

Application of AHP-DEMATEL and GMDH Framework to Develop an Indicator to Identify Failure Probability of Wave Energy Converter

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Abstract

The objective of the present study is to develop an extensive indicator which can represent the probability of failure of the wave energy converters. The objective was accomplished by the adaptation of a two-step methodology. In the first step, MCDM methods were used to estimate the priority values of the factors relevant to the probability of failure of the converter. In the second step, GMDH model was implemented to predict the values of the indicators which are directly proportional to the probability of failure of the converter. The significant parameters were identified by their consideration in different case studies and their influence on converter efficiency. The soft-computation methods like AHP-DEMATEL and GMDH were used to find the relative priority values of the parameters and to develop an automatic framework for estimation of the indicator. The indicator was made directly proportional to the ability of the converter to failure probability of wave energy in a specific location. The results from the multi-method estimation model were validated with the help of Multi Linear Regression Equation and some real time case analysis. With an accuracy of above, 99% the ensemble MCDM-ANN model depicts a reliability which ensures the author of its wide application for the real benefits like cost reduction and efficiency maximization of converters in the utilization of the potential energy of the locations. The model has the potential to become a tool with which engineers can easily identify the failure tendency of wave energy converters in specific locations.

Keywords: Analytical Hierarchy Process (AHP), Decision Making Trial and Evaluation Laboratory (DEMATEL), Ensemble Modeling, Group Method of Data Handling (GMDH), Wave Energy Converter

1. Introduction

Rising population levels around the world combined with depleting energy resources, particularly in the form of carbon deposits, have contributed to increasing pressures on global energy supply. In order to mitigate shortages in global energy supplies, nations are increasingly turning to renewable energy sources as a sustainable and secure source of energy¹. As a proportion of total energy production the capacity for energy contribution from renewable sources as of 2015 was estimated at 27.7%, which represented approximately 58.5% of the net additions to global power capacities in 2014² Of the various sources of renewable energy wind, solar power and hydroelectric power remain the most dominant sources of this observed growth in renewable energy output.

A wave energy converter is a device for extraction of energy from waves and conversion of the extracted energy into useful energy. The high cost of conversion and low extraction from the converter are the major obstacles to wide scale implementation of wave energy production plants.

Location selection for wave energy converter can be defined as the determination of a location, where all factors are considered in terms of maximization of output with minimization of cost. Also, it might be the most important decision which will affect the success of a project. The reason is that a good location can give the best results in and for this the location selection is the top priority before any other decisions. It becomes very difficult to compensate for the negative influence of a bad location decision³.

Several types of wave energy converters are already in

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works and their reviews on wave energy conversion have been published in book form, as conference and journal papers, and as reports⁴.

The problems with Wave Energy Converter (WEC) are that most of these works under specific wave climate⁵ and the power generation of these converters are not only dependent on the resources but also in the sea states⁶.

Failure of the converter may cause due to the failure of structure⁷. The major reasons for the failure of wave energy converters, which are also the cause of the high costs and low efficiency of the converters, were found to be wave breaking due to extreme events (and corrosion due to contacts with sea water^{8,9}). These failures occur due to the converter location, as well as the type of converters used for extraction. Although there are various methods to analyze the feasibility of converters in certain locations¹⁰ most of these are subjective¹¹ and applicable only to specific locations or converters^{5,12}.

This is why the present study aims to develop a single medium to estimate the probability of failure of a converter when installing in a location of interest. The objective of the present study is to develop an extensive indicator which can represent the failure probability of the converters.

2. Methods Adopted

The objective was accomplished by the adaptation of a two-step methodology. In the first step, Multicriteria Decision Making Method (MCDM) was used to estimate the priority values of the factors relevant to the probability of failure of the converter. In the second step, the same priority values were used to develop the model to identify the suitable converter for a location. In this regard, Group Method of Data Handling (GMDH) and MaxStat lite software was used.

An integrated Analytical Hierarchy Process (AHP) - Decision Making Trial and Evaluation Laboratory (DEMATEL) MCDM was used to estimate the priority values of the factors, relevant to identify the ideal converter for wave power generation.

2.1 AHP

The AHP is an MCDM method introduced by Thomas L. Saaty in 1980. It is based on the relative priorities assigned to each criterion's role in achieving the objective. In this method, the problem is broken down into its constituent

elements with the best alternative usually being selected by making comparisons between alternatives with respect to each attribute. AHP is widely used for decision making problems like Evaluation of Renewable Energy Project¹³, Energy- Aware Decision making¹⁴, Project Quality Evaluation in Construction Engineering¹⁵, Power System¹⁶ and Wind Energy¹⁷.

