problems occur with the original description.	B

2. **Selection of sub-criteria:** In the present study, sub-criteria were selected on the basis of a literature, experts and stakeholder survey showing in table 2.

Table 2
Table Showing a Description about the Selected Criteria

Name of Criteria	*Why used ?*	*B/ NB*
Loss (L) [7]	Impact of volume loss, frictional loss in the penstocks, turbine and generator along with other losses on the alternatives were considered while comparing the two alternatives based on this criteria	NB
Quality of Machine (QM) [8]	The alternatives were also compared with respect to the impact of quality of machines used in the HPP.	B
Energy Requirement (ER)	The amount of auxiliary power required to run the installed machines and the impact of the alternatives on the requirement of such power is also taken into consideration	B
Locational Interference (LI)	The interference of location on the alternatives were also included.	NB

3. **Selection of alternatives:** In the present investigation, factors were selected on the basis of a literature, expert and stakeholder survey and table 3 represents the description of that factors.

Table 3
Table Showing the Description about the Factors

Name of factor	*Why used ?*	*B/ NB*
Efficiency of penstock (EP) [9]	For run-of-the-river hydro projects, a por-tion of a river's water is diverted to a channel, pipeline, or pressurized pipeline (penstock) that delivers it to a waterwheel or turbine. The moving water rotates the wheel or turbine, which spins a shaft. The motion of the shaft can be used for mechanical processes, such as pumping water, or it can be used to power an alter-nator or generator to generate electricity [34, 35] . If efficiency of penstock is increased efficiency of HPP is also increased.	B
Efficiency of turbine (ET) [10]	The turbine turns the generator rotor which then converts this mechanical energy into electrical energy and the system is called hydro-electric power station [36-40]. If efficiency of turbine is increased efficiency of HPP is also increased.	B
Efficiency of generator (EG) [10]	As well known, hydro-turbines convert water pressure into mechanical shaft power which can be used to drive an electricity generator [41-43]. If efficiency of generator is increased efficiency of HPP is also increased.	B
Labour efficiency (LE) [11]	Technically trained manpower comprising of skilled engineers, supervisors, artisans, and managers etc. is required in every sphere of the power supply industry. Growing concern over environmental degradation and depletion of the conventional energy sources has made the task of electricity generation even more challenging and therefore quality standard of the manpower is becoming increasingly essential [44, 45]. If labour efficiency is increased efficiency of HPP is also increased.	B
Amount of discharge (AD) [12]	The actual output of energy at a dam is determined by the volume of water released (discharge) and the vertical distance the water falls (head). So, a given amount of water falling a given distance will produce a certain amount of energy. The head and the discharge at the power site and the desired rotational speed of the generator determine the type of turbine to be used [33].	B
Turbulence in water (TW) [13]	Turbulence in water is important for efficiency of HPP.	NB
Difference in supply and demand energy (DSD) [14]	It is necessary for both the government and people to make continuous efforts for further improvement of safety, energy security, economic efficiency and environment. In addition, it is expected that various elements of the Long-term Energy Supply and Demand Outlook may change, such as progress in energy efficiency and conservation, introduction of renewable energy, power generation cost of each power source, and trends over nuclear power plants [46].	NB
Pressure difference between inlet and power house (PIP) [15]	Pressure difference between inlet and power house is the most important for efficiency of HPP.	NB
Pressure difference between power house and tailrace (PH) [16]	Pressure difference between power house and tailrace is the most important for efficiency of HPP.	NB
Distance from nearest grid (DG) [16]	By use of this Apower grid," electricity can be interchanged among several utility systems to meet varying demands.	NB

In the MCDM method, the rank of the parameters was at first determined as per the importance of the variables in expansion of the objective function. In this regard, statistical methods like *t*-test, *x*-bar and μ-chart were utilized.

In this present study for finding the rank of each factor use some statistical method. For finding the rank of sub criteria with respect to *x*-bar first collect some random data in (0, 1) for each criteria also corresponding priority value taken randomly in that range. Here taken the sample space is 5 and size is taken 50. In next step apply the efficiency index on this data then we get 4 sets of data corresponding to each criteria. Then apply *x*-bar on this index value. For finding the rank of each factor select that corresponding average weighted value in which average X-Bar value is maximum index and table 4 represents the computational procedure of X-Bar. In this way apply μ-chart and Two-sample *t*-test for finding the rank of each factor.

