Global Scientific JOURNALS
GSJ: Volume 10, Issue 6, June 2022, Online: ISSN 2320-9186
www.globalscientificjournal.com

Multi-Criteria Decision Making Under Uncertainty in Planning Operation of Energy Systems

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ABSTRACT
This research presents, evaluate and illustrate how multi-criteria decision making (MCDM) methods can be used to assist decision making under uncertainty in energy system operation. The Microsoft excel v2016 was used to analyze the Analytical hierarchical Process (AHP) and Technique of Order Preference Similarity to the Ideal Solution (TOPSIS) MCDM for simple case considering three (3) energy systems such as diesel engine, gas turbine and solar system and complex case considering five (5) energy systems such as diesel engine, gas turbine, solar system, hydro turbine and steam turbine. Results obtained using AHP MCDM in the simple case gave 0.087 (8.7%), which is acceptable as it is less than 0.1(10%) and showed that Gas turbine was ranked as the best followed by Solar energy system and then Diesel engine. Also using TOPSIS MCDM the scale was from 1-10, where 9 is given to Gas turbine as this system emits more CO2 to the environment and equally showed that the Gas turbine was ranked as the best followed by Solar energy system and then Diesel engine. Also, results obtained in the complex case showed that despite the two different method 0.082 (8.2%), is acceptable likewise as it is less than 0.1(10%) for AHP. For this case, Hydro turbine was ranked as the best followed by Gas turbine and the others. The results obtained for the two-case showed that the two methods are good, but it depends on the decision maker to choose which one to use.

Keywords: AHP, Energy systems, Multi-criteria decision making (MCDM), TOPSIS.

1. INTRODUCTION
Energy is essential to all human activities and needed for sustainable development. Energy systems are primarily designed to supply energy services to end-users (Bukshaisha, 2018). Energy systems are getting more complex compared to its early stages due to the increase in demand, large transmission distances, environmental effects and different energy sources, thus operation of energy system from the generations to transmission, distribution and to the end-user requires proper operations planning and management to balance supply and demand (Rad, 2011). The operation of energy has long been of interest to decision-makers, particularly when dealing with energy demand and the optimal allocation of resources. Most of the decisions to be made by energy sector decision makers are subject to a significant level of data uncertainty. The uncertain parameters in in the operation of energy system can be generally classified into technical, economic, environmental and social parameters (Kumara et al., 2017).

This study would explore sources of uncertainties in the future operating conditions that are present in planning energy systems and present MCDM method that can be used to find out an apt solution to the energy system design problems, assist decision making under uncertainty in energy operation and provide deeper insight into energy planning and how it can be used as a tool for implementing sustainable development using two different MCDM methods. In addition to illustrating the two methods, this study is intended to lead to a preliminary judgment about their usefulness as supplementary decision-making tools for eventual practical use in energy operation.

Soroudi and Amraeeb (2017) presented a paper on Decision making under uncertainty in energy systems. In the paper, a new standard classification of uncertainty modeling techniques for decision making process was proposed. The methods were introduced and compared along with demonstrating their strengths and weaknesses. The promising lines of future researches were explored in the shadow of a comprehensive overview of the past and present applications. The possibility of using the novel concept of Z-numbers was introduced for the first time.
Kumar et al. (2017) presented a review of multi criteria decision making (MCDM) towards sustainable renewable energy development The review summarizes the essential aspects of MCDM techniques, energy based MCDM models and outlines various performance indicators which can be utilized to address the core issues for achieving the goals of sustainability in developing nations especially at rural levels. And also, developed an insight into various MCDM techniques, progress made by considering renewable energy applications over MCDM methods and future prospects in the area, an extensive review in the sphere of sustainable energy was performed by utilizing MCDM technique.

The aim of this research is to evaluate how multi-criteria decision making (MCDM) methods can be used to assist decision making under uncertainty in energy system operations. To achieve this aim, the following objectives were implemented:

i. To evaluate the application of the AHP method in making decision under uncertainty in the operation of energy systems for simple case such as Diesel Engine, Gas Turbine, Solar.
ii. To evaluate the application of the TOPSIS method in making decision under uncertainty in the operation of energy systems for simple case such as Diesel Engine, Gas Turbine, Solar.
iii. To evaluate the application of the AHP method in making decision under uncertainty in the operation of energy systems for complex case such as Diesel Engine, Gas Turbine, Solar, Hydro and Steam Turbine.
iv. To evaluate the application of the TOPSIS method in making decision under uncertainty in the operation of energy systems for complex case such as Diesel Engine, Gas Turbine, Solar, Hydro and Steam Turbine.
v. To compare the two methods to ascertain the better.

