TELKOMNIKA Indonesian Journal of Electrical Engineering
Vol. 13, No. 3, March 2015, pp. 425 ~ 430
DOI: 10.11591/telkomnika.v13i3.7069

Post Disaster Illumination for Underground Mines

S Vamsi Krishna*, Nitai Pal, Pradip Kumar Sadhu
Department of Electrical Engineering, Indian School of Mines (under MHRD, Govt.of India)
*Corresponding author, e-mail: vamsijrf@gmail.com

Abstract

Lighting systems provide mine workers improved visibility and contribute to improved safety, productivity, and morale. Lighting is critical to miners, since they depend heavily on visual cues to spot fall of ground, pinning & striking and slipping & tripping hazards. Most conventional systems of lighting are used in mines are extracting a lots of power and deal with major maintenance problems. Apart from the conventional grid-power lighting systems, additional emergency lighting system using green energy is mandatory in case of grid-power failure or in disaster situation of the underground mines. The luminous efficacy increases with switching frequency while providing eye comfort to user. Even though CFL has low power consumption for solar photovoltaic (SPV) power system, but CFL's electrical requirements are not easily met by hard-switched inverters due to their higher switching losses at higher frequencies and preheat and ignition voltage of CFL results lower efficiency. This paper demands well suited high frequency inverter and a series interrupting type charge controller for illumination at remote areas.

***Keywords**: BJT, CFL, fly-back Inverter, MCT, MOSFET, SMPS, SPV*

Copyright © 2015 Institute of Advanced Engineering and Science. All rights reserved.

1. Introduction

Sub surface mining operations are carried out in dynamic environment conditions that include dust, confined spaces, low reflective surfaces and low visual contrasts. These are dependent on the moisture condition of underground atmosphere. Underground mining operations are carried out in very dangerous environments and it is not comparable with any other surface oriented industries. In general, illumination in mines influenced by three main lighting design parameters: illuminance level on the surface, uniformity and glare [1]. To recognize underground mining hazards miners are very much dependent on visual cues. Some major types of hazards are roof falls, fire explosions & exposure of toxic gases, floods and vehicle accidents in underground mines. Mining is a hazardous calling requiring a continual state of awareness and an ability to recognize danger from many sources, which is impossible without adequate illumination. Under natural conditions it is always dark below ground and all light must be produced artificially [2, 3]. So, emergency lighting system is more predominant at the time of power failure in underground mines. A miner can work efficiently and give satisfactory results only if the miner can see what he is doing and is not hampered by inadequate illumination or annoying shadows. This situation is more complex in case of under coal mines. Coal has a reflection coefficient of approximately 5% which would provide insufficient reflected light for suitably adapted eyes to see to sufficient standard in areas of illumination of less than approximately 5 lux. This would ensure that equipment could be seen and slip and trip hazards would be quiet visible to any miner operating in and around the mining equipment. In disaster conditions, the role of lighting system is very crucial and critical. Normally, the environment of underground mines is very hazardous and low ventilated. During accidents it becomes worse and in these conditions nothing will happens without lighting [5]. The design of good lighting systems for underground coal mines is not easy task because of unique environment and work procedures encountered in underground coal mines. So, in order to overcome this and to improve mine safety during disaster conditions and productivity at normal condition, the emphasis is given to emergency lighting system in underground mines using green energy like solar photovoltaic (SPV) power system [4, 6].

Use of Compact Fluorescent Lamp (CFL) increases for photovoltaic lighting systems due to their high luminous efficiacy and ability to provide adequate lumen output for a given lighting application. The luminous efficacy increases with switching frequency while providing

Received November 21, 2014; Revised January 8, 2015; Accepted January 26, 2015

eye comfort to user. The low electrical consumption makes the CFL an ideal choice for solar photovoltaic (SPV) power system for emergency lighting systems of underground mines. 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 thye complex electrical requirements such as preheat and ignition voltage of CFL resulting in lower efficiency [4, 7].

Renewable energy source such as solar and wind are seems to be more costly as alternative for generating electricity, but, it is clean energy. The energy plants of this renewable sources much dependent on environmental constraints. These are lots of challenges in utilization of renewable energy sources for industrial applications [8].

