Reliable and cost-effective inter-unit communication for energy conservation

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***Abstract*—**-A key element to reduce power usage related to the lighting is by using low power consuming lights sources, like LEDs. This further necessitates the need of a proper driver system to maintain a constant LED output. Also, the system must provide various output light levels which refers to reduction in the power usage with respect to the actual usage needs of the user for that particular room/unit. This requires a system with inter-communication of power output levels, between a main room/master and other rooms/slaves. System described in this paper is designed taking into account the user power needs and requirements. The overall cost and the efficiency of the critical elements of the system is to be kept low.

Key words - *Duty Cycle (DC), LED current, Pulse Width Modulation (PWM), Microcontroller, Switching frequency (f_{sw}), MODBUS, Data Packets/messages.*

I. Introduction

With slowly vanishing energy resources, and, over consumption of the same by ever increasing modern lifestyle demands has made energy consumption or utilization a prime need of the hour. The motivation behind this paper is to present a basic level architecture demonstrating energy saving at the primary level [1].

The energy preserving method follows a simple master/unit/room-slave/unit/room communication protocol comprising: a) Re-distribution of power by a master, to each slave based on their utilization factor. b) Setting up and maintaining a certain output level, corresponding to the power based on their utilization in the master/slave circuitry. c) A communication with simple packet/message formats with lesser baud rates. The master is allotted to the unit predetermined by the end user at the time of installation. Mostly, it will refer to the unit with a predicted higher value of utilization.

For the purpose of understanding the complexities in realizing and implementing this method, the output of each unit is set as DC lighting. LEDs are chosen to serve this purpose of producing a constant light output for reasons like, long life, eco-friendly, high illumination (of about 180 lm/W at only 0.1W LED) and high reliability[3-4] among others. The master/slave circuit blocks are as shown in the Fig. 1. The underlying circuitry for master and slaves will remain same however, master will be provided with additional databases to store the states and utilization factor of each slave or unit. Each master/slave/unit/room comprises of a microcontroller, DC-DC converter (buck converter), gate driver, Feedback loop, to keep given I_{ref} constant to attain the desired output light intensity level, and LEDs.

The light output of an LED mainly depends on the current flowing through it, which has to be maintained constant to maintain the optical intensity stable. Linear regulators are avoided as they create voltage drops and switched mode input is used instead. With a wide range of illuminations, the current requirement also varies from 10mA to 2A. In order to achieve a high accuracy in maintaining a constant current over a wide range, a novel driver circuitry with a feedback controlled PWM is designed. PWM was chosen for dimming as it offers greater dimming flexibility than other dc dimming techniques [5]. Therefore, by changing the Duty Cycle (DC) of the input signal at the gate of main gate MOSFET of the buck converter, variation in the light output can be achieved. This variation is filtered out by the human eye to create an overall dimming effect.

Critical design factor for the circuitry illustrated in Fig. 1 is the gate driver, which is required to drive large gate current for a fast switching input. With the aim of reducing the overall system cost, and keeping the overall circuit simple, a resistive gate driver is employed, which is described in section IV. The software code for providing a reliable feedback by a microcontroller is further explained in the section.

II. Communication Overview

The overall system is build using three-wired communication, comprising of power line, command link and ground as shown in Fig. 2. It also demonstrates the use of a simple circuitry which provides a serial single-wired communication over the command link. Master can be a unit which decides on the output level corresponding to the utilization factor. This output level is transmitted in the form of packets to the corresponding slave (or room).

II. Message Format

Initially, is configured to set the master unit/room of the system. The message format similar to that used for MODBUS communication [6], is as shown in Fig. 3. The data byte is values given to denote levels between 0% (OFF) to 100% (fully ON giving highest light output). The function byte gives the data type depending on the type of message being sent.

