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Identification of Fatigue Proximity in Wave Energy Converter using Statistical Control Process, AHP and Neural Network Model

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ABSTRACT

The present work demonstrates the trend of Fatigue influenced to the Wave Energy Converters. The fatigue failure occurred due to various reasons in real field application of Wave Energy Conversion. All possible factors are considered to find out the fatigue trending. To analyze the fatigue probability Statistical Control Process and AHP is used, from the result a model is generated through Neural Network software named GMDH. There are significant uncertainties arising in particular from the lack of field tested result to calculate the fatigue trend on the devices. However applying various hypotheses for design and mechanical parameter, it was found that the benefits of fatigue influenced factors are all non beneficiary to Fatigue trend. After all the calculations it can predict the proximity of Fatigue failure in a Wave Energy Converter.

Keywords: Wave Energy Converter; Statistical Control Method; Fatigue Factors; AHP; Group Method of Data Handling (GMDH)

I. INTRODUCTION

The present demand of fossil fuel and burgeoning concentration of pollutants enforced scientists worldwide to look for alternatives to substitute conventional energy sources. Among the most suitable renewable, energy from ocean waves was found to be reliable and enough to satisfy global energy demand. But due to some location dependent factors this type of source is expensive and thus unpopular among the masses. One among the factors is the mechanical fatigue of the converters. This factor can be defined as weakness in machine parts or structures due to repeated variation of working load and widely [1], [2].

The fatigue of converters affects both the efficiency and operational life time and is considered whenever a design related problems are solved. As the factor can reduce the operating efficiency as well as life time of a converter estimation of the same can ensure prevention of economical liability and the life time of the converters. Different factors can influence fatigue in a converter. Some of the factors are Wave impact on the converter, bearing life maintenance etc. But not all the parameters are equally significant in influencing mechanical fatigue in a converter. The Wave Energy Converters (WECs) are used in ocean in various position like Offshore, Onshore, near shore, partially submerged i.e. floating, totally under water or established in the open atmosphere in shoreline of sea i.e. fixed structure. Different types of difficulties may come in WECs. Fatigue failure in WECs is significant important area to analyze specially for offshore and near shore structures.

The objective of this research is to predict the trend of the fatigue probabilities for any WECs in all probable wave power generation situations by using Statistical Control Chart (X, P, and R Chart) [15], AHP Multi Criteria Decision Making (MCDM) [6] and Neural Network (GMDH Software) Model [13].

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II. FATIGUE INFLUENCED FACTORS

2.1. Internal structure

Internal areas of the WECs are considered which are accessible for regular maintenance. These areas mainly submerged into the sea portion. Metal joints are welded or nut bolt system. Ultimate Stress and Allowable stress are to defined properly and Safety Factor to be considered ≥ 1.0[4]. Time to time overview of these sections is required.

2.2. External structures

External areas of WECs those are easily accessible for maintenance repairing and not accessible for regular inspection and repair in dry and clean conditions.[2] Safety Factor to be considered ≥ 1.0[4].

2.3. Non-accessible areas

These particular areas not planned to be accessible for inspection and repair during operation [1]. Because positions 150m below water level, it should be assumed inaccessible for service and inspection for maintenance [4].

2.4. Wave Impact, Wave Climate and Weather Condition

Increase in the weight of steel needed to face higher extreme waves, and changes in fatigue life of WEC components from operation in rougher weather [8]. For fatigue life even more than for structural costs, given the wide variety of proposed WECs and their components it is impossible to get results that could be generalized to all of them. It was chosen to illustrate the application of standard fatigue calculations to a particular WEC [10], [11].

2.5. Replacement Schedule for Bearings System

The replacement schedule for bearing will be the upper limit to the servicing interval. This part supports the gyroscopic mechanism of this WEC, hence rotation velocities are higher than those of bearings in many other power take off mechanisms. In addition the bearing is housed inside the hull and bearing life will be quite different for outside moving parts exposed to corrosion, lubricant contamination [2],[3]. It should be mentioned nonetheless that the calculation were repeated for different types of bearing under very different loads, and the relative changes in service life between different sea-states and climates were rather similar. Bearing fatigue is a constraint on maintenance that may be expected to be shared by many WECs [12]. These parts will be chosen so that loads are within their rated operating range, within the fatigue life. [1], [5]

2.6. The Manufacturer Range Rating

It indicates the Hydraulic load on the WECs, Hydraulic Motor rotation, gyroscopic velocity, Types of lubricant used, Optimum operating temperature. If the WECs are operated beyond the manufacturer defined range rating of the instruments the fatigue trend will be more [9].