Table 4
Represents the Computational Procedure of X-Bar.

							X-Bar Control		
	Here X_1, X_2, X_3 and X_4 are the index value.				Average	$Max(X_i) - Min(X_i)$	$y_1 - 0.577 * y_2$	y_1	$y_1 - 0.577 * y_2$
Sample	X_1	X_2	X_3	X_4	X-Bar	R-Bar	LCL	CL	UCL
1.	0.203	0.386	0.863	0.088	0.385	0.774	0.14	0.446	0.7514
2.	0.285	0.246	0.278	0.096	0.226	0.19	0.14	0.446	0.7514
3.	0.488	0.688	0.347	0.327	0.462	0.361	0.14	0.446	0.7514
4.	0.56	0.025	0.325	0.463	0.343	0.535	0.14	0.446	0.7514
5.	0.412	0.437	0.596	0.404	0.463	0.192	0.14	0.446	0.7514
6.	0.431	0.724	0.248	0.267	0.417	0.476	0.14	0.446	0.7514
7.	0.841	0.421	0.954	0.413	0.657	0.541	0.14	0.446	0.7514
8.	0.71	0.844	0.336	0.064	0.488	0.779	0.14	0.446	0.7514
9.	0.083	0.557	0.867	0.263	0.443	0.784	0.14	0.446	0.7514
10.	0.743	0.194	0.857	0.498	0.573	0.663	0.14	0.446	0.7514
					0.446	0.53			
					y_1	y_2			

3.2. Application of O.T

In the optimization technique the Eqn.1 is maximized and used to find the priority of the parameters with which the HPP will be predicted.

$$\max I_{performance} = I_{efficiency} \times (I_{failure})^{-1} \tag{1}$$

where,

$$I_{failure} = \begin{vmatrix} \dfrac{w_1^1 y_1(F)}{w_2^1 y_2(F) + w_3^1 y_3(F)} & \dfrac{w_4^1 y_4(F)}{w_2^1 y_2(F) + w_3^1 y_4(E)} \\ -1 & 1 \end{vmatrix}$$

$$I_{efficiency} = \begin{vmatrix} \dfrac{w_2^{11} y_2(E)}{w_1^{11} y_1(F) + w_4^{11} y_4(E)} & \dfrac{w_3^{11} y_3(E)}{w_1^{11} y_1(E) + w_4^{11} y_4(E)} \\ -1 & 1 \end{vmatrix}$$