2. Fly-back Inverter

Fly-back inverter is the most generally used switching mode power supply (SMPS) circuit for low power output applications. The output voltage of fly-back converter needs to be isolated from the input main supply. The circuit can offer single or multiple isolated output voltages and can operate over wide range of input voltage variation [9]. Even though the fly-back inverter is inferior in efficiency but simple topology and low cost makes it much popular in low output power applications [10, 11].

The generally used fly-back converter requires single controllable switch like MCT/MOSFET/BJT and the switching frequency is in the range of 100 KHz. In order to increase the efficiency, two-switch topology is much useful and offers less voltage stress across the switches. A fast switching device is used with fast dynamic control over switch duty ratio to maintaion the desired output voltage [12]. The transformer in the topology is for voltage isolation and for better matching between input and output voltage and current requirements. There is no need of using Snubber circuit for this topological model [13, 14].

3. Selection of Semiconductor Switch

Solid state power semiconductor devices have been developed to control of output parameters such as voltage, current, frequency, waveform and power. In a static power converter the power semiconductor devices function as switches. The time durations as well as the turn on and turn off operation of these switches are controlled in such a way that an electrical power source at the input terminals of the converter appears in a different form at its output terminals. In most type of converters, the individual switches in the converter are operated in a particular sequence in one time period and this sequence is repeated at the switching frequency of the converter [15, 16].

Schottky diode doesn't have a P-N junction. Instead, they employ a metal-to-silicon barrier. In this, the current flow is due to the flow of majority carriers. Therefore, they are suitable for use at very high frequencies. They are very widely used in switch mode power supplies (SMPS) which work at high switching frequencies [17].

MCT is a thyristor with two MOSFETs built into the gate structure. These internal MOSFETs are known as ON-FET and OFF-FET. It is a high frequency and low conduction drop switching device. ON-FET is responsible for turning on the MCT and OFF-FET is responsible for turning off the MCT [18]. The ON state losses of MCT are very low and it has large current carrying capability along with fast switching speeds. Although the MCT is a voltage controlled component, the short gate current pulses occur as a result of charging and discharging of the FET transistor capacities. It is similar to Thyristor forward voltage drop during conduction. But, it can be turned off by positive voltage pulse unlike the Thyristor, which makes absence of commutation circuit. Since, it is a voltage driven switch, it consumes very less power for switching- ON [19, 20].

The gate to source voltage controls the conduction state of the power MOSFET. Application of a gate to source voltage greater than the device threshold voltage will cause the power MOSFET to turn on by modulating grometry of the electrostatic conduction channel. It is a voltage controlled device and easy to control. This is best optimal for low-voltage operation at high switching frequencies. These do not have secondary breakdown area; their drain to source resistance has a positive temperature coefficient, so they tend to be a self-protective. These are generally used as a switch and have surge current protection built into their design, but for high current applications the bipolar junction transistor is a better choice [21].

Bipolar junction transistor (BJT) is a current controlled switch that can be considered as two diodes with a shared anode. The BJT conduction state is controlled by the level of current injection into the base terminal. It has substantial storage charge which limits its ability to turn off quickly [22]. The typical storage time and collector fall time is in the range of 1-5 μs. this turn-off time limits the maximum practical switching frequency of power supplies using BJT's as the power semiconductor switch [23].

4. Proposed Topology

A fly-back inverter is incorporated which provides basic electrical characteristics requirements of CFL and a fairly constant lumen output throughout the operating DC voltage range by a unique control. A series interrupting type charge controller makes the SPV system self sufficient for producing light at remote areas while maintain reliability. 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 [24]. Typical emergency lighting systems are shown in Figure 1, Figure 2 and Figure 3 using MCT, MOSFET and BJT respectively.