2. MATERIALS AND METHODS

The data that was used for this study are sample cases such as in hydro, fossil fuel and Solar power generation facilities which are related with CO2 emissions (kg/MWH), Costs ($/MWh) and Land Use (k/m2TWh) and were obtained from the International Energy Agency (IEA) and Transmission Company of Nigeria (TCN). Also, Excel was used for the computation.
Approaches to problem structuring are presented in Rosenhead (1989) and Belton and Stewart (2002) support the different “approaches which should be seen as complementary ways of helping the decision-makers to think about the situation and to determine relevant values”. Figure 1 shows a general step-by-step process in decision making. The data will be analyzed using multi-criteria decision-making tools such as AHP and TOPSIS.

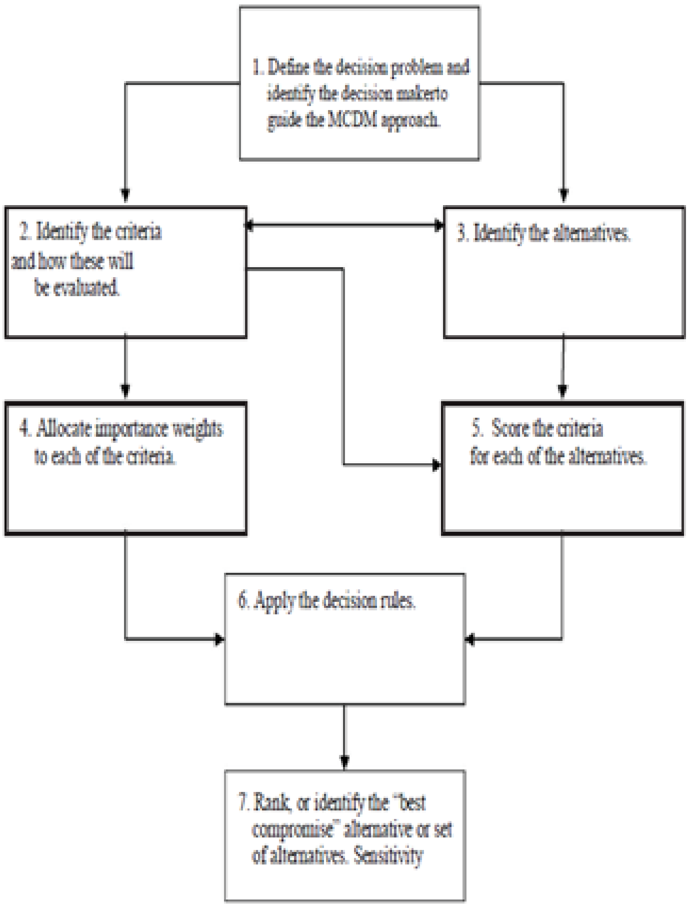

Fig. 1: Step by Step Process Involved in Decision Making Model

The following steps shown in Figure 1 are explained below:

Step 1: Define the Decision Problem and Identify the Decision Maker to Guide the MCDM Approach: This involves identifying the best energy system needed and tool needed for effective decision making.

Step 2: Identify the Criteria and how these will be Evaluated: CO2 emission, cost, land use, etc will be put into consideration

Step 3: Identify the Alternatives: Energy systems will be considered individually

Step 4: Allocate Importance Weights to each of the Criteria: Figures will be used to represent the degree of importance of the sets of criteria

Step 5: Score the Criteria for each of the Alternatives: inverse of the figures obtained.

Step 6: Apply the Decision Rules: This involves the consistency measure.

Step 7: Rank or Identify the "Best Compromise" Alternative or set of Alternatives: The final step in this process whereby we look at the best set of values closest to making an ideal decision.

A. The Analytical Hierarchy Process (AHP)

AHP is one of the multiple criteria decision-making methods that was originally developed by Saaty (1980). It provides measures of judgment consistency, derives priorities among criteria and alternatives, and simplifies preference ratings among decision criteria using pair wise comparisons. Figure 2 is a general graphical representation of an AHP problem and the steps is as follows:

i. Decompose the decision-making problem into hierarchy as shown in Figure 2.