2.2. Decision Making Trial and Evaluation Laboratory (DEMATEL)

The AHP-DEMATEL method originated from the Geneva Research Centre of the Battelle Memorial Institute¹⁸ and is especially pragmatic for visualizing the structure of complicated causal relationships. The method is applied in the determination of environmental performance¹⁹, developing models for improving the performance of solar farms²⁰ and evolution of the risk of failure²¹.

Table 1. Factors which influence the failure of a wave energy converter

Parameters	Type of Impact
Locational Aspects	
Significant Wave Height (W_1)	B
Wave Amplitude(W_2)	B
Wave Period (W_3)	B
Depth of the Ocean (W_4)	NB
Shipping Density (W_5)	B
Percentage of Regular Waves (W_6)	NB
Direction of Wave (W_7)	NB
Average Wave Power Level of the Sea (W_8)	B
Corrosion (W_9)	B
Survivability (W_{10})	NB
Design Aspects	
Size and Shape (Diameter, Draft, Displacement, Stroke Length, Height) (W_{11})	B
Mass of the Buoy (W_{12})	B
Thickness of the Material Used (W_{13})	B
Efficiency of Wave Rotor/Generator (W_{14})	NB
Efficiency of Turbine (W_{15})	NB
Efficiency of Energy Storage System (W_{16})	NB
Efficiency of Hydraulic System (W_{17})	NB
Power Conversion Efficiency at Constant or Nearly Constant RPM (W_{18})	NB

Two different types of parameters Table 1 were considered. Beneficiary (B) parameters vary directly

with the objective equation and non-beneficiary (NB) parameters increase with decreases in the magnitude of the objective function.

3. Detailed Methodology

The parameters were selected from the literature survey.

AHP-VIKOR was used as the MCDM method to find the priority value of each parameter.

The Group Method Data Handling (GMDH) ²¹ and MaxStat lite software were used as the predictive method for developing the model in the present study.

3.1 Selection of Criteria

3.1.1 Efficiency Potential

The commonly used equation for calculating the power potential, as proposed by Pontes et al. (1995) and Tucker and Pitt (2001), is given in Equation 1

$$P_w = \frac{\rho g^2}{64\pi} T_e H_s^2 \quad (1)$$

Where, P_w = average wave power; H_s^2 = significant wave height; T_e = peak period; ρ = density of water; and g = acceleration due to gravity.

As H_s squared is directly proportional to P_w , the efficiency potential or location with a high magnitude wave height will have a higher level of conversion efficiency. The relative score was calculated by Equation 2

$$RS = \left(\frac{R}{MaxR} \right)^{-1} \quad (2)$$

Where, $R = 1, 2, \dots, 7$; $Max(R) = 7$

3.1.2 Cost Potential

The cost potential of parameters depends on the proportionality of the parameter to the mooring cost or the cost required holding the converters in place.

The score of the parameters for the cost potential was calculated by Equation 3; here if ΔC is the difference in cost for two different locations and ΔH is the change in the wave height, then the cost potential of wave height can be represented by Equation 3.

$$C = \frac{\Delta C}{\Delta H} \quad (3)$$

The general equation for the estimation of the cost potential for the parameter is depicted in Equation 4.

$$C = \frac{\Delta C}{\Delta P} \quad (4)$$

Where, ΔP is the change in the magnitude of the parameter with respect to locations.

3.2 Selection of Alternatives

Eighteen different alternatives Table 1, based on location and design factor, were selected for the present investigation from the survey of the literature and expert's survey.

3.3 Development of the Model

The output of the model was the index value which is the ratio of the beneficiary factors and the non-beneficiary factors for the failure mode of a converter. The input to the model consisted of the eighteen factors Table 1. The index value was calculated with help of the equation 5.

$$Index = \frac{\sum W_n B_n}{\sum W_m N b_m} \quad (5)$$

where, W_n = weights of the parameter of positive influence.
 W_m = weights of the parameter of negative influence
 B_n = value of the beneficiary parameters
 $N b_m$ = value of the non-beneficiary parameter

The performance of the two models was analyzed by Mean Absolute Error (MAE) ²², PBIAS ²³, Correlation (R) ²³, MRE ²⁴ and RMSE ²⁵. An Equivalent Performance Index (EPI) was prepared to represent the performance of the models (Eqn.6). The model output is directly proportional to model efficiency.

