Efficient Artificial Lighting System For Surface Mine Haul Roads

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***Abstract*— Haul roads within the pit are one of the critical areas in surface mines where lighting installations are not permanent due to regular advancement of the working face. Due to this reason it is very difficult to maintain the lighting standards, as specified by various regulatory bodies. Lighting in mines presents special problems because of the dark surroundings and low surface reflectance. Hence, scientific design of artificial lighting is very important to achieve the minimum required lighting standards. Authors developed software, named SURLux, in MATLAB for design of illumination system, which incorporates all the design parameters. It also computes the total cost of the lighting system. In this paper a 1.0 km stretch of haul road is designed for four different types of sources namely, 150 and 250 W high pressure mercury vapor lamps (HPMV), and 150 and 250 W high pressure sodium vapor lamps (HPSV), at various pole heights (8, 10, 12, 14 and 16 m). From the results of the study it is observed that with 16 m height pole the total annual cost for 150 W HPSV is the minimum (Rs. 87,739/-). In most of the cases the cost is high with HPMV lamps. This is mainly because of their shorter life and relatively more number of poles. In general, lamp selection is made mainly based on efficacy and suitability to each situation. However, among the feasible alternatives for any project, the variant that offers the minimum total cost is finally selected.**

Keywords-Illumination,reflectance,haul road

I. INTRODUCTION

A surface mine which covers several square kilometers of land, where work is carried out round the clock, systematic artificial lighting is necessary for providing safe and efficient working environment. Haul roads within the pit are one of the critical areas where lighting installations are not permanent due to regular advancement of the working face (Bandhopadyay, 1989). Another major problem is dark surrounding and low surface reflectance. Due to this reason it is very difficult to maintain the lighting standards, specified by various regulatory bodies. In India Director General of Mines Safety (DGMS) guidelines suggests a minimum horizontal illuminance level of 0.5 lux in haul roads (CMR, 1957). But in reality uniformity ratio is also essential in design of illumination system for uniform distribution of light and to provide sufficient illuminance on visual task.

In mines design is based on overall uniformity ratio, which is ratio of minimum to the average illuminance level. Though Indian mining regulations do not mention about uniformity ratio, International Commission on Illumination (CIE), Austria stresses upon uniformity ratio as well. It is suggested that for uniform distribution of light, overall uniformity ratio should be at least 0.3 for haul roads (CIE, 1998). CIE also suggests for the average light level instead of minimum light level. As per Indian Bureau Standards, average illumination level to be maintained in any light traffic roadways is 4 lux (BIS, 1991). Hence scientific design of lighting is very important in mines so as to fulfill the minimum lighting standards specified by various regulatory bodies and to encounter adverse working condition.

II. PRINCIPLES OF HAUL ROAD LIGHTING

Six different types of light poles layouts are possible for haul roads such as single sided, double sided opposite, staggered, twin central, central catenary system and centrally suspended system (CIE 1999). Of these, single sided poles arrangement is the most prevalent one in mines as installation of poles and electrification process in this layout is simple.

A. Mounting Height

Luminaire mounting height depends on the lighting arrangement and effective road width. The effective width is the horizontal distance between luminaire and the far curb. To achieve good distribution of light across the roadway, mounting height, in general, is kept equal to the road width or around it (Bommel and Boer 1980).

B. Spacing

Luminaire or pole spacing for a given lighting arrangement and luminaire light distribution is dependent on the mounting height and the longitudinal uniformity planned for the installation. The greater the mounting height, the larger can be the spacing for a given longitudinal uniformity. Longitudinal uniformity is the ratio of minimum to maximum illuminance along a line parallel to the road axis through the observer's position. However, in practice, excellent illumination is considered to be the one when pole spacing is not more than 8 times the mounting height (Bommel and Boer 1980).

C. Overhang

Poles are generally installed somewhat off-set from the road edge (curb) to provide clearance to the vehicle. Luminaire is mounted on the ranging arm to adjust the distance between it and curb. Sometimes, projection of the luminaire lies inside the road from the curb, which is known as overhang. The main purpose of overhang is to provide better uniformity of light across the road.

