Haul Roads Lighting System for Open Cast Mine using Green Energy

Nitai Pal, S.Vamsi Krishna, Ramjee Prasad Gupta, Ayodhya Kumar and Upendra Prasad

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. 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 all feasible alternatives for any project, use of compact fluorescent lamp (CFL) with stand-alone lighting system is highly acceptable. Stand-alone photovoltaic lighting systems provides flexibility for changing the location of pole according to surface mine haul roads. The luminous efficacy increases with switching frequency while providing eye comfort to user. The low electrical consumption makes the CFL an ideal choice for solar photovoltaic (SPV) stand-alone lighting system for surface mine haul roads. The present role of this paper is to illuminate CFL at a constant level in varying state of charge of the battery.**

Index Terms—**Reflectance, Haul road, CFL, SPV, MCT**

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 [1]. 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 [2] & [4]. 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. Use of compact fluorescent lamp (CFL) with stand-alone lighting system is highly acceptable. Stand-alone photovoltaic lighting systems provides flexibility for changing the location of pole according to change of surface mine haul roads. However, the CFL's electrical requirements are not easily met by hard-switched inverters due to their higher switching losses at higher frequencies. The difficulty in meeting the complex electrical requirements such as preheat and ignition voltage of CFL resulting in lower efficiency. In order to make a successful photovoltaic lighting system, the first step is to select a well-suited high-frequency inverter and a series interrupting type charge controller for producing light at haul roads and remote areas of surface mine while maintaining reliability.

Nitai Pal, Associate Professor is associated with Dept. of Electrical Engineering of Indian School of Mines (Under MHRD, Govt. of India) Dhanbad, Jharkand – 826004, India Email: nitai_pal@rediffmail.com
S.Vamsi Krishna, Junior Research Fellow is associated with Dept. of Electrical Engineering of Indian School of Mines (Under MHRD, Govt. of India) Dhanbad, Jharkand – 826004, India Email: svamsi82@gmail.com
Ramjee Prasad Gupta, Lecturer is associated with Dept. of Electrical Engineering of BIT Sindri, Sindri, Dhanbad, Jharkhand, India Email: ramjee_gupta@yahoo.com
Ayodhya Kumar, Principal is associated with Govt. Women's Polytechnic, Jamshedpur, Jharkhand, India Email: principalak@gmail.com
Upendra Prasad, Assistant Professor is associated with Dept. of Electrical Engineering of BIT Sindri, Sindri, Dhanbad, Jharkhand, India Email: upendra_bit@yahoo.co.in

II. PRINCIPLES OF HAUL ROAD LIGHTING

Seven different types of light poles layouts are possible for haul roads such as single sided, double sided opposite, staggered, twin central, central catenary system, centrally suspended system [3] & [5] and single sided stand-alone photovoltaic lighting system. Among these, the single sided stand-alone photovoltaic lighting system arrangement is the most prevalent one in mines as installation of poles and electrification process in this layout is simple, as no connection is required from one pole to another pole. Fig. 1 shows an overview of open cast mine with uncovered coal seam. CFL with stand-alone solar lighting system is shown in Fig. 2 for surface mine haul roads.

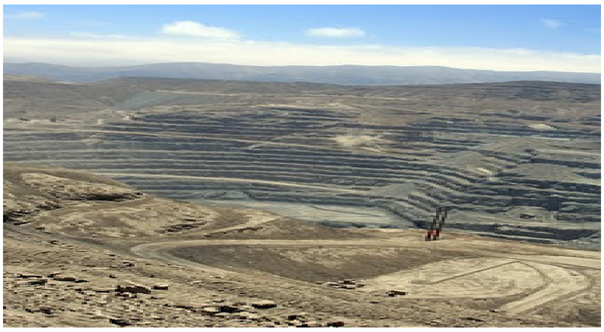

Fig. 1. open cast mine with uncovered coal seam

Fig. 2. CFL with stand alone lighting system for surface mine haul roads

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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.

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.

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. In general the angle varies from 10° to 15°.

III. PRESENT SCHEME

A series parallel resonant mode sine wave inverter is incorporated which provides basic electrical characteristics requirements of CFL, protection needs for higher reliability while offering higher inverter efficiency and above all a fairly constant lumen output throughout the operating DC voltage range by a unique control [6] & [7]. A series interrupting type charge controller makes the SPV system self sufficient for producing light at remote areas while maintaining reliability [8]. It is clear that the protection should be employed, not only for the lamp but also for battery charging, which are major components of the system. It should be efficient, reliable and robust enough against possible mal-operation. The block diagram of a typical stand-alone PV lighting system is shown in Fig. 3. The schematic circuit diagram of series parallel resonant mode sine wave inverter for operating CFL is depicted in Fig. 4.