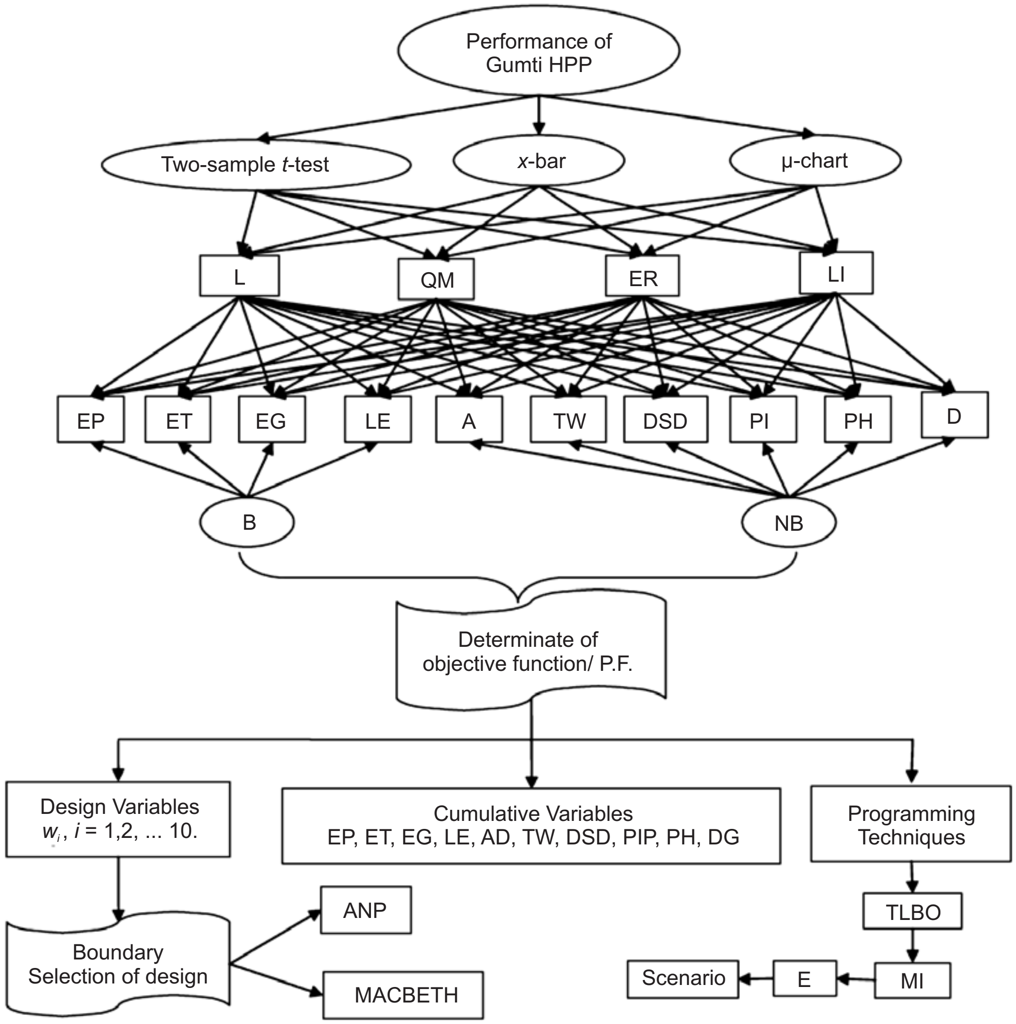

Figure 1: Figure showing a schematic of the proposed methodology

$$y_1(F) = \begin{vmatrix} w_1x_1 + w_2x_2 & w_3x_3 + w_6x_6 \\ \dfrac{-1}{w_4x_4 + w_5x_5} & \dfrac{1}{w_4x_4 + w_5x_5} \end{vmatrix}$$

$$y_2(F) = \begin{vmatrix} w_1x_1 + w_4x_4 & w_5x_5 \\ \dfrac{-1}{w_2x_2 + w_3x_3 + w_6x_6} & \dfrac{1}{w_2x_2 + w_3x_3 + w_6x_6} \end{vmatrix}$$

$$y_3(F) = \begin{vmatrix} w_2x_2 + w_3x_3 & w_6x_6 \\ \dfrac{-1}{w_1x_1 + w_4x_4 + w_5x_5} & \dfrac{1}{w_1x_1 + w_4x_4 + w_5x_5} \end{vmatrix}$$

$$y_4(F) = \begin{vmatrix} w_1x_1 & 0 \\ 0 & \dfrac{1}{w_2x_2 + w_3x_3 + w_6x_6 + w_4x_4 + w_5x_5} \end{vmatrix}$$

$$y_1(\text{E}) = \{y_2(\text{E})\}^{-1} =$$

$$y_4(\text{E}) = \begin{vmatrix} w_{10}x_{10} & 0 \\ 0 & \dfrac{1}{w_7x_7 + w_8w_8 + w_9x_9} \end{vmatrix}$$

$$y_3(\text{E}) = \begin{vmatrix} w_8x_8 & w_3x_3 \\ \dfrac{-1}{w_7x_7 + w_4x_4} & \dfrac{1}{w_7x_7 + w_4x_4} \end{vmatrix}$$

Subject to,

$$0.1824 \leq w_1 \leq 0.3194$$
$$0.1439 \leq w_2 \leq 0.1907$$
$$0.1418 \leq w_3 \leq 0.2306$$
$$0.1441 \leq w_4 \leq 0.1160$$
$$0.2507 \leq w_5 \leq 0.4776$$
$$0.1185 \leq w_6 \leq 0.1531$$
$$0.1600 \leq w_7 \leq 0.5812$$
$$0.2498 \leq w_8 \leq 0.5688$$
$$0.2902 \leq w_9 \leq 0.6000$$
$$0.3000 \leq w_{10} \leq 0.6000$$
$$0.2143 \leq w_1^1 \leq 0.2501$$
$$0.1541 \leq w_2^1 \leq 0.3214$$
$$0.1428 \leq w_3^1 \leq 0.2877$$
$$0.3082 \leq w_4^1 \leq 0.7500$$
$$0.1345 \leq w_1^{11} \leq 0.5625$$
$$0.2964 \leq w_2^{11} \leq 0.6250$$
$$0.3801 \leq w_3^{11} \leq 0.5625$$
$$0.1890 \leq w_4^{11} \leq 0.5625$$
$$0.1000 \leq x_i \leq 1.0000$$