$$EPI = \left\{ \frac{R_{ts}}{MAE_{ts} + MRE_{ts} + RMSE_{ts} + PBIAS_{ts}} * 0.6 \right\} + \left\{ \frac{R_{tr}}{MAE_{tr} + MRE_{tr} + RMSE_{tr} + PBIAS_{tr}} \right\} \quad (6)$$

Where, I_{ts} = Model output value for the testing model

I_{tr} = Model output value for the training model

Two steps were involved in the calculation of EPI. In 1st step, the values of Mean Absolute Error (MAE), PBIAS, Correlation (R), MRE and RMSE for both the testing and training phase were calculated for each model. In 2nd step, the EPI were calculated for each model. As the model is directly proportional to the EPI value, so the maximum EPI shows the best model among the two developed model.

3.4 Case Study

The failure probability of two converters, Pelamis²⁶ and Mighty Whale²⁷, were analyzed for three different locations Figure 1. The power potential per meter of wave crest of 20 KW was found in Location 1 (10.5° N, 75.5°E), 15.90 KW in location 2 (15.3°N, 73.78°E), 11.81 KW in location 3 (17.09°N, 73.8°E) using the wave power potential equation [1].

4. Results and Discussion

The study results can be divided into three parts. The results from MCDM, from developed model and from case study which are depicted in 4.1, 4.2 and 4.3.

4.1 Relative Weights (AHP-DEMATEL)

The priority values, as determined by the MCDM method is depicted in Figure 2.

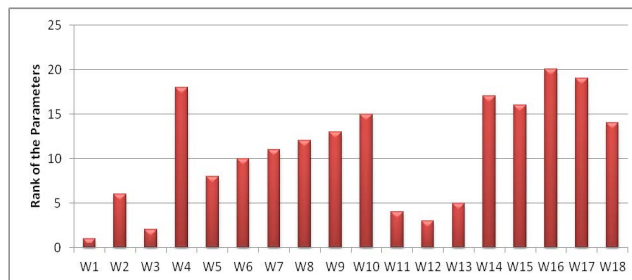


Figure 2. Rank of the parameters as per the priority value found from the AHP-DEMATEL MCDM meth.

As per the priority values as determined by the MCDM method (Figure 2), significant wave height (W_1) and Efficiency of Energy Storage System (W_{16}) were found to be the most important and least important parameters. So, it shows that significant wave height (W_1) is the most influential parameter as per the study objective.

