International Journal of Current Advanced Research
ISSN: O: 2319-6475, ISSN: P: 2319 – 6505, Impact Factor: SJIF: 5.995
Available Online at www.journalijcar.org
Volume 6; Issue 5; May 2017; Page No. 3783-3786
DOI: http://dx.doi.org/10.24327/ijcar.2017.3786.0367

Case Study

APPLICATION OF LED IN SURFACE MINES – A CASE STUDY

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ARTICLE INFO

Article History:

Received 24th February, 2017
Received in revised form 12th March, 2017
Accepted 8th April, 2017
Published online 28th May, 2017

Key words:

Illumination, Lux, Light source, LED

ABSTRACT

In surface mines where natural light is not available, especially during night hours, artificial light is provided for better seeing, which facilitates increased production, reduces worker's fatigue, protects their health, eyes and nervous system, and reduces accidents. The important aspect of lighting design is to provide sufficient illuminance on visual tasks. Scientific design of artificial lighting is very important to fulfill the lighting standards as prescribed by various regulatory bodies. The factors like type of luminaire, mounting height, pole interval, aiming angle etc., govern the design of lighting installation. As a case study, an illumination survey was carried out in a limestone mine and its existing lighting system is redesigned with different lighting sources, with the help of developed design model. This study demonstrated that by adopting the optimal design parameters in mine illumination, the minimum required lighting standards could be fulfilled and the total annual cost would come down to approximately 47%.

INTRODUCTION

A surface mine which consists of several square kilometers of land and where mining operations are carried out round the clock, systematic artificial lighting is necessary for providing safe and efficient working environment. In view of huge investment involved in mining projects, which involve powerful, large and heavy mobile equipment's, good working condition during night hours for increased productivity is a necessary (Anon, 1961; Anon, 1984; Mayton *et al*., 1991)· One major problem of lighting in surface mines is continuous changing of work place including haul roads within pit limits (Bandhopadhyay *et al*., 1989; Bandhopadhyay *et al*., 1991). Because of this, it is almost impossible to provide any kind of long term permanent structure for illumination. The shifting or erection of poles at regular intervals becomes necessary so as to ensure required light level as per the specified standards recommended by the Directorate General of Mines Safety (DGMS) for minimum illuminance level for various parts of mine.

In mines, where scientific design methodology for illumination is not practiced, light level at patches may be far below the standards.

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To achieve the minimum illumination standards and for economics of lighting system, illumination system should be designed considering various parameters, such as pole height, spacing between poles, tilt angle of luminaire etc. There are two methods of designing lighting system: lumen method and point-by-point method. Between these two methods point-by-point method is an accurate method of designing lighting system, in which illuminance level is computed at any point on the work place (Bommel *et al*., 1980).

In India, the mine lighting standard is based on the illuminace level i.e. light falling on the surface. The important aspect of lighting design is to provide sufficient illuminance on visual tasks. The illuminance level, distribution of light (i.e. uniformity) and glare are the three important design parameters, which influence the visibility during night times. However, glare is not a major problem in surface mines, as it can be easily avoided by mounting the luminaries high enough to be out of the vision field. Further, glare can also be reduced through proper angle of orientation of the luminaire.

Importance of Lighting Design

In many projects lighting is often the last item to be considered while estimating costing. Because of this low budgetary provision, the lighting installation may result in bad working environment, which may decrease human efficiency and increase accidental rate, thus affecting the expected performance of that project. It is therefore essential to design an energy efficient and cost effective lighting system in the early phase of the project for better working environment. This is possible with proper selection of design parameters. The light design parameters are decided based on the minimum illumination standards, which can be obtained from various combinations of design features of the illumination system. But in each case the energy consumption would be different and is the single highest cost component of any illumination system in the long run (Bright *et al*., 1949). Optimization of energy consumption in the illumination design would therefore reduce the overall lighting cost. But sometimes energy consumption by two lighting systems may be the same, in spite of its varied design parameters. In such cases, selection of optimum lighting design parameters is taken based on the total annual cost of entire lighting project. It comprises of fixed annual cost, running cost which includes maintenance cost. Among the said cost components, fixed annual cost mainly depends on the type of luminaire and the height of mounting (Bright *et al*., 1949).