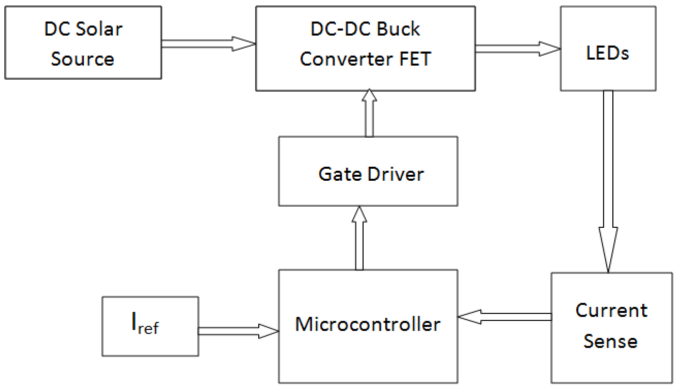


Fig. 1 Master/Slave unit overview

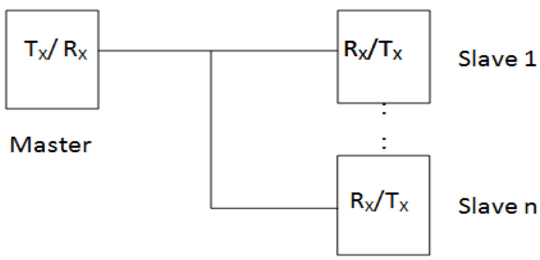


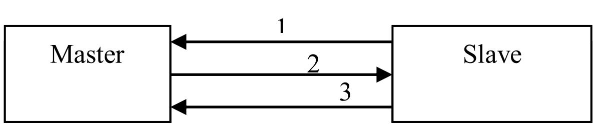
Fig. 1 Communication overview

DAB	SAB	FB	DB	CRC

DAB: Destination Address Byte
SAB: Source Address Byte
FB: Function Byte
DB: Data Byte
CRC: Error Check

Fig. 1 Communication message format

The communication is initiated by the user by pressing the switch ON as illustrated in Fig. 4.



1: Status Message
2: Level Set
3: Acknowledgement

Fig. 4 Communication process with message type

II. GATE DRIVER

A. Gate Drive: Hardware

The gate drive circuit shown in Fig. 5 consists of a gate driver for the main PMOSFET (Q_1), IRF9540N, of the buck, gate current limiting resistor, R_2 and an NPN gate drive transistor, Q_2. The purpose of R_1 is to provide a discharge path for the internal MOSFET capacitor between gate and source. The R_{SNS} resistor, in the feedback, is used to sense the current in the circuit by converting the inductor current to a differential voltage level. The output from R_{SNS} is fed to OPM, LM358. The purpose of the operational amplifier is to amplify the signal to a level lower than the saturation voltage level of the Microcontroller. The voltage (Vref) refers to a certain current value in the output circuit. Vref is later converted into the appropriate current value by the Microcontroller software. This value is then compared with a reference current to ensure that the accuracy of obtaining a constant current is maintained. A corresponding PWM output is produced to drive an NPN transistor (Q_2).

The resistors R_1 and R_2 form a divider network limiting the turn-on voltage (V_{gs}) of the main MOSFET (Q_1).

B. Gate Drive: Software

The algorithm used for achieving the required dimming level by adjusting the duty cycle(DC) is illustrated in Fig. 6. The duty cycle limit is set between a count of 10 and 150 of the microcontroller. A maximum of 160 is obtained from the switching frequency (f_{SW}) and internal maximum clock frequency of the microcontroller (clk),given by:

$$count = \frac{clk}{f_{sw}} \qquad (1)$$

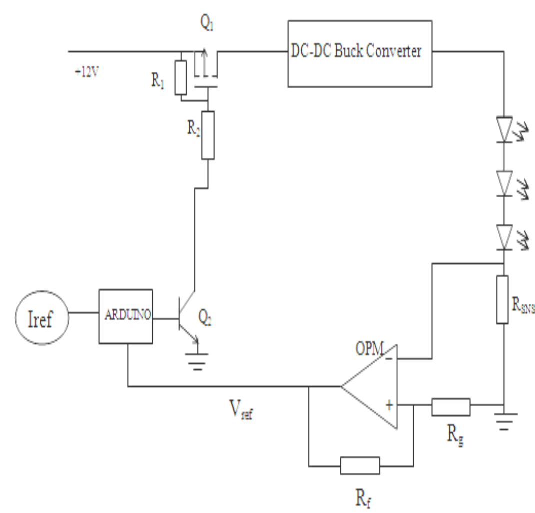


Fig. 5 Resistive gate drive circuit.

