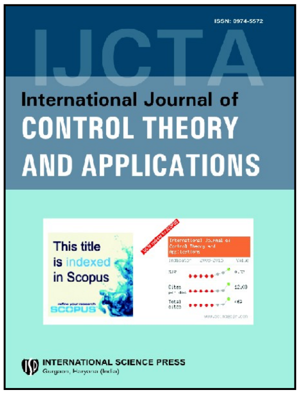

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Development of Location Suitability Index for Ocean Thermal Energy Conversion Systems

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Abstract: Ocean thermal energy conversion (OTEC) is one of the most promising and pollution free alternative sources of energy. In this process, the electrical energy could be generated by the utilization of thermal gradient (at least about 18°C) between the surface layer of the ocean and at depth of 750 to 1000 m. But the proliferation of OTEC system is still at a nascent stage and yet to be popularized due to the unsatisfactory level of cost-benefit ratio. The cost-benefit ratio of any system depends on the efficiency which for OTEC system deviates with different location dependent factors. So the fact of the matter is that location of the plant plays a significant role in improving the efficiency of the system. That is why identification of a suitable location is extremely significant for retrieving maximum utilization efficiency from the system. But presently there are no methods which can select a location based on the most significant parameters which have maximum impact on the utilization efficiency of the OTEC system. The present study proposed a new method which identifies the most consequential parameter and selects a location from where maximum utilization of the available resources can be possible. In this aspect, various literature, experts, and stakeholders are surveyed to identify the correlated positive and negative factors with respect to the conversion of ocean thermal energy with the help of these parameters an index was proposed which can reliably represent the suitability of the location for maximum utilization of ocean thermal energy. Five case locations are selected for suitability analysis around the Andaman and Nicobar Island, India because it is surrounded by the warm water and suitable with respect to bathymetry, environment, and socio-economic characteristics. The priority value of the parameters was estimated with the help of a new technique developed by hybridizing the statistical control charts techniques followed by EVAMIX Multi-Criteria Decision Making method. The most momentous parameter was also distinguished with the help of the priority values determined by the new method. In the index also the priority values were used as a multiplier and with the help of the index suitability of the selected locations were estimated. According to the result, the surface temperature is found to be a most significant parameter and that is why location 1 with the highest surface temperature among the selected locations was identified as the most suitable location for installation of OTEC systems compared to the other four locations.

Keywords: Ocean Thermal Energy Conversion, Multi-Criteria Decision Making, EVAMIX, Statistical Control Charts.

I. INTRODUCTION

The demand for the electricity is continuously increasing and the world is also running out of the resources of electricity. So in this scenario, the renewable energy resources must be developed. A major part of the electricity demand is fulfilled by the thermal power plant but it also increase the pollution and fuel used is in a thermal power plant is limited. There is a need for some alternative. So in this aspect, OTEC plant can be a very good and pollution free alternative to fulfill the energy demand because the ocean is the base of OTEC plant and the noxious by-product is not generated. Ocean works as the heat source for the OTEC plant and ocean is the largest absorber of solar energy on earth. Working temperature and pressure is low in this system so chances of operational hazards are also low than conventional plants [1].

The working principle of the OTEC is based on Rankine cycle [2]. In OTEC plant, thermal gradient between the surface temperature and temperature of the layer at the depth of 750 to 1000 m is used to generate the electricity. The required thermal gradient for energy conversion is minimum 18°C [3]. Closed cycle, open cycle, and hybrid cycle are the types of OTEC system. In closed cycle system, a low boiling point working fluid is used like Ammonia. Warm surface seawater exchange the heat with ammonia through a heat exchanger and by receiving the heat, ammonia gets vaporized. That vaporized ammonia rotates the low-pressure turbine to generate electricity. After expansion process, the ammonia again exchanges the heat with the cold deep water which is pumped through the second heat exchanger and turns to liquid from vapor and it is recycled. This procedure is also same for the open cycle OTEC but the difference is that in open cycle OTEC sea surface water is used as working fluid instead of ammonia. A vapor from sea surface water is used to rotate the turbine [4].