2.7. Foundation Design for Wave Energy Converters

Design of foundations for wave energy converters shall be based on site and location specific information. The selection of site investigations and the choice of these investigation methods will be taken into account the type and size of the wave energy devices, the uniformity of land and seabed conditions. For application of anchors the soil characteristics and range of soil or land strength properties will be analyzed. Site selection investigations should provide ample information about the land characteristics to a depth required to check effect of possible failure conditions [4].

III. METHODOLOGY

Methodology of this study is described in the flowchart of Fig 1. Initially the problems related to fatigue failure of WECs are considered because of better performance or improved output of huge investment regarding Wave Energy Conversion process. Major factors that influenced Fatigue are considered from the mechanical operation. Those parameters are placed properly by using Statistical Control Charts like X, R and P Charts [15]. These attribute charts are considered as criteria and the Fatigue parameters are considered as alternatives in the process of identifying the weights of parameters by using AHP [6]. After weights are found, the ANN software was trained by those weights and the model was generated to predict the Index value of Fatigue influence [13].

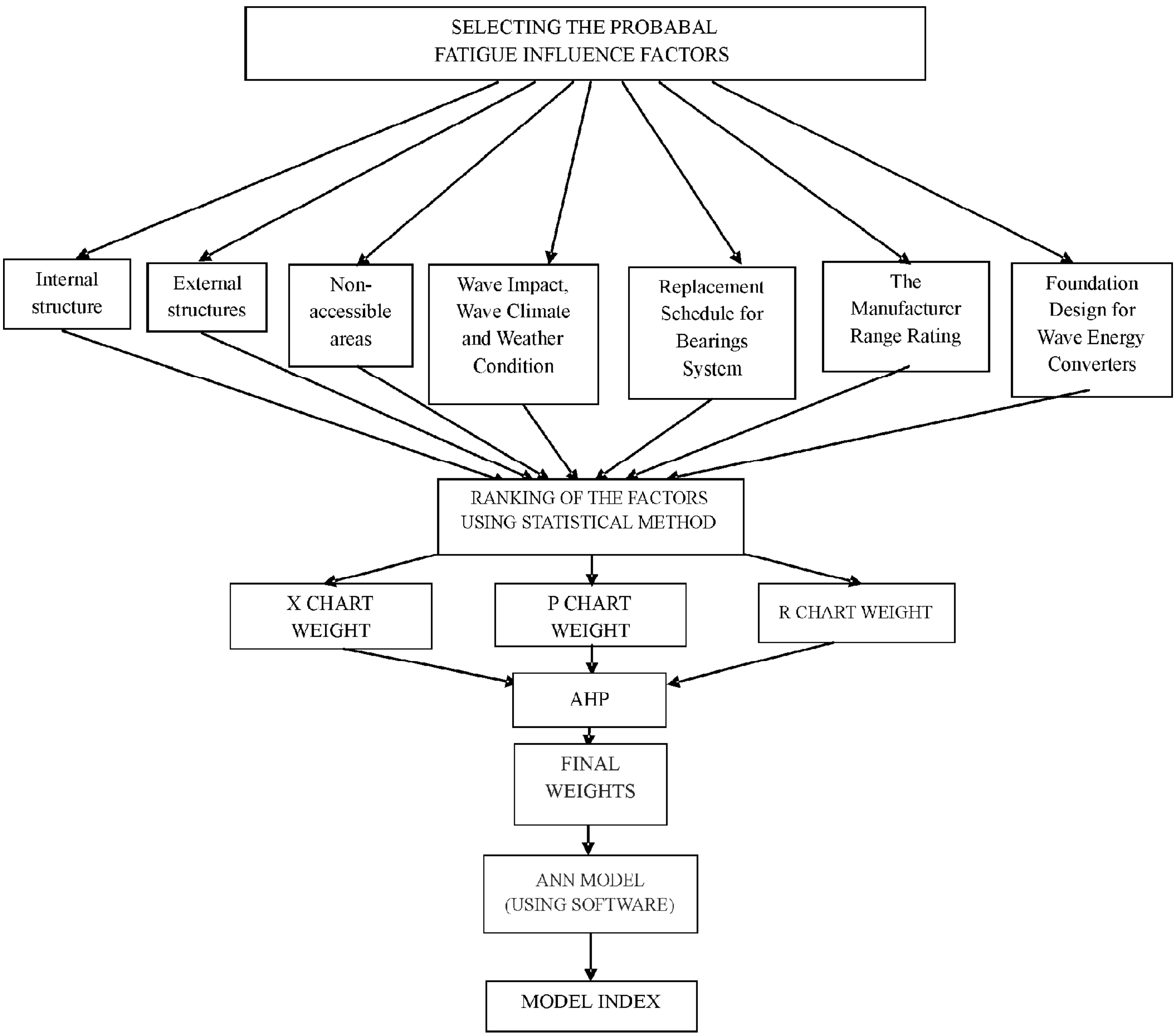


Figure 1: Flowchart of the total process