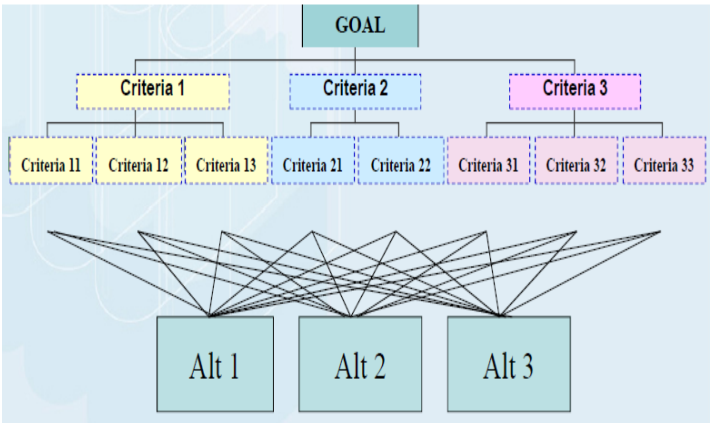

Fig. 2: Structure the Hierarchy (Saaty, 1980)

ii. Make pair wise comparisons and establish priorities among the elements in the hierarchy. The scale for the pairwise comparison is shown in Table 1.

Table 1: Scale for Pair Wise Comparison

SCALE	DEGREE OF PREFERENCE
1	Equal importance
3	Moderate importance of one factor over another
5	Strong or moderate importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Value for inverse comparison

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Results of the comparison (for each factors pair) were described in term of integer values from 1 (equal value) to 9 (extreme different) where higher number means the chosen factor is considered more important in greater degree than other factor being compared with.

iii. Synthesize judgments (to obtain the set of overall or weights for achieving your goal).

iv. Evaluate and check the consistency of judgments.

The consistency ratio is calculated using equation (2). The purpose for doing this is to make sure that the original preference ratings were consistent. There are three (3) steps to arrive at the consistency ratio:

i. Calculate the consistency measure.

ii. Calculate the consistency index (CI).

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (1)$$

i. Calculate the consistency ratio

$$CR = \frac{CI}{RI} \quad (2)$$

Where:

λ_{max} = maximum eigen value
RI = random index
n = size of comparison matrix

B. Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)

TOPSIS is a technique for order performance by similarity to ideal solution, developed by Hwang and Yoon (1981). TOPSIS is a classical MCDM used in many different areas such as supply chain management and logistics; design, engineering and manufacturing systems; business and marketing management; health, safety and environment management, and so forth (Behzadian *et al.*, 2012). It ranks alternatives based on the shortest distance from the positive ideal solution and the farthest from the negative ideal solution. Positive ideal solution is the most beneficial and lowest cost of alternatives and negative ideal solution is the lowest benefit and highest cost (Cheng *et al.*, 1999). The general TOPSIS process has the following steps (Joshi *et al.*, 2011):

Step 1: Defining decision matrices that can be expressed as follows:

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$$D = \begin{bmatrix} r_{11} & . & . & . & r_{1n} \\ . & . & & & . \\ . & & . & & . \\ . & & & . & . \\ r_{m1} & . & . & . & r_{mn} \end{bmatrix} \quad (3)$$

where i = 1, ..., m denotes the alternatives and j = 1, …, n refers to the attributes; r_{ij} represents the j^{th} attribute related to i^{th} alternative.

Step 2: Normalizing the value of decision matrices as follows

$$n_{ij} = \frac{r_{ij}}{\sqrt{\sum_{j=1}^{n} r_{ij}^2}} \quad (4)$$

where j =1, …, n; and i = 1…, m.

Step 3: Calculating the weighted normalized decision matrix by multiplying the normalized decision matrix by its associated weights:

$$W_{ij} = w_{ij} \times n_{ij} \quad (5)$$

where w_{ij} represents the weight of the j^{th} attribute related to i^{th} alternative

Step 4: Determining the positive ideal solution (A^+) and negative ideal solution (A^-)

$$A^+ = \{W_1^+, \dots W_n^+\} = \{(max\, W_{ij} / j \in J), (min\, W_{ij} / j \in J')\} \quad (6)$$

$$A^- = \{W_1^-, \dots W_n^-\} = \{(min\, W_{ij} / j \in J), (max\, W_{ij} / j \in J')\} \quad (7)$$

where J represents the positive factors and J′ is the negative factors. In this work, we used the maximum and minimum as the positive ideal and negative ideal, however, when the data is normalized in scale [0, 1] we also have the option of using 1 for the ideal and 0 for the negative ideal.

