Analysis of Noise Emitted from Electrical Machines Using TOPSIS Technique

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Abstract—**This paper studies the noise emitted from different types of electrical machines having various rating. Noise related parameters like LAeq (Equivalent continuous A-weighted sound level), LAE (Sound exposure level), LAV (Average sound level) and TWA (Time weighted average level) are measured in a machine laboratory. TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), an important MCDM (Multi Criteria Decision Making) tool, is used to identify the best alternative. After analyzing the noise exposure parameters from the electrical machines by TOPSIS technique, it is found that the DC Generator, Wound Rotor Induction Motor, and DC Shunt Motor are emitting maximum noise and are set as the worst machine for controlling the noise, causing environmental pollution in full order.**

Index Terms—**Noise dosimeter, LAeq (equivalent continuous A-weighted sound level), LAE (Sound exposure level), LAV (Average sound level), TWA (time weighted average level), MCDM (multi criteria decision making), AHP (analytical hierarchy process), TOPSIS (technique for order preference by similarity to ideal solution).**

I. Introduction

In human environment, noise is the most physical contaminant agent. Unlike other contaminant agents, the effects of noise may be unnoticed instantaneously and its accumulation can lead to a dangerous harmful effects to human as well as machines. In common use, the word noise means any unwanted sound or signal. Noise dose is given in terms of a value relative to unity or 100% of an “acceptable” amount of noise. Different parameters related to noise dose [1]-[9] are LAeq (Equivalent continuous A-weighted sound level), LAV (Average sound level), LAE (Sound exposure level), TWA (Time weighted average) etc. To calculate the sound pressure level (Lp, in decibels) the formula is used: Lp = 20log (P/P0), Where P is the root mean square (rms) sound pressure and P0 is the reference sound pressure (0.00002 N-m-2).

LAeq (Equivalent continuous A-weighted sound level) is the constant sound level that in a given time period would convey the same sound energy as the actual time varying A-weighted sound level. LAE (Sound exposure level) is defined as that level which is lasting for one second has the same acoustic energy as a given noise event lasting for a period of time T. LAV (Average sound level) is defined as the total energy averaged over the total time. TWA (Time weighted average) is the noise that is weighted over a certain amount of time such as 8 hours for machine noise. Noise dose readings have been taken for different DC machines such as DC shunt motor, DC generator and AC machines like wound rotor induction motor, squirrel cage induction motor, single phase induction motor and synchronous motor. It is very important to measure noise dose, as well as, different parameters related to noise dose or sound pressure level. The machines which produce noise levels as high as 120 dBA or more violate the rules of National Fire Protection Association guidelines (1993 A.D.) [8]. The legislation describe on OSHA (1992 A.D.) is that, when a human is exposed to 90 dBA for 8 hrs, he has a 100 percent dose. So, 100 percent noise dose is always representing the criterion dose whatever may be the duration of measurement [9]. Noise dose parameters like LAeq, LAE, LAV and TWA are estimated and analyzed by TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) technique for each electrical machine and lastly more noise exposing electrical machines are identified.

II. Instrument Used

Brüel & Kjær made Noise Dosimeter Type 4444, a robust and lightweight instrument, is used for assessment and recording of noise levels associated with Electrical Machines. Specifications of the Noise Dosimeter conform to the following National and International Standards [8]-[9]: IEC61252, ANSI S1.25, IEC60651.1979 Type 2a, IEC60804.2000 Type 2a, ANSIS1.4.1983 Type S(1) ANSIS1.43.1997. The Supplied Microphone has the following specification:

Type: 1/4″ Microphone with Integral Cable Connector: 5-pin LEMO. The Measurement Control has the specification as stated herein:

Manual Control: using keys for Start/Pause/Continue and Stop. After the Start key is pressed, measurement starts and the clock reaches 00 seconds.

The Measuring Ranges are as follows: Linearity and Indicator Ranges at 4 kHz (IEC60804): 30.100: 43.100 dB (A and C), 50.120: 50.120 dB (A and C), and 70.140: 70.140 dB (A and C).

The Peak Range is as below:

C-weighted or Linear Peak over the top 40 dB of each measurement range: 30.100: 63.103 dB Peak,

50.120: 83.123 dB Peak, 70.140: 103.143 dB Peak.

The Frequency Weightings are supplied as:

RMS Detector: A or C, Peak Detector: C or L (Linear).

The Time Weightings can be taken as:

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Fast, Slow and Impulse (RMS detector).