IV. RESULTS AND DISCUSSION

Statistical Control Chart (X, P and R Chart) were used to ranking the seven fatigue influenced parameters as per their weightage value. AHP was used to detect the relative importance of the alternative with respect to the criteria for unbiased and objective decision making [6].

Table 1
Final Weights of Fatigue Parameters by AHP methods

Fatigue Influence Factors (Non Beneficiary)	*Parameter Weights* X Chart	R Chart	P Chart	*Criteria Weights*	*Final Weights*
INTERNAL STRUCTURE	0.1443	0.1456	0.1603	0.5556	0.1465
EXTERNAL STRUCTURE	0.1519	0.1304	0.1636	0.3333	0.1460
NON - ACCESSIBLE AREAS	0.1502	0.1520	0.1197	0.1111	0.1474
WAVE IMPACT, CLIMATE	0.1393	0.1342	0.1478		0.1386
BEARING LIFE	0.1200	0.1547	0.1315		0.1328
MANUFACTURER RANGE RATING	0.1508	0.1500	0.1434		0.1497
FOUNDATION DESIGN	0.1435	0.1330	0.1336		0.1389

ANN Software predicted algorithm:

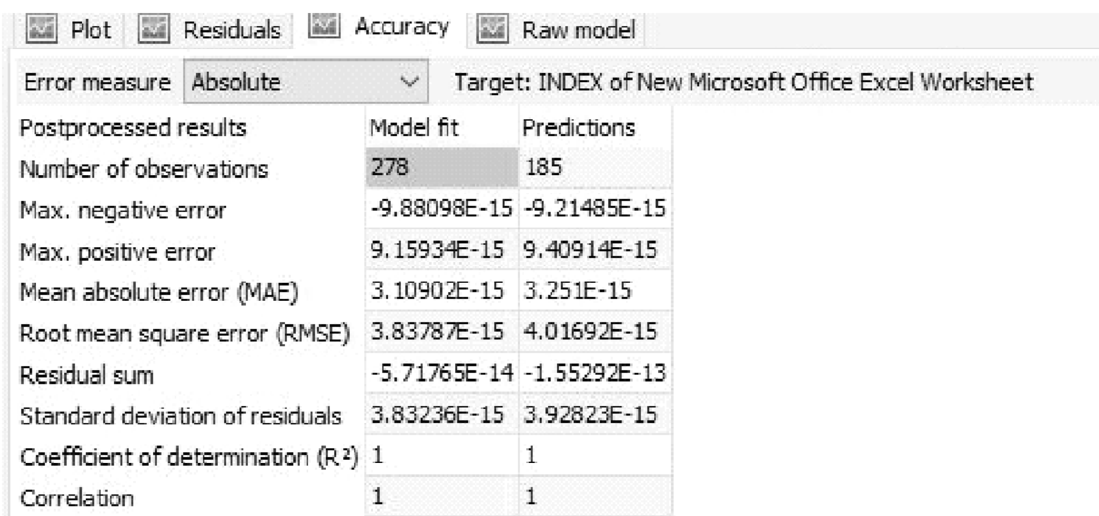
$$F_I = N_C + \Sigma_{n=1}^{n}(w_n x_n) \ldots\ldots\ldots\ldots \ (i) \qquad [13]$$

F_I= Fatigue Index, N_C = Neural Network Model Constant = **207784 × 10**$^{-13}$ [Obtained by GMDH Software]

W_n = Weight of the parameter, X_n = Parameter data (Scale to 1)

5.1. Application of Neural Network

The present investigation is to detect and estimate the correlation between the variables as input and the output as model index. Thus, the selected parameters are used inputs and the feasibility index (model index) was considered as the output [7].