Step 5: Calculating the distance of all alternatives to the positive ideal solution (D_i^+) and the negative ideal (D_i^-) solution.

$$D_i^+ = \sqrt{\sum_{j=1}^{n} (W_{ij} - W_j^+)^2} \quad (8)$$

$$D_i^- = \sqrt{\sum_{j=1}^{n} (W_{ij} - W_j^-)^2} \quad (9)$$

Where $i = 1, \dots\dots\dots, m$

Step 6: Calculating the relative closeness of each alternative as follow:

$$C_i^* = \frac{D_i^-}{D_i^+ + D_i^-} \quad (10)$$

where C_i^* relies between 0 and 1 and the higher value corresponds to better performance.

3. RESULTS AND DISCUSSION

I. MCDM Using AHP

This section involves the evaluation of the decision making on operation of energy systems using AHP. Results were obtained by simulating three energy systems such as Diesel engine, Gas turbine and Solar systems for a simple case and also Diesel engine, Gas turbine, Solar, Hydro turbine and steam turbine for a complex case.

A. Simple Case Evaluation with AHP

The results for the simple case evaluation using AHP is presented in Table 1 below. It shows the figures which represents the pairwise comparison as given by the user using AHP Saaty's scale which was obtained by taking the inverse of the chosen number from the scale.

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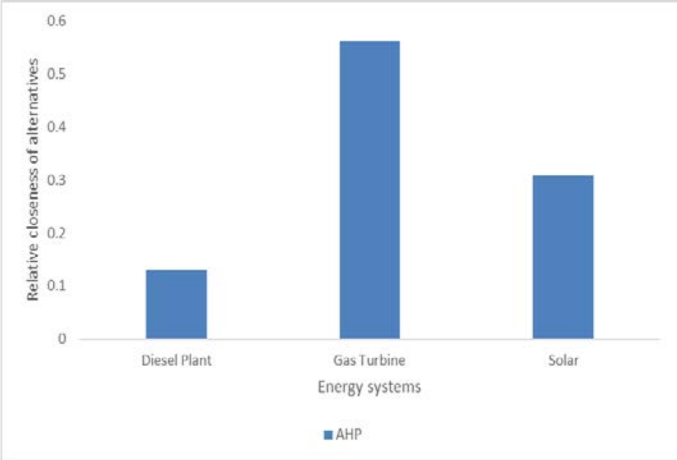

Fig. 3: AHP Application for the Simple Case

The AHP application for the simple case involving the three energy systems such as Diesel engine, Gas turbine and Solar is presented in Figure 1 above. Consistency ratio was calculated to ascertain the user's judgement. The result obtained was 0.087 (8.7%), which is acceptable as it is less than 0.1(10% standard). The product of the matrix gave the ranking for the operation of energy systems as shown in Appendix I, which indicate that the Gas turbine was the best option followed by Solar and then Diesel as shown in Figure 1.

B. Complex case with AHP

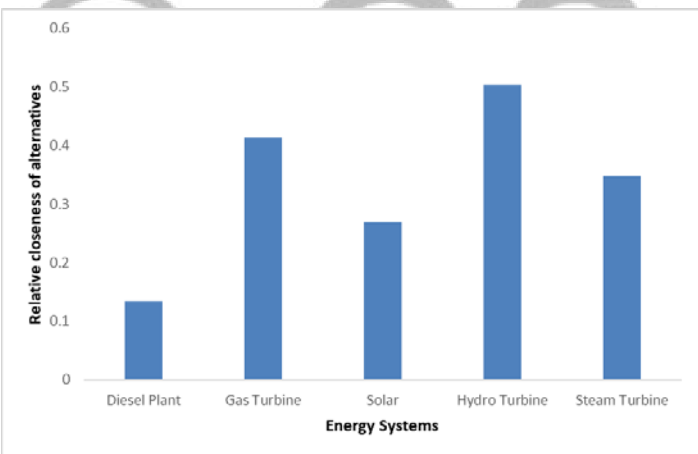

Fig. 2: Complex Case Evaluation using AHP

The AHP application for the complex case involving the five (5) energy systems such as Diesel engine, Gas turbine, Solar, Hydro and steam turbine is presented in Figure 2 Consistency ratio was calculated to ascertain the user's judgement. The result obtained was 0.082 (8.2%), which is acceptable as it is less than 0.1(10% standard). The product of the matrix gave the ranking for the operation of energy systems, which indicate that the Hydro turbine was the best option followed by Gas turbine, and then Steam turbine and then Solar and then Diesel engine as shown in Figure 2.

