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Penstock material selection in small hydropower plants using MADM methods

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ABSTRACT

Small hydropower (SHP) is a promising source of renewable and clean energy. Selection of proper material for different components of SHP projects in general and penstock in particular is one of the most challenging tasks as civil work components contribute substantially in the overall cost of the project. There is no systematic and efficient approach found in the literature for selecting best material and consequently engineers take number of criteria for such selection. In the recent time, the verities of material are increasing very fast with various properties, which make material selection process complicated. In the present study, an effort has been made to apply Multiple Attribute Decision Making (MADM) methods for solving the material selection problem for penstock in SHP installations. Analytic hierarchy process (AHP), technique for order preference by similarity to ideal solution (TOPSIS) and Modified TOPSIS methods are used to select the best material. Four alternative materials such as polyvinyl chloride (PVC), high-density polyethylene (HDPE), glass reinforced polymer (GRP) and mild steel (MS) and five assessment attributes/criteria such as yield strength, life, thickness, cost of material and maintenance cost have been considered in the analysis. Two case studies have also been analyzed and included in the study. It has been found that TOPSIS and Modified TOPSIS methods are best suited for penstock material selection and mild steel is the suitable material as compared to other materials.

Contents

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Acronyms

SHP small hydro power
MADM multiple attribute decision making
AHP analytic hierarchy process
TOPSIS technique for order preference by similarity to ideal solution
Modified TOPSIS modified technique for order preference by similarity to ideal solution
PVC polyvinyl chloride
HDPE high-density polyethylene
GRP glass reinforced polymer
MS mild steel
P power
W watt
ηt hydraulic efficiency of the turbine
ρw density of water
g acceleration due to gravity
Q discharge
h head of water acting on the turbine
kg/m^3 kilogram per cubic meter
m/s^2 meter per square second
m^3/s cubic meter per second
m meter
kW kilo Watt
SAW simple additive weighted
ELECTRE elimination and choice translating reality
WPM weighted product method
VIKOR vise kriterijumska optimizacija kompromisno resenje
GTMA graph theory and matrix representation approach
COPRAS complex proportional assessment
EVAMIX evaluation of mixed data
FAD-MSI fuzzy axiomatic design-model selection interface
ECD environmentally conscious design
IDEA integrated decision aid
PROMETHEE preference ranking organization method for enrichment of evaluations
MPa mega Pascal
mm milli meter
gm/cm^3 gram per cubic centimeter
GPa gega Pascal
Rs/m/year rupees per meter per year
Rs/m rupees per meter
$ dollar
MODM multi-objective decision making
DM decision maker
YS yield strength
L life
T thickness
C cost of material
MC maintenance cost
GM geometric mean
CV consistency value
λ_{max} eigen value
CI consistency index
RI random index
CR consistency ratio
MSI material selection index
O&M operation and maintenance
AHEC Alternate Hydro Energy Centre
m/s meter per second

1. Introduction

In recent years, varieties of materials are available and the material selection plays a significant role in engineering and other fields. Material selection with minimum cost and better performance is a challenging task [1]. Understanding of functional requirements and performance criteria is needed for material selection for each component in any field. With increase in the availability of number of materials, the selection processes take more time and become complex [2,3]. The objectives of material selection process are to choose the best material with low cost, prolonged life, less maintenance cost, lesser in weight and good performance. The material, which has more than two alternatives and attribute/criteria, can be selected by formulating the MADM problem [4,5].

1.1. Small hydropower (SHP)

Small hydropower is one of the earliest known renewable energy technology in existence in the country since the beginning of the 20th century. It is a proven and clean source of energy. In hydropower, electricity is generated, when water pressure is converted into mechanical energy by using hydro turbine and that energy is used to derive the electric generator [6]. The power available is proportional to the product of head and discharge. The mechanical power, *P* (in W), produced at the turbine shaft can be estimated as

$$P = \eta t \rho w g Q h \quad (1)$$

where ηt is the hydraulic efficiency of the turbine, ρw the density of water (kg/m^3), g the acceleration due to gravity (m/s^2), Q the discharge (m^3/s) and h is the head of water acting on the turbine (m). Hydropower projects are classified based on installed capacity. Classification of SHP schemes in India is described in Table 1 [6,7]. Different countries follow different norms to define SHP based on installed capacity.

The basic components of small hydropower scheme can be broadly classified as (i) civil works and (ii) electro-mechanical equipment. Fig. 1 shows a schematic for various components of typical small hydropower scheme. Civil works of small hydropower scheme generally comprise of diversion weir and intake – is required for diverting the flow of water from the river or stream