Development of Design and Cost Model

Advances in the lighting technology have shown that there is tremendous scope for energy conservation in lighting system (Kurian *et al*., 2002). Consequently, cost effective lighting installations have become synonymous with energy efficient lighting systems (Bright *et al*., 1949). Hence, a scientific approach in the illumination design would contribute to efficient lighting without much addition to the total mining project cost (Karmakar *et al*., 2002; Karmakar *et al*., 2004).

While calculating illuminance, one may wish to know the illuminance at a specific point or may be interested in the average uniform horizontal illuminance across the work plane. Based on this principle, there are two methods of design techniques: lumen method and point-by-point method. The lumen method applies only to regular arrays of luminaires (Durrant *et al*., 1977; Ronald *et al*., 1991). For other arrangements it is necessary to calculate the effect of individual luminaires at particular points to get the net illuminance. In these situations the point-by-point approach is adopted.

Based on two basic laws of lighting i.e. inverse square law and cosine law a general equation was developed, as given in Equation 1, for design of lighting system based on point by point by method. Using this equation for any type of lighting system the design parameters can be optimized so as to fulfill the minimum lighting standards as prescribed by the various regulatory bodies. Further, a set of equations were also formulated for calculating the annual cost of entire lighting project. The total annual cost is the sum of fixed annual cost, annual running cost and annual maintenance cost.

$$E_h = \sum \frac{I(c_m, \gamma_m) \times UF}{r_m^2 \times IMF} \times \cos \gamma_m \qquad (1)$$

where,
E = horizontal illumination level, in lux
I = luminance intensity, in lumen
C = horizontal angle between the line joining the point of measurement and the pole
base with the kerb line of the road, in degree
γ = vertical angle between the vertical and the line joining the source to the point of
measurement, in degree
r = inclined distance (in meters) from the source to the point of measurement, m.
UF = utilization factor, and
IMF = inverse maintenance factor

Case Study

As a case study a limestone mine is considered, in which 2x40W FTL lamps were used for illuminating haul roads. The heights of poles were 8m, placed 2m beyond the kerb of the roadway. The lamps were mounted on light arms of 2m length having 30° tilt angle. The width of the roadway was 12m. The spacing between the poles was ranging from 19m to 21m. The measured horizontal illuminance levels along this roadway show that in some of the patches the illuminanance level is below 0.5lux (minimum required illuminance level as per DGMS). It may be due to large spacing between poles and improper orientation of lamps, in some of the locations. Also, because of this, in many stretches of roadway the uniformity ratio is below 0.3 (minimum uniformity ratio required as per CIE and BIS standards). For redesign of lighting system a stretch of haul road of 860m length is selected. Figure 1 shows the existing lighting system along the length of roadway.

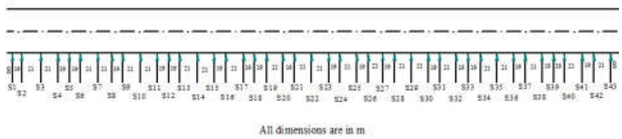

Fig 1 Existing lighting system with 2x40W FTL lamps

Table 1 Input parameters for the programme

WATTAGE OF LAMP	80
SALVAGE VALUE OF LUMINARIES IN Rs	0
RATE OF INTEREST IN %	10
LIFE OF LUMINARE IN YEARS	4.5000
INITIAL COST OF LUMINARIES IN Rs	79550
NUMBER OF LUMINARE	43
PRICE OF EACH LUMINARE IN Rs	1850
SALVAGE VALUE OF POLE IN RS	0
LIFE OF POLE IN YEARS	60
INITIAL COST OF POLES	292400
UNIT POLE COST IN Rs	6000
UNIT POLE INSTALLATION COST IN Rs	500
UNIT POLE FITTINGS COST IN Rs	150
UNIT POLE FITTINGS INSTALLATION COST IN RS	150
TOTAL NUMBER OF POLES	43
SALVAGE VALUE OF CABLE IN Rs	860
LIFE OF CABLE IN YEARS	40
INITIAL CABLING COST IN Rs	3.7201e+04
CABLE COST IN RUPESS/Km	20000
TOTAL LENGTH OF CABLE IN Km	0.8600
CABLE LAYING COST IN Rs/Km	20000
UNIT PRICE OF LAMP IN RS	925
NUMBER OF LAMPS	2
ENTER THE NUMBER OF LAMPS IN A PARTICULAR TYPE	43
AVERAGE LAMP LIFE IN HOURS OF A PARTICULAR TYPE	20000
BURNING HOURS PER YEAR OF THE SWITCHING MODE	4380
KILLOWATT-HOUR PRICE IN Rs	7.5000
TOTAL WATTS PER LUMINAIRE OF A PARTICULAR TYPE	80
BALLAST LOSS /LUMINARIES IN WATTS	12
MAINTANANCE COST PER LUMINAIRE IN Rs	50
ENTER THE LABOUR COST PER LAMP REPLACEMENT	12
NUBER OF CLEANINGS PER ANNUM	4