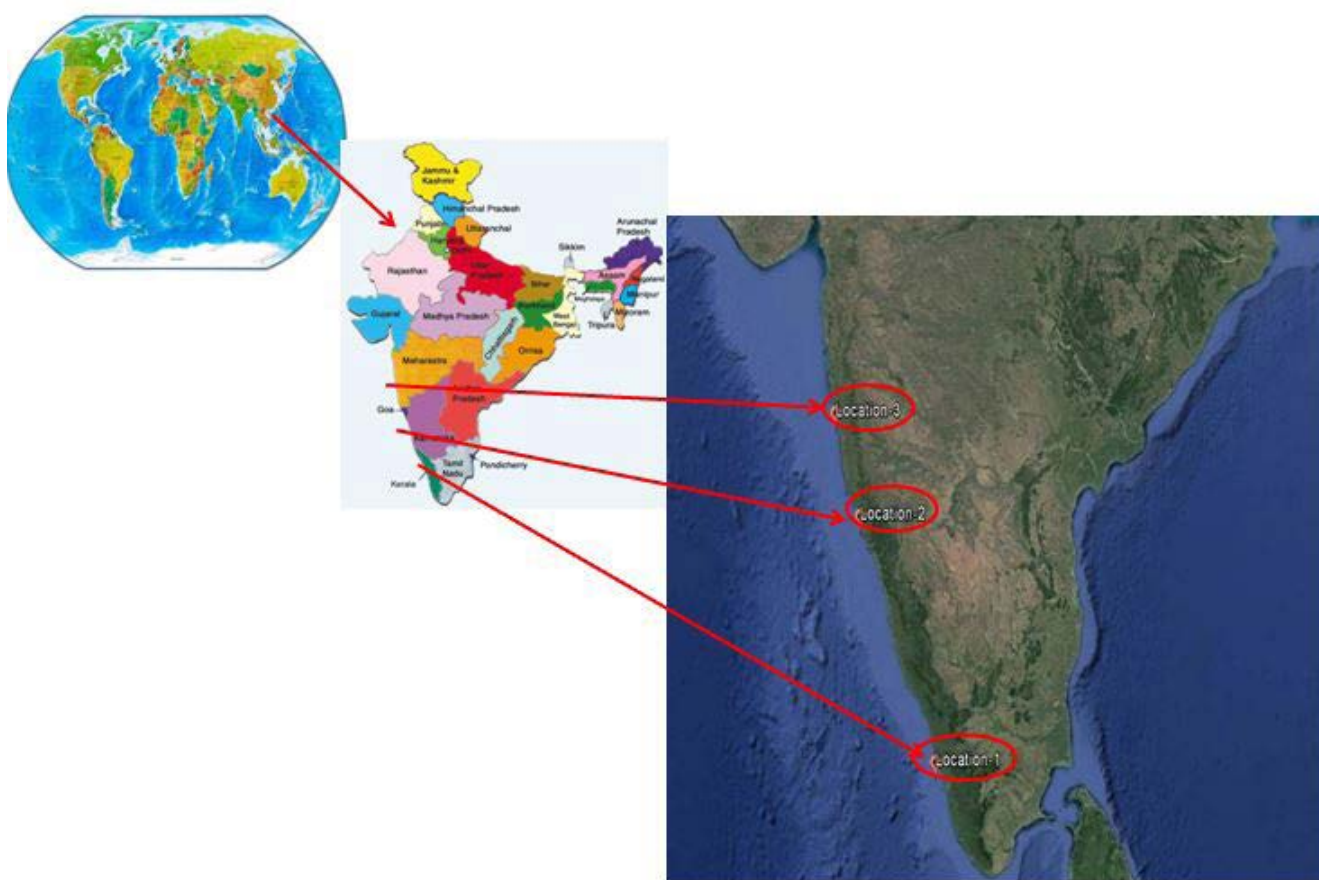


Figure 1. Location map for the present study objective.

4.2 EPI Value

Table 2 shows the EPI of the two different developed models i.e. model developed by GMDH and Model developed by MaxStat Lite Software.

Table 2. Two developed model and the corresponding EPI values

Model Developed by GMDH			
	Training	Testing	EPI
PBIAS	3.73264×10^{-14}	0.054635	42.3831
MRE	-0.00016	-0.00017	
MAE	0.007055	0.008639	
RMSE	0.009252	0.011669	
CORRELATION	0.997377	0.994987	
Model Developed by MaxStat Lite Software			
	Training	Testing	EPI
PBIAS	0.115423	0.25562	4.19166
MRE	0.002256	0.001089	
MAE	0.023888	0.015995	
RMSE	0.02589	0.06053	
CORRELATION	0.998562	0.992159	

Between the two different models, model developed by GMDH was found to have the maximum EPI i.e. 42.3831. So, the EPI value (Table 2) shows that the model developed by GMDH is best between the two models.

4.3 Case Study: Index value of three different locations with two different converters is showing in Figure 3.

It can be seen from the Figure 3 that Location-1 having the highest potential where Pelamis converter has lower failure probability. Between the two converters, Mighty Whale was found to be the most vulnerable and Pelamis was found to be the least vulnerable.

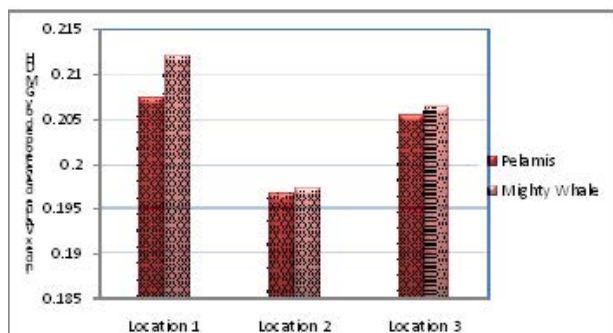


Figure 3. Model output for three different locations predicted by the GMDH m.

5. Conclusion

The present study attempts to develop a new indicator represent the failure probability of the converters in a specific location. This model is made objective by the application of MCDM and cognitive with the help of GMDH and Statistical software. The best model was identified from the two different models having the same inputs and output. The model with the highest efficiency was found to have a correlation value of 0.9973, which shows the reliability of the model. As per the case studies, Pelamis has the lower failure probability in each of the location.

Although the model has the potential to become a tool with which engineers can easily identify the ideal wave energy converters in specific locations, this method has some limitations. The importance of the variables was estimated by the one single hybrid MCDM methods but may change if other MCDM methods are used. This shows that the model is dependent on the type of methods utilized to find the priority value of the parameters. These drawbacks can be mitigated if some uniform policies are adopted regarding the selection of method, criteria, and alternative while the indicator is implemented in a decision support system.

6. References

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