OTEC plant can be established offshore as well as onshore. Both types of plant have some merit and demerit for example onshore plant require valuable land, large amount of pumping power and installation cost is also high but maintenance cost is low on the other hand offshore plant does not need any valuable land, pumping power is also less required but maintenance cost is high, expenses of transporting energy is high, also it needed a large structure to anchor down and protect the plant from natural hazards [5].

The only aspect due to which OTEC systems are not widely utilized for generation of energy is due to the high cost-benefit ratio where due to the impact of different location dependent parameters the efficiency of the energy conversion deviates. The efficiency of the plant depends on the energy source [6]. The energy source for the OTEC system is the thermal gradient and thermal gradient varies place to place [4]. So the location plays a very important role. At the location, the impact of the negative parameter should be minimum and impact of the positive parameter should be maximum. In order to select a location for the plant, some important factor must be taken into account because those factors directly affect the plant. Those factors are warm sea surface temperature, deep cold water temperature, depth of the deep cold water or water column, a distance of thermal gradient column from the shore, wave height, wind speed, surface current, environment impact, and natural hazards [7].

The performance of the plant depends on a thermal gradient. 10 to 15% power increases with an increment of 1°C in a thermal gradient [8]. Thermal gradient varies with the place so this factor needs more attention in the selection of the location. The distance of thermal gradient column from the shore is mainly responsible for the cost because if the thermal gradient column would be away from the shore then the cost of the piping system and expenses of transporting energy will also be increased. So with respect to cost, this factor is very important. The depth of the deep cold water affects the power consumed by the pump. If the cold water is available at the short depth then power required for the pump would be less because a major part of developed power is used to run the pump that’s why the efficiency of the plant is not so effective[9]. Thus this is also a considerable factor in the selection of location. Wave height, wind speed, and surface current also hold a position during the selection of the location. These three factors are directly affecting the structure of the plant so the intensity of these factors should be low for smooth operation [10]. Environmental impact and natural hazards also take a position in location selection procedure because if the availability of the flora and fauna would be high then installation procedure of plant may face difficulties. Natural hazards like a cyclone, Tsunami can damage the plant so consideration of environmental impact and natural hazards is important [11]. So on the basis of the above factor, a method is proposed which gives the optimal results and also gives the result with respect to factor that which factor is more important for the particular location.

II. OBJECTIVE

The present study tries to develop a method which will cognitively select an ideal location for installation of OTEC system which will ensure maximum utilization of energy resources. In this regard the main objectives of the study are:

I. Identification of the most significant parameters which has tangible impacts of the utilization efficiency of the system.

II. Determination of the rank of importance of the selected parameters based on their impact on utilization efficiency of the system

III. Determination of the relative ranking of the parameters to find the priority of the factors.

IV. Development of the Location Suitability Index for identification of the most suitable location among the many available options.

Overall the main aim of the investigation was to propose a new method for selection of an ideal location for OTEC systems.

III. BRIEF METHODOLOGY

The present investigation utilized statistical control chart in a new way to identify the ranking of the parameters based on their significance on the output. The control charts are used for identification of uncertainties by the determination of higher and lower limits and any output value which is out of the two limits are taken as uncertainty.

In the present investigation, the value of the index was taken as the system output and five instances of the factors were selected as samples and a corresponding set of index values were taken as the output. The five set of priority value was also selected and randomly changed to generate five set of different output value at every iteration. The iterations were continued until and unless the value of the outputs remains within the limits and is maximum compared to the other outputs. The corresponding priority values give the importance of the parameters which were used to find the rank of the parameters based on their contribution to the output value. The method was non-parametric but yields an unbiased representation of the selected factors.

To include parametric influence the EVAMIX-AHP [12-14] method was used to find the relative significance and final priority value of all the parameters. With these priority values, the index was developed as a segmented function of the product of priority parameters and their priority values in such a manner that the value of the index will be directly proportional to the suitability of the index.

The index value of the selected case study locations was calculated based on the average annual value of the parameters and based on the index value the most suitable location for installation of the OTEC system was identified.

IV. DETAILED METHODOLOGY

The new method which was developed for the present investigation to identify and distinguish locations suitable for installation of the OTEC systems comprises of five major steps:

1. Identification of the correlated factors with the help of literature, expert and stakeholders' survey

2. Application of control chart for ranking the parameters based on their contribution to the index value which represents the suitability of the locations

3. Application of the EVAMIX method for determination of the relative ranking considering parametric effects of the parameters.

