Analysis of Noise Emitted from Electrical Machines Using TOPSIS Technique

Pijush Kanti Bhattacharjee, *Member, IACSIT*, Tirtharaj Sen, Debamalya Banerjee, and Bijan Sarkar

**Abstract**—This paper studies the noise emitted from different types of electrical machines having various rating. Noise related parameters like L_{Aeq} (Equivalent continuous A-weighted sound level), L_{A} (Sound exposure level), L_{A} (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.

**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 L_{Aeq} (Equivalent continuous A-weighted sound level), L_{A} (Average sound level), L_{A} (Sound exposure 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).

**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, ANSI/IEC61893 Type 2
- ANSI/IEC61893 Type S
- 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).

Manuscript received on November 1, 2011; revised January 4, 2012.

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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 pairwise 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 = {S1, S2,……, Sn} is a discrete set of n possible noise parameters and Θ = {Q1, Q2,……, Qθ} is a set of θ attributes of fatal effect. W= [W1, W2,……, Wθ] 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_{An} (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>
<thead>
<tr>
<th>Srl. No.</th>
<th>Name of the Machine</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>DC Generator</td>
<td>1 kW, 220 V, 1500 rpm, 4.55 Amp</td>
</tr>
<tr>
<td>A2</td>
<td>Synchronous Motor</td>
<td>240 W,120 V,1500 rpm, 2 Amp</td>
</tr>
<tr>
<td>A3</td>
<td>Single Phase Induction Motor</td>
<td>1.5 HP, 220/240V, 1-Phase, 1425 rpm, 13 Amp</td>
</tr>
<tr>
<td>A4</td>
<td>Squirrel Cage Induction Motor</td>
<td>5.5 kW, 415 V ± 10 %, 50 Hz, 3-Phase, 1440 rpm</td>
</tr>
<tr>
<td>A5</td>
<td>Wound Rotor Induction Motor</td>
<td>1 HP, 415 V, 3-Phase, 1450 rpm, 1.6 Amp</td>
</tr>
<tr>
<td>A6</td>
<td>DC Shunt Motor</td>
<td>5 HP, 220 V, 1500 rpm, 23 Amp</td>
</tr>
</tbody>
</table>

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

\[
D = \begin{bmatrix}
C_1 & C_2 & \cdots & C_n \\
A_1 & x_{11}^* & x_{12}^* & \cdots & x_{1n}^* \\
A_2 & x_{21}^* & x_{22}^* & \cdots & x_{2n}^* \\
\vdots & \vdots & \vdots & \ddots & \vdots \\
A_n & x_{n1}^* & x_{n2}^* & \cdots & x_{nn}^*
\end{bmatrix}
\]

(1)

A1, A2,……, Am are possible alternatives among which decision makers have to choose and C1, C2,……, Cn are criteria with which alternative performances are measured, xij is the rating of alternative Ai with respect to criterion Cj.

Weights, W = [W1, W2,……, Wθ]; While Wj is the weight of criterion Cj.

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.

\[
D^* = \begin{bmatrix}
G_{11}^* & G_{12}^* & \cdots & G_{1m}^* \\
G_{21}^* & G_{22}^* & \cdots & G_{2m}^* \\
\vdots & \vdots & \ddots & \vdots \\
G_{m1}^* & G_{m2}^* & \cdots & G_{mm}^*
\end{bmatrix}
\]

(2)

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

\[
G_{ij}^* = \frac{g_{ij}}{\sqrt{\sum_{k=1}^{n}(g_{kj})}}
\]

(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, $V_{iY} = G_{iY}^* \times W_Y$.

The weighted normalized decision matrix $D^*$ is:

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

Normalized Decision Matrix, $R_{ij} = \frac{d_{ij}}{\sqrt{\sum_i d_{ij}^2}}$ (5)

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

$$V = R \times RP$$ (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:

$$S_i^+ = \sqrt{\sum_{j=1}^{n} (V_{ij} - G_{i}^{max})^2}$$ (7)

$$S_i^− = \sqrt{\sum_{j=1}^{n} (V_{ij} - G_{i}^{min})^2}$$ (8)

where $i = 1, 2, ..., n$.