II. MCDM using TOPSIS

The TOPSIS multi-criteria decision-making method for the simple and complex cases is given as follows:

A. Simple Case of Evaluation Using TOPSIS

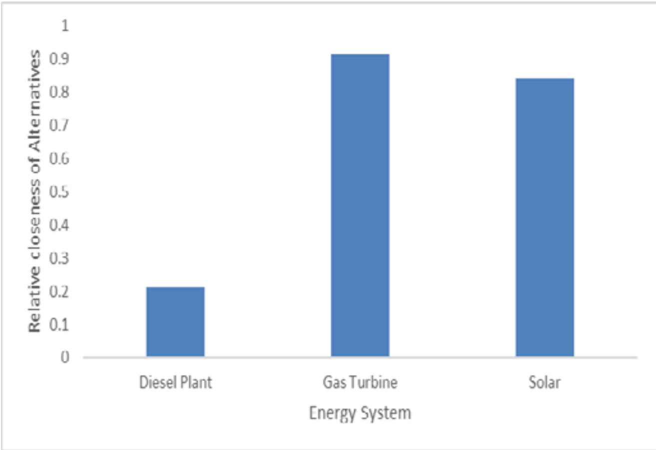

Fig. 3: Simple Case Evaluation using TOPSIS

Figure 3 shows the result for the TOPSIS method for the simple case, scores were given to the three energy generation systems by the user. The process of evaluating TOPSIS was carried out and in this case, the Gas turbine alternative was the best alternative among the three energy generation systems as the ideal solution was closer to the Gas turbine compared to the solar energy generation and Diesel engine as shown in Figure 4.3.

B. Complex Case of Evaluation Using TOPSIS

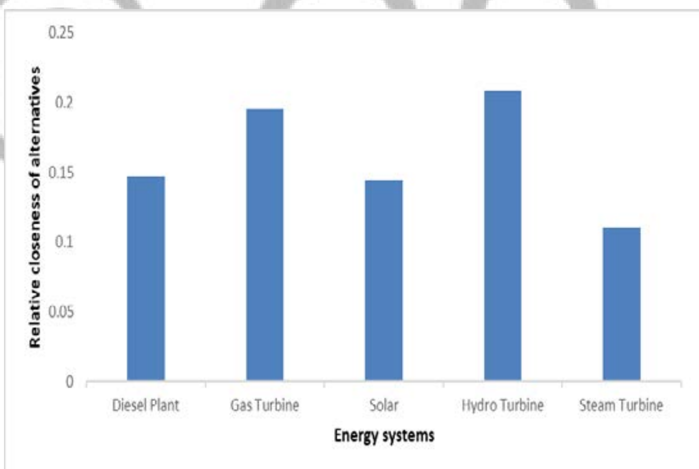

Fig. 4: Complex Case Evaluation Using TOPSIS

Figure 4 shows the result for the TOPSIS method, scores were given to the five energy generation systems by the user. The process of evaluating TOPSIS was carried out and in this complex case, the Hydro turbine alternative was the best alternative among the five (5) energy generation systems as the ideal solution was closer to Hydro turbine generation compared to the other four (4) as shown in Figure 4.

III. AHP and TOPSIS Comparison for the Simple and Complex Cases

The comparison for the AHP and TOPSIS multi-criteria decision-making methods for the simple and complex cases is given as follows:

A. AHP and TOPSIS Comparison for the Simple Case

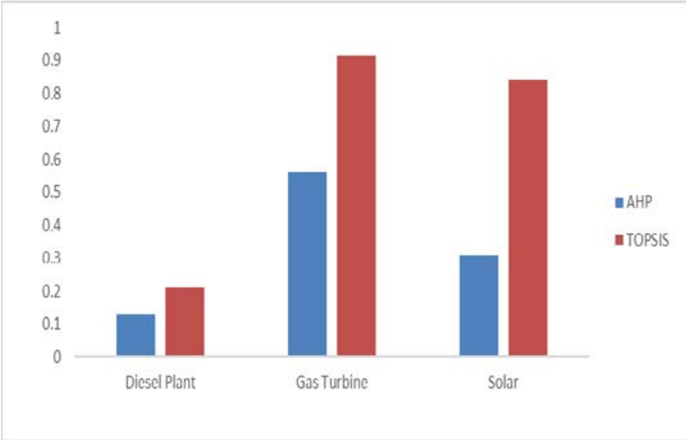

Fig. 5: AHP and TOPSIS Comparison for the Simple Case

Figure 5 shows the comparison of the two methods used in the evaluation of the best energy generation system for the simple case (considering three energy generation systems). The results showed that despite the two different method used, Gas turbine was the best option and then Solar and then Diesel.