D. Inclination

Inclining or tilting the luminaires up from the horizontal is done to increase light coverage across the road width at a given mounting height. But too much of tilting will diffuse the light and reduce its distribution along the longitudinal direction of the road. It is recommended that the angle of tilt with respect to the normal height of mounting be limited to an absolute maximum of 10°, a top limit of 5° being preferable (Bommel and Boer 1980). In general the angle varies from 10° to 15°.

III. DEVELOPMENT OF DESIGN MODEL

Two fundamental laws in lighting design are inverse square law and cosine law. According to this law, horizontal (E_h) illumination at point P is given by (1).

$$E_h = \frac{I_{(C,\gamma)}}{r^2} \times \cos\gamma \tag{1}$$

Where,

E_h = horizontal illuminance (in lux) at the point of measurement,

$I_{(C,\gamma)}$ = intensity (in candela) from the source to the point of measurement

γ = angle between the vertical and the line joining the source to the point of measurement, and

r = inclined distance from the source to the point of measurement.

In Fig. 1,

$$\cos\gamma = h / r \tag{2}$$

$$r = \sqrt{a^2 + b^2 + h^2} \tag{3}$$

Where,

h = vertical height of source from the measurement surface.

a = distance from the source to the point of measurement along γ – plane, and

b = distance from the source to the point of measurement along C-plane

From (2) and (3), horizontal illuminance at point P is given by,

$$E_h = \frac{I_{(C,\gamma)}}{h^2} \times \cos^3\gamma \tag{4}$$

Considering utilization factor (UF) and inverse maintenance factor (IMF), authors have incorporated the effect of tilt angle in the following way:

$$E_h = \frac{I_{(C,\gamma_m)} \times UF}{{r_m}^2 \times IMF} \times \cos^3\gamma_m \tag{5}$$

where,

γ_m = modified incident angle of light ray with the vertical, and

r_m = modified inclined distance between the source and the point of measurement.

Using (5), program has been developed in MATLAB for performing basic luminance and illuminance calculations. Because the MATLAB commands are similar to the expression of engineering steps in mathematics, writing computer solution in MATLAB is much quicker than using a high level language such as C or FORTRAN (Etter, 1997). Many MATLAB features and virtually all toolboxes are implemented in programmable “M-files” that gives the user access to the source code and algorithm.

IV. DEVELOPMENT OF COST MODEL

The cost of any lighting project is calculated under three major heads i.e. fixed annual costs, running costs and maintenance cost. The fixed annual cost consists of annual depreciation and annual interest on luminaires, poles and cables. Running cost is the sum of lamp cost per year, energy cost per year and labor cost for lamp replacement. Maintenance cost is the total sum of cleaning charges of lamps and luminaires per annum. The total annual cost (TAC) is given by

TAC = Fixed annual cost + Running cost + Maintenance cost. (6)

Using (6) a computer model has been developed in MATLAB. This model can be utilized for calculation of total annual cost of lighting system, which may involve lamps of different types and wattage. Henceforth, in this paper, the developed software package for surface mine haul road design would be called as ‘SURLux’.

V. SELECTION OF OPTIMUM DESIGN BASED ON COST OF LIGHTING SYSTEM

For the sake of comparison of various types of lighting systems, a stretch of 1.0 km long haul road was considered with 12 m width, which is quite common in surface mines. It is designed for four different types of luminaries namely, 125 and 250 W high pressure mercury vapor lamps (HPMV), and 150 and 250 W high pressure sodium vapor lamps (HPSV), at various pole heights (8, 10, 12, 14 and 16 m). Tilt angle of luminaire was kept constant at 10°, as it is giving best results at this angle (Bommel and Boer 1980).