The Exchange Rate for the instrument is: 3 dB (always), plus one additional exchange rate of 4, 5 or 6 dB.

Summary of Default Setups [8]-[9] are followings: Measurement Range (dB) for OSHA, MSHA, DOD, ACGIH, METER, SLM are 70 to 140 dB. Time weighting for OSHA, MSHA, DOD and ACGIH are slow and for METER and SLM are fast. Exchange Rate for OSHA, MSHA, and DOD are 3 and 5 and for ACGIH, METER, SLM are only 3. Threshold (dB) value for OSHA, MSHA, DOD, and ACGIH are 80 dB and this is not applicable for METER and SLM. Criterion Level (dB) for OSHA and MSHA is 90 dB, whereas 85 dB for DOD and ACGIH. This Criterion Level is not applicable for METER and SLM.

III. Methodology

TOPSIS method [4]-[7] in Multi-criteria Decision making tool, is a Technique for Order Preference by Similarity to Ideal Solution. The principle behind TOPSIS is that the chosen alternative should be as close to the ideal solution as possible and as far from the negative-ideal solution as possible. The ideal solution is formed as a composite of the best performance values exhibited (in the decision matrix) by any alternative for each attribute. The negative-ideal solution is the composite of the worst performance values. Proximity to each of these performance poles is measured in the Euclidean sense (e.g., square root of the sum of the squared distances along each axis in the "attribute space"), with optional weighting of each attribute [5]-[7].

TOPSIS is very simple and easy to implement. For that it is used when the user prefers a simpler weighting approach. On the other hand, the AHP (Analytical Hierarchy Process) approach provides a decision hierarchy and requires pair wise comparison among criteria. The user needs a more detailed knowledge about the criteria in the decision hierarchy to make informed decisions in using the AHP. TOPSIS method is firstly proposed by Hwang and Yoon [5]. According to this technique, the best alternative would be the one that is nearest to the positive ideal solution and farthest from the negative ideal solution. The positive ideal solution is a solution that maximizes the benefit criteria and minimizes the cost criteria, whereas the negative ideal solution maximizes the cost criteria and minimizes the benefit criteria. In other words, the positive ideal solution is composed of all best values attainable of criteria, whereas the negative ideal solution consists of all worst values attainable of criteria. In this study, TOPSIS method is used for determining the final ranking of the operating systems. TOPSIS is proposed for prioritizing the preference of supplier that is very suitable for solving the group decision making problem in an uncertain environment. Here, $S = \{S_1, S_2, \ldots, S_n\}$ is a discrete set of n possible noise parameters and $Q = \{Q_1, Q_2, \ldots, Q_\theta\}$ is a set of θ attributes of fatal effect. $W = \{W_1, W_2, \ldots, W_\theta\}$ is the vector of attribute weights so that they must sum to 1, otherwise it is normalized. Here, the attribute ratings of suppliers for the subjective attributes and the attribute weights are considered as linguistic variables.

Noise exposure related parameters like L_{Aeq} (Equivalent continuous A-weighted sound level), L_{AE} (Sound exposure level), L_{AV} (Average sound level) and TWA (Time weighted average level) are measured in a machine laboratory at Asansol Engineering College, Asansol, India, for a time period of two hours in each individual electrical machine having different ratings. Maximum and minimum noise exposures are identified using TOPSIS technique.

TABLE I: Specifications of the Machines Used

Srl. No.	Name of the Machine	Specifications
A1	DC Generator	1 kW, 220 V, 1500 rpm, 4.55 Amp
A2	Synchronous Motor	240 W,120 V,1500 rpm, 2 Amp
A3	Single Phase Induction Motor	1.5 H.P, 220/240V, 1-Phase, 1425 rpm, 13 Amp
A4	Squirrel Cage Induction Motor	5.5 kW, 415 V ± 10 %, 50 Hz, 3-Phase, 1440 rpm
A5	Wound Rotor Induction Motor	1 H.P, 415 V, 3-Phase, 1450 rpm, 1.6 Amp
A6	DC Shunt Motor	5 H.P, 220 V, 1500 rpm, 23 Amp

Step-1:

Arrange different noise parameters which are collected from different electrical machines according to their preferences on attribute weights.

Step-2:

Construct the decision matrix D as

$$D = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \end{array} \tag{1}$$

$A_1, A_2, \ldots, A_m$ are possible alternatives among which decision makers have to choose and $C_1, C_2, \ldots, C_n$ are criteria with which alternative performances are measured, xij is the rating of alternative A_i with respect to criterion C_j, Weights, $W = [W_1, W_2, \ldots, W_n]$; While W_j is the weight of criterion C_j.