B. AHP and TOPSIS Comparison for the Complex Case

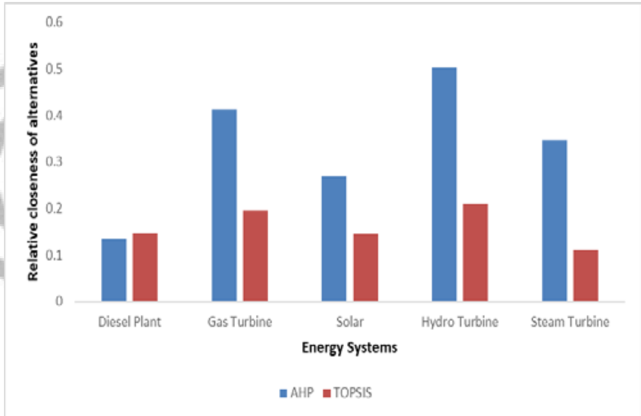

Fig. 6: AHP and TOPSIS Comparison for the Complex Case

Figure 6 shows the comparison of the two methods used in the evaluation of the best energy generation system for the complex case (considering five (5) energy generation systems). The results showed that despite the two different method used, Hydro turbine was ranked as the best followed by Gas turbine and the others.

4. CONCLUSIONS

This study involves two different methods (AHP and TOPSIS) in evaluating the best energy generation systems using Microsoft Excel 2016. It includes the comparison of the two methods to ascertain the best method to choose. The findings of the study are summarized as follows:

i. For a simple case using AHP, the consistency ratio was calculated to ascertain the user's judgement. The result obtained was 0.087 (8.7%), which is acceptable as it is less than 0.1(10%). The product of the matrix gave the ranking for the operation of energy systems, which indicates that the Solar was the best option followed by Diesel and then Gas Turbine hence the Objective for a simple case using AHP was achieved.

ii. For a simple case using TOPSIS, the Solar alternative was the best alternative among the three energy generation systems as the ideal solution was closer to the solar energy generation compared to the Diesel Engine and Gas Turbine hence the objective for a simple case using TOPSIS was achieved.

iii. For a complex case using AHP, the consistency ratio was calculated to ascertain the user's judgement. The result obtained was 0.082 (8.2%), which is acceptable as it is less than 0.1(10%). The product of the matrix gave the ranking for the operation of energy systems, which shows that the Hydro Turbine was the best option followed by Gas Turbine, Steam Turbine, Solar and Diesel Engine hence the objective was achieved for a complex case using AHP

iv. For a complex case using TOPSIS, the Hydro Turbine alternative was the best alternative among the five (5) energy generation systems as the ideal solution was closer to Hydro Turbine generation compared to the Gas Turbine, Steam Turbine, Solar and Diesel Engine hence the objective was achieved for a complex case using TOPSIS.

v. Comparing the two methods used in the evaluation of the best energy generation system for both the simple case (considering three energy generation systems) and complex case (considering five (5) energy generation systems). Both methods were found to have produced similarly ideal results and were found effective for usage hence the desired objective was achieved.

5. ACKNOWLEDGEMENTS

It is with great sense of gratitude I sincerely appreciate my main supervisor Engr. Dr. B. Nkoi for his consistent and continuous guidance all through the course of this work and also the other supervisors who steadfastly saw through the work and also contributed in appropriate areas.
I will also not fail to appreciate the head of department of Mechanical Engineering Prof J. I. Sodiki for his kind assistance all through the era of the course work and guidance through the seminar stages and also the Dean of the Faculty of Engineering Prof Ahiakwo for the role he played in ensuring timely seminar scheduling.
Also, I deeply appreciate Prof. Ujile, Dr. Isaac, Engr Mrs Nungah, Dr. Orike, Dr. Braide for the knowledge they impacted and also their various contributions in this work.
Also not forgetting to mention Oceaneering services Nig. Ltd, Federal Ministry of Power, Works and Housing for the materials they provided in aiding this work, Prof and Dr. Mrs. M. F. N. Abowei for their Guidance from the selection of this topic and ensuring its smooth progression and also Engr. Keribo Kurotamunoye for his research experience to make this work a success.
I would also like to appreciate my parents Chief and Mrs I.I. Afagha for their support and encouragement, not forgetting my lovely children Miss Epere Deborah Afagha and Master Kokakan Joshua Afagha who have continued to inspire me throughout the course of this work.

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