PERFORMANCE EVALUATION OF SMALL HYDROPOWER PROJECTS IN MAHARASHTRA

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ABSTRACT
Performance evaluation of small hydro power projects is essential to monitor effective functioning of the projects. Performance evaluation helps to improve functional quality and reliability of the projects. This paper aims to evaluate performance, and rank the Small Hydro Projects (SHP) which are currently in operation. Nine SHPs namely Konal, Deoghar located in Sindhudurg district, Sonawade located in Sangli district, Darna located in Nashik district and Chitri, Radhanagari, Kumbhi, Kasari, Kadvi located in Kolhapur district of Maharashtra, India; are considered for present study. The SHPs are evaluated based on 10 performance indicators namely, Installed capacity, Average Head, Average Discharge, Cost of Energy Generation, Cost of Project, O & M Cost, Labour Cost, Average Power Output, Capacity Utilization Factor and Internal Rate of Return. Analytic Hierarchy Process (AHP) is used to rank of the SHPs and evaluate the performance. This paper will certainly help to select the best SHP amongst the group of nine SHPs in Maharashtra. The findings shall help the projects to determine their strengths, weaknesses and provide directions for future improvements based on indicators.

KEYWORDS: *Small Hydropower Projects, Performance evaluation, Multi-Criteria Decision Making, Analytic Hierarchy Process.*

I. INTRODUCTION

Performance Evaluation is a systematic process of obtaining information to be used to assess and improve a project. It helps to compare the performance of a system with others or with the same system over time.

Small Hydro Projects (SHPs) having generation capacity in the range of 2 MW – 25 MW is considered to play a critical role in improving the overall energy scenario of the Maharashtra State in India. There are 42 SHP projects already producing electricity and many ambitious power projects are under construction. Funding agencies, Ministry of New and Renewable Energy (MNRE), under Government of India forces, performance evaluation of new SHP projects for subsidies [1].

This study aims to evaluate performance of small hydro projects which are currently in operations and selecting best one among the projects under study.

Analytic Hierarchy Process (AHP) is used to rank the SHP and thus evaluate performance.

The paper is divided into sub sections, section 2 presents recent literature on performance evaluation of hydropower projects and various Multi-Criteria Decision Making (MCDM) techniques used in performance evaluation of hydropower projects. Section 3 presents Case Study of SHPs. Section 4 deals with the indicators that influence performance of small hydropower projects and brief general discussions on AHP. Section 5 presents analysis of results evaluated by AHP method. Section 6 discusses conclusion and section 7 gives future scope of the study.

II. LITERATURE SURVEY

There are numerous studies on performance evaluation using MCDM methods. Since our problem is evaluating performance of SHPs and selecting the best SHP, in this paper we focused on following aspects of literature: Performance evaluation of SHP and MCDM techniques used for evaluating hydro power projects performance.

2.1 Performance evaluation of SHP

Jyoti Prasad and Shiva Prasad [2] evaluated performance of five micro hydro projects based on Project efficiency, Plant outage and Utilization factor. They found low Plant outage and Utilization factor values. They identified causes and suggested remedial measures for the same. Verma and Arun Kumar [3] tested and evaluated 18 new SHP to verify that all parts, systems and auxiliaries in power station are correctly performing their assigned functions. They concluded that the provisions expected in the power plant were missing; knowledge of personnel in the field of fluid dynamics and measurement techniques was not adequate. Amir Pasha Zanjani Nasab [4] presented preliminary financial analysis of SHP from the perspective of investors based on projected cash flow model for the project life cycle. He concluded that the projects with generation capacity between 6 to 11 MW are not attractive from financial perspective. Capacity Factor of the power plant and estimation of project development cost is highly important. Kucukali [5] aimed to introduce a new approach for hydropower projects risk assessment through the fuzzy set concepts. He found that the most concerned risks are site geology and environmental issues. Yongqian Liu et al. [6] presented an economic performance evaluation method for Hydroelectric Generating Units (HGU) to evaluate the overall performance of HGUs. They focused on analyzing the energy flow of the HGU.