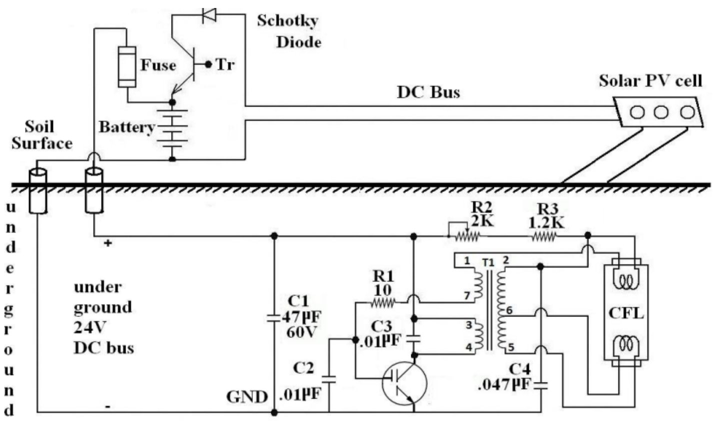

Figure 1. Fly-back inverter for operating CFL using MCT

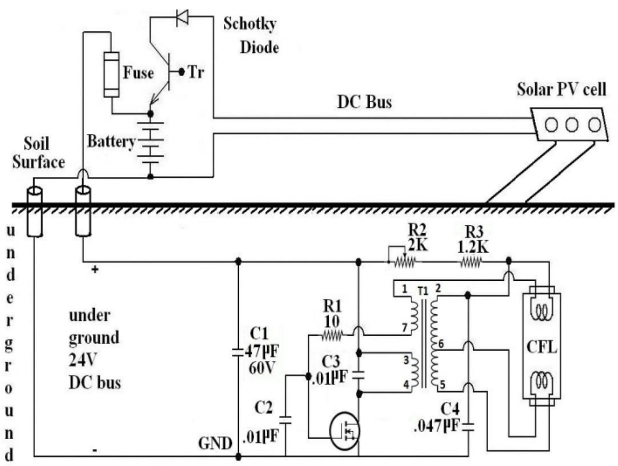

Figure 2. Fly-back inverter for operating CFL using MOSFET

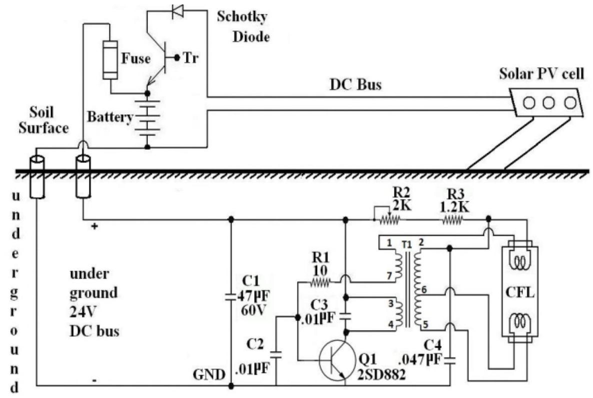

Figure 3. Fly-back inverter operating using BJT

These sre many designs exist for driving CFL. However it is not easy to ensure smooth start up and long life while maintaining adequate lumen output. Some relevant electrical parameters of the lamp are listed in Table 1. 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). The lamp needs constant voltage and hence current to maintain the lumen output during it's entire operating range of varying input voltage [4], [25-26]. Due to daily variation of solar insolation the energy available from a PV module follows rough sine wave 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. Transistor (Tr) is used as series interrupting device of charge controller [4], [26-27]. Whereas, the semiconductor switch (MCT/MOSFET/BJT) is chosen as power device for the fly-back inverter. For the system under consideration has the losses in the series interrupting device are $i^2R \leq$ 0.25W at peak power point and the series element drop is 0.12V at peak current. This ensures maximum energy transfer to battery from the PV array, while preventing an overcharge condition. When sufficient PV module voltage isdeveloped and exceeds the available predetermined battery voltage, transistor (Tr) starts conducting. As the battery voltage rises to set level, the drive signal to transistor (Tr) is cutoff and charging is stopped [26], [28-29].

After the turn-on of transistor (Tr) the storage battery starts charging as well as the underground proposed system takes the power for emergency lighting. The current path will be through R2, R3, CFL terminals, Ferrite core transformer terminals 1 & 7, R1 and C2. This current preheats the terminal coil of CFL which is required for ignition. Once the capacitor C2 charged, the semiconductor switch (MCT/MOSFET/BJT) turns on which allows the current flowing through C3 and ferrite core transformer terminals 3&4. The capacitor C3 charges while C2 discharges. After fully charging of capacitor C3, it discharges through the ferrite core transformer terminals 3&4 and the voltage appears in secondary winding across terminals 2&5. This high amount of voltage makes the ignition of CFL. The sequential turn ON and turn OFF operation of semiconductor switch provides the generation of AC voltage. This AC voltage maintains the ignition voltage of CFL and the capacitors C1 & C4 are used to stabilize the voltage across transformer terminals.