Now prepare the pair wise comparison matrix [4]-[5].

Step-3:

Standardize the evaluation matrix in Eq. (2), the process is to transform different scales and units among various criteria into common measurable units to along comparisons across the criteria.

$$D^* = \begin{pmatrix} G_{11}^* & G_{12}^* & \cdots & G_{1\theta}^* \\ G_{21}^* & G_{22}^* & \cdots & G_{2\theta}^* \\ \vdots & \vdots & \ddots & \vdots \\ G_{n1}^* & G_{n2}^* & \cdots & G_{n\theta}^* \end{pmatrix} \tag{2}$$

Assume G_{iY} to be of the evaluation matrix D of alternative I under evaluation criterion k, then an element G_{iY} of the normalized evaluation matrix D* can be calculated by Equation (3).

$$G_{iY}^* = \frac{G_{i\gamma}}{\sqrt{\sum_{i=1}^{n}(G_{i\gamma})}} \tag{3}$$

Step-4:

Construct the weighted normalized decision matrix in

Equation (4). Considering the relative importance of each attribute, the weighted normalized evaluation matrix is calculated by multiplying the normalized evaluation matrix G_{iY}^* with its associated weight W_Y to obtain the result V_{iY}, So, $V_{iY} = G_{iY}^* X W_Y$.

The weighted normalized decision matrix $D^{*'}$ is:

$$D^{*'} = \begin{pmatrix} V_{11} & V_{12} & \cdots & V_{16} \\ V_{21} & V_{22} & \cdots & V_{2\theta} \\ \vdots & \vdots & \ddots & \vdots \\ V_{n1} & V_{n2} & \cdots & V_{n\theta} \end{pmatrix} \quad (4)$$

$$\text{Normalized Decision Matrix, } R_{ij} = \frac{Dij}{\sqrt{Dij2}} \quad (5)$$

Step-5:

Construct the Weighted Normalized Decision Matrix V which is found by the following relation (5).

$$V = R \ X \ RP \quad (6),$$

where R is the Normalized Decision Matrix and RP is the relative priority.

Step-6:

Calculate the separation of each alternative from the positive ideal solution and negative ideal solutions in equations (7) to (10) respectively. This means that S_i^+ is the distance in Euclidean sense of each alternative from the positive ideal solution and S_i^- is the distance from the negative ideal solution and those are defined as followings:

$$S_i^+ = \sqrt{\sum_{\gamma=1}^{\theta}\left(V_{i\gamma} - G_i^{max}\right)^2} \quad (7)$$

$$S_i^- = \sqrt{\sum_{\gamma=1}^{\theta}\left(V_{i\gamma} - G_i^{min}\right)^2} \quad (8)$$

where i = 1, 2,…, n.

In this V_{iy} is the particular component or parameter value of a machine, G_i^{max} is the maximum value for that parameter and G_i^{min} is the minimum value for that parameter in weighted normalized decision matrix.

Ideal Solution is determined from Step-5,

A^+ = Maximum weighted normalized value for a particular factor

$$\text{i.e, } A^+ = \{V_1^+, V_2^+, V_3^+, V_4^+, V_5^+, V_6^+\} \quad (9)$$

A^- = Minimum weighted normalized value for a particular factor

$$\text{i.e., } A^- = \{V_1^-, V_2^-, V_3^-, V_4^-, V_5^-, V_6^-\} \quad (10)$$

Step-7:

The relative closeness to the ideal solution is calculated in Equation (11).

$$C_i^* = \frac{S_i^-}{S_i^+ + S_i^-}; \quad (11),$$

where i= 1, 2,…….., n, and $0 \le C_i^* \le 1$.

IV. Results and Discussion

For analysis of the noise exposure from electrical machines, a Machine Laboratory is selected at Asansol Engineering College, Kanyapur, Asansol, West Bengal, India. Six different electrical machines having various ratings are operated for a period of two hours. All noise parameters by Noise Dosimeter instrument are measured. Different electrical machines are set as alternatives (A1 to A6) in row, and different noise parameters as factors (F1 to F6) in column are arranged as shown in TABLE II for implementing Step-1.

The decision matrix (D) as well as pair wise comparison matrix is constructed as shown in TABLE III for Step-2. Each component in D is found dividing respective mean value of the column by the respective mean value of row in TABLE II. Thus D is noted in TABLE III.