2.2 MCDM Techniques

The vagueness in definition of properties and data scarcity problem in material science for the selection of material can be easily solved using MCDM. Priyabrata Adhikary, et al. [7] suggested the fuzzy optimized material selection output by Weighted Average Method for penstock of a hydro turbine project. Priyabrata Adhikary, et al. [8] proposed model for the SHP turbine manufacturer selection problem composed of Simple Additive Weighting (SAW), Weighted Product method (WPM) and AHP-TOPSIS methods. Priyabrata Adhikary, et al. [9] evaluated applicability of MCDM to decision makers during the SHP planning and development. They applied MOORA (Multi Objective Optimization on the Basis of Ratio Analysis) and WPM (Weighted Product Method) methods for validation. It is concluded that although the procedures of the considered preference ranking methods substantially differ from each other, but there are similarities in the concepts they use to reach the final evaluation and ranking. Priyabrata Adhikary, et al. [10] also attempted to discuss types of SHPs and present methodology on development, operation and maintenance of SHPs. Ansali et al. [11] applied fuzzy MCDM methods for selection of best energy source for electricity generation. They ranked by techno-economic method and fuzzy MCDM. It was concluded that small hydro power is the best option. Anagnostopoulos, et al. [12] evaluated the Water Resources Planning problem of operation of dams using the AHP and Promethee methods. The authors found that the final rankings obtained by both applications are similar. Shashi Bhattarai [13] assessed rankings of hydropower projects by AHP method. He concluded there is strong need to promote AHP application. Singh, et al. [14] expressed that AHP is well balanced method to identify the critical equipments of a coal based power plant and rank them accordingly.

Various MCDM methods were used by researchers for selection of material, best energy sources, hydraulic turbine, choosing best alternative technology like renewable v/s non renewable with limited criteria's. No literatures discussed the performance of SHPs by using several criteria's via AHP technique. Also the performance evaluation of hydro power projects are done with lesser number of parameters and holistic approach is not considered. It is observed that scientific techniques are rarely used for doing performance evaluation of SHPs.

This paper aims a systemic study to help performance evaluation of the small hydro power projects. The performance evaluation is done using Analytic Hierarchy Process (AHP) methodology.

III. CASE STUDY

Project executing agencies in India, has laid maximum emphasis on the full development of its hydro potential being a clean & renewable source of energy. Private sector participation is encouraged for development of Small Hydro Projects (SHP) up to 25 MW.

Government identified or self identified SHP sites proposed by the developers are governed by state hydel policy [15]. The SHPs are allotted under this policy on BOT basis for the operative period of 30 years. The developer shall develop and commission the project as per policy norms.
In this detail study, the performance evaluation is carried out for selected 9 Dam foot power houses under SHP schemes located in Maharashtra. The input data of SHPs were collected since commissioning of the project. The data was acquired from project developers and Hydro electric departments.
Figure 1 shows the geographic location of nine SHPs. The nomenclature defined for SHPs as alternatives with Installed capacity are presented in table 1.

Table 1 SHPs under study

Alternatives	Name of SHP	Installed capacity
A1	Konal	2 x 5 MW
A2	Deoghar	1 x 1.5 MW
A3	Sonawade	2 x 2.2 MW
A4	Darna	1 x 2.45 MW
A5	Chitri	1 x 2 MW
A6	Radhanagari	2 x 5 MW
A7	Kumbhi	1 x 2.5 MW
A8	Kasari	1 x 2.5 MW
A9	Kadvi	1 x 1.5 MW

3.1 Organization of Data

The month wise input data of rotation days, water releases, net head, discharge, power output, units generated, costs of projects etc. were collected from the project developers and Hydro electric departments. From these data the average values of water head, discharge and power output are calculated since date of commissioning to December 2012. Capacity utilization factor was calculated by units generated in kWh per year/ (Installed capacity in kW x hrs per years).
The indicators are decided through literature review of performance evaluation and interview with experts in the hydropower projects. The nomenclature defined for indicators chosen as criteria's are;
C1. Installed capacity,
C2. Average Head,
C3. Average Discharge,
C4. Cost of Energy Generation,
C5. Cost of Project,
C6. Operation and Maintenance (O&M) Cost,
C7. Labour Cost,
C8. Average Power Output,
C9. Capacity Utilization Factor and
C10. Internal Rate of Return
A payoff matrix is developed using the input data.