Table 1. Comparison of Switching Devices for Economic Operation

CFL Parameters	18W	26W	32W
Lamp current (A)	0.22	0.39	0.39
Lamp voltage (V)	120	120	120
Equivalent wattage (W)	65	100	100
Initial lumens (lumen)	1200	1700	2400
Minimum O.C.V Ignition voltage (V_{rms})	550	550	560
Max. O.C.V. (V_{rms}) Non-ignition voltage	250	265	265
Dimming range (I_{dmin}- I_{dmax})	0.02-0.16	0.03-0.25	0.03-0.25
Lamp test current (A)	0.2	0.3	0.3
Rated resistance (from cathode resistance test)	26	13	13

5.Experimental Results

A prototype board was constructed and it showed fairly constant lumen output over varying input voltage for the same operating switch of the inverter. The experimental results considering for 18W CFL lamp are referred in Table 2, average overall efficiency and mean lumen output for 18W, 26W and 32W CFL sre given in Table 3.

Table 2. Battery Terminal Voltage VS Efficiency for 18W CFL

Sl No	V	I	f	V_{MCT}	V_{MOS}	V_{BJT}	η
1	24.00	0.81	32.2	101.82	96.45	104.72	92.59
2	23.60	0.82	32.2	101.75	96.10	104.55	93.01
3	23.20	0.83	32.2	100.52	95.80	103.82	93.47
4	22.70	0.85	32.2	99.57	94.75	102.89	93.28
5	22.50	0.86	32.2	99.31	94.15	101.70	93.02
Average overall efficiency of the inverter for 18W CFL = 93.07 %							

Table 3. Comparison among Overall Efficiency using Different Switches with CFL Power Rating

Sl No	CFL Output Power rating	Mean Lumens	Overall %Efficiency of the Inverter
1	18W	1010	93.07
2	26W	1365	91.94
3	32W	2040	89.11

6. Conclusion

A fly-back inverter is well suited for meeting compact fluorescent lamps (low power CFL i.e. 18W/26W/32W) complex characteristics. To ensure uniform light output throughout the operating discharge range. DC storage battery will be charged sufficiently. The time duration of uniform light output depends on the ampere-hour (AH) capacity of storage battery. On the other hand, the life of the DC storage battery increases with proper charging rate and prevention of deep discharges. When a standard battery of 24.0V is applied the efficiency of inverter is stands at 92.59%. When the battery is under lower limit voltage, efficiency of inverter is almost 93.02%. Efficiency of inverter is slightly decreases with the increase of CFL output power rating. Since, the result shows that voltage across the terminal of CFL $V_{BJT}>V_{MCT}>V_{MOS}$, the brightness of lamp is slightly more in case of BJT and then it decreases for MCT and MOSFET respectively. Lighting plays as significant role in underground mining operations. Underground mines are entirely reliant on artificial sources of illumination. Without appropriate and effective lighting, there is much probability of accidents and less production. Apart from the conventional grid-power lighting systems, additional emergency lighting system using green energy is obligatory in case of grid-power or in disaster condition of the underground.

References

[1] M Aruna, SM Jarlikar. Design of Lighting System for Surface Mine Projects. *Telkomnika.* 2012; 10(2): 235-244.

[2] CDJ Statham. Underground Lighting in Coal Mines. *IET JOURNALS & Magazines.* 1956; 103(10): 396-409.

[3] WH Lewis. Underground Coal Mine Lighting Handbook. *Information Circular United States Department of the Interior, Bureau of Mines*, 9074.

[4] HV Joshi. Solar PV Charge Controller and an Efficient SPRL MOSFET based sine wave symmetrical inverter for Compact Fluorescent Lamp. *In Proc. Power Electronics and Drive Systems, IEEE* .1997; 1: 150-152.

[5] N Pal, SV Krishna, RP Gupta, A Kumar, U Prasad. *Haul Roads Lighting System for Open Cast Mine using Green Energy.* In Proc. IMECS. 2012; 987-990.

[6] L Laskai and M Ilie. An Approach for selecting Switching Devices for CFL Ballasts. *IEEE Trans. Industrial Application.* 2001; 37(1): 268-275.

[7] N Pal, PK Sadhu, A Kumar, U Prasad. *Energy Efficient Solar CFL Lighting System using MOSFET Based High Frequency Inverter for Remote Areas.* Proc. In ICCAE. 2010; 5: 646-649.