Another objective of this study was to determine in which scenario the performance of Gumti HPP will be maximum. To create the scenario, formula (2) was used. All this data was normalized by the formula (3).

$$cs = nc \times a\% \tag{2}$$

$$\text{Normalized} = \begin{cases} \dfrac{\max x_i - x_i}{\max x_i - \min x_i}, & \text{if } x_i \text{ is B} \\ \dfrac{x_i - \min x_i}{\max x_i - \min x_i}, & \text{if } x_i \text{ is NB} \end{cases} \tag{3}$$

In the optimizer phase, the indicator function was taken as the objective function, the p.v. of parameters as the design variables, and the p.v. determining MCDM phase was used as a constraint. The TLBO programs techniques were used as the programming techniques.

$$\text{Max/ Min Z} = f(x_1, x_2, x_3, \ldots\ldots)$$

Subject To

$$\text{L}_i \leq x_i \leq \text{U}_i, i \in \text{N}$$
$$x_i \geq 0$$

Where Max/ Min Z is called objective function or indicator, x_i is called design variable, L_i and U_i are selected by MCDM methods. L_i and U_i are called lower and upper bounds of design variable.

3.3. Validation of the model

1. **Sensitivity analysis:** The sensitivity analysis was performed with the help of the Multiple Input One output Tornado method developed by SensIt Limited [47]. The range for the input variables were varied between 0 to 1.The impact of each input is then observed on the output and the results were compared with the weights of the variables found from the new MCDM approach.

2. **Scenario analysis:** As the method also aimed to include the impact of extreme events within the priority value of the control variables (*c.v.*), ten different scenarios were devised to represent the impact of extreme events in the priority values of the control variables following the IPCC Climate Change Scenarios A2 and B2.

3. **Case study:** Gumti is one of the larger rivers in Tripura, India which flows westward and discharges into Bangladesh. Figure 2 showing Location of Gomati River. Due to the construction of a dam for the hydropower plant, a large reservoir was created, known as Gumti reservoir. This reservoir is at the upper catchment of the Gumti River. The storage capacity of the reservoir is 23570 hectare meter. The submerged area at F.R.L of 92.05m and M.W.L. of 95.25m was found to be 46.34and 74.86sqkmrespectively. With the help of this reservoir, Gumti Hydro Power plant generates power to mitigate the crisis of power in Tripura. The design capacity of this hydropower plant was 15 MW. It has three units. The first and second units were commissioned in 1976 and the last in 1984. However, out of a 15MW capacity, at present only 8MW-9MW power is produced from Gumti HPP during the rainy season. During the dry season production reduces to 0.5MW [6].