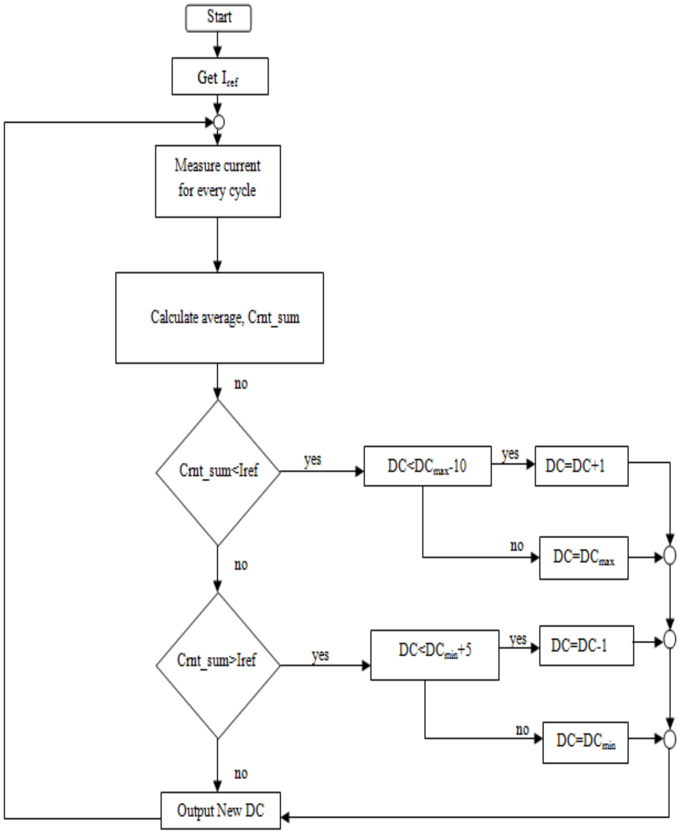


Fig. 6 Flowchart showing Duty Cycle (DC) adjustment for achieving target dimming current.

IV. RESULTS AND ANALYSIS

Buck converter provides the DC-DC conversion required to maintain the necessary constant lower voltage level. The output voltage is primarily dependent on the number and the required forward voltages of LEDs. For this paper, 3 LEDs with a minimum forward voltage of 2.7V each are used. That necessitates an output of at least 8.2V for the LEDs to produce a luminous output. The parameters of Buck converter are designed [7] and are listed in below:

TABLE I
PARAMETERS OF DC-DC BUCK CONVERTER

Parameters	Value
Nominal input voltage, Vin	12V
The minimum output voltage, Vo	8.2V
Switching frequency, f_{sw}	100kHz
Maximum rated LED current, I_{LED}	300mA
Duty cycle ratio, DC	0-1
Inductor, L	47µH
Input capacitor, Cin	220µF
Output capacitor, Cout	10 µF
Sense resistor, R_{SNS}	2Ω, $\pm$ 1%

Figures 7, 8 show the output voltage waveform at the gate of the main MOSFET (Q_1) of the buck converter. Figures 4 and 5 show the gate waveforms for different values of LED current. The efficiencies are measured for each value. The efficiency rise from 76% to 80% is noticed when the output current is increased from 200mA to 300mA. It can be seen that the output current increases with the increase in the duty cycle and the average output current (I_{avg}) can be expressed as:

$$I_{avg} = DCI_{LED} \quad (2)$$

.where DC is the duty cycle.

The efficiency is also increased, inferring its dependence on the rise and fall times of the gate waveform.

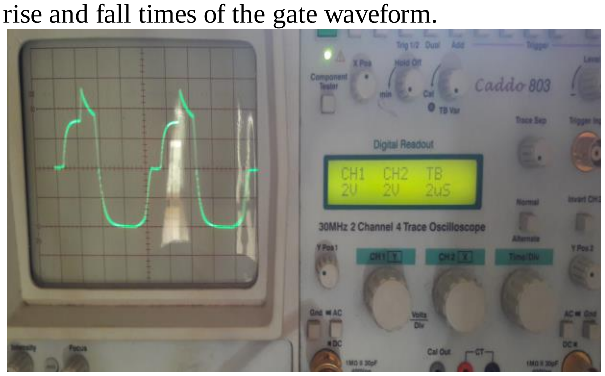


Fig. 7 Resistive circuit gate waveform at I_{LED}=200mA

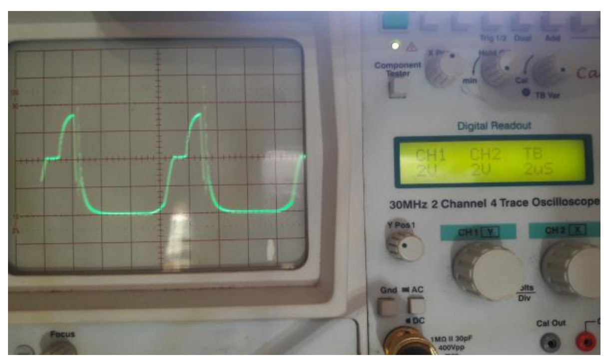


Fig. 8 Resistive circuit gate waveform at I_{LED}=300mA

Figure 9 shows that the packets for a reference current of 200mA for a particular level of output light are received and as discussed in flowchart in Fig. 6, the DC value adjusts itself until constancy in current is approached.