Using developed design program SURLux, maximum pole spacing was determined, for a given pole height and luminaire distribution, in compliance with the required lighting standards (minimum illuminance level – 0.5; average illuminance level – 4.0 lux; overall uniformity ratio – 0.3). Fig. 2 shows typical output of design model for 250 W HPSV lamps at 12 m height poles. By optimizing the pole spacing, number of poles required for each type of sources to illuminate the entire length of road was calculated. While calculating the number of poles, fractional number has been rounded off to the nearest integer and it has been increased by one to have poles at the both ends of the road. The respective total annual costs were calculated with the help of developed cost program SURLux. Table-1 shows the details of the lighting installations and total costs per annum for different types of sources. In some of the cases it is not possible to satisfy all the three parameters, at the same time (represented by asterisks in Table-1). Table-2 shows typical output of cost model for design with 250 W HPSV lamps.

VI. OVERALL DISCUSSION

As observed from Table-1, total costs for the design with 150 W HPSV lamps at 16 m height is the lowest (Rs. 87,739/-), whereas the total cost is high with 125 W HPMV lamps at 14 m pole heights (Rs. 4,20,071/-). A close look for comparison of different sources reveals some interesting points.

In most of the cases cost is high with HPMV lamps compared to HPSV lamps. This is mainly because of their shorter life and relatively more number of poles compared to HPSV lamps. However uniformity ratio is high with these lamps. It is also found that HPSV lamps offers minimum cost at increased pole heights, whereas the cost increases with decrease in pole heights. Similar situation may arise with other types of sources, at different combination of design parameters. Hence one must take the decision for feasibility of different types of lighting systems based on total annual cost.

VII. CONCLUDING REMARKS

It has to be borne in mind that optimum design achieved by this study is valid only for the chosen illumination standards. In fact the design parameters i.e. spacing and number of poles will vary with the change in standards. In overall the study reveals that height of mounting is very important to achieve all the required lighting standards at the same time.

Lamp selection is made mainly based on efficacy and suitability to each situation. Because of long life and efficient penetration character in dusty and foggy environment high pressure sodium vapor lamps are giving very good performance in surface mine lighting. For small projects lighting can be designed based on optimum energy consumption. No doubt, energy efficient design has a tremendous impact on cost. But the final decision on which lighting system is to be installed should be based on total cost, which should include the initial cost of the installation as well as its operating and maintenance cost.

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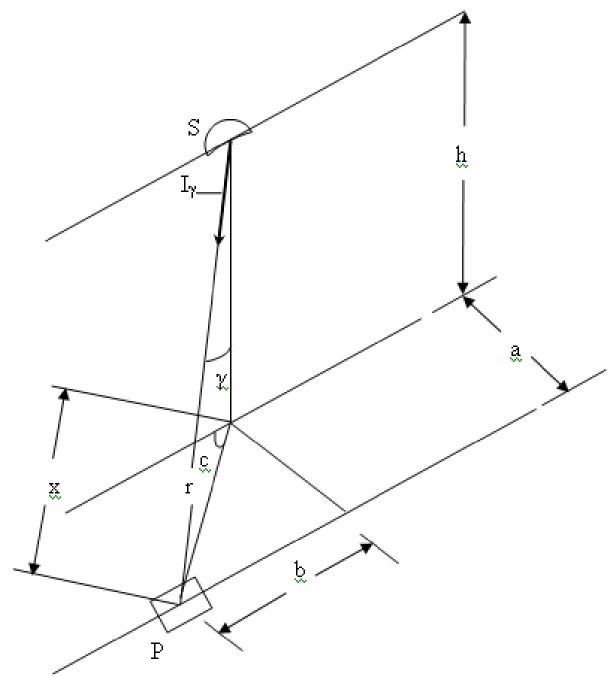