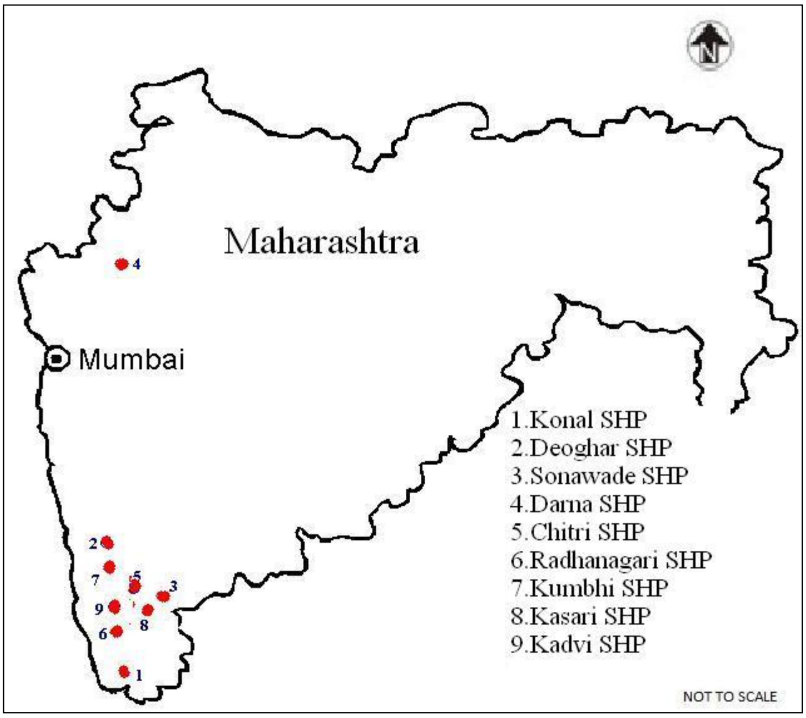

Figure 1: Index map showing SHPs

IV. PERFORMANCE INDICATORS

Indicators are the variables or parameters that influence the performance of any hydro power project. The type of performance measures chosen depends on the purpose of the performance assessment activity. The general guidelines used to choose the Performance indicators are as follows:

- The indicators are based on a relative comparison of absolute values.
- The set of indicators is small, yet reveal sufficient information about the output of the system.
- Data collection procedures are not too complicated or expensive.
- The indicators relate to outputs and are bulk measures of the project

4.1 Installed capacity

It is total capacity in kW or MW of all the turbine generator units installed in the power house. It may vary with SHP.

4.2 Average Head

The head acting on the turbine is the gross head less all hydraulic losses in water conductor system. Difference between reservoir level and Tail water level gives the gross head. The hydraulic losses will depend on SHP layout. The power potential is governed by the head available at project site. The performance and efficiency of turbine varies with head.

4.3 Average Discharge

This is the volume in cubic meter per second of water available for power generation. When irrigation/ domestic/ industrial releases are used for power generation, the water available for generation should be strictly as per irrigation/ domestic/ industrial demand and generation will have to be synchronized with these releases.

4.4 Cost of Energy Generation

It is considered as the most preferred option for judging economic viability. To compute the cost of energy generation Total annual charges & energy benefits are considered. Total annual charges includes loan repayment, interest on loan, O & M charges, interest on working capital, maintenance of intake and lease charges.

4.5 Cost of Project

The total cost of project includes civil and electro-mechanic works. It includes mainly: the cost of preliminary survey and investigations for projects, cost of land, cost for intake structure, wells, gates, hoists, penstock, power house, switchyard, tail race channel, plantation, special tools and plants, generating plants equipments, transmission lines and terminal equipments and miscellaneous works.

4.6 O& M Cost

Operation and maintenance (O & M) cost of small hydropower project (SHP) contribute substantially in their annual costs. It includes cost operation, control and maintenance turbine generator units and auxiliary equipment in hydroelectric power generating stations. O&M function is responsible for smooth, efficient, reliable and cost effective generation with well planned effective and optimum maintenance strategy.

The SHP is economically self-sustainable if the yearly O & M expenditure incurred on the project is met from its own revenue.

4.7 Labour Cost

It is the annual expenditure incurred on skilled, semi-skilled labor for operation, maintenance, control, and testing. It also includes expenditures on Security Staff/Other Staff.

4.8 Average Power Output

Power Output depends on discharge, net head available and efficiency of turbine, generator and the gear box.