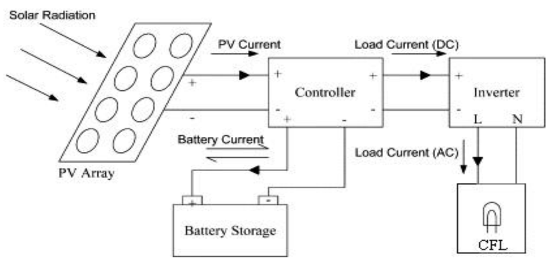

Fig. 3. Block diagram of present scheme

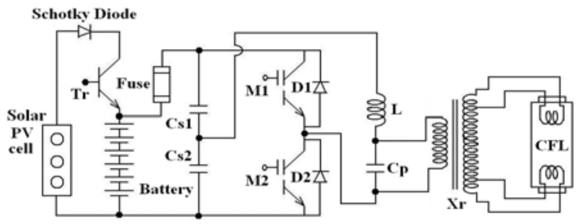

Fig. 4. Series Parrel resonant mode sine wave inverter for operating CFL

There are many designs exist for driving CFL. However, it is not easy to comply with complex but minimum essential needs of lamp's electrical parameters to ensure smooth start up and long life while maintaining adequate lumen output. Some relevant electrical parameters of the lamp are listed in Table-I [12] & [13].

TABLE I
PARAMETERS FOR CFL 9W LAMP

		Preheating:	
V/I ratio	280 Ω	Min. preheat current	135 mA
Ballast rated	74 V	Max. preheat current	400 mA
Calibration current	170 mA	Max. O.C.V. during preheat	150 V
Lamp voltage	48 V	Max. O.C.V. after preheat	290 - 340 V
Lamp current	170 mA	Burning:	
		Max. current in any lead	240 mA
		Min. operating current	120 mA
		Max. operating current	190 mA

It is observed from lamp manufacturer's instructions that due to their compact construction CFLs perform better with a warm start (certain preheat voltage is applied before ignition voltage is applied to lamp). Once turned ON the lamp behaves like a resistive load. The lamp needs constant voltage and hence current to maintain the lumen output during it's entire operating range of varying input voltage.

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In this paper, a charge controller which ensures charging of battery from PV array, with minimum losses and a series parallel resonant mode high frequency inverter using MCTs are discussed for operating the CFL. The spacing and number of poles for the given case has not considered through mathematical approach because the environment of haul road is too complex. The authors suggest that number of stand-alone systems can be adjusted as per working environment of haul road experimentally.

IV. CHARGE CONTROLLER

Referring Fig. 3, due to daily variation of solar insolation (incident solar radiation), the energy available from a PV module follows roughly a sine curve which needs to push this energy to the battery with minimal loss, while preventing a possible reverse power flow of energy from battery to PV modules in nights.

A typical (30 W) PV module's parameters are: V_{max} - 16.2 V, I_{max} - 1.85 Amps and I_{sc} - 2.2 Amps.

The V-I characteristics of monocrystalline PV modules are best suited for battery charging, hence a simple ON-OFF control of the charging device is adequate. The schottky type blocking diode, which has a low forward voltage drop is used in series with the PV array, resulting lower losses.

BJT is used for the series-interrupting device of charge controller, whereas, MCT (Turn-on time 0.4μSec, Turn-off time 1.25 μSec for an MCT of 500 V) is chosen as power devices for the half bridge series parallel inverter. For the typical system under consideration, the losses in the series interrupting device are I-squared times R, on or less than 0.25 W at peak power point and the series element drop is 0.12 V at peak current. This ensures maximum energy transfer to battery from the PV array, while preventing an overcharge condition.

When sufficient PV module voltage is developed and exceeds the available predetermined battery voltage, BJT (Tr) starts conducting because it would have received turn ON command by the control unit, which also makes adequate base-emitter (V_{be}) voltage available to Tr. Subsequent current limit is not essential because of characteristics of PV module and it's load-matching feature to battery charging. As the battery voltage rises to set level, the drive signal to Tr is cut off and charging is stopped. The recharge does not commence immediately, until the battery voltage is sufficiently lower than the over-voltage trip point.

V. INVERTER FOR LAMP

Referring Fig. 3, the proposed series parallel resonant mode inverter is operated above resonant frequency [9], [10] & [11], This circuit topology is chosen because of the following advantages

1) symmetrical and sine wave output waveform.
2) ease of output voltage control by change of inverter frequency.
3) ZVS (zero voltage switching) operation in above resonance frequency region to reduce switching losses even at higher switching frequency [5 & 6].
4) short circuit proof.