4. Development of the index as a representative of the location suitability

5. Suitability analysis of the selected case study areas with the help of the index

The next section describes the way control chart is utilized for ranking the parameter based on their contribution to the output value.

4.1. Statistical control chart (X-bar)

The statistical control charts are utilized to identify uncertainty in the output of a system. In this aspect, the control charts estimated an upper and lower limit with the help of the mean and standard deviation (for X-bar method) and then the value of the output is monitored. If at any instant (both time and space) the value drifts away from the bounded domain of upper and lower limit is taken as uncertainty and relevant measures were implemented to enforce the output again into the domain of reliability. The control chart method was widely used in uncertainty analysis and for condition monitoring of a system [15-17].In the present investigation, the method was utilized to identify the non-parametric rank of importance for the parameters which is selected at the survey stage.

In the present investigation, the value of the index was taken as the output value of the system. The value of the parameters was collected from the selected five locations. All the values of the temporal parameters are monthly average and for spatial factors, values vary with the locations.

Five set of priority values were also selected and varied randomly within 0 to 1 for each of the parameters. Based on the five set of priority values five set of index values can also be estimated. All the random values were changed during the iterations and when the maximum value of the index can be found from the domain of reliability the corresponding priority values were utilized to rank the parameters as per their contribution to the output value. More the priority value more important will be the parameter. Although this is a non-parametric method but it gives an unbiased representation of the significance of each of the parameter in the maximization of the output value. Fig.1 Depicts the steps followed in the statistical control chart phase.

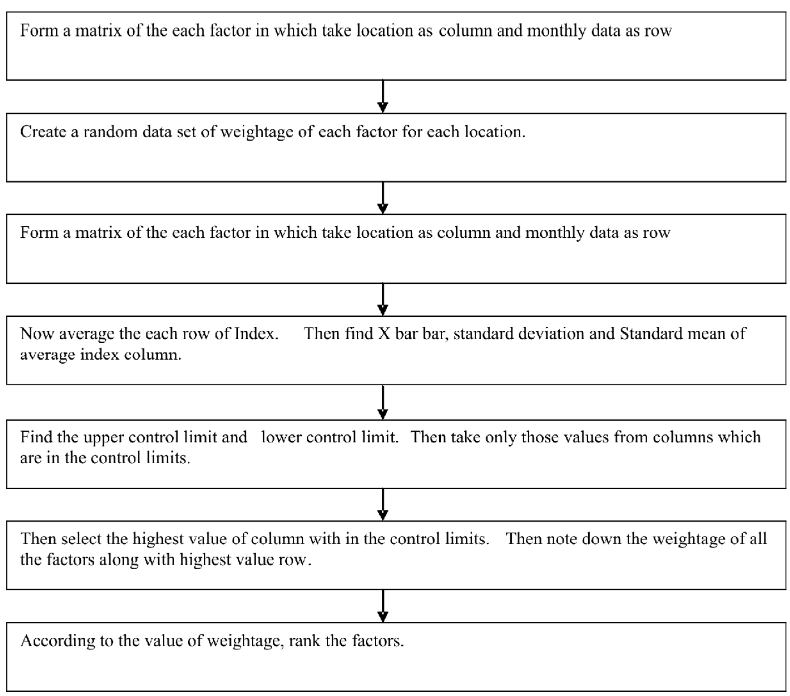

Figure 1: Steps for Statistical control charts (X bar)

4.2. Application of EVAMIX-AHP method

The EVAMIX method [12] was used to find the relative ranking of the parameter which considers the parametric influence of each of the parameters based on Cost, Efficiency, and Environmental impact. Fig. 2 depict the steps adopted to implement *Evamix-AHP Method*