TABLE II: Different Noise Parameters Value

Factors Vs Alternatives	L_{Aeq} (F1) dB	L_{AE} (F2) dB	L_{AV} (F3) dB	TWA (F4) dB	RMS Max (F5) dB	RMS Min (F6) dB
DC Generator (A1)	86.6	115.9	86.4	61.0	90.9	79.5
Synchronous Motor (A2)	77.1	106.7	0	0	85.3	74.4
Single Phase Induction Motor (A3)	73.0	88.7	0	0	76.5	0
Squirrel Cage Induction Motor (A4)	78.3	107.7	70.6	45.4	90.1	70.4
Wound Rotor Induction Motor (A5)	84.5	113.9	84.5	59.3	87.0	82.5
DC Shunt Motor (A6)	82.2	111.9	81.8	56.9	86.0	77.9
SSQ (Sum of Square)	38800.95	69779.5	26280.81	12536.26	44474.16	29686.43
SSRT (Square Root of SSQ)	196.97	264.15	162.11	111.96	210.88	172.29
MEAN	80.28	107.46	53.88	37.1	85.96	64.11

TABLE III: Pair Wise Comparison Matrix

	F1	F2	F3	F4	F5	F6	RP (Relative Priority)
F1	1.00	1.33	0.67	0.46	1.07	0.79	0.1318
F2	0.74	1.00	0.50	0.34	0.79	0.59	0.0980
F3	1.49	1.99	1.00	0.68	1.59	1.18	0.1963
F4	2.16	2.89	1.45	1.00	2.31	1.72	0.2857
F5	0.93	1.25	0.62	0.43	1.00	0.74	0.1230
F6	1.25	1.67	0.84	0.57	1.34	1.00	0.1651

where RP (in a row value) = G. M. of a row/ ΣG.M.

G.M. means geometric mean, e.g.,

G.M. of F1 = $(1.00 \ X \ 1.33 \ X \ 0.67 \ X \ 0.46 \ X \ 1.07 \ X \ 0.79)^{1/6}$ = 0.8380, ΣG.M. = 6.3584, RP1 = 0.8380/6.3584 = 0.1318

Now the evaluation matrix is standardized or normalized, i.e., each component or parameter value of a machine is divided by the corresponding SSRT in TABLE II, and it is presented in TABLE IV for adopting Step-3.

TABLE IV: STANDARDIZED (NORMALIZED) EVALUATION MATRIX

	F1	F2	F3	F4	F5	F6
A1	0.4396	0.4387	0.5329	0.5448	0.4310	0.4614
A2	0.3914	0.4039	0	0	0.4044	0.4318
A3	0.3706	0.3357	0	0	0.3627	0
A4	0.3975	0.4077	0.4355	0.4055	0.4272	0.4086
A5	0.4289	0.4311	0.5212	0.5296	0.4125	0.4788
A6	0.4173	0.4236	0.5045	0.5082	0.4078	0.4521

The weighted normalized decision matrix is constructed using the relation $G_{iY}^* = \frac{G_{iY}}{\sqrt{\sum_{i=1}^{n}(G_{iY})}}$ as shown in TABLE V for Step-4 and Step-5. The weighted normalized evaluation matrix is computed by multiplying the normalized evaluation matrix G_{iY}^* with its associated weight W_Y to get the result $V_{iY} = G_{iY}^* \text{ X } W_Y$.

So, the weighted normalized decision matrix $D^{*'}$ is obtained as shown in TABLE V.

TABLE V: WEIGHTED NORMALIZED DECISION MATRIX

	F1	F2	F3	F4	F5	F6
Weights	0.1318	0.0980	0.1963	0.2857	0.1230	0.1651
Objecti-ve	Min	Min	Min	Min	Min	Min
A1	0.0579	0.0429	0.1046	0.1556	0.0530	0.0761
A2	0.0515	0.0396	0	0	0.0497	0.0713
A3	0.0488	0.0329	0	0	0.0446	0
A4	0.0524	0.0399	0.0855	0.1158	0.0525	0.0674
A5	0.0565	0.0422	0.1023	0.1513	0.0507	0.0790
A6	0.0550	0.0415	0.0990	0.1452	0.0501	0.0746
Max Value	0.0579	0.0429	0.1046	0.1556	0.0530	0.0790
Min Value	0.0488	0.0329	0	0	0.0446	0

The separation of each alternative from the positive ideal solution and negative ideal solution are calculated as shown in TABLE VI for Step-6.