There were total 43 poles of 8m height. Using developed cost model total annual cost for the existing lighting system is computed. Table 1 gives the input parameters for the programme. Table 2 represents the output of the computer programme for the respective lighting system shown in Figure 1. The total annual cost for the existing lighting system is □ 59,574/-.

NUBER OF CLEANINGS PER ANNUM	4
ANNUAL DEPRICIATION ON LUMINARIES	1.4854e+04
ANNUAL INTEREST ON LUMINARIES	7955
ANNUAL DEPRICIATION ON POLES	96.3485
ANNUAL INTERESTS ON POLES	29240
ANNUAL DEPRICIATION ON CABLE	82.1091
ANNUAL INTERESTS ON CABLE	3.7201e+03
LAMP REPLACEMENT COST PER YEAR	1.7421e+04
ENERGY COST PER YEAR	1.2995e+05
ANNUAL MAINTANACE COST PER YEAR	8600
ANNUAL RUNNING COST PER YEAR	1.4760e+05
FIXED ANNUAL COST	5.5947e+04
TOTAL ANNUAL COST	2.1215e+05

Table 2 Output of the cost programme

Redesign of Existing Lighting System

The existing lighting system (i.e. with 2x40W FTL) is redesigned by adopting optimum lighting design parameters and by doing this the number of poles increased to 48. Figure 2 shows the proposed lighting system with 2x40W FTL lamps mounted at 8 m height poles. Similarly, the lighting system is also designed for another five types of light sources, such as 100W HPSV, 70W HPSV, 80W HPMV, 70W MH and 24W LED. For redesign of lighting system, the tilt angle is taken as 14° with 0m light arm length (i.e. source is directly mounted on the pole). The pole height and their interval are selected based on the results as obtained from the design programme.

In mines, generally lamps were burning from 6 pm to 6 am i.e. for 12hr. But some of the mines are operated only up to 10 pm. By keeping this in mind, the design is also made for LED source with micro controller based photosensor, which is placed on the body of the lamp.

When a natural day light reduces to an illuminance level of 60lux in the evening, the LED light automatically turn-on at rated voltage and it continues to glow at this voltage up to 12 mid night. From 12 midnight onwards till 6 am the LED source consumes only 50% of the rated voltage and the lux levels will be 50% of the rated lux. The LED light source will turn-off when the natural day light increases to a level of 68-70lux in early morning hours. Table 3 and Table 4 gives the details of lighting parameters and total annual cost, respectively for all the redesigned lighting systems. However, for easy reference, design parameters and annual cost of existing lighting system is also indicated in these tables.

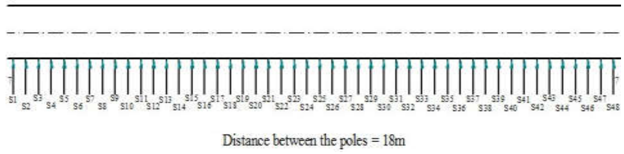

Fig 2 Proposed lighting system with 2x40W FTL lamps

RESULTS AND DISCUSSION

The total annual cost of the different lighting systems is given in the Table 4. Using the data of this table, a bar chart is drawn (which is shown in Figure 3), by plotting type of sources along X-axis and total annual cost along Y-axis. As shown in Figure 3, when the lighting system is redesigned with existing source, by adopting optimum design parameters (so as to fulfil the minimum lighting standards), there is an increase of □ 24,293/- (11.45% increase) in total annual cost. But when the system is redesigned with 70W HPSV and 24W LED sources, the annual cost will be below the redesigned system with 2x40W FTL sources. Among six types of sources the annual cost is the minimum for LED sources (i.e. □ 1,22,591/-). There is a reduction of 48.15% in annual cost when compared to redesigned system with existing light source. By incorporating micro controller based photosensor in LED sources, the annual cost is further reduced to □ 1,12,539/-. This is mainly because of saving of □ 10,052 in annual running cost.