[8] JO Petinrin, M Shaaban. Overcoming Challenges of Renewable Energy on Future Smart Grid. *TELKOMNIKA Indonesian Journal of Electrical Engineering.* 2012; 10(2): 229-234.

[9] DB Murthy, MK Kazimierczuk. Two Transistor Zeta-Flyback DC-DC Converter with Reduced Transistor Voltage Stress. *Electronics Letters*. 2010; 46(10).
[10] HE Tacca. Single Switch Two Output Flyback Forward Converter Operation. *IEEE Trans. Power Electronics*. 1998; 13(5): 903-911.
[11] B Han, G Ledwich, G Karady. Study on Resonant Fly-back Converter for DC Distribution System. *IEEE Trans. On Power Delivery*. 1999; 14(3): 1069-1074.
[12] Y Jang, DL Dillman, MM Jovanovic. A New Soft-Switched PFC Boost Rectifier with Integrated Flyback Converter for Standby Power. *IEEE Trans. On Power Electronics*. 2006; 21(1): 66-72.
[13] HS Chung, WL Cheung, KS Tang. A ZCS Bidirectional Flyback DC/DC Converter. IEEE Trans. On Power Electronics. 2004; 19(6): 1426-1434.
[14] M Ferdowsi, A Emadi, M Telefus, C Davis. Pulse Regulation Control Technique for Flyback Converter. *IEEE Trans. on Power Electronics*. 2005; 20(4): 798-805.
[15] RW Johnson, JR Bromstead, GB Weir. 2000C Operation of Semiconductor Power Devices. *IEEE Trans. on Components, Hybrids and Manufacturing Technology*. 1993; 16(7).
[16] R Krisshman. High Temperature Electronics. Wiley- IEEE Press, Edition. 1. 1999:336-341.
[17] DA Grant. Power Semi-Conductors Innovation and Improvement Continue to Challenge the Designer. *IET, New Developments in Power Semiconductor Devices*. 1991:1-6.
[18] H Ye, P Haldar. A MOS Gated Power Semiconductor Switch Using Band-to-Band Tunneling and Avalanche Injection Mechanism. *IEEE Trans. on Electron Devices*. 2008; 55(6).
[19] M Trivedi, S Pendharkar, K Shenai. Switching Characteristics of MCT's and IGBT's in Power Converters. 1996; 43(11): 1994-2003.
[20] F Bauer, H Hollenbeck, T Stockmeir, F Wolfgang. Current Handling and Switching Performance of MOS Controlled Thyristor (MCT) Structures. *IEEE Journals & Magazines*. 1991; 12(6): 297-299.
[21] D Kzum, JH Park, T Krishnamohan, HSP Wong, KC Saraswat. The Effect of Donor/Acceptor Nature of Interface Traps on Ge MOSFET Characteristics. *IEEE Journals & Magazines*. 2011; 58(4): 1015-1022.
[22] RG Roozbahani. BJT-BJT, FET-BJT and FET-FET. *IEEE Journals & Magazines*. 2004; 20(6): 17-22
[23] BK Bose. Evaluation of Modern Power Semiconductor Devices and Future Trends of Converters. *IEEE Trans. on Industry Applications*. 1991; 28(2).
[24] SB Kjaer, JK Pedersen, F Bleebjerg. A Review of Single –phase Grid Connected Inverters for Photovoltaic Modules. *IEEE Trans. on Industry Applications*. 2005; 41(5): 1292-1306.
[25] F Blaabjerg, Z Chen, SB Kjaer. Power Electronics as Efficient Interface in Dispersed Power Generation Systems. *IEEE Trans. on Power Electronics*. 2004; 19(5).
[26] T Shimizu, O Hashimoto, G Kimura. A Novel High-performance Utility- Interactive Photovoltaic Inverter System. *IEEE Trans. on Power Electronics*. 2003; 18(2): 704-711.
[27] N Pal, SV Krishna, PK Sadhu. Designing Haul Road Lighting System. *Australasian Mine Safety Journal (AMSJ)*. 2013; 18: 42-45.
[28] SB Kjaer. Design and Control of an Inverter for Photovoltaic Applications. Thesis. Alborg University, Denmark; 2005.
[29] T Shimizu, M Hirakata, T Kamezawa, H Watanabe. Generation Control Circuit for Photovoltaic Modules. *IEEE Trans. on Power Electronics*. 2001; 16: 293-300.