TABLE VI: SEPARATION OF EACH ALTERNATIVE FROM POSITIVE AND NEGATIVE IDEAL SOLUTIONS

S_1^+	0.0029	S_1^-	0.2029
S_2^+	0.1878	S_2^-	0.0718
S_3^+	0.2041	S_3^-	0
S_4^+	0.0461	S_4^-	0.1593
S_5^+	0.0056	S_5^-	0.1994
S_6^+	0.0133	S_6^-	0.1912

The relative closeness to the ideal solution is computed form TABLE VI and it is shown in TABLE VII for Step-7. Closeness coefficients for different electrical machines are graphically plotted in Fig. 1.

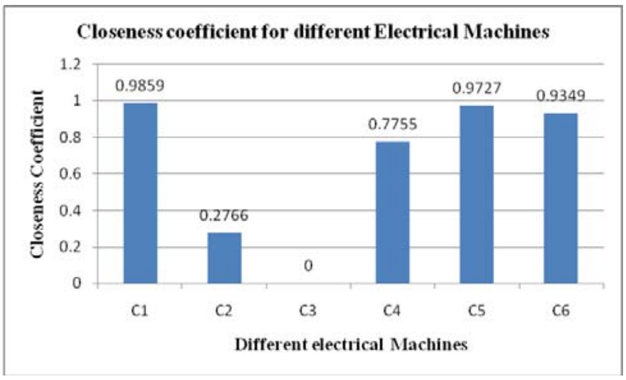

Fig. 1. Closeness coefficient for different electrical machines

TABLE VII: RELATIVE CLOSENESS TO THE IDEAL SOLUTION

C1	0.9859
C2	0.2766
C3	0
C4	0.7755
C5	0.9727
C6	0.9349

From the above TABLE VI and TABLE VII, it is evident that maximum value for closeness co-efficient is 0.9859 (C1) which is a DC Generator and minimum value for closeness co-efficient is 0 (C3) which is a Single Phase Induction Motor. The maximum sound exposure is found from C1, i.e., DC Generator whose rating is 1 kW, 220 V, 1500 rpm, 4.55 Amp, whereas minimum sound exposure is obtained from C3, i.e., Single Phase Induction Motor whose rating is 1.5 H.P (1.119 kW), 220/240 V, 1-Phase, 1425 rpm, 13 Amp. The power rating of other machines is not very much less as compared to DC Generator. From the power rating point of view, the noise exposure from Squirrel Cage Induction Motor which has greater power rating than that of DC Generator, must show more noise exposure, but practically more noise emits from DC Generator (C1), Wound Rotor Induction Motor (C5), and DC Shunt Motor (C6), because of those electrical machines (C1, C5 and C6) encounter some extra power losses in bearing and other associated parts. So, for controlling and minimizing noise exposure, regular preventive and predictive maintenance to the electrical machines are required. Most of the manufacturing industries in West Bengal, where much sound exposure are observed in rolling mills, press shop etc., maintenance work should be done on a regular basis. One can easily investigate by hearing the level of noise sound, that there is a fault appearing in the electrical machine. Further detailed study of fault locations in the electrical machines are carried out by analysis of the frequency of noise emanating sound and study of noise related parameters like Equivalent continuous A-weighted sound level (L_{Aeq}), Sound exposure level (L_{AE}) etc. from the respective electrical machine by different techniques, as done in this paper by using TOPSIS technique.

V. CONCLUSION

By carrying out one of the MCDM tools, known as TOPSIS, the ranking of the alternatives has been arranged and C1, i.e., DC Generator; C5, i.e., Wound Rotor Induction Motor; C6, i.e., DC Shunt Motor are found as highest value. So our preference is switched over to DC Generator (C1), Wound Rotor Induction Motor (C5), and DC Shunt Motor (C6) for controlling the noise exposure which is the main cause for producing environmental pollution. From the study it is evident that closeness coefficient of C3 position (Single Phase Induction Motor) is zero. The study is based on relatively few measurements on selective electrical machines and the analysis may be interpreted as representative for various electrical machines universally. The results show that relatively three electrical machines (C1, C5 and C6) out of six electrical machines emitted high maximum noise levels for respective time allotted during testing. It has been suggested that the noise exposure level

85 dB (A) maximum should be the guideline value for environmental noise-induced annoyance. The present study compares the effects of noises emitted from various electrical machines applied with the same equivalent noise levels. While doing the laboratory study on response to noise, the type of activity based annoyance by electrical machine noises are investigated, and also in case of performing, reading and listening. This noise related environmental pollution analysis using TOPSIS technique can be implemented for different mechanical machines also.

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