4.9 Capacity Utilization Factor

The extent of the use of the generating plant is measured by the Capacity Utilization Factor. It measures the effective utilization of the total installed capacity of the plant.

Capacity Utilization Factor should be greater than 25 %, for an economically feasible project.

4.10 Internal Rate of Return (IRR)

IRR is the actual rate of return an investment is expected to yield. Hence IRRis considered as an indicator by Financial Institutes for assessing viability of the project.

In this study, our interest is in performance evaluation of small hydro projects and selecting the best one. But this is a complex issue that specially depends on the water availability, head available, financial aspects etc. Hence, Analytic Hierarchy Process (AHP) method is used to select the best SHP among the alternatives.

4.11 AHP method

The Analytical Hierarchy Process based multiple criteria analysis deals with the relative priority of importance of each factor by pairwise comparison of all factors with respect to a certain criteria. A hierarchical structure of these factors is formed by grouping them into different levels. The hierarchy incorporates the knowledge, the experience and the intuition of the decision-maker for the specific problem.

The hierarchy evaluation is based on pair-wise judgment between the factors. The decision maker compares two alternatives Ai and Aj using a criterion and assigns a numerical value to their relative weight. The result of the comparison is expressed in a fundamental scale of values ranging 1(Ai, Aj contribute equally to the objective) to 9 (the evidence favoring Ai over Aj is of the highest possible order of affirmation).

Eigen vector approach is used to compute the weights of criteria/alternatives for the pairwise comparison matrix. The Eigen vector corresponding to maximum Eigen value (λmax) is computed to determine the weight vectors of the criteria/ alternatives. To evaluate the consistency of the obtained results three components are needed from the analysis namely Consistency Index (CI), Random Consistency Index (RI) and Consistency Ratio (CR).

$$\text{Consistency Index (CI)} = \frac{(\lambda max - n)}{(n-1)} \qquad (4.1)$$

Where, λmax is the maximum Eigen value and n is the size of the pairwise comparison matrix.
The RI had been calculated as an average of CI's of many thousand matrices of the same order whose entries were generated randomly from the scale 1 to 9 with reciprocal effect. The ratio of CI and RI for the same order matrix is called the consistency ratio CR. Thus

$$CR = \frac{CI}{RI} \qquad (4.2)$$

In general, a consistency ratio of 10% (0.1) or less is usually acceptable.
At the final step of the calculation, the overall preference matrix would be constructed by multiplying all the weights with the factors, therefore the results are added to get the composite score of each factor.

V. RESULT AND DISCUSSIONS

The average value of water head, discharge and power output are calculated since date of commissioning to December 2012 for each alternative. All input data such as Installed capacity, Average Head, Average Discharge, Cost of Energy Generation, Cost of Project, Operation and Maintenance (O & M) Cost, Labour Cost, Average Power Output, Capacity Utilization Factor and Internal Rate of Return are organized and used for formation of payoff matrix.
The relative weights of each criterion are estimated according to their importance. The top priority assigned to criterion C1, C2, C3, C9, C10 as per their higher values, whereas importance of criterion C4 as per their lower value. However, weights of criterion C5, C6, C7, C8 are estimated with expert's opinion by equivalent weights as per MW of installed capacity. The first priority to criterion C5, C6, C7 is assigned as per their lower weights, while to criterion C8 as per their lower value. These weights are further used for solving study problem by AHP method.
The pair wise comparison matrix of criteria is formulated and solved by power method to obtained maximum Eigen value. Then Consistency ratio (CR) is calculated. Similarly pairwise comparative matrix of hydro projects for each criterion is solved. It is found that all judgments are consistent.
The summation of products of the weights of hydro projects with reference to each criterion by the weights of corresponding criterion yields the global utility of hydro project. Overall utility values of alternatives are computed. The SHP which is defined to be the best has the highest overall utility value; accordingly, ranking of hydro projects is done. Table 2 presents weights of SHPs with reference to each criterion, overall utility value of each hydro project and corresponding ranking pattern.