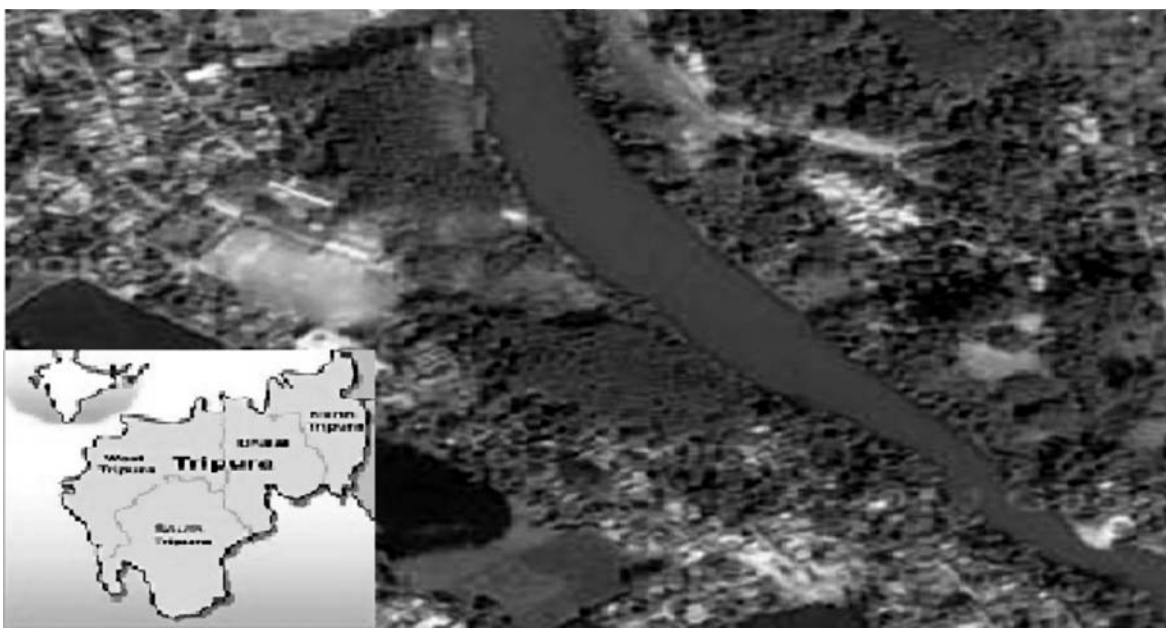

Figure 2: Figure showing Location of Gomati River

4. **Data collection:** In the present investigation Gomati HPP was taken as a case study where the new method was applied. The financial feasibility of the existing project was analyzed using the profit function, developed with the help of Benefit to Cost Ratio and priority values of the Benefit and Cost factors in proportion to the profit of the plant.

Table 5 shows the collected data for all factors which impact directly or indirectly on the performance of the Gumti HPP. The data was collected for the normal scenario from Tripura government reports.

Here all this data normalized by using the Eqn. 3. Here some factors are beneficial their corresponding data calculated by first equation of the Eqn. 3 and for non-beneficial data apply second equation of the Eqn. 3. When all this data are normalized then all this factors are unit less.

Table 5
Table represents Normalized data of Gumti HPP in Normal Scenario

Name of factor	*Normalized Data(Actual Data divided by the Maximum average Value in a Year)*
Efficiency of penstock (EP)	0.227405
Efficiency of turbine (ET)	0.16035
Efficiency of generator (EG)	0.145773
Labor efficiency (LE)	0.174927
Amount of discharge (AD)	0.145773
Turbulence in water (TW)	0.058309
Difference in supply and demand energy (DSD)	0.014577
Pressure difference between inlet and power house (PIP)	0.029155
Pressure difference between power house and tailrace (PH)	0.014577
Distance from nearest grid (DG)	0.029155

4. RESULTS AND DISCUSSION

In this investigation, criteria were selected as some statistical methods [48, 49] for finding the rank of parameters. Figure 3 and 4 show the ranking of each alternative with respect to each sub-criterion.

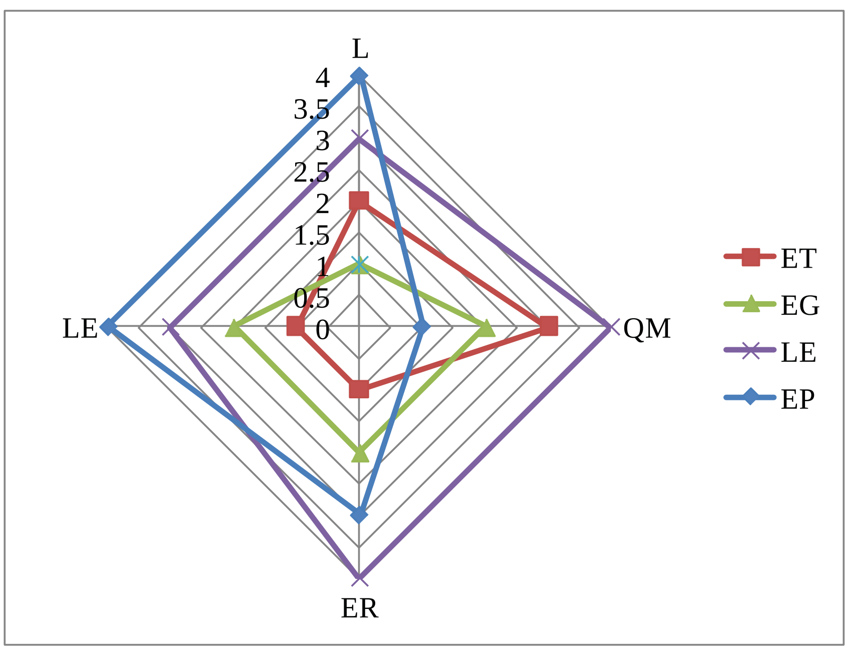

Figure 3: Shows the ranking of the factor of efficiency with respect to sub-criteria