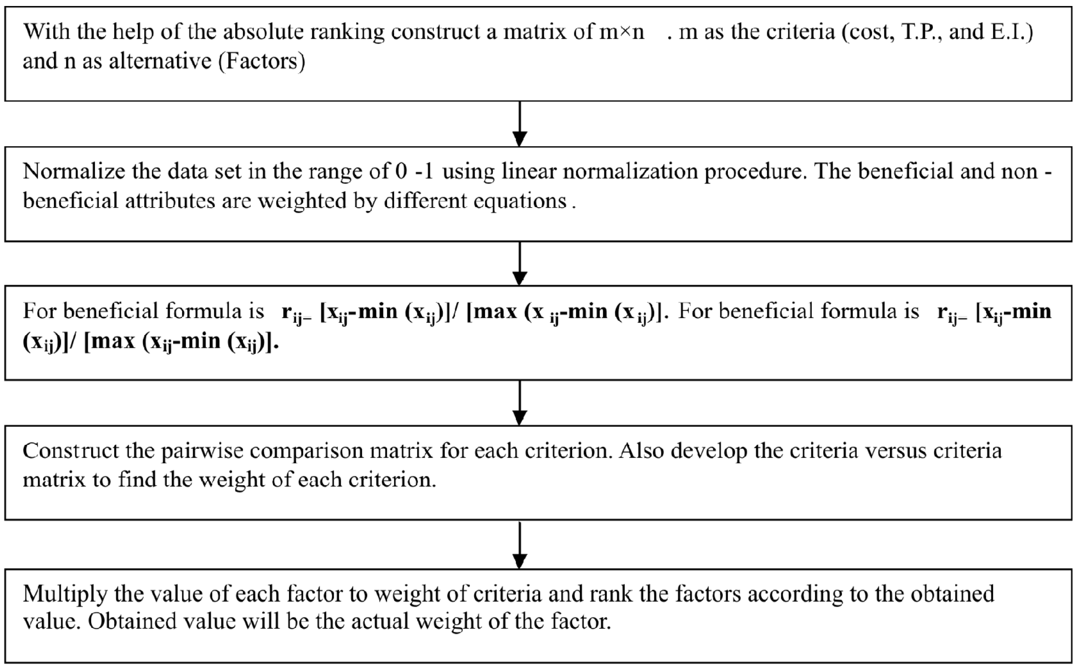

Figure 2: Steps for Evamix method

4.3. Development of the Index

The index gives the most suitable location on the basis of the index value. The index value for a location is the summation of multiplication of the normalized value of factor and their weight.More the value of the index more suitable will be the location for installation of OTEC systems.

$$\text{Index value} = f_1 w_1 + f_2 w_2 + \ldots\ldots\ldots\ldots f_n w_n$$

$$\text{I.V.} = \Sigma\, f_a \times w_a$$

4.4. Case Study

The Andaman and Nicobar, India region, shown in Fig.3 is selected for the analysis because it is surrounded by the warm sea surface water and other condition like bathymetry, environmental, socio-economic are also seems suitable for the OTEC plant. The area of the Andaman and Nicobar is 8,249 square km and the population is 380,500. Most of the electricity is generated by the diesel thermal power plant so there is a requirement of such type of renewable energy plant. So Andaman and Nicobar is a suitable region for the OTEC plant.

So after analyzing the bathymetry map of the above region five locations are selected for the suitability analysis. The five locations are-

1. Location 1- 13°22´30.00" N 93°22´ 30.00" E
2. Location 2- 13°22´30.00" N 92°22´ 30.00" E
3. Location 3- 11°52´30.00" N 93°22´ 30.00" E

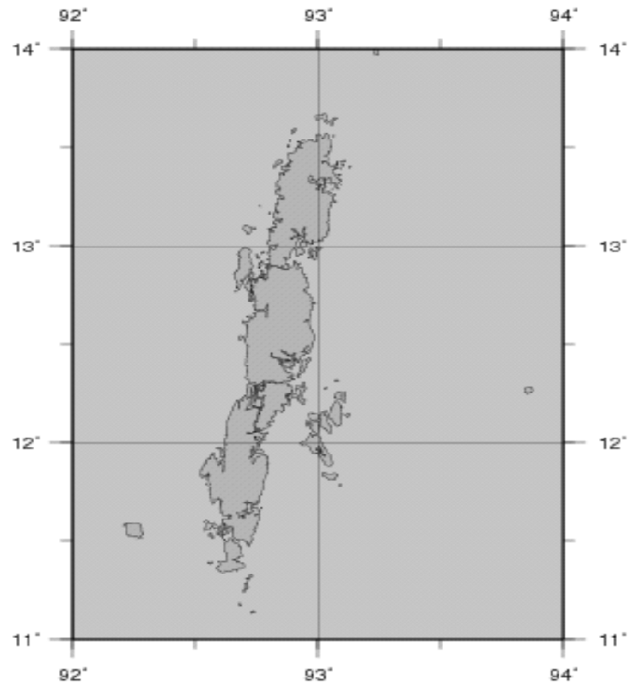

Figure 3: Map of Andaman and Nicobar and This figure is taken from the World Ocean Atlas 2009 (WOA09)