Table 2 Global overall utility

Criteria's / Alternatives	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	Global overall utility	Rank
	Normalized values of Criteria's											
	0.083	0.184	0.190	0.057	0.028	0.021	0.016	0.263	0.118	0.040		
A1	0.240	0.313	0.096	0.073	0.018	0.050	0.025	0.034	0.221	0.207	0.1451	2
A2	0.028	0.045	0.021	0.035	0.314	0.223	0.314	0.023	0.153	0.074	0.0619	7
A3	0.157	0.030	0.375	0.314	0.155	0.035	0.223	0.314	0.313	0.316	0.2485	1
A4	0.064	0.022	0.141	0.155	0.073	0.025	0.073	0.223	0.104	0.035	0.1209	3
A5	0.042	0.221	0.028	0.107	0.223	0.314	0.107	0.106	0.069	0.050	0.1082	5
A6	0.240	0.069	0.191	0.050	0.050	0.073	0.155	0.023	0.045	0.168	0.0954	6
A7	0.100	0.104	0.042	0.025	0.107	0.155	0.018	0.049	0.022	0.025	0.0598	8
A8	0.100	0.153	0.064	0.223	0.025	0.018	0.050	0.155	0.045	0.107	0.1135	4
A9	0.028	0.045	0.042	0.018	0.035	0.107	0.035	0.072	0.030	0.018	0.0466	9
Total	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	

In accordance with the results generated in table 2, alternative A3 (Sonawade SHP) has the highest overall utility value of 0.2485 in comparison with the rest of the alternatives and the last rank is A9 (Kadvi SHP) with lowest overall utility value of 0.0466.

According to site conditions, Sonawade SHP gets constant water releases from escape and head generates uninterrupted power. It computes highest capacity utilization factor. This factor is highly dependent on number of days of operation and units generated. The Konal SHP has less efficient scores, thus second rank. Site situation shows that Konal SHP has high water head with low discharge. Capacity utilization factor of Konal is nearly 50% then Sonawade SHP which is second highest value. It indicates lesser extent of use of generating plant as compare to installed capacity. Darna SHP is having low water head but its discharge is higher than Konal SHP. Hence, Sonawade, Konal and Darna SHP are showing very good performance and found highly efficient, as the projects are generating constant outputs. They are profit making SHPs since commissioning.

Deoghar, Kumbhi and the last rank is Kadvi SHP needs improvement in their performance. Capacity utilization factor of Kumbhi and Kadvi is very poor. They require much improvement in their performance and needs stringent monitoring.

The possible shortcomings for low performances are;

a. Very less or no availability of head and discharge in some month.
b. Outage factor of generating plant is high.
c. Cost of projects is high comparative to installed capacity.
d. Improper maintenance of generating plants, equipments and Transmission.

VI. CONCLUSION

The present study evaluated the performance of Small Hydro Projects (SHPs), in Maharashtra; which are currently in operation, using AHP method.

It is concluded based on national SHP standards that the projects are functioning well, satisfying the norms. However following specific conclusions are drawn from the study.

1. Sonawade SHP generates more energy throughout the year in comparison with the rest of the projects, and first with overall utility value 0.2485. Konal SHP and Darna SHP are ranked as second and third respectively.
2. The ranking patterns of AHP shows the relative performance as better to poor in order as Sonawade SHP, Konal SHP, Darna SHP, Kasari SHP, Chitri SHP, Radhanagari SHP, Deoghar SHP, Kumbhi SHP and Kadvi SHP.
3. The typical characteristics of Sonawade SHP, Konal SHP and Darna SHP should be considered for benchmarking of SHP.
4. The present methodology is so developed that the same can be applied for yearly performance evaluation of the similar projects for consistent monitoring.
5. The ranks obtained for SHPs in the present study are based on the available input and are also indicator specific. The first author has taken up the study as an academic exercise only to exploit application of scientific methods.

VII. FUTURE SCOPE OF THE STUDY

In this paper, AHP technique is applied in order to evaluate the performance of small hydropower projects. We treat each project as an alternative average generation data since date of commissioning was considered. Ten statistical based performance indicators were identified and applied for decision making.

Following points are suggested for further study

a) Additional qualitative indicators on social and environmental aspects of the region can be considered.
b) Other methods of MCDM methods such as Data Envelopment Analysis (DEA), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Elimination and Et Choice Translating Reality (ELECTRE), Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) can be applied.
c) With the inclusion of qualitative and subjective indicator, uncertainty in expert's opinion Fuzzy MCDM can be explored.

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