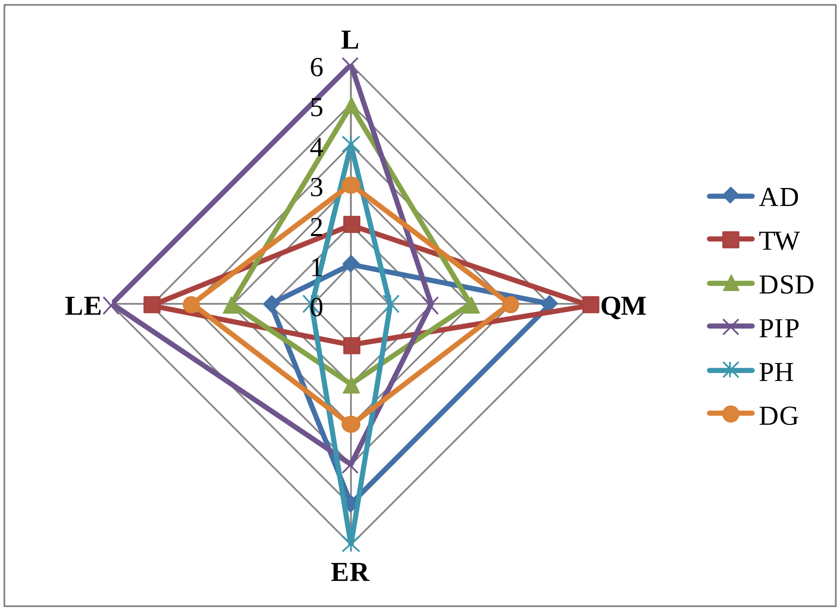

Figure 4: Shows the ranking of the factors with respect to sub-criteria

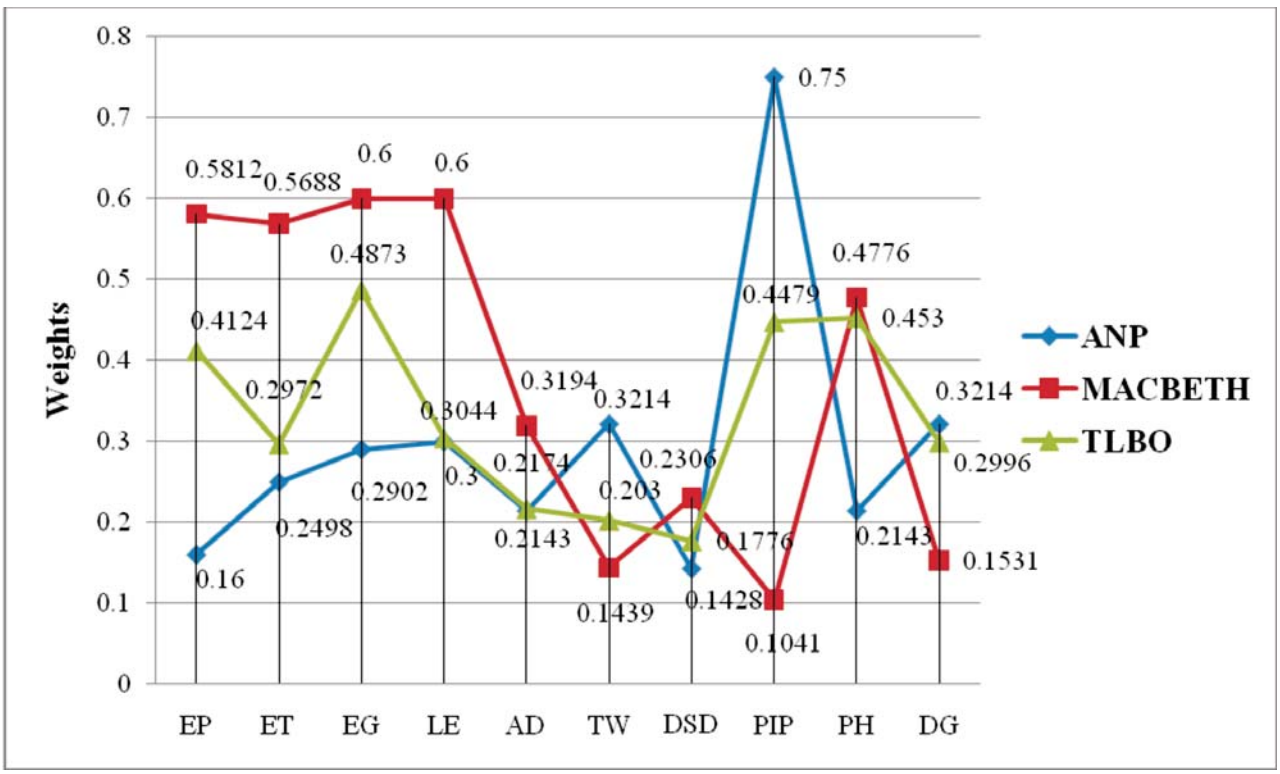

Figure 5: Figure showing the comparison of p.v. as estimated by ANP, MACBETH and DMO

Figure 5 shows the *p.v.* of each factor by MCDM and O.T. in the optimal scenario. MIP Efficiency of Generator by the O.T. method. The optimal point by TLBO is (0.4124, 0.2972, 0.4873, 0.3044, 0.2174, 0.2030, 0.2876, 0.4479, 0.4530, 0.2996).

The new method identified that the most important parameter (MIP) of performance of Gumti HPP is Efficiency of generator, which concords with what isalso recommended by the studies such as those by [31, 32].

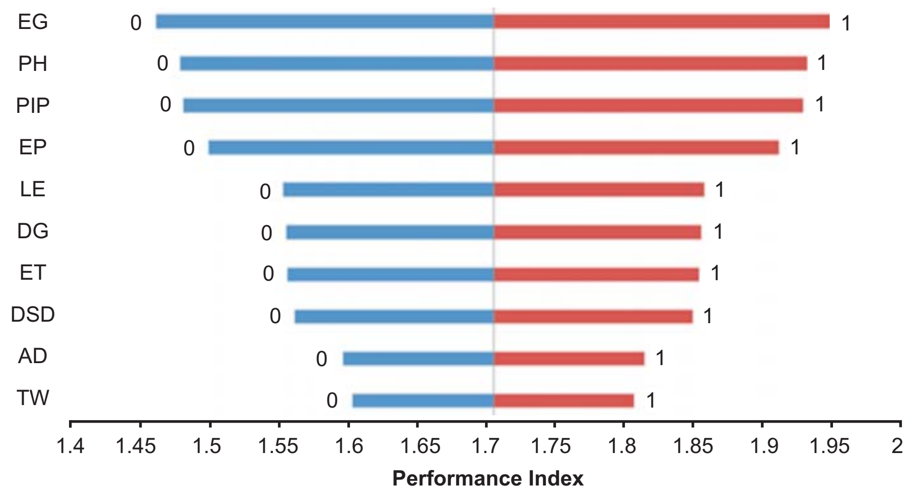

Figure 6: Figure showing the Sensitivity Analysis of Alternatives

In different case studies, the validation of the model was conducted by sensitivity analysis and the application of the model. From Figure 6, it can be seen that MIP found by the optimization of Efficiency of Generator is the most sensitive input parameter for performance of the HPP, with a swing[2] value of 18.9 %. The second most sensitive parameter is Pressure difference between power house and tailrace, and the least most sensitive parameter is Turbulence in water with swing[2] values of 16.3 % and 3.3 % respectively. Swing[2] value is the deviation in input parameter. From the optimization techniques, it was also found that the priority value of the most sensitive parameter was maximum and the least sensitive parameter was minimum.

Table 6
Table Showing the Most Important Parameter

With respect to	*Most Important Parameter*
Criteria:	
1. L	EG
2. QM	EP
3. ER	ET
4. LE	ET
MCDM:	
1. ANP	EG, LE
2. MACBETH	LE
Optimization :	
1. TLBO	EG

5. SCENARIO ANALYSIS

The *p.v.* of each of the input parameters were also identified under likely and unlikely conditions. The conditions were formulated by increasing and decreasing parameters simultaneously (EP, ET, EG, LE, AD, TW, DSD, PIP, PH, DG) with 5%, 10%, 15%, 20%, 50% and 100%. If all these parameters increased or decreased simultaneously by 5-15% and 20-100% from normal conditions, these scenarios are called likely and unlikely scenarios. This means that the value of the Profit Function (P.F.) (see Table 7) was maximized at a scenario where all these parameters were 50% less than the cost at normal conditions. It was also assumed that all these parameters will be modified at the same time.