4. Location 4- 11°37´30.00" N 93°07´ 30.00" E
5. Location 5- 12°52´30.00" N 92°07´ 30.00" E

Following monthly data is collected for the above five locations.

Time Period 2005 to 2012.

I. F_1- Sea surface temperature (°C)

II. F_2- Cold water temperature (°C)

III. F_3- Depth of cold water layer from surface (meter)

IV. F_4- Distance of thermal gradient from shore (km)

V. F_5- Wave height (feet)

VI. F_6- Wind (knot)

VII. F_7- Surface current (knot)

For Sea surface temperature and cold water temperature monthly, climatological data is collected from the World Ocean Atlas 2009 (WOA09). Depth is determined by the Bathymetry charts. The distance of thermal gradient from the shore is calculated from Google earth. Wave height and wind speed data is collected from NOAA's WAVEWATCH III global wave model. Surface current data obtained from the data is found from the HYCOM .08 Model.

V. RESULT

The results are shown in the Fig.4 shows that the absolute ranking of each factor with respect to cost in which it is found that the factor 4 (Distance of thermal gradient from shore) has the highest value is means it is most significant parameter with respect to cost for the location selection. Fig.5 shows that with respect to technical performance factor 1 (surface temperature) is most significant and Fig.6 shows that with respect environmental impact factor 4(Distance of thermal gradient from shore) is most significant. Fig.7 shows the relative ranking of all factors on the basis of the value obtained from the Evamix method by which factor 1(Sea surface temperature) and factor 2 (cold water temperature) are found most significant.

After applying all the values in index it is found that Location one is the most suitable location which is shown in Fig. 8.