In this $V_{ij}$ 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$^+=\text{Maximum weighted normalized value for a particular factor}$

i.e., $A^+ = \{V_{1}^+, V_2^+, V_3^+, V_4^+, V_5^+, V_6^+\}$ (9)

A$^−=\text{Minimum weighted normalized value for a particular factor}$

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

Step-7:
The relative closeness to the ideal solution is calculated in Equation (11).

$$C_i^+ = \frac{S_i^−}{S_i^+ + S_i^−}$$ (11),

where $i=1, 2, ..., n$, and $0 \leq C_i^+ \leq 1$.

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

<table>
<thead>
<tr>
<th>Factors</th>
<th>$L_{Aeq}$ (F1)</th>
<th>$L_{Aeq}$ (F2)</th>
<th>$L_{Aeq}$ (F3)</th>
<th>TWA (F4)</th>
<th>RMS Max (F5)</th>
<th>RMS Min (F6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC Generator (A1)</td>
<td>86.6</td>
<td>115.9</td>
<td>86.4</td>
<td>61.0</td>
<td>90.9</td>
<td>79.5</td>
</tr>
<tr>
<td>Synchronous Motor (A2)</td>
<td>77.1</td>
<td>106.7</td>
<td>0</td>
<td>0</td>
<td>85.3</td>
<td>74.4</td>
</tr>
<tr>
<td>Single Phase Induction Motor (A3)</td>
<td>73.0</td>
<td>88.7</td>
<td>0</td>
<td>0</td>
<td>76.5</td>
<td>0</td>
</tr>
<tr>
<td>Squirrel Cage Induction Motor (A4)</td>
<td>78.3</td>
<td>107.7</td>
<td>70.6</td>
<td>45.4</td>
<td>90.1</td>
<td>70.4</td>
</tr>
<tr>
<td>Wound Rotor Induction Motor (A5)</td>
<td>84.5</td>
<td>113.9</td>
<td>84.5</td>
<td>59.3</td>
<td>87.0</td>
<td>82.5</td>
</tr>
<tr>
<td>DC Shunt Motor (A6)</td>
<td>82.2</td>
<td>111.9</td>
<td>81.8</td>
<td>56.9</td>
<td>86.0</td>
<td>77.9</td>
</tr>
</tbody>
</table>

### TABLE III: PAIR WISE COMPARISON MATRIX

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

where $R P$ (in a row value) = $G$. M. of a row/ $\Sigma G$. M.

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

$G$. M. of F1 = $(1.00 \times 1.33 \times 0.67 \times 0.46 \times 1.07 \times 0.79)^{1/6} = 0.8380$, $\Sigma G$. M. = $6.3584$, $R P_1 = 0.8380/6.3584 = 0.1318$

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.
The weighted normalized decision matrix is constructed using the relation $G_i^* = \frac{g_i}{\sum_{i=1}^{n}g_i}$ as shown in TABLE V for Step-4 and Step-5. The weighted normalized evaluation matrix is computed by multiplying the normalized evaluation matrix $G_i^*$ with its associated weight $w_i$ to get the result $V_i^* = G_i^* \times W_i$.

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

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

<table>
<thead>
<tr>
<th>S_i</th>
<th>S_p</th>
<th>S_n</th>
</tr>
</thead>
<tbody>
<tr>
<td>S_1</td>
<td>0.0029</td>
<td>S_2</td>
</tr>
<tr>
<td>S_2</td>
<td>0.1878</td>
<td>S_3</td>
</tr>
<tr>
<td>S_3</td>
<td>0.2041</td>
<td>S_4</td>
</tr>
<tr>
<td>S_4</td>
<td>0.0461</td>
<td>S_5</td>
</tr>
<tr>
<td>S_5</td>
<td>0.0056</td>
<td>S_6</td>
</tr>
<tr>
<td>S_6</td>
<td>0.0133</td>
<td>S_7</td>
</tr>
</tbody>
</table>

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.

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), 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 ($L_{A_{eq}}$), Sound exposure level ($L_{AE}$) etc. from the respective electrical machine by different techniques, as done in this paper by using TOPSIS technique.
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.

REFERENCES

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