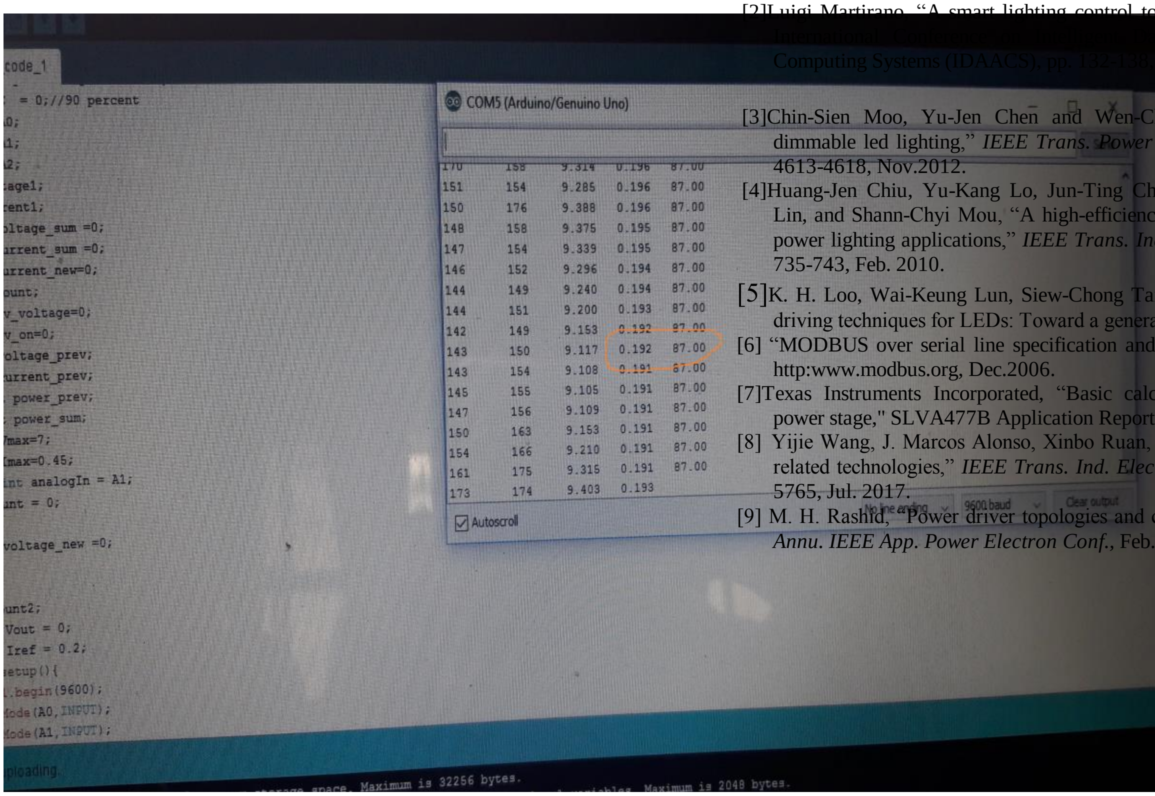


Fig. 9 DC self- adjusted to count of 87 (i.e. 50%) to obtain 0.192~0.2 A current.

V. CONCLUSION

A simple LED gate drive circuit is presented consisting of easily available gate resistors. The current in the circuit is maintained constant by equivalently adjusting the PWM duty cycle through a feedback loop. With an efficiency of more than 80%, for currents higher than 300mA, this circuit presents an economical solution for fast switching gate drive for the main MOSFET. The initial setup of the overall system was achieved with user being given the privilege of setting up the master for the system. With lower volume of data packets and lower baud rates, the data could be transmitted faster over long distances without erroneous packets. The simplicity and the cost factor of the proposed system design also make it suitable for practical rural en energy management systems.

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