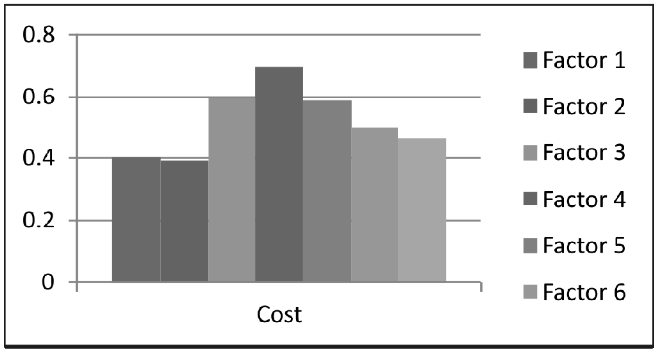

Figure 4: Weightage value of each factor for cost

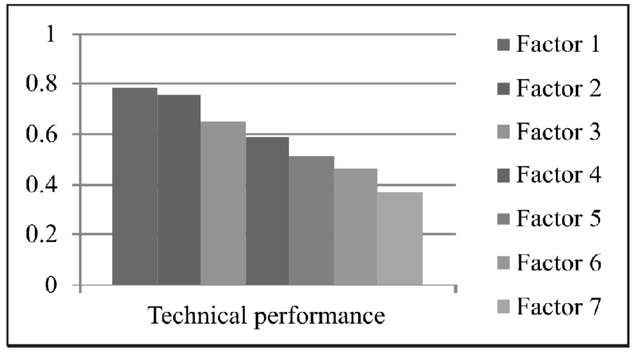

Figure 5: Weightage value of each factor for TP

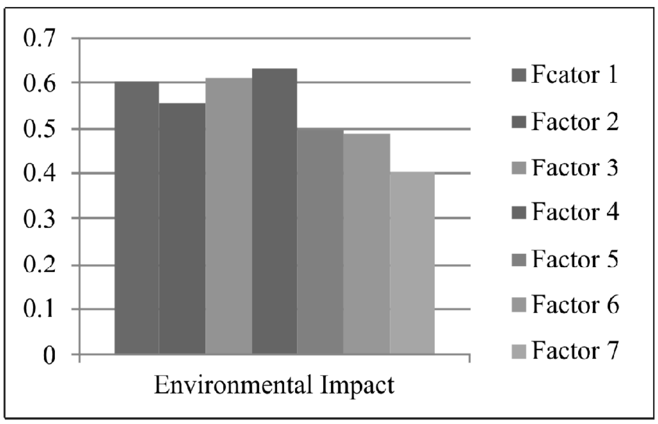

Figure 6: Weightage value of each factor for EI

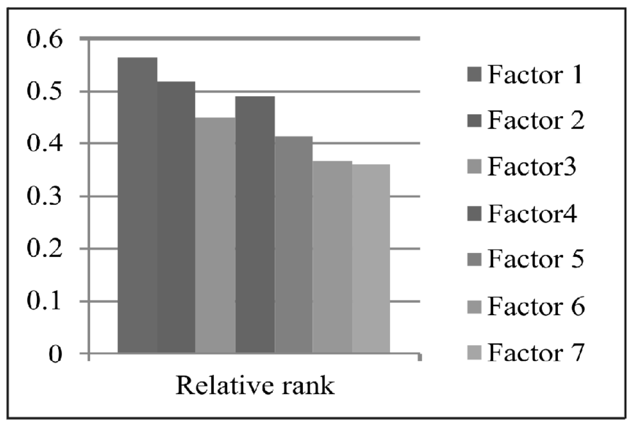

Figure 7: Weightage value obtained by Evamix method

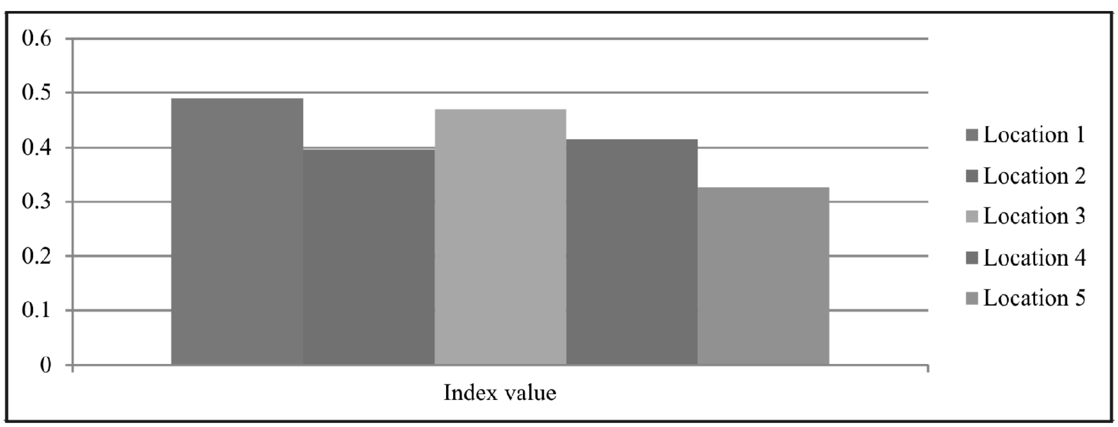

Figure 8: Value of index for each location

VI. CONCLUSION

The present study tries to propose a new method to identify a suitable location for installation of OTEC systems. The method utilized statistical control charts as a ranking method for arranging the parameters based on their contribution to the output value. The EVAMIX-AHP method was used to find the relative and parametric ranking of the parameters based on their conceptual significance on maximizing the output value. The output value is the index which is directly proportional to the suitability of the location for installation of OTEC system. Five locations were selected for application of the index and to find the location suitability of them based on the index values. According to the results most, significant parameters was found to be surface temperature and the most suitable location for the **OTEC installation was** location 1 because it has the temperature gradient of about 22.57875°C which is highest among all five so this location. The distance from the shore for this location is also less among all the selected study areas. The Wave height, Wind speed, and surface current of the location are also not very high which justifies the selection of the location as most ideal with respect to the installation of OTEC plant.

Although the index was able to find the location most suitable for the OTEC installation but this selection may vary with the change in the method applied for ranking the parameters. That is why when comparing the method used for ranking must be uniform so that reference level of comparison remains uniform.

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