Postprocessed results	Model fit	Predictions
Number of observations	278	185
Max. negative error	-9.88098E-15	-9.21485E-15
Max. positive error	9.15934E-15	9.40914E-15
Mean absolute error (MAE)	3.10902E-15	3.251E-15
Root mean square error (RMSE)	3.83787E-15	4.01692E-15
Residual sum	-5.71765E-14	-1.55292E-13
Standard deviation of residuals	3.83236E-15	3.92823E-15
Coefficient of determination (R²)	1	1
Correlation	1	1

Figure 2: Analysis of Accuracy of the Model developed by GMDH software

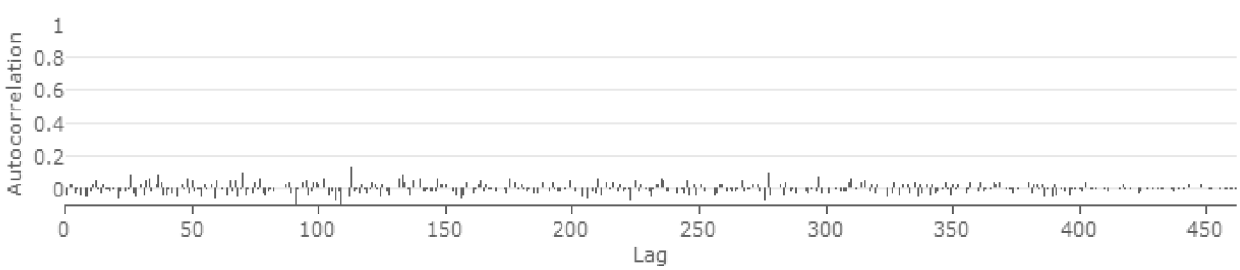


Figure 3: Autocorrelation

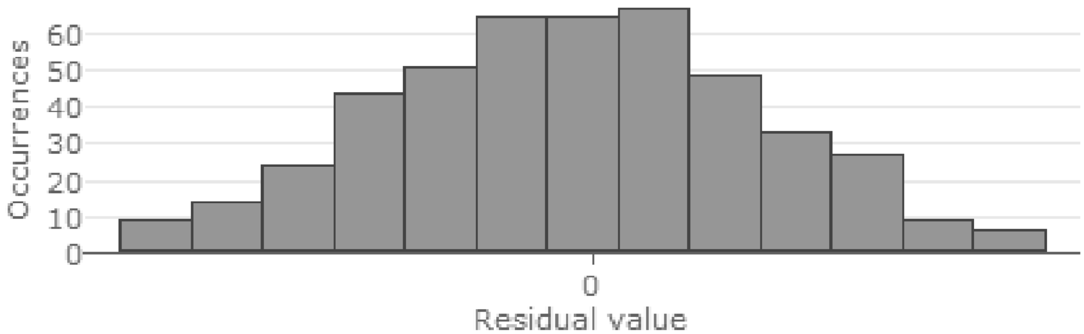


Figure 4: Occurrence of Residual Values

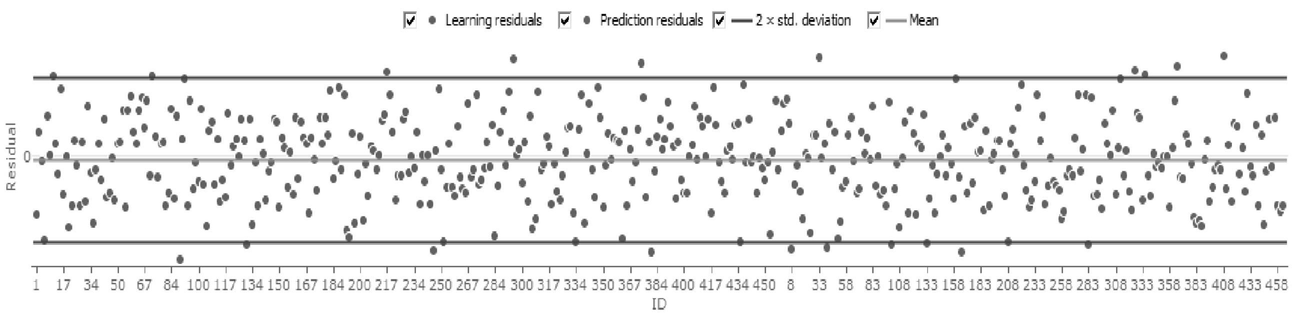


Figure 5: Distribution of Residual

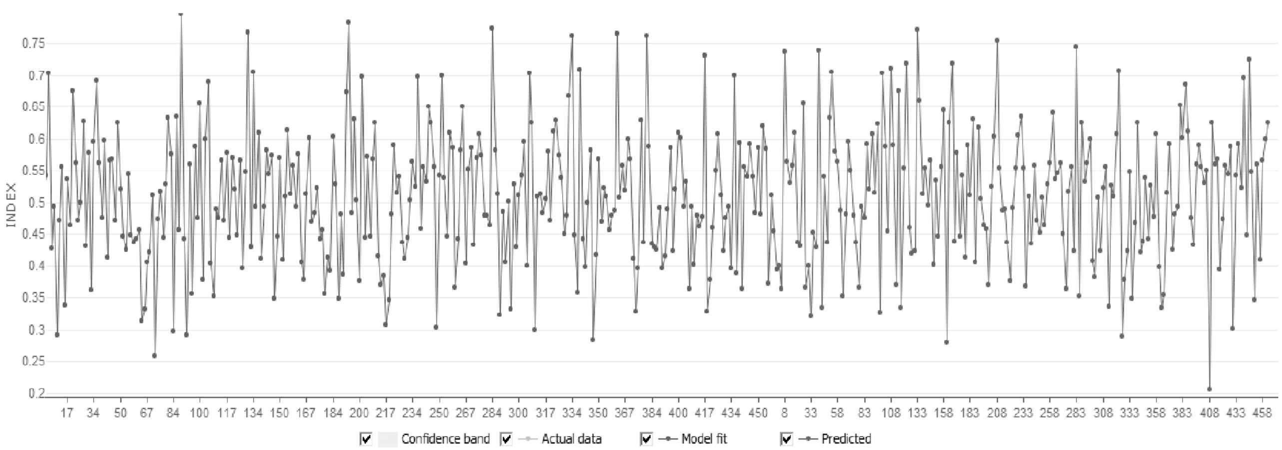


Figure 6: Comparison between actual and predicted values

5.2. Sample Model Data generated from GMDH Software

Table 2
Sample model.index data

Sl No	*Internal Structure*	*External Structure*	*Non - Accessible Areas*	*Wave Impact, Climate*	*Bearing Life*	*Manufacturer Range Rating*	*Foudation Design*	*Index*	*Model. index*
1	0.0489	0.6250	0.3514	0.1309	0.2255	0.8821	0.5001	0.3999	0.3999
2	0.2727	0.5472	0.8131	0.8171	0.7911	0.5407	0.0211	0.5419	0.5419
3	0.4223	0.7377	0.8629	0.6492	0.7969	0.5981	0.8712	0.7032	0.7033
4	0.9458	0.0374	0.1687	0.2314	0.2182	0.2131	0.7357	0.3640	0.3640
5	**0.0253**	**0.0718**	**0.4221**	**0.0703**	**0.7216**	**0.5856**	**0.1496**	**0.2905**	**0.2905**

From the Table 2 third reading has a more tendency of fatigue failure whereas fifth one has a lower chance of fatigue failure on WEC.

V. CONCLUSION

The present study tried to estimate the probability of fatigue of wave energy converter with the help of an index by implementation of statistical control charts, AHP and Group Method of Data Handling, a new variant of Neural Network technique.

According to the results Manufacturer predefined range rating of material parameter was found to be most significant among the selected factors and have the highest priority value as determined by the AHP method. However non accessible area of a converter was identified as the second and internal structures was as the third most important parameter in estimation of the index which represents the fatigue probability of a converter. The GMDH model was used to map the selected input factor and the index and to develop an automatic framework for estimation of the chance of mechanical fatigue. In this aspect the model performance was satisfactory and its accuracy level was approximately near about the input variables. However the lack of application in real time scenario may raise question about the reliability and practical feasibility of the indicator. But this can be dealt in further studies so that a simple, cost-effective and automatic system can be used widely.

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