Figure 1. Illuminance on a horizontal plane

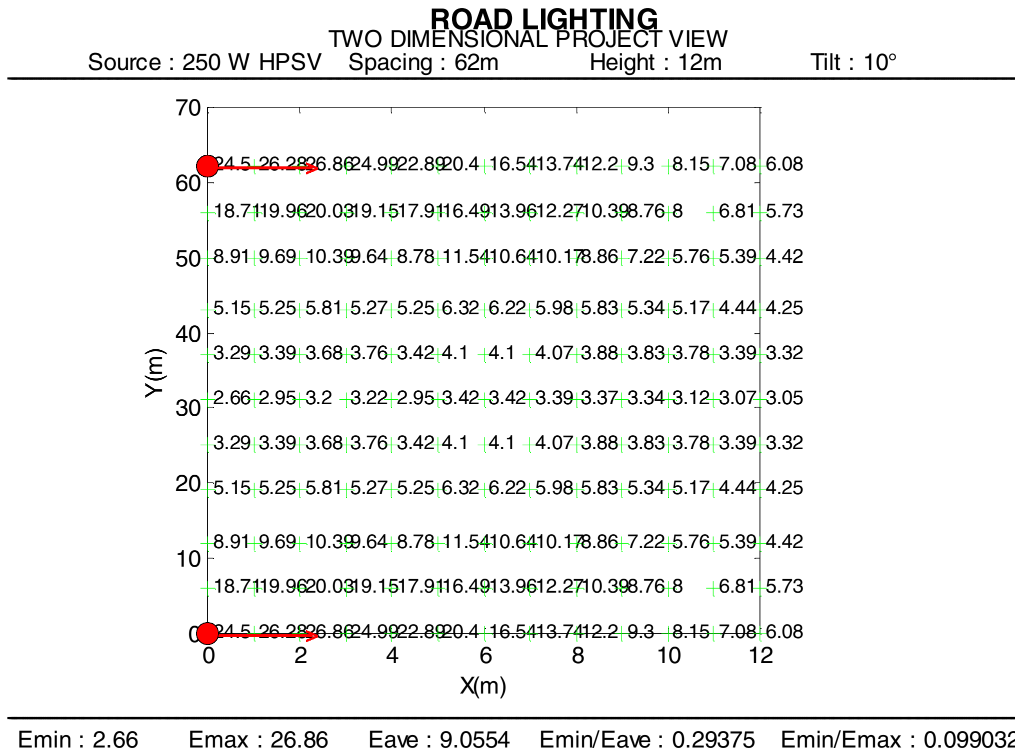

Figure 2. Spot horizontal illuminance levels for 250 W HPSV sources.

TABLE I. COMPARATIVE ANALYSIS OF OPTIMUM LIGHTING ARRANGEMENTS FOR VARIOUS TYPES OF SOURCES

Source	Height of pole (m)	Spacing (m)	Minimum illuminance level (lux)	Average illuminance level (lux)	U_o	No. of poles	Total cost per annum (Rs.)
125 W HPMV	8	34	1.27	3.98	0.31	30	1,48,404
	10	27	2.42	4.00	0.60	38	2,03,332
	12	20	3.2	4.08	0.78	51	2,85,000
	14	14	3.32	4.05	0.81	72	4,20,071
	16 *	-	-	-	-	-	-
250 W HPMV	8	25	2.91	9.79	0.29	41	3,43,845
	10	38	1.86	6.02	0.30	27	2,38,544
	12	47	1.36	4.49	0.30	22	2,00,343
	14	46	1.73	4.05	0.42	23	2,15,304
	16	40	2.28	4.06	0.56	26	2,49,719
150 W HPSV	8 *	-	-	-	-	-	-
	10 *	-	-	-	-	-	-
	12	25	4.71	15.98	0.29	41	2,73,247
	14	58	2.57	7.97	0.32	18	1,25,891
	16	89	1.45	4.93	0.29	12	**87,739**
250 W HPSV	8	34	5.69	18.95	0.30	30	2,56,364
	10	55	3.25	11.20	0.29	19	1,71,170
	12	62	2.66	9.05	0.29	17	1,57,683
	14	70	2.27	7.35	0.30	15	1,43,283
	16	80	1.76	5.90	0.29	14	1,37,450

*design parameters not satisfying minimum lighting standards (Note: 1 US $= approx. 45.00 INR Rs)

TABLE II. TABLE-2: COST CALCULATION FOR 250 W HPSV LAMPS AT 12 M HEIGHT POLES

COST CALCULATION
Fixed costs : Rs.46162
Lamp costs : Rs.3078
Energy costs : Rs.107639
Labour costs for lamp replacement : Rs.124
Maintenance cost : Rs.680
TOTAL ANNUAL COST : Rs.157683