From table I , it is seen that the lamp needs a certain minimum voltage during preheat (before applying ignition voltage to turn ON), without exceeding a defined time duration for preheat voltage, a certain minimum ignition voltage and thereafter the burning voltage determined by the lamp ratings and applied voltage.

VI. OPERATION OF INVERTER

When switch is turned ON, the input voltage of the series parallel resonant mode sine wave inverter is adjusted such that the output voltage produced in the order of 130-150 V RMS (maximum limit of preheat voltage). This results in heating of lamp cathodes equally by selecting tap on the output transformer Xr. After a preset time (preheat interval), the switching frequency is brought near resonant frequency to achieve maximum voltage gain for producing ignition voltage across Xr secondary, which turns ON the lamp when the threshold is crossed. After turning ON the lamp voltage and hence Xr secondary voltage is reduced to ON-state lamp voltage, determined by the power setting of the inverter. This lamp voltage and hence lamp current are hereafter kept constant to give constant lumen output by controlling switching frequency against increase / decrease in DC input voltage which changes as a result of varying state of charge of the battery.

VII. PROTECTIONS

The inverter control signals are disabled if the battery voltage reduces below set level (battery low trip point). However, they are subsequently enabled only when battery voltage sufficiently recovers after a charge, thereby preventing frequent turn OFF-ON. This is essential to prevent return-ON of lamp, because the falling battery voltage recovers and follows the discharge curve determined by new rate of discharge once the discharge current is stopped due to trip.

Simulation of PV source was done from a current limited DC regulated power supply. After turning ON the lamp, the inverter output was intentionally short circuited near lamp terminals for 1 minute and short circuit was then removed. The lamp started glowing after removal of short circuit. The DC blocking capacitors C_{S1} & C_{S2} ensure that DC component in the inverter is avoided. A sine waveform ensures a compact design of the gap less high frequency transformer and lower losses.

VIII. RESULTS

A prototype board is constructed and it shows a fairly constant lumen output over varying input voltage. Throughout the experiment the output power of each CFL is assumed to be constant as its specified rating of manufacturer. As the battery terminal voltage decreases with respect to time of discharge the lumen output of CFL also decreases. To maintain constant lumen output of CFL, the inverter operating frequency is decreased. As a consequence, the discharge current of storage battery is increased. The battery discharge

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current is measured by digital dc ammeter and the corresponding battery terminal voltage is measured by digital dc voltmeter. The ac voltage across CFL is measured by using a CRO. The voltage across CFL is almost constant which offers constant lumen of CFL. Thereafter, the efficiency of inverter is calculated from experimental data. The experimental results are referred in tables II & III.

TABLE II
CFL OUT-PUT POWER RATING: 9W

Sl No.	Terminal voltage of storage battery (Volt)	Discharge current of storage battery (Ampere)	Inverter Operating Frequency (kHz.)	Voltage across CFL (Volt)	Efficiency of the Inverter (%)
1	12.85	0.74	120.40	52.92	94.65
2	12.50	0.76	118.60	52.81	94.74
3	12.00	0.79	116.00	52.73	94.94
4	11.50	0.82	113.80	52.62	95.44
5	11.00	0.86	110.00	52.51	95.14
6	10.50	0.90	107.40	52.39	95.23
7	10.00	0.95	103.60	52.30	94.74
8	09.50	1.00	99.10	52.18	94.74
9	09.09	1.04	95.00	52.07	95.20
Overall % Efficiency of the Inverter for 9 W CFL = 94.98 %					

TABLE III
CFL OUT-PUT POWER VS OVERALL EFFICIENCY

Sl No.	CFL Out-put Power Rating (W)	Overall % Efficiency of the Inverter
1	5	96.93
2	7	95.85
3	9	94.98
4	11	93.62
5	18	92.71

IX. CONCLUSION

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. The lamp selection is made mainly based on efficacy and suitability to each situation. A series parallel resonant mode sine wave inverter is well suited for meeting compact fluorescent lamp's complex characteristics. To ensure uniform light output through out the operating voltage range on input DC battery voltage variation from full charge voltage to lower charge limit voltage, inverter frequency will change automatically by voltage to frequency converter, towards the resonant frequency. When battery is fully charged, the voltage remains in it 14.21 V. At this situation, the inverter operates at 70% of resonant current and when the battery is under lower limit voltage, it will operate at 100% of resonant value. The inverter efficiency was found to be above 94% for a 9W CFL.

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