Table 3 Design parameters of existing and proposed illumination systems

Sl. NO	Illumin-ation System	Type of Source	Mount-ing Height (m)	Pole Spacing (m)	No. of Pole	E_{min} (lux)	U_0
1	Existing	2x40 FTL	8	Not uniform	43	lux level not adequate	below 0.3
2	Proposed	2x40 FTL	10	18	48	satisfying minimum lux level	satisfying minimum level
3	Proposed	100W HPSV	10	20	45	satisfying minimum lux level	satisfying minimum level
4	Proposed	70W HPSV	8	19	45	satisfying minimum lux level	satisfying minimum level
5	Proposed	80W HPMV	8	16	54	satisfying minimum lux level	satisfying minimum level
6	Proposed	70W MH	8	17	51	satisfying minimum lux level	satisfying minimum level
7	Proposed	24W LED	8	17	51	satisfying minimum lux level	satisfying minimum level
8	Proposed	24W LED	8	17	51	satisfying minimum lux level	satisfying minimum level

Table 4 Annual cost of existing and proposed illumination systems

Sl. No.	Illumination system	Type of source	Energy consumptio (KWhr)	FAC (□)	ARC (□)	AMC (□)	TAC (□)
1	Existing	2x40 FTL	15067.20	55,947	147602	8600	2,12,149
2	Proposed	2x40 FTL	16819.00	62010	164832	9600	2,36,442
3	Proposed	100W HPSV	19710.00	76,200	1,95,587	9,000	2,80,787
4	Proposed	70W HPSV	13797.00	75,590	1,41,507	9,000	2,26,097
5	Proposed	80W HPMV	18921.60	87,515	1,85,080	10,800	2,83,395
6	Proposed	70W MH	15636.60	1,13,660	1,87,876	10,200	3,11,736
7	Proposed	24W LED	5361.12	59,121	53,270	10,200	1,22,591
8	Proposed*	24W LED*	5361.12	59,121	43,218	10,200	1,12,539

*operating with 50% rated voltage

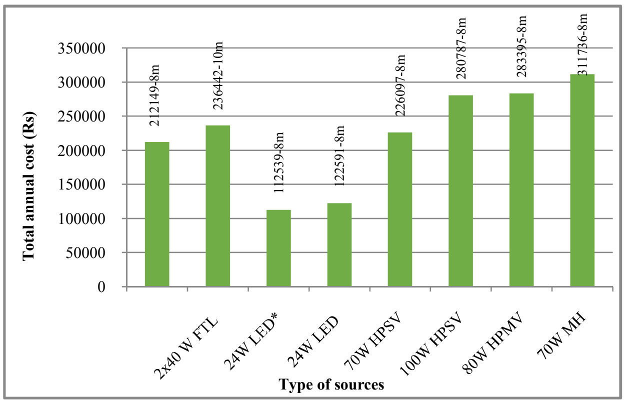

Fig. 3 Bar chart showing total annual cost for various types of sources

CONCLUSIONS

The case study of a mine shown that by adopting the optimal design parameters in mine illumination, the minimum required lighting standards could be fulfilled and the total annual cost would come down to approximately 47%. Lamp selection is made mainly based on efficacy and suitability to each situation. Because of long life and high luminous flux, LED sources offers low total annual cost, with lowest energy consumption. However, due to efficient penetration character in dusty environment, which generally encountered in surface mines, HPSV lamps are giving very good performance. HPSV and LED lamps are recommended for surface mine lighting as they have high luminous flux as well as longer economic life compared to other types of light sources.

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How to cite this article:

Aruna M *et al* (2017) 'Application Of Led In Surface Mines – A Case Study', *International Journal of Current Advanced Research,* 06(05), pp. 3783-3786. DOI:http://dx.doi.org/10.24327/ijcar.2017.3786.0367

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