Table 7
Showing Scenario Analysis in Likely and Unlikely conditions

Scenario		*Increasing/Decreasing all the parameters simultaneously*	*Index value*
Likely Scenario	Scenario 1	5%	1.150162
	Scenario 2	10%	1.040099
	Scenario 3	15%	0.939606
	Scenario 4	-5%	1.405045
	Scenario 5	-10%	1.553728
	Scenario 6	-15%	1.719902
	Normal Scenario		1.271232
UnlikelyScenario	Scenario 1	20%	0.847488
	Scenario 2	50%	0.423744
	Scenario 3	100%	0
	Scenario 4	-20%	1.906847
	Scenario 5	-50%	3.813695
	Scenario 6	-100%	–

From the table 6 scenario-6 is best and scenario-3 is worst with respect to the index compared to the value of index and among the likely scenario as well as scenario 5 is best and scenario-3 is worst with respect to the index compared to the value of index and among the unlikely scenario.

6. CONCLUSION

The present investigation has attempted to identify the most important parameters which can maximize the performance of the Gumti HPP with the help of optimization techniques used as MCDM methods. If the MIP can be identified then this single parameter can be utilized for the regulation of the performance of the HPP. In this regard, one optimization technique was applied after the ten most important parameters were identified with the help of a literature, expert and stakeholder's survey. According to the results, EG was found to be the most important parameter. A scenario analysis was also conducted with the p.v. of all the parameters under likely and unlikely scenarios. The study results show that in normal conditions EG will be the most important parameter to regulate the performance of the HPP. The change in the index value compared to the index value in the normal condition is 1.719902 for the likely and 1.719902 for the unlikely scenarios. According to the performance, most and least efficient scenario was observed in scenario 5 best with respect to the index compared to the value of index and among the unlikely scenario. The main benefit of this method is it identifies one single parameter which have the highest impact, compared to all the selected parameters, on the output for generation of optimal performance from the HPP. This 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. The method can be utilized for monitoring the performance of the HPP in real time through out the year. The index value can be used for comparing the performance of various HPPs in a common time scale so that proper mitigation measures can be adopted the improve the performance of the HPP which have a low value of the indicator. But index have some limitation and among them the introduction of new method, alternative or criteria will actually give different value for indicating the performance of the same HPP. This drawback of the index can be rectified by adopting an uniform policy for comparing or analyzing the performance of the HPPs.

7. ABBREVIATIONS

Symbol	*Description*	*Symbol*	*Description*
y_1(F)	Magnitude of L for failure	y_1(E)	Magnitude of L for efficiency
y_2(F)	Magnitude of QM for failure	y_2(E)	Magnitude of QM for efficiency
y_3(F)	Magnitude of ER for failure	y_3(E)	Magnitude of ER for efficiency
y_4(F)	Magnitude of LI for failure	y_4(E)	Magnitude of LI for efficiency
x_1	Magnitude of AD	x_7	Magnitude of EP
x_2	Magnitude of TW	x_8	Magnitude of ET
x_3	Magnitude of DSD	x_9	Magnitude of EG
x_4	Magnitude of PIP	x_{10}	Magnitude of EP
x_5	Magnitude of PH	w_7	P.V. of EP
x_6	Magnitude of DG	w_8	P.V. of ET
w_1	P.V. of AD	w_9	P.V. of EG
w_2	P.V. of TW	w_{10}	P.V. of EP
w_3	P.V. of DSD	w_1^{11}	P.V. of L for efficiency
w_4	P.V. of PIP	w_2^{11}	P.V. of QM for efficiency
w_5	P.V. of PH	w_3^{11}	P.V. of ER for efficiency
w_6	P.V. of DG	w_4^{11}	P.V. of LI for efficiency
w_1^1	P.V. of L for failure		
w_2^1	P.V. of QM for failure		
w_3^1	P.V. of ER for failure		
w_5^1	P.V. of LI for failure		

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